User's Manual

⁄⁄⁄ Measure **Ready**
M91 FastHall™
Measurement Controller

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Revision 1.5   10 February 2021

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LIMITED WARRANTY STATEMENT

WARRANTY PERIOD: THREE (3) YEARS

1. Lake Shore warrants that products manufactured by Lake Shore (the "Product") will be free from defects in materials and workmanship for three years from the date the Product leaves Lake Shore (the "Warranty Period"). If Lake Shore receives notice of any such defects during the Warranty Period and the defective Product is shipped freight prepaid back to Lake Shore, Lake Shore will, at its option, either repair or replace the Product (if it is so defective) without charge for parts, service labor or associated customary return shipping cost to the Purchaser. Replacement for the Product may be by either new or equivalent in performance to new. Replacement or repaired parts, or a replaced Product, will be warranted for only the unexpired portion of the original warranty or 90 days (whichever is greater).

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EU DECLARATION OF CONFORMITY

$$C\,E$$

This declaration of conformity is issued under the sole responsibility of the manufacturer.

Manufacturer:

Lake Shore Cryotronics, Inc.
575 McCorkle Boulevard
Westerville, OH 43082
USA

Object of the declaration:

Model(s): M91
Description: FastHall™ Controller

The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

2014/53/EU   Radio Equipment Directive

References to the relevant harmonized standards used to the specification in relation to which conformity is declared, full or in part:

EN 61010-1:2010
   Overvoltage Category II
   Pollution Degree 2

EN 301 489-17 V3.2.0:2017

FCC CFR 47, Part 15, subpart B:2017, Class A

ICES-003, Issue 6:2016, class A ITE

Signed for and on behalf of:
Place, Date:
Westerville, OH USA
10-JAN-2019

Scott Ayer
Director of Quality & Compliance

Electromagnetic Compatibility (EMC) for the MeasureReady® M91 FastHall™ Measurement Controller

Electromagnetic Compatibility (EMC) of electronic equipment is a growing concern worldwide. Emissions of and immunity to electromagnetic interference is now part of the design and manufacture of most electronics. To qualify for the CE Mark, the MeasureReady® M91 FastHall™ measurement controller meets or exceeds the requirements of the European Radio Equipment Directive 2014/53/EU.

The instrument was tested under normal operating conditions with sensor and interface cables attached. If the installation and operating instructions in this user's manual are followed, there should be no degradation in EMC performance.

Exposure to RF interference greater than that found in a typical laboratory environment may disturb the sensitive measurement circuitry of the instrument.

Pay special attention to instrument cabling. Improperly installed cabling may defeat even the best EMC protection. For the best performance from any precision instrument, follow the grounding and shielding instructions in the user's manual. In addition, the installer of the instrument should consider the following:

- Shield measurement and computer interface cables.
- Leave no unused or unterminated cables attached to the instrument.
- Make cable runs as short and direct as possible. Higher radiated emissions are possible with long cables.
- Do not tightly bundle cables that carry different types of signals.

EU DECLARATION OF CONFORMITY

$$C\,E$$

This declaration of conformity is issued under the sole responsibility of the manufacturer.

Manufacturer:

Lake Shore Cryotronics, Inc.
575 McCorkle Boulevard
Westerville, OH 43082
USA

Object of the declaration:

Model(s):   HMT-TT-MAN
Description: MeasureReady™ FastHall™ Station

The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

2014/35/EU   Low Voltage Directive
2014/53/EU   Radio Equipment Directive
2011/65/EU   RoHS Directive

References to the relevant harmonized standards used to the specification in relation to which conformity is declared:

EN 61010-1:2010, AMD1:2016
   Overvoltage Category II, Pollution Degree 2

EN 301 489-17 V3.2.0:2017

EN 50581:2012

Signed for and on behalf of:
Place, Date:
Westerville, OH USA
04-SEP-2020

Scott Ayer
Director of Quality & Compliance

Table of Contents

Chapter 1: Introduction

1.1 General

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

Traditionally, the DC field measurement technique has been sufficient to measure materials with mobilities down to approximately 1 cm2/V s. However, the emerging class of photovoltaic (solar cell), thermoelectric and organic electronic materials are characterized by low mobilities that are difficult, if not impossible, to measure. It is challenging to extract the diminishingly small Hall voltage from the background noise that is produced by such materials using DC field techniques. To solve this problem, it has been necessary to use the AC field technique which enables Hall measurements down to 0.001 cm2/V s, but this has the disadvantage of having significantly increased measurement time. The MeasureReady® M91 FastHall™ measurement controller, with FastHall technology, was designed to solve the low mobility measurement problem, while reducing the amount of time required for a typical Hall analysis. Typical low mobility measurements can be completed in less than a minute.

The M91 FastHall™ measurement controller can provide a full range of Hall measurements on van der Pauw and Hall bar samples. The standard system is capable of DC field measurements and has a resistance range from 0.5 mΩ to 10 MΩ. With the option to upgrade to high resistance, the resistance range of the measurement is increased to 200 GΩ.

1.2 Overview

The M91 FastHall™ measurement controller is a revolutionary, all-in-one instrument that delivers significantly higher levels of precision, speed, and convenience to researchers involved in the study of electronic materials.

Featuring Lake Shore's patented* new FastHall™ measurement technique, the M91 fundamentally changes the way the Hall effect is generated and measured by eliminating the need to switch the polarity of the applied magnetic field during the measurement. This breakthrough results in faster and more accurate measurements, especially when using high field superconducting magnets or when measuring very low mobility materials.
*Protected by US patent number 9797965. Other patents pending.

FastHall vs. conventional Hall measurement time of an IGZO sample

Conventional Hall

FastHall™

Time (s)

1.3 s   114 s
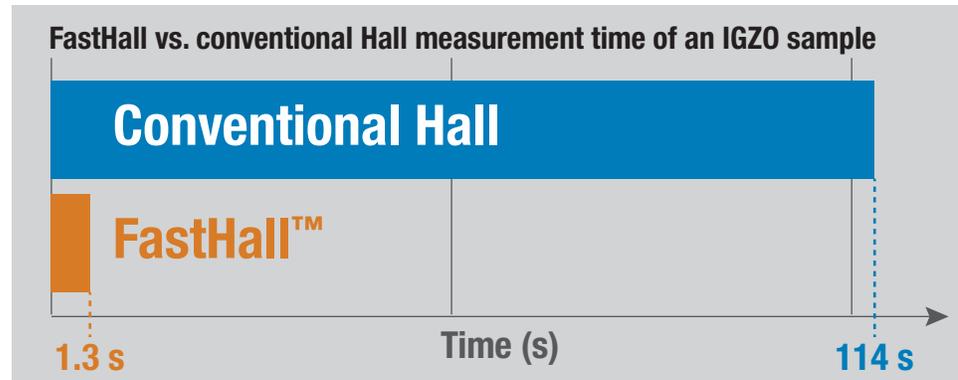
*FIGURE 1-1 **FastHall vs. conventional Hall measurement time***

1.2.1 Optimization

The M91 provides an automatic method to optimize the setup and measurement parameters for your material, which can then be used in all subsequent measurements. This is based on finding a contact check result with a correlation coefficient greater than 0.9999 on all four contacts. The optimization method allows the user to rapidly find the proper excitation value and settle time for a sample without a lengthy manual trial and error step. Setup parameters are then used in subsequent resistivity and FastHall™ setups, but only if linking mode is enabled (see SCPI Command **FASThall[:VDP]:STARt:LINk**). The optimization method can also be used in measurements where the sample parameters may change during the measurement, for instance, in variable temperature measurements. The user can bypass the optimization method and manually select all desired operating parameters.

The Link mode uses setup parameter information from the previously-run contact check and/or resistivity measurement so that the user does not have to manually enter these parameters for a resistivity or FastHall™ measurement. Link mode only applies to configurations for van der Pauw samples. Manual mode allows the user to have full control over all of the input parameters. The optimization method runs independent of a contact check sequence, and it selects the optimum excitation type, value, range and settle time for the user. Link mode is used to either pass the parameters from contact check to a resistivity measurement, or to pass the parameters from contact check and/or resistivity measurement to a FastHall™ measurement.

1.2.2 Single Instrument

Traditional Hall effect measurement systems (HMS) provide basic electrical measurement instrumentation combined with a generic switch unit to measure sample resistivity and Hall voltages. But they must also rely on separate PC-based software to perform pre- and post-processing calculations in order to ultimately derive the physical parameters of carrier type, carrier concentration, mobility, and the Hall coefficient that researchers need to know. The M91 FastHall™ measurement controller combines all of the necessary HMS functions into a single instrument, automating and optimizing the measurement process, and directly reporting the desired parameters.

The standard M91 integrates:

- Current source
- Synchronous voltage measurement
- Multi-position switching
- High level automated routines for ohmic contact check, resistivity, Hall voltage, and a full list of derived parameters with a single command
- General purpose analog and digital I/O for simple system integration

The high-resistance option enables measurement of samples up to 200 GΩ.

1.2.3 Low Mobility Materials

Hall effect measurement is a key step in characterizing the transport properties of novel electronic materials and devices. It is commonly performed using the traditional DC field method, requiring little more that a stable current source, a voltmeter, a switch and a magnet and is relatively straightforward and reliable for simpler materials with higher mobilities. However, the difficulty increases and accuracy of measurement decreases as material mobilities decrease. This is often the case in promising new semiconductor materials such as photovoltaics, thermoelectrics, and organics.

For the past several years, AC field techniques using advanced lock-in amplifiers and longer measurement windows to extract smaller Hall voltage signals have been used to explore these materials. But extended measurement intervals can also add new forms of error from thermal drift effects. Results take longer to get, sometimes many hours for very low mobility materials. The FastHall™ technique eliminates both issues — it accurately measures even extremely low mobility materials in seconds.

1.3 Features

- FastHall™ technology eliminates the need for magnetic field reversal for van der Pauw samples
- Applicable to any magnet type
- More than 100 times faster than previous Hall measurements
- Ideal for measuring low mobility materials
- Hall analysis including calculation of derived parameters for van der Pauw and Hall bar samples
- Manual step-by-step operation for full parameter control
- Extends mobility range down to 0.001 cm^2/V s, without using AC field techniques
- High-resistance option enables measurement of samples from 10 MΩ to 200 GΩ
- Derived parameter calculations that include the errors of all measurements in the calculation
- Operation over simple SCPI command interface or in conjunction with MeasureLINK™-MCS software
- Digital and analog I/O for simplifying integration and data gating
- 3-year standard warranty

1.4 Fields of Study

The M91 FastHall™ measurement controller, using only a DC field and patented technology base on reverse field reciprocity theorem, provides Hall measurements to facilitate the broadest range of research applications. The M91 coupled with the MeasureLINK™-MCS software for variable temperature and variable field-dependent magnetotransport measurements provides a means to understand fundamental processes in solid state physics and materials science.

1.4.1 Photovoltaic and Thermoelectric Applications

Photovoltaic (solar cell) and thermoelectric materials are often characterized by low mobilities. This characteristic makes them difficult or impossible to measure using traditional DC field Hall methods. The M91 allows measurement of these materials with only a DC field. Eliminating the requirement for AC fields with van der Pauw samples, Hall measurements can be performed on a wide range of magnet systems. The magnet configuration can be chosen based on material and sample consideration. In previous systems using AC fields, the measurements were difficult or even impossible to use with superconducting magnets or permanent magnets.

1.5 Hall Effect Measurements

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

Hall measurement systems use a material's Hall effect to determine Hall mobility. The Hall measurement is also used to determine the associated properties of carrier concentration, resistivity, and carrier type.

The MeasureReady® M91 FastHall™ measurement controller can provide a full range of Hall measurements on both Hall bar and van der Pauw samples. It can perform full standards-based measurements when necessary, or a smaller subset when desired. The traditional Hall effect may be the only measurement needed when measuring well-behaved semiconductors. Other methods are used to determine mobility especially when the mobility is low or hard to derive.

1.5.1 Field Hall Nomenclature

This section provides an explanation of the naming conventions and nomenclature used in this manual and in the MeasureLINK™-MCS software. The units used for the quantities defined here, and conversion between common systems of units can be found in section 1.5.2.

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

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

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

$$R_H = \frac{tV_H}{I\,B}$$

Hall voltage is the most critical measurement needed in order to determine the Hall coefficient. Later sections will describe the exact methods used in the M91 FastHall™ measurement controller to get the best possible measurement of the Hall voltage. The Hall voltage contains other information about the electrical transportation properties of the material. For instance, the sign of the Hall voltage is positive if the carriers in the material are holes, and it is negative if the carriers in the material are electrons.

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

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

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

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

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

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

This same Hall factor is also the ratio of the Hall mobility to the drift mobility. Drift mobility is defined as the carrier velocity per applied electric field. Although the Hall factor can be calculated, the calculation can be difficult and often only represents an approximation. Absent of any better information, it is reasonable to use a Hall factor of 1. This manual will assume the Hall factor is 1, but the MeasureLINK™-MCS software will allow the user to enter a Hall factor and use the Hall factor to calculate results.

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

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

In the figure below, the area is the width (w) times the thickness (t), so the equation for resistivity becomes:

$$\rho = \frac{R\,w\,t}{L}$$
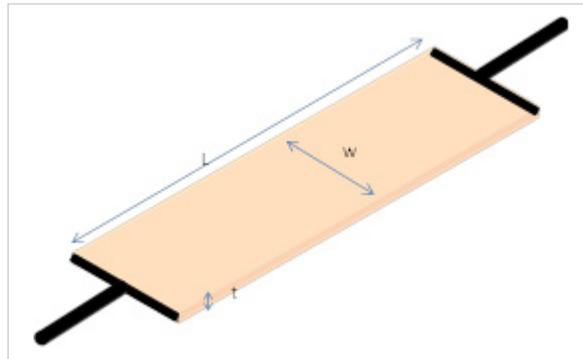
FIGURE 1-2 *Resistivity*

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

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

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

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

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

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

$$R_{H_{sheet}} = \frac{V_H}{I\,B}$$

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

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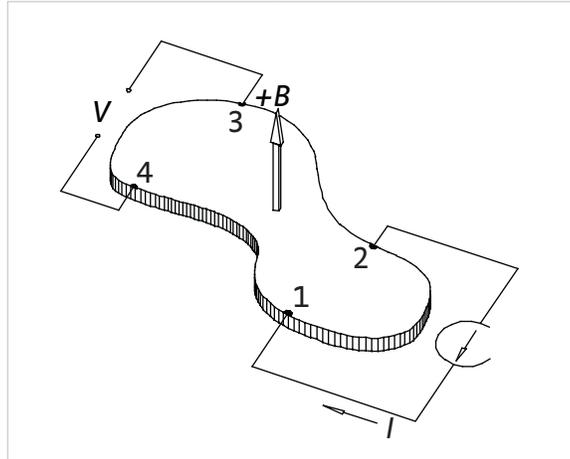
FIGURE 1-3 *Measuring voltage*

1.5.2 Field Hall System of Units

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

Quantity	Symbol	SI	=Factor X	Laboratory
Carrier concentration	n, p	m^{-3}	10^{-6}	cm^{-3}
Charge	q, e	C	1	C
Current	I	A	1	A
Hall coefficient	R_H	m^3/C	10^6	cm^3/C
Sheet Hall coefficient	R_{Hsheet}	m^2/C	10^4	cm^2/C
Magnetic induction[1]	B	T	10^4	G
Mobility	μ_H	$m^2/V \cdot s$	10^4	$cm^2/V \cdot s$
Electric potential[2]	v	V	1	V
Resistivity	ρ	$\cdot\Omega$	10^2	$\cdot\Omega\cdot cm$
Sheet resistivity	ρ_{sheet}	$\Omega/\square$	1	$\Omega/\square$
Resistance	R	$\cdot\Omega\cdot$	1	$\cdot\Omega\cdot$

To use this table, 1 SI unit = (factor) × 1 laboratory unit. For example, $1T = 10^4 G$
1. Magnetic induction is also called magnetic field
2. Electric potential is also called voltage

TABLE 1-1 *Unit systems and conversions*

1.5.3 Hall Voltage

When the combination of a magnetic field and a flowing current in a material produces a new voltage, the Hall voltage, it is called the Hall effect. The Hall effect is illustrated in FIGURE 1-4 and can be explained as a long thin material with a current, I, flowing along the length. The current, I, is the total charge per second and is related to the velocity (V_x) by I = neV_x w t, where n is the volume concentration of the carriers in the material and V_x is the velocity of the carriers. If a static (DC) magnetic field is present in the z direction (into the plane of the paper in FIGURE 1-4), then there is a force on the charges given by -eV_xB. This force, called the Lorentz force, pushes the carriers along the curved lines in FIGURE 1-4.

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

$$V_H = \frac{IB}{tne}$$

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

The result that the Hall voltage is proportional to the magnetic field is the basis for Hall magnetic field sensors. In our application, we turn this around and use the Hall effect and the known magnetic field to study the properties of the materials.
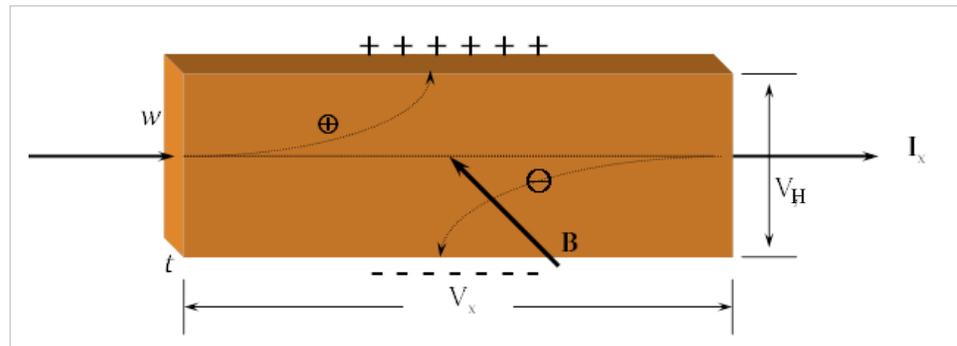
FIGURE 1-4   *Hall effect*

1.5.4 Resistivity

The resistivity of a material does not depend on the size or shape of the sample. It also does not depend on the position of electrical contacts used in the measurement. The fact that resistivity is independent of these properties complicates the measurement. Over the years, many protocols have been developed to meet these requirements, the most common being for van der Pauw (section 1.5.6.3.2).

1.5.5 Hall Measurement Optimization

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

This section identifies several factors that must be considered when optimizing a Hall measurement to separate the desired signals from the unwanted signals. It then references various sections within the manual that explains these factors. Many of the factors involve significant trade offs in sample preparation complexity, equipment cost, and measurement time. This section also highlights many of the features of the MeasureReady® M91 FastHall™ measurement controller to help optimize Hall measurements for a wide variety of samples, along with the dominant error sources that make them necessary.

1.5.5.1 Sample Type and Structure

A simple, square van der Pauw sample structure is the most common structure, and it is adequate for most materials. Section 1.5.6.1 describes how some more complex van der Pauw structures can reduce uncertainty especially when it is difficult to control the exact contact size and location. Similar information for Hall bar samples is given in section 1.5.7.1. The M91 supports two of the most common sample types: van der Pauw and Hall bar. There are significant advantages and disadvantages to each type as described in section 1.5.6.4 and section 1.5.7.4.

1.5.5.2 Current Reversal

Hall voltage measurements suffer from all of the unwanted voltages present in typical resistance measurements, in addition to those that arise in the presence of magnetic field (section 1.5.5.4).

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

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

The desired voltage is proportional to the excitation current magnitude and polarity. The unwanted signals mentioned above are not proportional to current. Current reversal provides a straight forward method for separating the desired signals from the undesired signals.

1.5.5.2.1 Nernst Effect Voltage (V_N)

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

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

1.5.5.2.2 Righi-Leduc Voltage (V$_R$)

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

1.5.5.3 Field Magnitude

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

1.5.5.4 Field Reversal

DC Hall measurements require field reversal. Hall voltage is proportional to the magnetic field magnitude and polarity. Some unwanted signals are not proportional to field. This allows a straight forward method for separating the desired signals from those undesired signals—field reversal.

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

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

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

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

$$V_+ = V_H + V_M$$

If field is reversed the measured voltage (V$_-$) is:

$$V_+ = -V_H + V_M$$

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

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

Several other unwanted voltages depend on the sample temperature, temperature gradients and magnetic field. Many can be eliminated by a combination of current and field reversal, but others cannot. One example that cannot be eliminated in one of these ways is the Ettingshausen effect voltage (section 1.5.5.4.1).

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

This voltage is also present in the final measured voltage. The M91 measures the sum of the Hall voltage and the Ettingshausen effect voltage. The user must determine if the Ettingshausen voltage is small for their samples.

1.5.5.5 Geometry Averaging

Measurement uncertainty can result if a sample is not homogeneous. By definition, for a homogeneous sample, the voltage $V_{ij,kl}$ that is measured is equal to the voltage $V_{kl,ij}$ measured with the current and voltage leads interchanged. For non-homogeneous samples, the best approximation that can be made is to average these two voltages. In Hall measurements, this is called geometry averaging. It is implemented in both Hall voltage and resistivity measurements. The exact implementation is dependent on the sample structure (section 1.5.5.1). Geometry averaging is available via the M91 and MeasureLINK™-MCS software.

1.5.5.6 Measurement Averaging

Measurement averaging is available via the MeasureLINK™-MCS software. Measurement averaging averages individual measurements used in the derivation of Hall measurement results. It can reduce uncertainty and improve resolution by rejecting environmental noise, system noise, and sample noise. The improvement depends on the signal-to-noise ratio of the measurement configuration, and the number of samples averaged. Averaging more samples requires longer measurement time.

1.5.6 Van der Pauw Samples

The van der Pauw structure is probably the most popular Hall measurement structure, primarily because it requires fewer geometrical measurements of the sample. In 1958, van der Pauw[1] solved the general problem of the potential in a thin conducting layer of arbitrary shape. His solution allowed resistivity measurements to be made on any sample of uniform thickness, provided that the sample was homogeneous and there were no physical holes in it. All that is needed to calculate sheet resistivity or carrier concentration is four point contacts on the edge of the surface (or four line contacts on the periphery); an additional measurement of sample thickness allows calculation of volume resistivity. These relaxed requirements on sample shape simplify fabrication and measurement in comparison to Hall bar techniques.

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

1.5.6.1 Structures of van der Pauw Samples and Their Errors

The structure of a practical van der Pauw sample is very similar to the ideal structure shown in FIGURE 1-5. Over the years, many variations of the structure have been developed to control and quantify the errors associated with finite contact sizes. We can summarize some of these effects here.
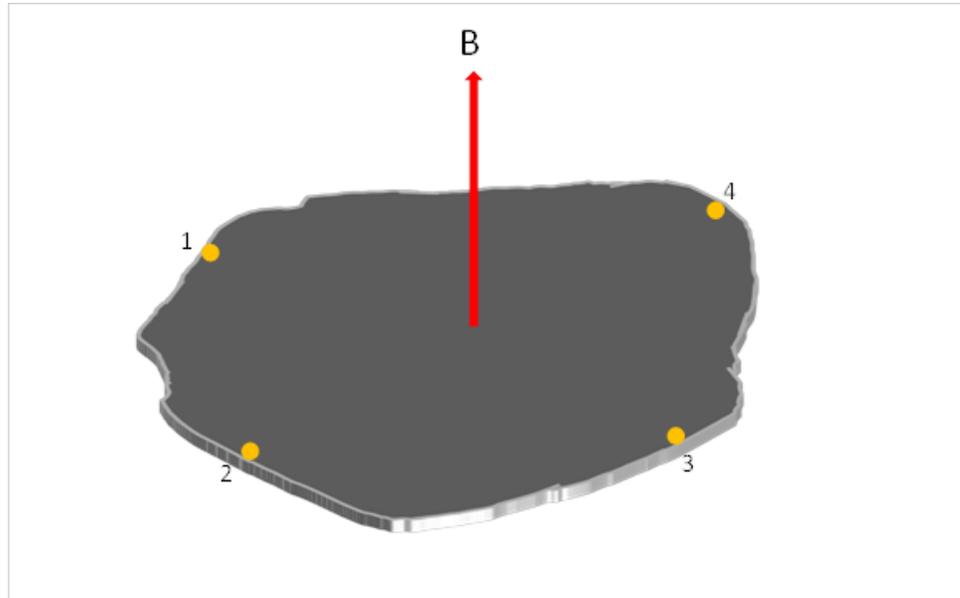
FIGURE 1-5   *Four point contacts*
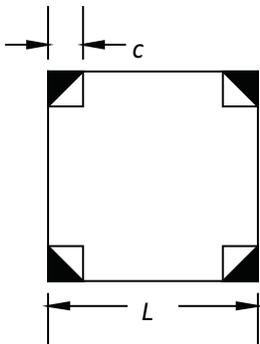
FIGURE 1-6   *Square structure*

1.5.6.1.1 Square Structures

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

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

---

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

1.5.6.1.2 Circular Structures

Circular van der Pauw structures (FIGURE 1-7) fare slightly better. Van der Pauw[1] gives a correction factor for circular contacts of

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

per contact, which results in a correction of $\Delta\rho/\rho$ = -1% for (c / l) = ⅙ for four contacts. For the Hall voltage, van der Pauw[1] gives the correction

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

per contact. At (c / l) = 1/6, this results in a correction of 13% for four contacts.
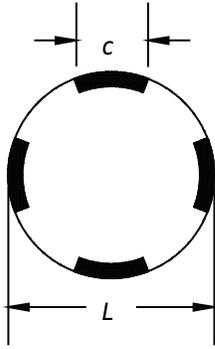
FIGURE 1-7 **Circular structure**

1.5.6.1.3 Cloverleaf Structures

Van Daal[1] reduced these errors considerably (by a factor of 10 to 20 for resistivity, and 3 to 5 for Hall coefficient) by cutting slots to turn the sample into a cloverleaf (FIGURE 1-8). The cloverleaf structure is mechanically weaker than the square and round samples unless it is patterned as a thin film on a thicker substrate. Another disadvantage is that the active area of the cloverleaf is much smaller than the actual sample.
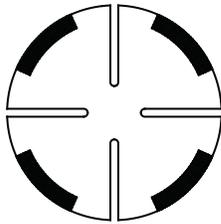
FIGURE 1-8 **Cloverleaf structure**

1.5.6.1.4 Greek Cross Structures

One of the best van der Pauw geometries to minimize finite contact errors is the Greek cross (FIGURE 1-9). Its advantage over simpler van der Pauw structures is similar to placing Hall bar contacts at the ends of arms. David and Beuhler[2] analyzed this structure numerically. They found that the deviation of the actual resistivity ρ from the measured value ρ_m complied with this equation:

$$E = 1 - \frac{\rho}{\rho_m} = (0.59 \pm 0.006\ \exp[-(6.23 \pm 0.02)\frac{a}{c}]$$
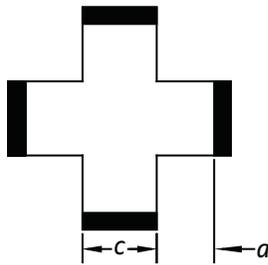
This is a very small error: for c / (c + 2a) = 1/6, where c + 2a corresponds to the total dimension of the contact arm, the error is about 10^{-7}.

Hall coefficient results are substantially better. De Mey[3] has shown that

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

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

FIGURE 1-9 **Greek cross**

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

1.5.6.2 Ideal Measurements of Samples with van der Pauw Structure

This section presents the theory of Hall measurements and resistivity measurements on ideal van der Pauw samples. Ideal measurements means perfect 2D uniform samples with four point contacts on the edges, as shown in FIGURE 1-5. The contacts are numbered in the counterclockwise direction. The voltmeter and current source used are assumed to be perfect. In section 1.5.6.3 these restrictions will be relaxed and the measurement in real materials with real instruments will be described.

1.5.6.2.1 Hall Voltage Measurements on van der Pauw Samples
In the ideal van der Pauw structure, to measure Hall voltage, connect the current source across one diagonal and measure the voltage between the other diagonal contacts.

$V_H = V_{31,42} = V_{42,13}$

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

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

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

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

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

1.5.6.3 Calculations for van der Pauw Samples

Section 1.5.6.3.1 and section 1.5.6.3.2 describe the Hall voltage and resistivity calculations for van der Pauw samples.

1.5.6.3.1 Hall Voltage Calculations for van der Pauw Samples
The Hall voltage is calculated from the current reversed (section 1.5.5.2), field reversed (section 1.5.5.4), geometry averaged (section 1.5.5.5) voltage. The two geometries used in the average are the current reversed, field reversed voltage between contact 4 and 2 with the current applied between contacts 1 and 3 and the field reversed voltage between contacts 1 and 3 with the current applied between contact 4 and 2:

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

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

1.5.6.3.2 Resistivity Calculations for van der Pauw Samples
In section 1.5.6.2.2 the resistivity of an ideal van der Pauw structure was defined as

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

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

As explained in section 1.5.5.2, using current reversal will minimize errors associated with instrumentation offsets and thermoelectric voltages. When the current reversal method is applied to the resistivity measurement, the resistivity is calculated by:

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

As explained in section 1.5.5.5, geometry averaging is used to reduce material inhomogeneous effects in the measurement. The M91 measures the resistivity in both configurations and averages the result. The first measurement is:

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

The second measurement is:

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

The best estimate of the resistivity then, is:

$$\rho = \frac{\rho_A + \rho_{AB}}{2}$$

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

1.5.6.4 Advantages and Disadvantages of van der Pauw Structures

The advantages of van der Pauw samples include:

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

The disadvantages of van der Pauw samples include:

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

1.5.7 Hall Bar Samples

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

1.5.7.1 Structures of Hall Bar Samples

The MeasureReady® M91 FastHall™ measurement controller supports two different Hall bar structures. These will be referred to as 1-2-2-1 (FIGURE 1-10) and 1-3-3-1 (FIGURE 1-11).

An ideal six-contact 1-2-2-1 Hall bar structure (FIGURE 1-10) is symmetrical. Contact separations a and b on either side of the sample are equal, with contacts located opposite one another. Contact pairs are placed symmetrically about the midpoint of the sample's long axis. This structure allows two equivalent measurement sets to check for sample homogeneity in both resistivity and Hall coefficient. However, the close location of the Hall voltage contacts to the sample ends may cause the end contacts to short out the Hall voltage, leading to an underestimate of the actual Hall coefficient. While the 1-2-2-1 Hall bar structure is included in the American Society of Testing and Materials (ASTM) Standard F76, the contact numbering given here differs from the standard.
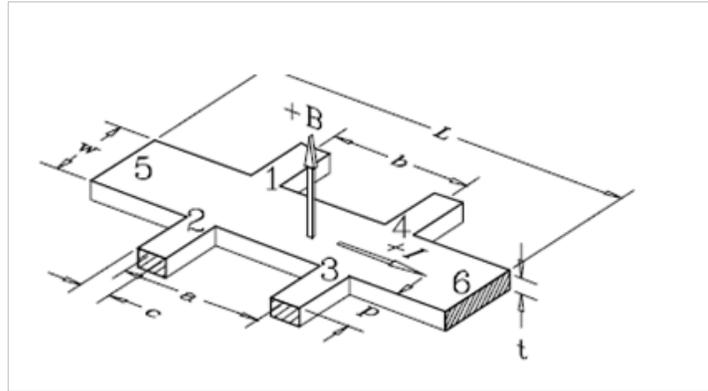
FIGURE 1-10   *1-2-2-1 Hall bar structure*

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

The eight-contact Hall bar attempts to combine the homogeneity checks possible with the 1-2-2-1 six-contact geometry and the benefit of measuring the Hall voltage in the center of the sample. It allows two resistivity measurements compare for homogeneity, but only one Hall voltage measurement. The 1-2-2-1 six-contact measurements can be made using an eight-contact Hall bar, simply by moving the electrical connections to the appropriate points. The eight-contact Hall bar geometry is included in ASTM Standard F76, but the contact numbering given here differs from the standard.
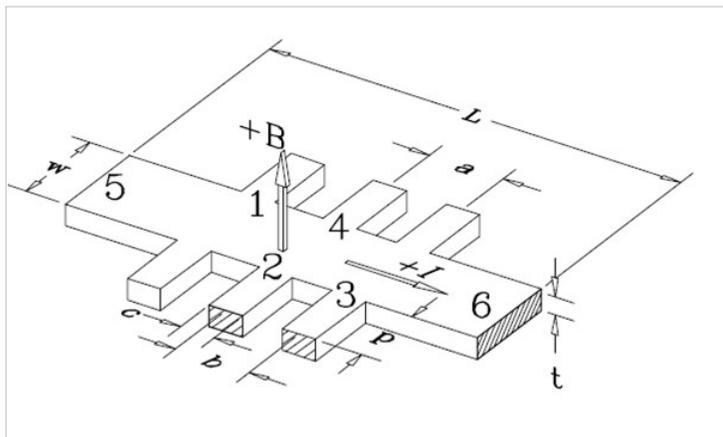
FIGURE 1-11   *1-3-3-1 Hall bar structure*

Geometrical error sources in the Hall bar arrangement are caused by deviations of the actual measurement geometry from the ideal of a rectangular solid with constant current density and point-like voltage contacts.
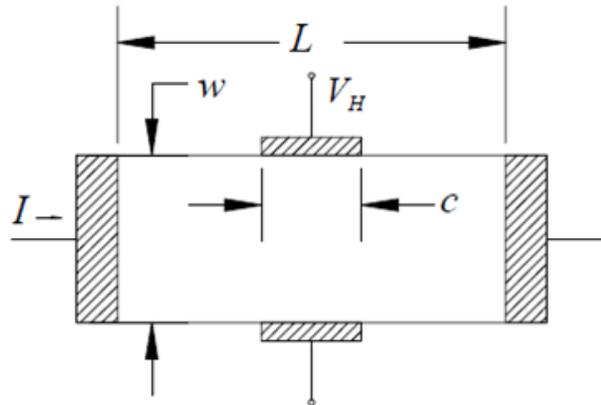
*FIGURE 1-12 **Hall bar with finite voltage contacts***

The first geometrical consideration with the Hall bar is the tendency of the end contacts to short out the Hall voltage. If the aspect ratio of sample length to width (l / w = 3), then this error is less than 1%[1]. Therefore, it is important l / w ≥ 3.

The finite size of the contacts affects both the current density and electric potential in their vicinity, and may lead to fairly large errors. The errors are larger for a simple rectangular Hall bar than for one in which the contacts are placed at the end of arms.
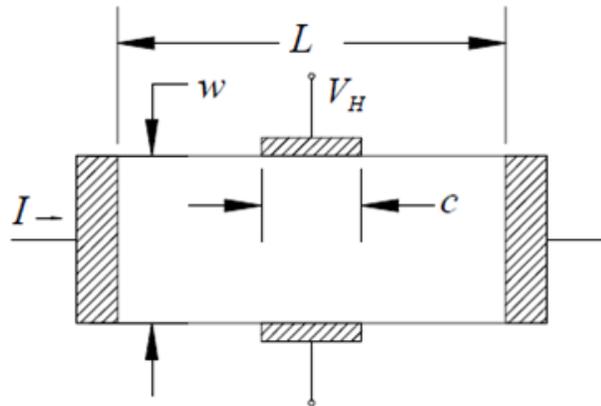
FIGURE 1-13

For a simple rectangle, FIGURE 1-13, the error in the Hall mobility can be approximated (when µB << 1) by:[2]

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

1. Chwang, R., Smith, B.J. and Crowell, C.R., "Contact size effects on the van der Pauw method for resistivity and Hall coefficient measurement", Solid-State Electron. 17 (Dec. 1974) 1217 – 1227.
2. Perloff, D.S., "Four-point probe sheet resistance correction factors for thin rectangular samples". Solid-State Electron. 20 (Aug 1977) 681 – 687.

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

c/w = 0.2, then $\dfrac{\Delta\mu_H}{\mu_H} = 0.13$, which is certainly a significant error.

Reduce the contact-size error to acceptable levels by placing contacts at the ends of contact arms (FIGURE 1-14)[1]. The following aspect ratios yield small deviations from the ideal: $p \approx c,\ c \leq w/3,\ l \geq 4w$.
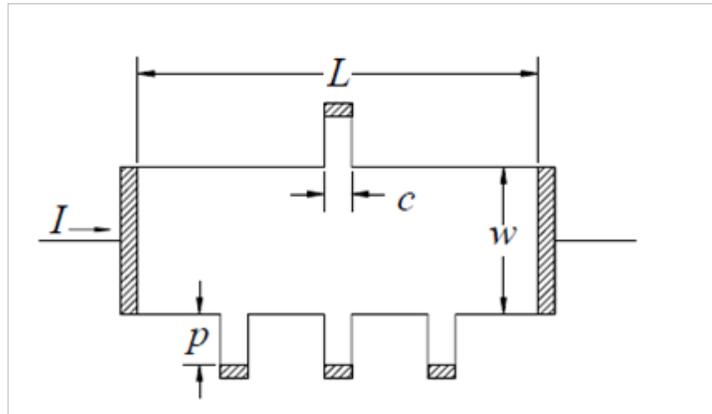
FIGURE 1-14 **Contacts at the end of the contact arms**

1.5.7.2 Ideal Measurements of Samples with Hall Bar Structure

A typical Hall bar is shown in FIGURE 1-10. In a Hall bar, the current source is always connected to contacts 5 and 6. The voltage can be measured between any of the four contacts on the sides of the Hall bar.

1.5.7.2.1 Hall Voltage Measurements on Hall Bar Samples
In the ideal Hall bar structure, the Hall voltage is the voltage between contacts 3 and 4 or contacts 2 and 1.

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

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

1.5.7.2.2 Resistivity Measurements on Hall Bar Samples
The resistivity can be calculated from:

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

where w is the width of the Hall bar, t is the thickness of the Hall bar and a is the center-to-center distance between contacts 2 and 3.
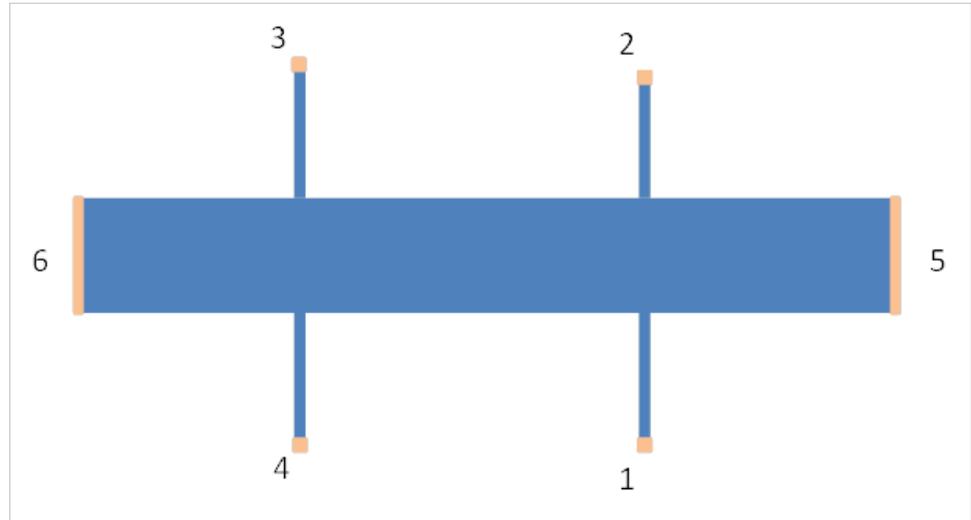
FIGURE 1-15

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

1.5.7.3 Calculations for Hall Bar Samples

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

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

- *Current reversal:* as explained in section 1.5.5.2, using current reversal will minimize the errors associated with instrumentation offsets and thermoelectric voltages. For Hall bar geometries, the current is only applied to contacts 5 and 6 so current reversal means interchanging contact 5 and 6.
- *Field reversal:* as explained in section 1.5.5.4, measuring the Hall voltage, and plus and minus fields, and subtracting the results removes many errors due to material properties and contact placement.
- *Geometry averaging:* in section 1.5.5.5., geometry averaging was defined as the average of two measurements by interchanging the current source and voltmeter. Since in the Hall bar measurement, the current source is always on contacts 5 and 6, this definition of geometry averaging does not apply.
  - For the Hall bar 1-2-2-1 geometry, averaging for the Hall voltage is defined as the average of the voltage measured across contacts 1 and 2, and the voltage measured across contacts 3 and 4. This average removes some of the effects of any non-homogeneity in the sample.
  - For the Hall bar 1-3-3-1 geometry, averaging is not defined and this step is skipped.

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- For Hall bar sample 1-2-2-1, the Hall voltage is:

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

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

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

1.5.7.3.2 Resistivity Calculations for Hall Bar Samples

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

- *Current reversal:* as explained in section 1.5.5.2, using current reversal will minimize errors associated with instrumentation offsets and thermoelectric voltages. For the Hall bar structure, the current is only applied to contacts 5 and 6 so current reversal means interchanging contact 5 and 6.
- *Geometry averaging:* in section section 1.5.5.5, geometry averaging was defined as the average of two measurements by interchanging the current source and voltmeter. Since in the Hall bar measurement, the current source is always on contacts 5 and 6, this definition of geometry averaging does not apply.

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

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

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

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

1.5.7.4 Advantages and Disadvantages of Hall Bar Structure

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

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

1.6 Materials

- *Solar cells:* OPVs, a:Si, uSi, CdTe, CuInGaSe (CIGS)
- *Organic electronics:* OTFTs, Pentacene, Chalcogenides, OLEDs
- *Transparent conducting oxides:* InSnO (ITO), ZnO, GaZnO, InGaZnO (IGZO)
- *III-V semiconductors:* InP, InSb, InAs, GaN, GaP, GaSb, AIN based devices, high electron mobility transistors (HEMTs) and heterojunction bipolar transistors
- *II-VI semiconductors:* CdS, CdSe, ZnS, ZnSe, ZnTe, HgCdTe
- *Wide bandgap materials:* GaN, GaO, AlN, BN, doped diamond
- *Elemental semiconductors:* Ge, Si on insulator devices (SOI), SiC ,SiGe , based devices: HBTs and FETs
- *Dilute magnetic semiconductors:* GaMnAs, MnZnO
- *Other conducting materials:* Metal oxides; organic and inorganic conductors
- *Magnetoresistors (MR):* MR, Giant-MR, Tunneling-MR, and Colossal-MR devices
- *2D materials:* graphene
- *High temperature superconductors*

1.7 Direct and Derived Measurements

- Hall voltage
- Resistivity
- Hall coefficient
- Carrier type/concentration/density
- Hall mobility
- Magnetotransport

1.8 Application Software

The MeasureReady® M91 FastHall™ measurement controller includes Lake Shore's MeasureLINK™-MCS software. This is a Windows application program which includes a scripting function that allows users the ability to use predefined scripts for measuring or writing their own scripts for custom measurements. See section 3.4 for more details.

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1.9 Configuring Measurements

A variety of measurement options are available to enable you to configure the M91 FastHall™ measurement controller for best performance with your samples and their characteristic properties. The firmware for the M91 can be updated using the Ethernet connection on the M91, making it easy to keep the M91 up-to-date with the latest firmware.

The high resistance option increases the resistance range from 10 MΩ to 200 GΩ. This option is field-installable at any time.

1.9.1 Standard Input Parameters

It is recommended that the following parameters be set to default, unless an experienced user is operating the instrument.

- *Excitation Measurement Range: T*he excitation measurement range corresponds to the range that measures the excitation. In most cases it is the same range as the excitation range. Users should set this parameter to AUTO under typical cases.
- *Resistivity:* The resistivity parameter is required to run a FastHall™ or DC Hall measurement if the user wants the mobility. Otherwise, the resistivity parameter can be set to default, which omits the resistivity parameter. The results will then omit the mobility calculations.
- *Field:* A FastHall™ or DC Hall measurement requires the value of the field the sample is subjected to during the measurement. Measure the field prior to running the measurement. No field reversal is required. The entered field value will be used for both +B and -B calculations.
- *Field Reversal:* This option is available to run a DC Hall measurement without field reversal. This essentially runs "half" of the DC Hall measurement, up until the field would be typically reversed. This option is available for customers who wish to take anomalous Hall effect measurements, for example.

1.9.2 Advanced Input Parameters

The following parameters can be used for in-depth measurement setup.

- *Sample to Minimum SNR:* The FastHall™ command allows the user to set their minimum desired signal-to-noise ratio (SNR). The instrument will ramp up its sampling until the user specified SNR is reached, or it will notify the user it cannot reach the minimum SNR criteria. The user does not have to figure out how many samples to take to meet their SNR criteria.
- *Blanking time:* The blanking time is the time the instrument waits before taking a measurement on each sample point. High resistances require a longer blanking time.
- *Voltage Compensation Samples:* This parameter relates to a FastHall™ measurement and is only for users who have the high resistance option. The parameter allows the user to specify the number of points to sample over when using voltage excitation, to match the current measurements of the various contacts.

1.9.3 Mobility Range

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

The M91 FastHall™ measurement controller combines the best of both DC and AC field measurement capabilities, the result of which is the widest mobility range of any commercially available HMS. For van der Pauw samples, the field reciprocity theorem can be used to remove the requirement for field reversal. This can extend the mobility range of the DC field measurements to as low as 0.001 cm^2/(V s). For Hall bar samples (where the field reciprocity theorem does not apply), traditional DC field methods can be used for mobility to 1 cm^2/(V s).

1.9.4 Resistance Range

Along with Hall mobility and other sample parameters, resistance measurements are one of the fundamental building blocks that define the capabilities and performance specifications of your M91. In order to enable measurement of the broadest range of materials, it is critical that your system be capable of measuring a very wide range of resistances.

Like the mobility range, the M91 offers the widest possible resistance range. The M91 takes great care in controlling low currents and small voltages present in electron transport systems. While the standard configuration is capable of measuring resistances from 0.5 MΩ to 10 MΩ, resistance measurement options allow you to measure resistances all the way down to 10 µΩ and as high as 200 GΩ when working in DC fields. The high end is limited to 8 GΩ when working in AC field. This wide resistance range ensures you can study the broadest range of materials.

1.9.5 Magnet Configuration

The M91 FastHall™ measurement controller is designed to work with any magnet system including:

- ■ Permanent magnets
- ■ Electromagnets
- ■ Superconducting magnets
- ■ Pulsed magnets

FastHall™ technology eliminates the need for magnetic field reversal when measuring van der Pauw samples.

1.10 Specifications

For specifications, see: https://www.lakeshore.com/M91/.

Feature	Description
Ambient temperature	23 °C to ± 5 °C at rated accuracy 10 °C to 35 °C at reduced accuracy
Power requirement	100 V to 240 V (universal input), 50 Hz or 60 Hz, 30 VA
Size	217 mm wide × 87 mm high × 369 mm deep (8.5 in × 3.4 in × 14.5 in), half rack
Weight	3.2 kg (7 lb)
Approval	CE mark

TABLE 1-2 **Key specifications**

1.11 Safety Summary and Symbols

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.

The MeasureReady® M91 FastHall™ measurement controller 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.

- Indoor use
- Altitude to 2000 m
- 23 °C ± 5 °C at rated accuracy
- 10 °C to 35 °C at reduced accuracy, <65% relative humidity non-condensing
- Overvoltage category II
- Pollution degree 2
- Mains fluctuations up to ±10%

Ground the Instrument
To minimize shock hazard, the instrument is equipped with a 3-conductor AC power cable. Plug the power cable into an approved 3-contact electrical outlet or use a 3-contact adapter with the grounding wire 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.

Ventilation
The instrument has ventilation holes in its side covers. Do not block these holes when the instrument is operating. Ensure that there is 1 in (25 mm) clearance on both sides of instrument after rack mounting.

Do Not Operate in an Explosive Atmosphere
Do not operate the instrument 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 position the instrument so that it is difficult to disconnect the power cord.

Child Safety
This equipment is not suitable for use in locations where children are likely to be present.

Do Not Substitute Parts or Modify Instrument
Do not install substitute parts or perform any unauthorized modification to the instrument. Return the instrument to an authorized Lake Shore Cryotronics, Inc. representative for service and repair to ensure that safety features are maintained. If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

Cleaning
Do not submerge instrument. Clean only with a damp cloth and mild detergent. Exterior only.

Desktop Installation
When installing the instrument in a desktop environment, ensure it is mounted on a flat, level surface.

1.11.1 Electrostatic Discharge

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

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

1.11.2 Identification of Electrostatic Discharge Sensitive Components

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

FIGURE 1-16 *Symbols indicating ESD sensitivity*

1.11.3 Handling Electrostatic Discharge Sensitive Components

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

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

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

1.11.4 Equipment Safety Symbols

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

*FIGURE 1-17 **Safety symbols***

Chapter 2: Installation

2.1 General

This chapter provides general installation instructions for the MeasureReady® M91 FastHall™ measurement controller. Please read this entire chapter before installing the instrument and powering it on to ensure the best possible performance and maintain operator safety. For instrument operating instructions, refer to Chapter 3. For computer interface installation and operation, refer to Chapter 4. Refer to section 6.6 for front and rear panel connector pin-out details.

2.2 Inspection and Unpacking

Inspect shipping containers for external damage before opening them. Photograph any container that has significant damage before opening it. Inspect all items for both visible and hidden damage that occurred during shipment. If there is visible damage to the contents of the container, contact the shipping company and Lake Shore immediately, preferably within five days of receipt of goods, for instructions on how to file a proper insurance claim. Lake Shore products are insured against damage during shipment, but a timely claim must be filed before Lake Shore will take further action. Procedures vary slightly with shipping companies. Keep all damaged shipping materials and contents until instructed to either return or discard them.

Open the shipping container and keep the container and shipping materials until all contents have been accounted for. Check off each item on the packing list as it is unpacked. Instruments themselves may be shipped as several parts. The items included with the M91 are listed below. Contact Lake Shore immediately if there is a shortage of parts or accessories. Lake Shore is not responsible for any missing items if not notified within 60 days of shipment.

If the instrument must be returned for recalibration, replacement or repair, a Return Authorization (RMA) number must be obtained from a factory representative before it is returned. Refer to section 6.8.3 for the Lake Shore RMA procedure.

Items Included with the MeasureReady® M91 FastHall™ measurement controller:
- M91 FastHall™ measurement controller
- Accessory kit:
    - USB Type-A to USB Type-C™ adapter
    - USB Type-A male to USB Type-B male cable, 2 m
    - Two 10-pin terminal block mating connectors, used for digital I/O
    - One 2-pin terminal block connector, used for signal return
- MeasureReady® M91 FastHall™ Measurement Controller Quick Start Guide
- Line power cord

2.3 Front Panel

The MeasureReady® M91 FastHall™ measurement controller has a 5 in capacitive touch, color TFT display with LED backlight, which is used to display relevant output settings and the instrument state.

I NOTE **No measurements can be started from the front panel screen; it is used only to display high-level measurement results.**
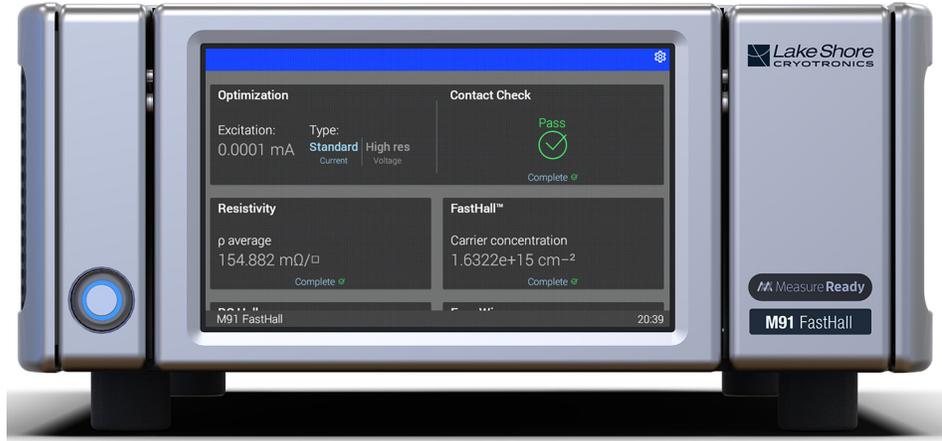
*FIGURE 2-1 **Front panel***

	Connector	Description
1	Power button	The power button puts the instrument into sleep mode.
2	TiltView™ touchscreen	The screen adjusts from a 0° to a 47° viewing angle, whether mounted in a rack or on a bench top.

*TABLE 2-1 **Front panel connections***

2.3.1 TiltView™ Touchscreen

The TiltView™ feature makes seeing the screen and operating the touch interface comfortable from any angle, even when mounted in a rack. The screen adjusts from a 0° to a 47° viewing angle, whether mounted in a rack or on a bench top.
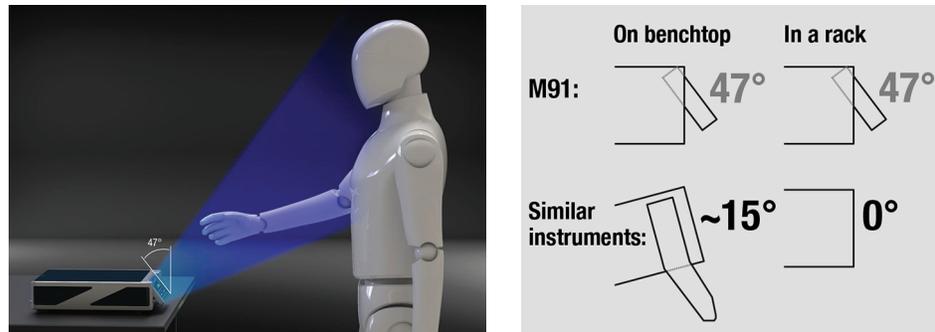
*FIGURE 2-2 **TiltView™ angle comparison***

2.4 Rear Panel

This section provides a description of the M91 FastHall™ measurement controller rear panel connections.

⚠ CAUTION

Always turn off the instrument before making any rear panel connections.
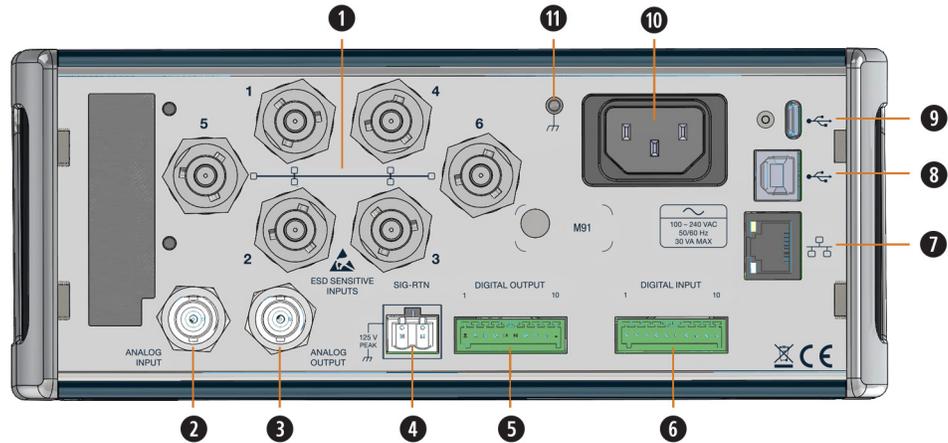
FIGURE 2-3 Rear panel

	Connector	Description
1	Triaxial sample connectors	Connectors for van der Pauw (1-4) or Hall bar sample (1-6).
2	Analog input	Reads voltages in range -10 V to 10 V.
3	Analog output	Settable output voltage between -10 V and 10 V.
4	Signal return	Connects to voltage source for gated Hall measurements.
5	Digital output	General purpose outputs, includes 5 V power.
6	Digital input	General purpose inputs, includes 5 V power.
7	RJ-45 Ethernet interface	The Ethernet interface is provided to allow connection to a computer network.
8	USB Type-B communications interface	The USB interface is provided for serial communication and connects to most modern computers.
9	USB Type-C™ thumb drive interface	Only used for firmware updates.
10	Line input assembly	Power is provided through the line input assembly.
11	Chassis ground connection	Connect the chassis ground to the signal return connector on the rear of the M91.

TABLE 2-2 Rear panel connections

2.4.1 Triaxial Sample Connectors

The rear panel has six triaxial connectors to connect to your sample. For a van Der Pauw measurement, use terminals 1-4. For a Hall Bar measurement, use all 6 terminals. If using a triaxial to BNC adapter, the following configuration must be used:

- Center conductor between the BNC and triaxial connected
- Shields tied together
- Triaxial guard floating

See section 5.3 for a list of accessories which can be purchased from Lake Shore.
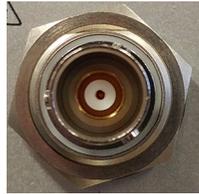
FIGURE 2-4   *Triaxial sample connectors*

2.4.1.1 Triaxial Sample Connectors

- *Center conductor:* signal.
- *Inner shield:* attached to the driven guard.
- *Outer shield:* attached to the return signal.

NOTE

For best performance, it is recommended to leave the guard signal unattached at the DUT end of the triaxial cable.

WARNING

Never connect the guard to any other output, including output low. Doing so may cause damage to the MeasureReady® M91 FastHall™ measurement controller.

2.4.1.2 Cabling Considerations

The M91 FastHall™ measurement controller was designed to use triaxial cabling to connect the instrument to the DUT. If the user wants to make their own cabling, the following items should be kept in mind in order to maintain signal quality and keep noise to a minimum:

- The M91 has two "grounds". The first and most obvious is the chassis which is power line ground for safety to the user. The second is output low, which is also referred to as "source common." It is isolated from the chassis ground. However, a 1 MΩ resistor and 22 nF connect the two together, loosely.
- It is optional whether or not to connect output low to chassis, depending on the application. In many cases, connecting output low to chassis is the simplest way to use the device. However, the isolation allows for a grounding scheme that avoids ground loops from multiple connections with other equipment such as the single point ground method for elimination of ground loops.
- When using the output for either voltage or current, the current return path for the signal must always be to output low and never to the chassis itself, regardless of the grounding scheme, to reduce noise to the lowest level.

2.4.2 Analog I/O Summary

The analog I/O is used for triggering control-related equipment.

FIGURE 2-5 *Analog connector*

2.4.2.1 Analog Input

The M91 FastHall™ measurement controller has an analog input that can read voltages between -10 V and 10 V. The safe input voltage range is ± 15 V.

2.4.2.2 Analog Output

The M91 has an analog output that can source voltages between -10 V and 10 V. The analog output's voltage can rise ± 15 V in an overload condition.

2.4.3 Digital I/O Summary

A common use for the digital I/O is to provide positive sample ready indications when the sample is positioned in both 0 field and known field conditions, using a limit switch. Both the digital input and digital output terminals supply a 5 V power supply. The 5 V is able to drive a wide variety of limit switches. The pin assignments can be found in the table below.

2.4.3.1 Digital Input

There are four independent, optically isolated digital inputs. The maximum low-level input voltage is 1 V, and the minimum high-level input voltage is 4 V. The safe input range is -5 V to 32 V.
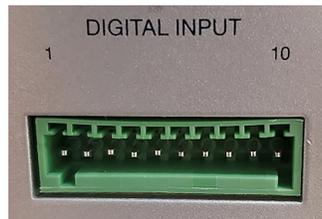
FIGURE 2-6 *Digital I/O port*

	Digital input description
1	Ground
2	+5 V
3	Digital input 4 low
4	Digital input 4 high
5	Digital input 3 low
6	Digital input 3 high
7	Digital input 2 low
8	Digital input 2 high
9	Digital input 1 low
10	Digital input 1 high

TABLE 2-3 *Digital input pinouts*

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2.4.3.2 Digital Output

There are four independent digital outputs which use solid state relays. The maximum output voltage is 32 V, and the maximum output current is 1.5 A.

	Digital input description
1	Ground
2	+5 V
3	Digital output 4 low
4	Digital output 4 high
5	Digital output 3 low
6	Digital output 3 high
7	Digital output 2 low
8	Digital output 2 high
9	Digital output 1 low
10	Digital output 1 high

*TABLE 2-4   **Digital output pinouts***

2.4.4 Line Input Assembly

This section describes how to properly connect the M91 FastHall™ measurement controller to line power. Please follow these instructions carefully to ensure proper operation of the instrument and the safety of operators.

*FIGURE 2-7   **Line input assembly***

2.4.4.1 Power Cord

The M91 includes a 3-conductor power cord that mates with the IEC 320-C14 line cord receptacle. Line voltage is present on the two outside conductors and the center conductor is a safety ground. The safety ground attaches to the instrument chassis and protects the user in case of a component failure.

WARNING

Always plug the power cord into an easily accessible, properly grounded receptacle to ensure safe instrument operation.

CAUTION

Do not position the instrument so that it is difficult to disconnect the power cord.

NOTE

If the power cord is damaged or lost, it must be replaced. Contact Lake Shore for a replacement to ensure proper voltage, current and type of cord.

Chapter 3: Operation

3.1 General

This chapter provides instructions for the general operating features of the MeasureReady® M91 FastHall™ measurement controller.

The M91 is an all-in-one instrument for making Hall effect measurements. It is designed to work with many different sample holders and magnet systems.

The M91 coordinates the collection and analysis of Hall data for many important Hall measurements. These functions are completed by sending a sequence of SCPI commands to the M91 to control the data collection, analysis and for sending back the results.

3.2 Instrument Power

The M91 is powered on by plugging in the power supply. The instrument powers up with the output disabled. The instrument should be powered on for 30 min before using for rated specifications.

Refer to the table below for details on the power button operation.

Power mode	Power button LED	Enter mode by:	Return to ON by:
ON	On	Plug the instrument into an outlet	N/A
SLEEP	Slow pulse	Short press of the power button	Short press of the power button

TABLE 3-1 **Instrument power**

- *ON*: normal operation.
- *SLEEP*: lower power state with main board powered down, but operating system remains active for wake-up.

3.3 Overview

The example commands in this chapter are shown using the Lake Shore software program, MeasureLINK™-MCS. Most functionality is contained in the pre-defined measurements and scripts in MeasureLINK™. For manual control, SCPI commands can be sent by any software program, such as LabView, terminal emulator or a dedicated custom program. This software permits the user to build and send SCPI commands to the M91 FastHall™ measurement controller as well as other system components (e.g., temperature and field controllers) that are typically needed to complete a full measurement.)

The MeasureReady® M91 FastHall™ measurement controller executes a complete Hall measurement. Each of the measurement steps has an associated SCPI command, which allows the user to implement that step in either:

- *Manual SCPI commands:* with manual configuration, the user specifies values for each of the command input parameters directly in the command call.
- *Link SCPI commands:* with link configuration, the user runs the contact check command first, then the subsequent commands use the input parameters determined in the contact check directly, without having to provide them on the command line. This permits the M91 to automatically determine the best excitation and ranging parameters for the measurement conditions, and then use these inputs for subsequent resistivity and FastHall™ commands.

A complete list of SCPI commands can be found in section 4.5.

NOTE **No measurements can be started from the front panel screen; it is used only to display high-level measurement results.**
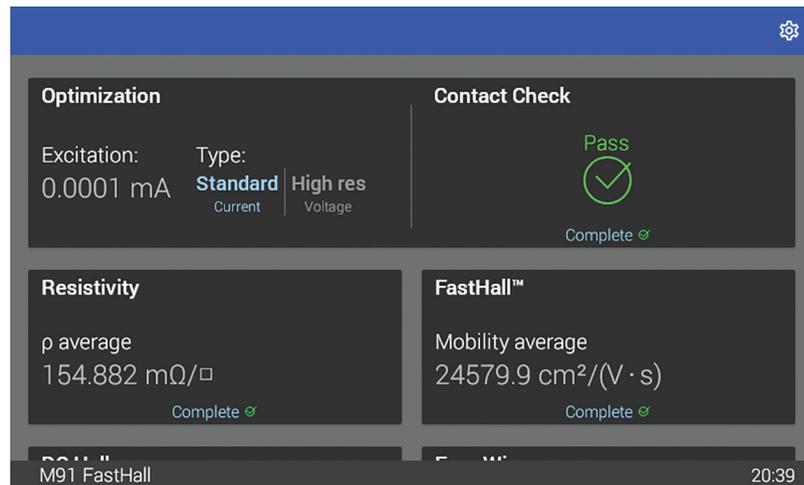
FIGURE 3-1 **Home screen**

3.4 MeasureLINK ™-MCS Software

A license for MeasureLINK™-MCS software is included with the M91. The software can be downloaded at no charge from https://www.lakeshore.com/software/. An activation code is required. If you don't have one, contact Lake Shore. The scripting development license (ML-SDL), which allows users to edit the standard experiments and create new ones, can be purchased from Lake Shore. MeasureLINK software and the scripting development license need to be reactivated annually.

The software allows the user to combine environmental and electrical instrumentation into a coordinated measurement system. The software provides a simple software driver connection for Lake Shore instruments, and a generic driver for third-party instruments. MeasureLINK™ has a built in Visual Basic interpreter that permits simple user Interfaces and measurements, including the ability to construct, save and run data tables, charts and output files.

In addition to MeasureLINK™-MCS, the user can use SCPI commands to communicate with the M91 by using either a serial port or an Ether net connection. The M91 SCPI command set is a high-level collection that focuses on specific Hall measurement functions (for instance "measure resistivity" or "measure Hall"). The M91 controls all the functions required to do the measurement, and all calculations related to the results. For instance, the "measure resistivity" command returns the resistivity and standard error of the resistivity of the sample. The "measure Hall" command returns carrier type, carrier concentration, Hall coefficient, and when coupled with a resistivity measurement, the mobility. All measurements and calculations results include average values and standard errors. These features make it easy to interface with any program or language.

The M91 supports measurement of van der Pauw samples in both the FastHall™ mode and the traditional DC Hall method, and Hall bar samples with the traditional DC Hall method. Please see https://www.lakeshore.com/software/ for software updates, and to download the MeasureLINK™-MCS software manual. See the integrated Help files within the MeasureLINK™-MCS software for specific scripting examples for the M91..
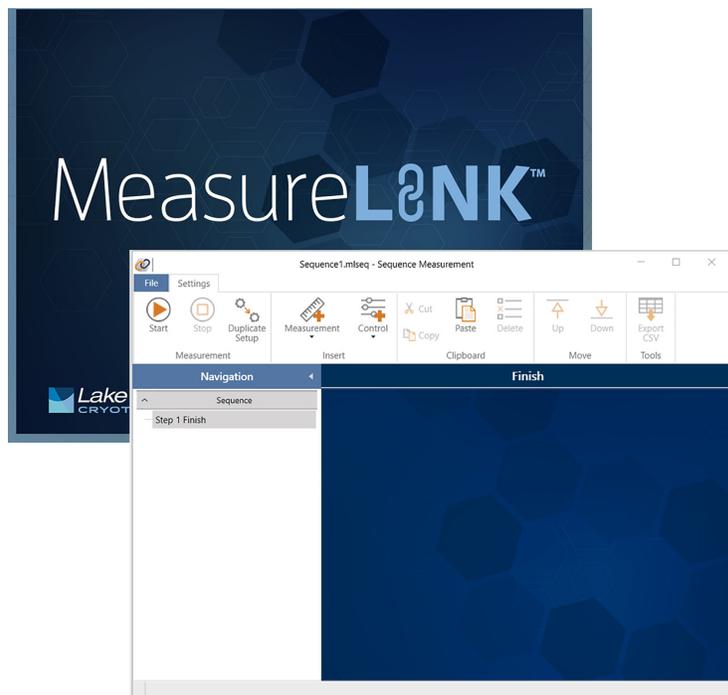
FIGURE 3-2 **MeasureLINK™-MCS software interface**

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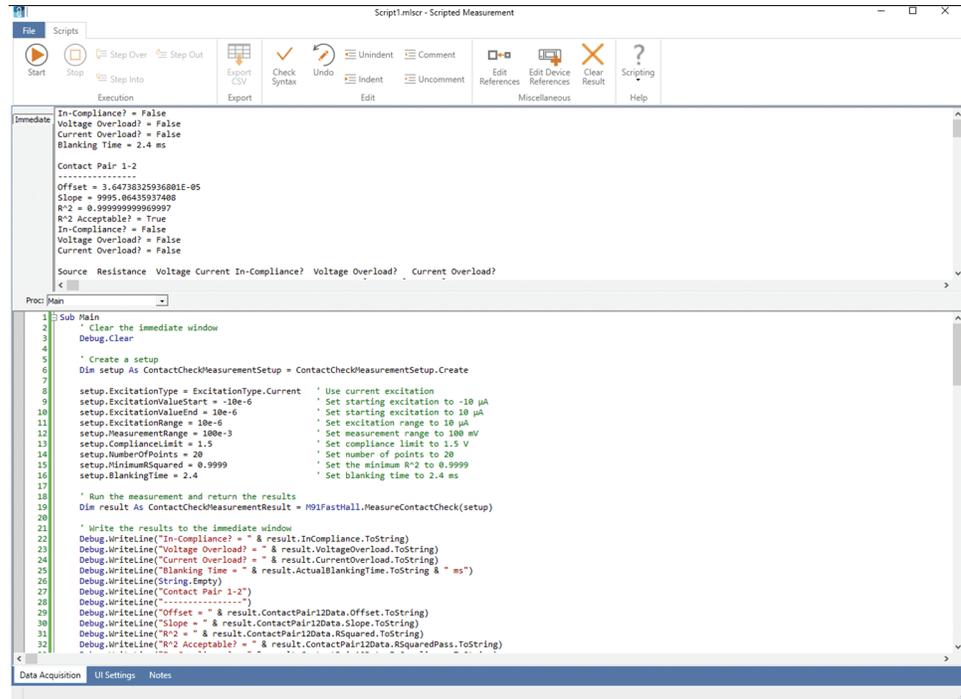
FIGURE 3-3   *MeasureLINK™-MCS software scripting interface*

3.5 Connect to the Instrument

You must use SCPI commands or MeasureLINK™-MCS software to run measurements. Use the command list (see section 4.5) and your favorite serial terminal program (such as Putty or Termite) to communicate with the M91 via the remote interface. The USB connection will be listed as a virtual COM port on your PC. If you are not able to connect, make sure you have the correct COM port selected. You can do this by checking Device Manager:
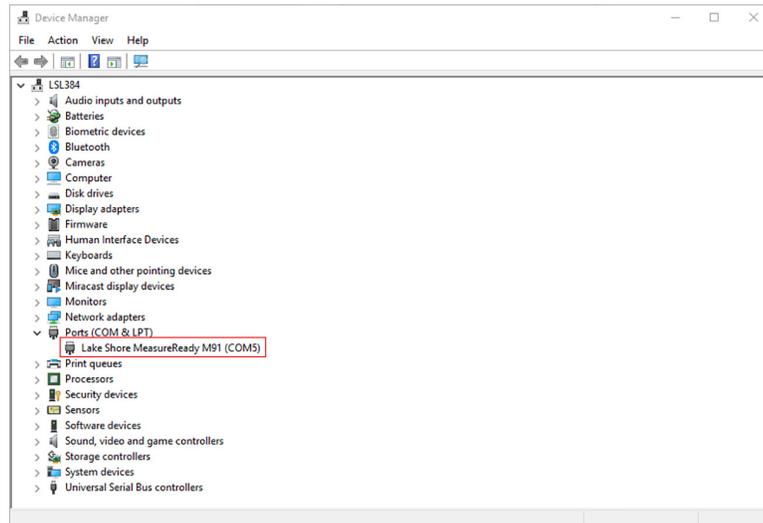
FIGURE 3-4   *Device Manager*

If the instrument is connected and you are still unable to see the M91 in this view, you may need to install the USB driver that can be found on the Lake Shore Software web page: https://www.lakeshore.com/software/. If you have previously downloaded the driver, you may need to update it when adding a new instrument.

3.6 Measurement Connections

3.6.1 Sample Connections

For a van der Pauw sample use the triaxial connectors on the rear panel labeled 1-4 (triaxial connectors 5 and 6 are unused). For a Hall bar sample, use the triaxial connectors 1-6.
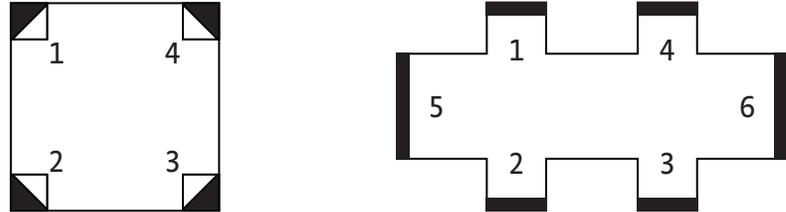
FIGURE 3-5   Left: van der Pauw samples; Right: Hall bar sample

3.6.2 Gate Biasing

When using the Lake Shore MeasureReady® 155 Precision I/V Source as a gate bias supply for gated Hall measurements, normal operation is to connect the Model 155 source common (pin 1 on the digital I/O connector) to the signal return connection on the rear panel of the M91. In the less common situation (where the gate circuit on the sample has a different return than the measurement return), this connection between the 155 and M91 would not be used.
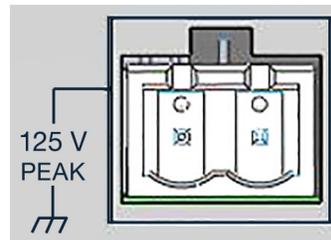
FIGURE 3-6   Instrument ground

3.7 Measurement Structure with SCPI Commands

3.7.1 Starting a Measurement

The MeasureReady® M91 FastHall™ measurement controller executes the following measurements: contact check, resistivity, and Hall measurement. Each time a new measurement is run, it overwrites the existing measurement data of its type (a contact check will overwrite a contact check, but will not overwrite a resistivity measurement). Cycling power or resetting the instrument will clear all data.

All setup parameters related to running a measurement are contained in the measurement-specific start command. This commands sets parameters such as measurement/excitation settings, safety limits, sample properties, and any other required inputs needed in calculating the output.

Each command input parameter is designated as either required or optional. For example, the sample thickness parameter on both the resistivity and FastHall™ commands is listed as an optional parameter. If a thickness is provided, the volumetric resistivity (Ω cm) and carrier concentration (cm^{-3}) are calculated. However, if the parameter is not specified, the sheet resistance ($\Omega/\square$) and sheet carrier concentration (cm^{-2}) are calculated. Note that the Hall mobility calculation doesn't directly depend on the sample thickness, so it remains unchanged. Details on starting each measurement are provided below.

3.7.1.1 Link Measurements

The purpose of linking within measurements is to easily transfer data between measurements. For consistency, all data passed from the instrument is displayed in common lab (SI) units. See section 1.2.1 for further information.

NOTE

This feature is only available for van der Pauw samples.

Follow the steps below to use linking.
1. **Run a contact check measurement (manual or auto)**
   `CCH:START`
   The following parameters are used automatically as inputs to resistivity and FastHall™ when linking is used: excitation type, excitation value, excitation range, measurement range, current limit, and voltage compliance.
2. **Run a resistivity link measurement**
   `RES:START:LINK`
   The resistivity measurement will automatically pull in the parameters listed in step 1. The following parameters will are used automatically used as inputs to FastHall™ linking: resistivity and sample thickness. A contact check must have been completed prior to running a resistivity link measurement.
3. **Run a FastHall link measurement**
   `FAST:START:LINK <enter field value>`
   The FastHall measurement will automatically pull in the parameters listed in steps 1 and 2. A contact check measurement must have been completed prior to running a FastHall link measurement. A resistivity measurement must have been completed prior to the FastHall link measurement to pull in a resistivity value for a full Hall analysis.

NOTE

Only the field value is a required parameter when using the measurement link commands. All other parameters are either pulled in from previous measurements or set to default values. Any of the default values can be manually overwritten.

3.7.2 During the Measurement

During a measurement, the measurement card on the instrument's front panel displays a progress wheel spinning to indicate the measurement is running. Each measurement has a SCPI command to query if the measurement is still running or to abort the measurement. For example, the resistivity query is:

`RESistivity:RUNNing?`

Use these commands to reset the measurement to a not run state, canceling any running measurement. The data stored in the specific command will be cleared:

`CCHeck:RESet`
`FWIRe:RESet`
`FASThall:RESet`
`HALl:RESet`
`RESistivity:RESet`

These commands will also cancel any running measurement, and clear all measurement data.
`*rst`

> **NOTE**
>
> **High resistance samples require a longer blanking time and will experience a longer measurement duration. If the instrument is incorrectly connected (for example, if the instrument is not connected to any sample), measurements may take up to 10 minutes to execute. The reset command (*RST) is useful in this situation.**

3.7.3 View Measurement Results

When a measurement has been completed, the corresponding measurement card on the instrument's interface will update to the latest results. Click the card to view the high-level results. The results are available in a standard SCPI format string or in JSON format. The most readable format is the JSON pretty format (`set pretty=1`), which is available to any query that returns in JSON. There are multiple levels of the results structure to give the user full transparency of the data collected. Below is a summary of how the results are structured.

- *All Results:* Returns all measurement data stored.
  `RESistivity:RESult:JSON:ALL? 1`
  `RESistivity:RESult:STANdard`
- *Summary Level Results:* Returns the measurement results.
  `RESistivity:RESult:JSON:SUMMary? 1`
  `RESistivity:RESult:STANdard:SUMMary?`
- *Data Level Results:* Returns calculations taken for a given sample point.
  `RESistivity:RESult:JSON:DATA? <sample index>, 1`
  `RESistivity:RESult:STANdard:DATA? <sample index>`
- *Raw Results:* Returns the measured voltage, current, and calculated resistance using current reversal for a given contact configuration and sample point.
  `RESistivity:RESult:STANdard:RAW? <sample index>, <contact configuration>`

3.8 Running a Hall Analysis Using SCPI Commands

3.8.1 Step 1: Contact Check

Contact check is required to validate that the physical sample contacts are sufficient for the Hall analysis to be complete accurately over the specified range of excitations. This is done by rotating through either four contact alignments (for van der Pauw samples) or six contact alignments (for Hall bar samples). For each alignment, the excitation is swept through a specified range of values and the response is measured.

The results are fit to a linear function and the figure of merit for the fit (R^2 coefficient) is compared to a pass/fail criteria (typically $R^2 \geq 0.9999$) for each contact pair. View the results from a SCPI command or view the high-level results from the M91 front panel. The front panel displays the R^2 values along with a pass/fail indication and overload or current limit status. Additional parameters are the slope, offset, and the individual IV data points.

> **NOTE**
>
> **Proceeding to resistivity or Hall analysis with poor contact results will likely introduce high bias errors into the results.**

3.8.1.1 Contact Check with Automatic Parameter Optimization

Auto contact check optimizes the instrument's excitation and measurement settings. The instrument will determine if the sample is best suited for current excitation or voltage excitation, if the user has the high resistance option. Users without the high resistance option will only have current excitation available. The M91 will then determine the optimum excitation range, excitation span, and measurement range. The excitation span in auto contact check will span from negative to positive excitation. The instrument's front panel displays the high-level results and indicates that the excitation and measurement settings were optimized.

Example:
The contact check can be run with no parameters. The default selections are:
- *Maximum current:* set to 100 mA
- *Maximum voltage:* set to 10 V
- *Number of points:* set to 11
- *Minimum R^2:* set to 0.9999

These defaults are acceptable for many experiments, but the more general form allows the user to specify the settings. In the example below, the following settings were used:
- *Maximum current:* set to 100 mA
- *Maximum voltage:* set to 10 V
- *Number of points:* set to 21
- *Minimum R^2:* set to 0.99995

```
CCHeck:STARt 100e-3,10,21,0.99995
```
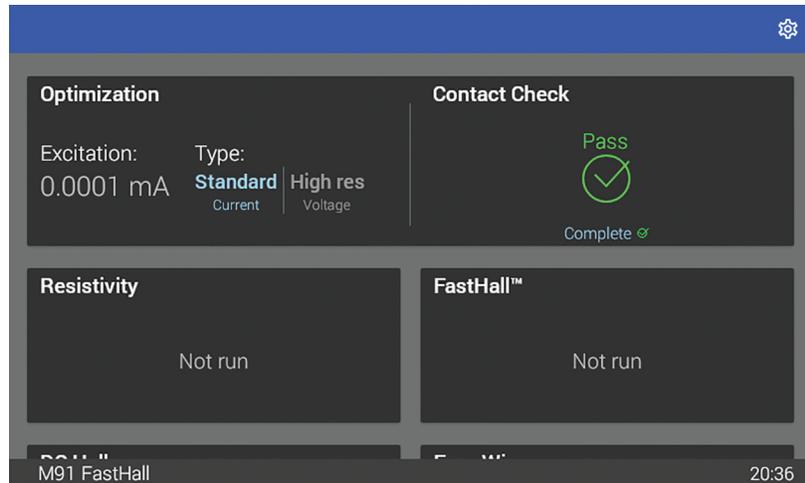
FIGURE 3-7 Contact check with optimization

3.8.1.2 Manual Contact Check

Manual contact check allows the user to specify all input parameters manually.

Example:
The example below runs a contact check using current excitation. 11 points will be taken spanning from +10 μA to -10 μA on the 10 μA range, with the following settings:

- *Measurement range:* set to 100 mV
- *Compliance limit:* set to 10 V
- *Minimum R2:* set to .9999
- *Blanking time:* set to default

```
CCHeck:STARt:MANual CURRENT,10e-6,-10e-6,10e-6,100e- 3,10,
11,0.9999,DEF
```
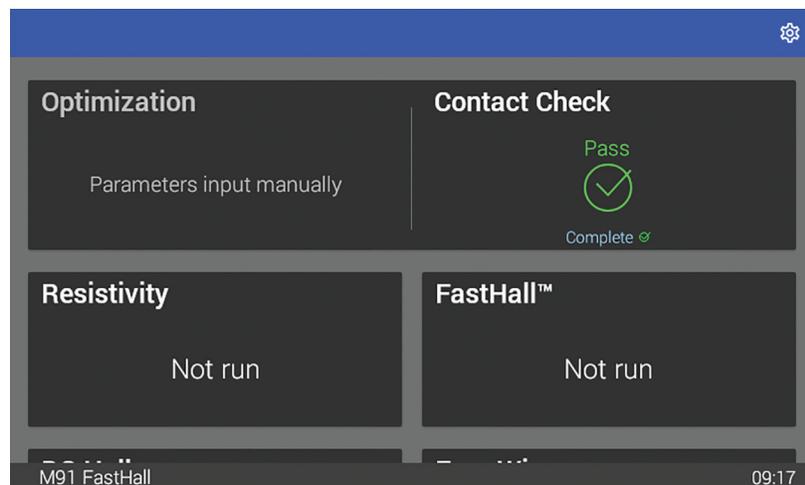

FIGURE 3-8 Manual contact check
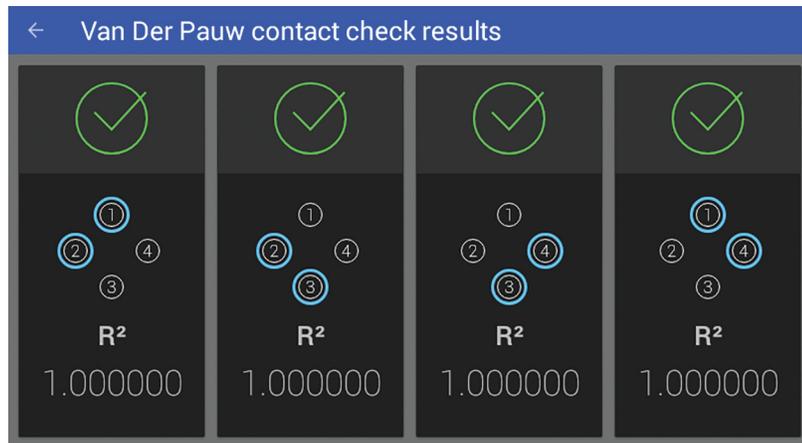
FIGURE 3-9 **Contact Check results**
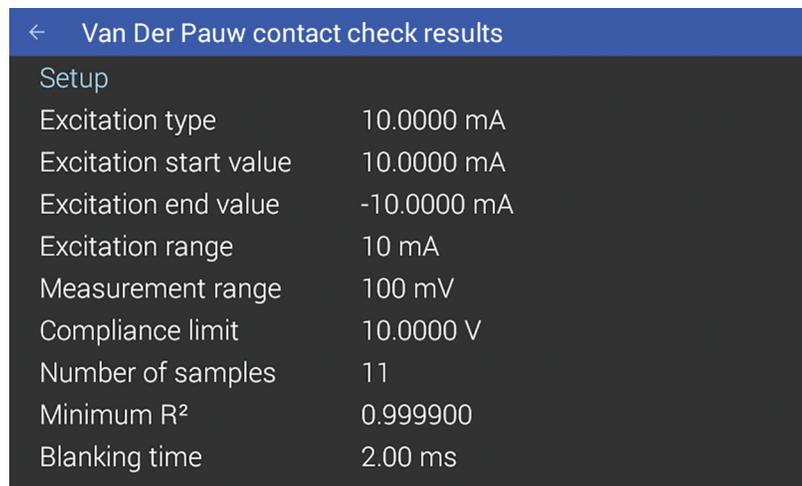
FIGURE 3-10 **Contact Check results**

3.8.2 Step 2: Resistivity

This measurement determines the resistivity of the sample between two adjacent points. In this measurement, the sample should be subjected to zero field. View the results from a SCPI command or view the high-level results from the M91 front panel. Results returned are resistivity, F-value, and geometry dependent values.

For hard to measure samples, it is common to increase the number of independent measurements taken during a single resistivity determination. This permits the standard error to be calculated and reported. The M91 allows two ways of controlling the number of samples collected:

■ Specify the number of samples directly.
■ Specify a minimum signal-to-noise ratio (SNR). Samples are continuously collected until the SNR reaches the specified minimum SNR. A maximum number of samples is also specified to place an upper bound on the number of samples attempted.

3.8.2.1 Manual Resistivity

Example with minimum SNR:
The example below runs a resistivity measurement using the following settings:

■ *Current excitation:* 10 µA on the 10 µA range
■ *Excitation measurement range:* set to AUTO
■ *Measurement range:* set to 100 mV
■ *Compliance limit:* set to 1.5 V
■ 100 samples will be taken
■ *Blanking time:* set to 2.4 ms
■ *Sample thickness:* set to 0
■ *Minimum SNR:* set to 30

```
RESistivity:STARt CURRent,10e-6,10e-6,AUTO,100e-3,1.5,100,
2.4,0,30
```


FIGURE 3-11 **Resistivity**

Example with specified number of samples:
The example below runs a resistivity measurement using the following settings:

■ *Current excitation:* 10 µA on the 10 µA range
■ *Excitation measurement range:* set to AUTO
■ *Measurement range:* set to 100 mV
■ *Compliance limit:* set to 1.5 V
■ 30 samples will be taken
■ *Blanking time:* set to 2.4 ms

- *Sample thickness:* set to 0
- *Minimum SNR:* set to infinity

```
RESistivity:STARt CURRent,10e-6,10e-6,AUTO,100e-3,1.5,30,
2.4,0,INF
```

3.8.2.2 Resistivity with Linked Parameters

The resistivity measurement will automatically pull in the parameters listed in contact check. The following parameters will be automatically used as inputs to resistivity linking: sample thickness. A contact check must be completed prior to running a resistivity link measurement.

The example below runs a resistivity measurement with linked parameters using the following optional settings:
- *Measurement range:* set to 100 mV
- *Sample thickness:* set to 0
- *Minimum SNR:* set to 30
- *Max number of samples:* 100

```
RESistivity:STARt:LINK 100e-3,0,30,100
```

3.8.3 Step 3: Hall Measurement

To complete a Hall measurement, run a FastHall™ measurement (for van der Pauw samples only), or the traditional DC Hall method is available for both van der Pauw and Hall bar samples. See Chapter 1 for more information on Hall theory.

3.8.3.1 FastHall™

The FastHall™ command utilizes the FastHall technology developed by Lake Shore Cryotronics. It permits a full Hall analysis to be completed without performing an actual field reversal step, as with a traditional Hall analysis.

3.8.3.1.1 Manual FastHall™

Example:
The example below runs a FastHall measurement using the following settings:
- *Current excitation:* 10 µA on the 10 µA range
- *Excitation measurement range:* set to AUTO
- *Measurement range:* set to 10 V
- *Compliance limit:* set to 10 V
- *Max number of samples:* 130
- *Field value:* set to 0.5 T
- *Resistivity:* set to 0.1
- *Blanking time:* set to default
- *Number of voltage compensation samples to average:* set to default
- *Sample thickness:* set to default
- *Minimum SNR:* set to default

```
FASThall:STARt CURRent,10E-3,10E-3,AUTO,10,10,.5,30,.1,DEF,
DEF,DEF,DEF
```

FastHall™ results (2018-11-19 at 17:44, 579 ms)

Setup

Field	500.00000 mT
Resistivity (ρ)	100.000 mΩ/□
Excitation current	10.0000 mA
Excitation range	10 mA
Measurement range	10 mV
Compliance limit	10.0000 V
Number of samples	5

Warnings (none)

*FIGURE 3-12 **FastHall Measurement***

3.8.3.1.2 FastHall™ with Linked Parameters

The FastHall measurement will automatically pull in the parameters determined in the contact check step. A contact check measurement must have been completed prior to running a FastHall link measurement. If a resistivity measurement has been run, the resistivity parameters are pulled into the FastHall measurement as well. If no resistivity measurement has been run, the FastHall measurement will not calculate a mobility.

Only the field value is a required parameter when using the measurement link commands. All other parameters are either pulled in from the previous measurements or set to default values. Any of the default values can be manually overwritten.

The example below runs a FastHall measurement with linked parameters using the following settings:

- *User defined field reading:* set to 0.5 T
- *Measurement range:* set to 10 V
- 30 samples will be taken
- *Minimum Hall voltage SNR:* set to default
- *Number of voltage compensation samples to average:* set to default
- *Sample thickness:* set to default

```
FASThall:STARt:LINK 0.5,1,30,DEF,DEF,DEF
```

3.8.3.2 DC Hall

A DC Hall measurement is available for both van der Pauw and Hall Bar samples. DC Hall requires the magnet field to physically change from +B to -B in a Hall measurement.

During a DC Hall measurement, the measurement will pause to allow for the user to manually switch the polarity of their field. This is unique to the DC Hall measurement; no other measurements require a manual field reversal. During the pause, the instrument's front panel will indicate that it is waiting for a continue command. Manually change the polarity of the field, then send the continue SCPI command to have the measurement complete:

```
HAL:CONTinue
```

| NOTE ▷   **DC Hall measurements support manual parameter inputs only.**

3.8.3.2.1 Manual DC Hall

Due to DC Hall requiring the field to be manually reversed, the measurement needs to pause halfway through so the field can be changed. Measure the field the sample is subjected to prior to running a DC Hall measurement, and enter it into the `HAL:STARt` command. View the results from a SCPI command or view the high-level results from the M91 front panel. The output calculates the Hall voltage, carrier density, carrier type, and mobility. Reference the SCPI results for an in-depth view of all the measurement data used in the calculations.

Example:

The command below runs a DC Hall measurement on a van der Pauw sample, using the following settings:

- *Excitation:* set to current, with an excitation of 10 mA on the 10 mA range
- *Excitation measurement range:* set to AUTO
- *Measurement range:* set to 1 V
- *Compliance limit:* set to 10 V
- 100 samples will be taken.
- *Field value:* set to 500 mT
- Field reversal will be implemented
- *Resistivity:* set to 0.1.

`HAL:HBAR:START Current,10E-3,10E-3,AUTO,1,10,100,.5,DEF,0.1`

After the HAL:START command has completed, the display on the M91 will change to "waiting" indicating that the field on the sample is ready to be reversed. Once this is completed, the following command should be issued to the M91 to permit the second part of the measurement to proceed:

`HAL:CONTinue`

←	DC Hall results for VanDerPauw		
Setup			
Field	900.00000 mT		⌄
Resistivity (ρ)	100.000 mΩ/□		
Current	10.0000 mA		
Warnings (none)			⌄
Results			
	Average	Standard error	
Mobility	179.075 m²/(V·s)	0.00330 m²/(V·s)	
Carrier	3.48542e+17 m⁻²	6.41833e+12 m⁻²	

*FIGURE 3-13 **DC Hall Measurement***

3.8.4 Four Wire Measurement

Use four wire measurement to take samples for an IV curve, or to determine settling times.

Example:
The command below measures the resistance between contact pairs 1 and 2 with the following settings:

■ *ContactPoint1:* set to terminal 5
■ *ContactPoint2:* set to terminal 6
■ *ContactPoint3:* set to terminal 3
■ *ContactPoint4:* set to terminal 1
■ *Excitation type:* set to Current
■ *Excitation value:* set to 500 μA
■ *Excitation range:* set to 1 mA
■ *Measurement range:* set to 1 V
■ *Excitation measurement range:* set to 1 mA
■ *Compliance limit:* set to 1.5 V
■ *Blanking time:* set to default
■ *Maximum number of samples:* set to default
■ *Minimum SNR:* set to default
■ *Excitation reversal:* set to excitation reversal

```
FWIRe:STARt 5,6,3,1,CURRent,500e-6,1e-3,1.0,1e-3,1.5,
2.4e-3,100,30,1
```

←	Four wire measurement results	
Setup		
Excitation contact pair	1-2	
Sense contact pair	1-2	⌄
Excitation type	Current	
Excitation value	10.0000 mA	
Warnings (none)		⌄
Results		
Resistance	10.993354 Ω	
Resistance standard error	15.703592 μΩ	
Resistance SNR	700053.45	
Current	10.01633 mA	
Current standard error	5.775908 nA	
Voltage	0.1101130 V	
Voltage standard error	0.0000982 mV	

FIGURE 3-14 **Four wire measurement**

3.9 Advanced Operation

The following sections explain the more advanced features of the MeasureReady® M91 FastHall™ measurement controller.

3.9.1 Digital I/O

The M91 comes equipped with a digital I/O connector for general purpose input/output (GPIO) use, allowing for integration of hardware control or monitoring into any experiment. There are four dedicated inputs, and four dedicated outputs, all referenced to chassis ground. Control and monitoring of the digital I/O pins can only be performed over the remote interface.

3.9.1.1 Configuration

The digital I/O is configured to be able to operate over a wide voltage range. The outputs are relays that give the user a method to control their external environment using the M91. A 5 V power source is available on the digital I/O connector as an additional power supply.

3.9.1.2 Manual Inputs

The M91 can presently only configure its inputs for manual use. However, a SCPI command has been created to set the function of a given input, allowing for future growth. The state of the input pins can be read using the `DIGital:IDATa?` query. The result is a bitwise representation of the logic level presented at the respective inputs (i.e., bit 0 = state of input 1, bit 1 = state of input 2).

Interface Commands: `DIGital:INPut#:FUNCtion`, `DIGital:IDATa`

3.9.1.3 Manual Output

The `DIGital:OUTput#:FUNCtion` command is used to configure a specific output to manual mode. The `DIGital:OSETting` command is used to configure the state of an output pin that is configured for manual mode. When the output is turned on the relay is closed, and when the output is turned off the relay is open.

NOTE

The setting is not applied for a given output if that output is configured for a function other than manual.

IInterface Commands: `DIGital:OUTput#:FUNCtion`, `DIGital:OSETting`

3.9.2 Analog I/O

The M91 comes equipped with an analog input and output allowing for integration of hardware control or monitoring into any experiment. The input is designed to read voltages between -11 V and +11 V. The voltage is read using the `ANALog:INPut?` query. The `ANALog:OUTPut:SETTing` command is used to configure an output between -10 V and +10 V.

3.9.3 Sample Protection

When a measurement is configured to run using current excitation, the user is required to enter the voltage limit the current excitation must stay within, with the intent of protecting the sample under test. The compliance voltage can be set between 1 V and 10 V. When a measurement is configured to run using voltage excitation, the user is required to enter the current limit the voltage excitation must stay within. The current limit can be set between 0 mA and 100 mA.

3.9.4 High Resistance Option (M9-ADD-HR)

The high resistance firmware upgrade enables the MeasureReady® M91 FastHall™ measurement controller to source voltage and measure current, which is an advantage for high resistance samples. The high resistance firmware upgrade enables the user to make measurements on samples greater than 10 MΩ. When in high resistance mode, the excitation changes from current excitation to voltage excitation. Sourcing with a voltage instead of a current removes cable capacitance effects, which is especially critical for high resistances. Contact Lake Shore to purchase this option. See section 6.3.3.2 for instructions on how to send a license key to the instrument.

Blanking time is especially critical. See section 1.9.2 for more information.

3.9.5 Ground Connections

The ground connection provides a convenient place to attach your measurement system to the chassis of the M91. Some care must be used to determine how to make proper connections. Improper connections can increase the noise of your M91 measurements.

Connect the chassis ground to the signal return connector on the rear of the M91. For more information and additional suggestions, refer to the Lake Shore web site https://www.lakeshore.com/.

FIGURE 3-15 *Chassis ground*

3.9.6 System Settings

The System settings menu is provided to view general instrument settings, update firmware, and view legal information containing Communication Certifications and Open Source Software licenses. To find these settings, tap the Settings menu (top left corner of the screen).

3.9.6.1 About

The following fields are displayed on the About tab:
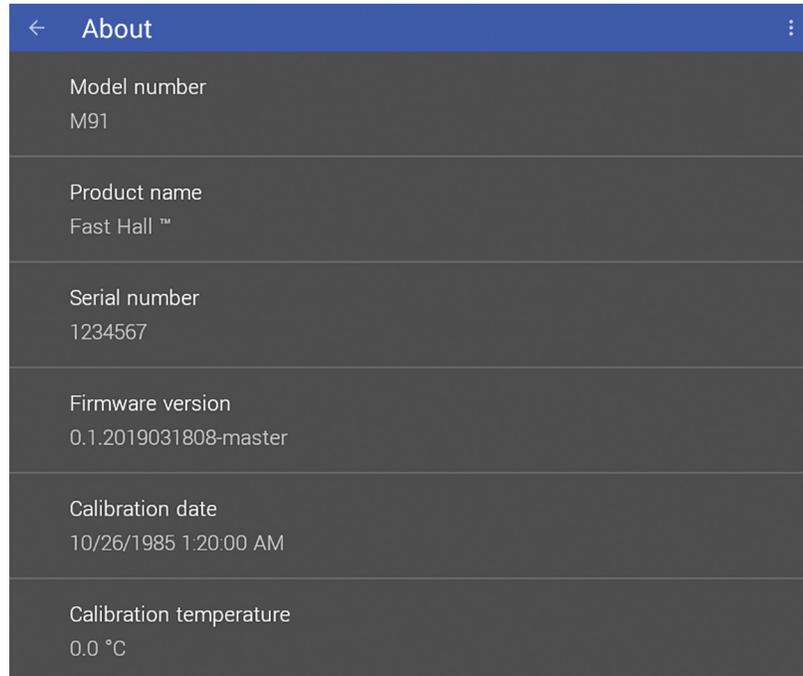
FIGURE 3-16   **System settings: About tab**

Field	Description
Model number	This field displays the model number.
Product name	This field will always display FastHall™.
Serial number	The unique identifier for this specific instrument, assigned during manufacturing.
Firmware version	The semantic version number assigned to the Lake Shore Firmware (LSFW) package presently running.
Calibration date	The date and time the M91 was last calibrated successfully at Lake Shore.
Calibration temperature	The ambient temperature experienced by the M91 at the time of calibration.

TABLE 3-3   **About fields**

3.9.6.2 Connectivity

The following fields are displayed on the Connectivity tab. Touch the enable switch next to each option to change settings:
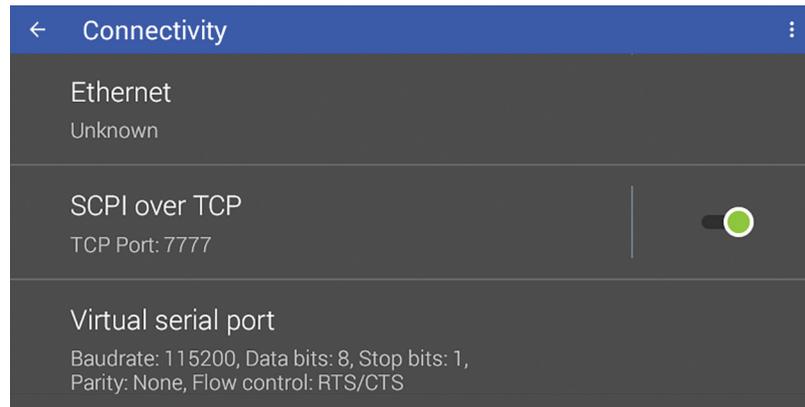
FIGURE 3-17 System settings: Connectivity

Field	Description
Ethernet	Touch the Ethernet box to see IP settings.
SCPI over TCP	Determines whether the M91 will respond to SCPI commands from the Ethernet connection. If this option is turned off, the instrument will only respond to SCPI commands over the USB connection. This feature must be turned on if the GPIB adapter is connected to the M91.
Virtual serial port	Enables serial communications via USB.

TABLE 3-4 Connectivity fields

3.9.6.3 Display and Sound

The front panel display brightness can be adjusted for optimal viewing. The default value should work well in most standard environments, but deviations in room temperature and extreme viewing angles can cause the display brightness to require adjustment for optimal viewing.

As with many touchscreen LED backlit displays, keeping the brightness to a minimum will help to maximize the life of the display. The half-life of the display is rated with a typical value of 30,000 hours. In addition, to help further maximize the life of the display, the M91 implements an auto dimming function when the display has not been touched for a prolonged period of time.

The M91 FastHall™ measurement controller will produce sounds on various presses of the screen as a means to provide feedback to the user that a key press has occurred. The volume setting can be set to 100%, 75%, 50%, 25%, or off.

Interface Command: `SYSTem:BEEPer:VOLume`
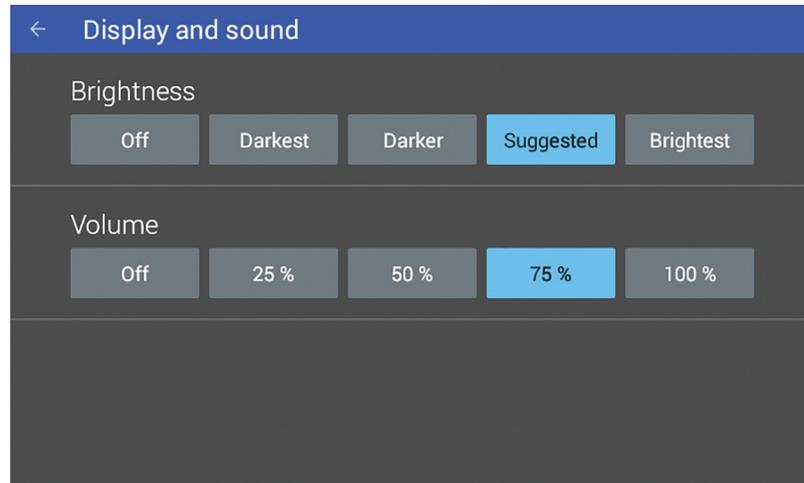
*FIGURE 3-18 **Display and sound***

3.9.6.4 Legal

This screen is available for the user to see the various communication certifications to which the M91 adheres. In addition, the attribution notices for the open source software used in the M91 are listed here.

3.9.6.5 Update

See section 6.3.3 for information on firmware updates.

3.9.6.6 Privacy

If enabled and an internet connection is present, the instrument will periodically send usage statistics and crash reports to identify problems that could be addressed. No personally identifiable information or measurement data is collected or sent with this service.

3.9.6.7 Date/Time

The M91 contains a real-time clock, allowing the current date, time, and time zone to be stored. The time, date and time zone can be set and viewed via the front panel or over the remote interface.

In addition, the M91 has a feature to automatically set its date and time with a network connection.

Interface Commands:
`SYSTem:DATE`
`SYSTem:AUTODATETIME`
`SYSTem:TIME`
`SYSTem:TZONE`
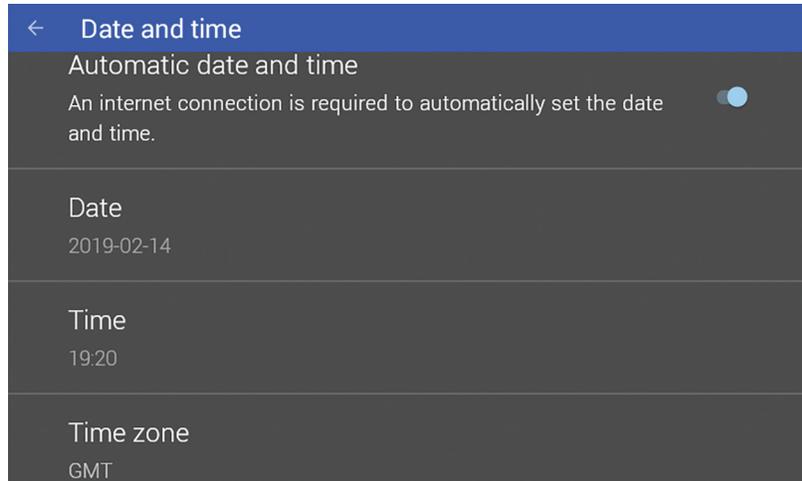
FIGURE 3-19 **Date and time**

3.9.6.8 Factory Reset

This feature resets all instrumentation settings to their defaults. See section 6.3.1.

3.10 Signal Return

The signal return is a connection to the measurement common of the MeasureReady® M91 FastHall™ measurement controller. For example, if the M91 is used as a current source, the current is returned to this point. If the M91 is used as a voltage source, the low side of the voltage source is connected to the signal return. In general, if the source is connected between terminals k and j of the sample, contact j is connected internally to the signal return.

◤Chapter 4: Computer Interface Operation

4.1 General

This chapter provides operational instructions for the remote interface for the Lake Shore MeasureReady® M91 FastHall™ measurement controller. The M91 supports the following remote interfaces for direct user control:

- USB (emulating a serial communications port)
- Ethernet

NOTE ▷ **M91 FastHall™ measurement controllers sold prior to August 2020 also included Wi-Fi capability. Please see: https://www.lakeshore.com/instruments-wi-fi-addendum.pdf/.**

The M91 FastHall™ measurement controller adheres to the Standard Commands for Programmable Instruments (SCPI) standard, as discussed in section 4.2, regardless of the remote interface selected for user control.

Lake Shore's fully-integrated MeasureLINK™-MCS software is a Windows® graphic menu-driven interface for operation, data acquisition, and analysis. For further information, see the MeasureLINK™-MCS software manual.

4.2 Standard Commands for Programmable Instruments (SCPI)

The M91 adheres to the SCPI command language. SCPI is a standardized command language, presently maintained by the Interchangeable Virtual Instruments (IVI) Foundation, used for controlling test and measurement instruments. SCPI provides instrument control with a standardized command syntax and style.

The following sections provide a brief overview of the SCPI language, syntax, and behavior, that will allow a new instrument user to get up and running quickly. The complete SCPI specification can be found on the IVI website: http://www.ivifoundation.org/docs/scpi-99.pdf.

4.2.1 Command Types

There are two different types of SCPI commands that the M91 responds to: common and subsystem.

4.2.1.1 Common

SCPI builds upon the IEEE 488.2 standard. Because of this, several of the commands found in IEEE 488.2 are required by the M91 to be considered SCPI compliant. These commands include, but are not limited to, functionality to reset (***RST**), clear the status registers (***CLS**), or identify the instrument (***IDN?**).

These commands are identifiable by the fact that they:
1. Always consist of three letters and
2. Are always preceded by an asterisk

4.2.1.2 Subsystem

In addition to the common commands, SCPI defines subsystem commands. If the M91 FastHall™ measurement controller is considered a "system", then the logical grouping of its various functions can be considered different "subsystems", forming a hierarchical "tree". Each subsystem is comprised of program headers. Together, these comprise the individual SCPI command. The following is an example of several M91 SCPI commands and how they fit into the hierarchical tree:

:DISPlay
  :BRIGhtness ‹brightness›
  :ENABle ‹bool›

4.2.2 Queries

Many times, a command will have a corresponding query. Queries require a question mark at the end of the command header. If a query requires a parameter, place the question mark at the end of the header and before the query parameters.

4.2.3 Optional Commands

If a command header is enclosed in brackets ([]), then it is optional. Do not include the brackets if you send the optional command to the instrument. For example, the following command messages are both valid, since the AUTO header is optional:
CCHeck:STARt:AUTO
CCHeck:STARt

4.2.4 Short and Long Form

SCPI specifies a short and long form for its command headers. The command header is completely spelled out in the long form while it is abbreviated to the first three or four letters for short form. The following is an example of the same command in both short and long form:
CCHeck:STARt
CCH:STAR

4.2.5 Number Suffix

When a command header is used to represent multiple instances of a given function of the instrument, the selection of which to use is designated by a numeric suffix attached to the command header. This suffix is applicable for both short and long forms.
Examples:
DIGital:OUTput1:FUNCtion MANual
DIG:OUT2:FUNC TRIG

4.2.6 Multiple Commands in a Single Message

Many times, it is desirable to chain multiple commands and queries together into one message transmission. To do this, separate each command/query with a semicolon and be sure to include a colon before the next command, unless it is a common command which uses the "*" prefix.

If multiple commands are provided in a given message, the M91 will process the commands in the order in which they were received. Subsequently, if multiple queries are included in chained message, the M91 will respond to the queries in the order in which they were received.

As an example, the following command message sets the analog output to 10 V, will query the contact check results, resistivity results, and request a response of "1" once all the commands are processed.

Sent:**ANALOG:OUTPUT:SETTING 10;:CCH:RES:JSON? 1;:RES:RES:JSON? 1;*OPC?**
Received: **10**

4.2.7 Terminators

All data in a given SCPI message is encoded in the American Standard Code for Information Interchange (ASCII) format. A special ASCII character, the line feed (hex 0A, decimal 10), is required by the instrument to know where the SCPI message ends. The instrument also allows an optional carriage return (hex 0D, decimal 13) to precede the line feed.

4.2.8 Message Flow Control

It is important to remember that the user program is in charge of SCPI communication at all times, independent of the communications bus used to control the instrument. The instrument cannot initiate communication, determine which device should be transmitting at a given time, or guarantee timing between messages. All of this is the responsibility of the user program.

Most commands sent to the M91 FastHall™ measurement controller will execute within 100 ms of the last character being transmitted. However, the SCPI command protocol does not specify that an instrument return an acknowledge message when a given command is finished executing. Because of this, a user program could potentially flood and overload the instruments SCPI buffer.

Therefore, it is highly recommended to append the Operation Complete Query (*OPC?) to the end of any given command string. The operation complete query is a SCPI mandated IEEE 488.2 query that will cause the instrument to send a "1" back to the user program when all commands have been processed. This scheme closes the timing loop and provides the proper balance for a user program to maximize command throughput yet not risk overrunning the instrument SCPI buffer. *OPC? can be appended onto a single command or a chained SCPI message.

The following example sets digital output 1 on, sets the analog output to 10 V, and waits for "1" to be returned when the commands have been processed:
DIGital:OSETting 1;: ANALOG:OUTPUT:SETTING 10;*OPC? 1

4.2.9 Output Types

The results can be outputted in JSON format or standard SCPI format. JSON (Javascript Object Notation) is a common way of serializing data with a human readable output. For more information, see http://www.json.org. Standard SCPI results follow the format defined in the SCPI-99 standard:
http://www.ivifoundation.org/docs/scpi-99.pdf.

4.3 Status and Error Reporting

4.3.1 Status System Overview

The MeasureReady® M91 FastHall™ measurement controller implements a status system compliant to the SCPI-99 standard. The SCPI status system is derived from the status system called out in chapter 11 of the IEEE 488.2 standard. The status system provides a method of recording and reporting instrument information. At the center of the status system is the status byte register. This register contains summary bits from other status registers, providing the user one register to periodically query to determine if further interrogation of the instrument is required.

In addition to the status byte and its complementary service request enable register, the status system is made up of standard, questionable, and operation status register sets. Each one of those register sets comprises three types of registers: condition, event, and enable. In addition, the status system contains an output buffer and error queue. A diagram of the status system is shown below.
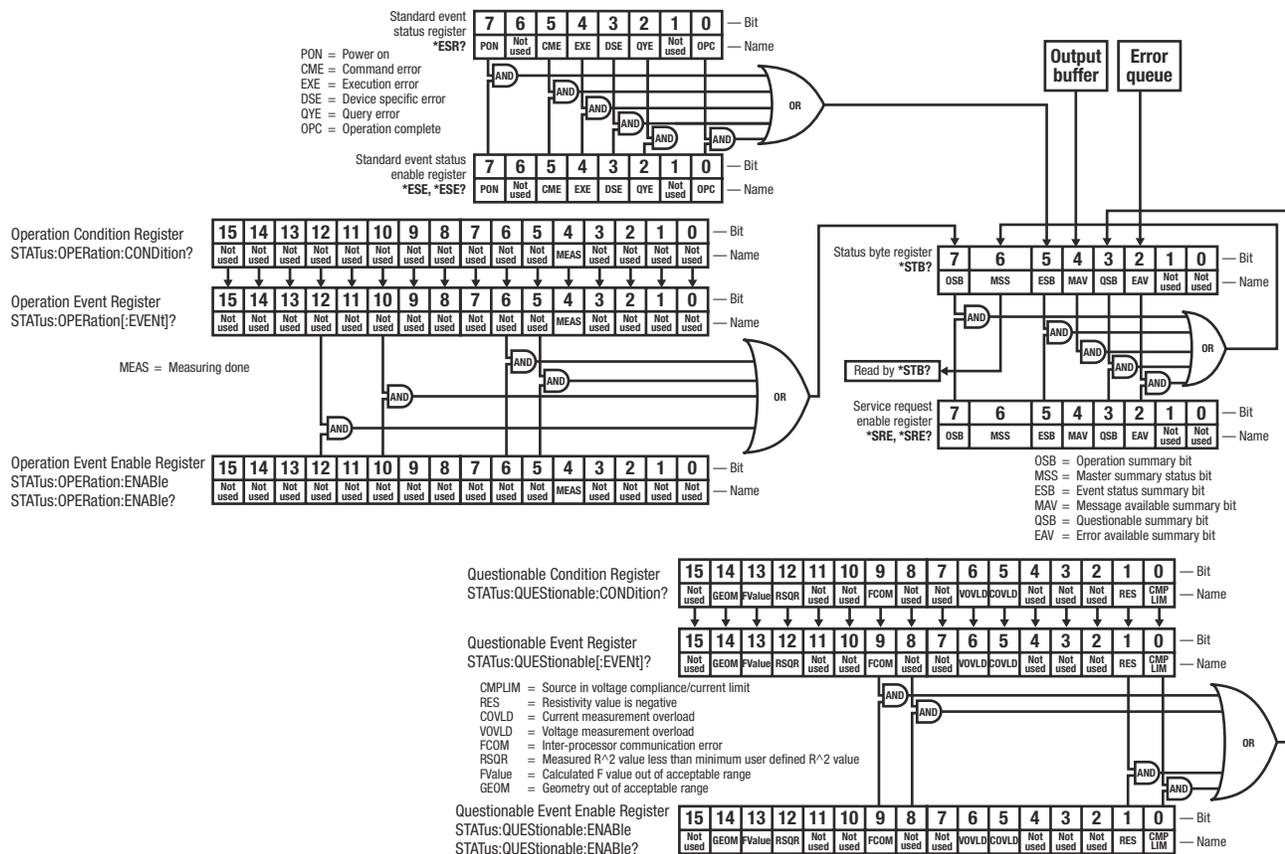
FIGURE 4-1 *Status system*

4.3.1.1 Status Byte Register

The status byte register, typically referred to as the status byte, is a non-latching, read-only register that contains all of the summary bits from the register sets. The status of the summary bits are controlled from the register sets as explained in section 4.3.2.1 to section 4.3.2.5. The status byte also contains the Master Summary Status (MSS) bit. This bit is used to report if any of the summary bits are set via the *STB? command. The status of the MSS bit is controlled by the summary bits and the service request enable register.

4.3.1.2 Service Request Enable Register

The service request enable register determines which summary bits in the status byte will set the MSS bit of the status byte. The user may write to or read from the service request enable register. Each status byte summary bit is logically ANDed to the corresponding enable bit of the service request enable register. When a service request enable register bit is set by the user, and the corresponding summary bit is set in the status byte, the MSS bit of the status byte will be set.

4.3.1.3 Conditional Registers

Each register set (except the standard event register set) includes a condition register as shown in FIGURE 4-1. The condition register constantly monitors the instrument status. The data bits are real-time and are not latched or buffered. The register is read-only.

4.3.1.4 Event Registers

Each register set includes an event register as shown in FIGURE 4-1. Bits in the event register correspond to various system events and latch when the event occurs. Once an event bit is set, subsequent events corresponding to that bit are ignored. Set bits remain latched until the register is cleared by a query command (such as *ESR?) or a *CLS command. The register is read-only.

4.3.1.5 Enable Registers

Each register set includes an enable register as shown in FIGURE 4-1. An enable register determines which bits in the corresponding event register will set the summary bit for the register set in the status byte. The user may write to or read from an enable register. Each event register bit is logically ANDed to the corresponding enable bit of the enable register. When an enable register bit is set by the user, and the corresponding bit is set in the event register, the output (summary) of the register will be set, which in turn sets the master summary status bit of the status byte register.

4.3.1.6 Register Read/Write Behavior

4.3.1.6.1 Reading Registers

Any register in the status system may be read using the appropriate query command. Some registers clear when read, others do not (section 4.3.1.6.3). The response to a query will be a decimal value that corresponds to the binary-weighted sum of all bits in the register (TABLE 4-1). The actual query commands are described later throughout section 4.5.

Position	B7	B6	B5	B4	B3	B2	B1	B0
Decimal	128	64	32	16	8	4	2	1
Weighting	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Example: If bits 0, 2, and 4 are set, a query of the register will return a decimal value of 21 (1+4+16)

TABLE 4-1 **Binary weighting of an 8-bit register**

4.3.1.6.2 Programming Registers

The only registers that may be programmed by the user are the enable registers. All other registers in the status system are read-only registers. To program an enable register, send a decimal value that corresponds to the desired binary-weighted sum of all bits in the register (TABLE 4-1). The actual commands are described throughout section 4.5.

4.3.1.6.3 Clearing Registers

The methods to clear each register are detailed in the table below.

Register	Method	Example
Condition registers	None: registers are not latched	—
Event registers: Standard event status register Operation event register	Query the event register	*ESR? (clears standard event status register)
	Send *CLS	*CLS (clears both registers)
	Power on instrument	—
Enable registers: Standard event status enable register Operation event enable register Service request enable register Questionable event enable register	Write 0 to the enable register	*ESE 0 (clears standard event status enable register)
	Power on instrument	—
Status byte	There are no commands that directly clear the status byte as the bits are non-latching; to clear individual summary bits clear the event register that corresponds to the summary bit—sending *CLS will clear all event registers which in turn clears the status byte	If bit 5 (ESB) of the status byte is set, send *ESR? to read the standard event status register and bit 5 will clear
	Power on instrument	—

TABLE 4-2 **Register clear methods**

4.3.2 Register Details

4.3.2.1 Status Byte Register

The summary messages from the event registers and the output buffer set or clear the summary bits of the status byte register (FIGURE 4-2). These summary bits are not latched. Clearing an event register will clear the corresponding summary bit in the status byte register. Reading all messages in the output buffer, including any pending queries, will clear the message available bit. Reading all errors out of the queue will clear the error available bit. The bits of the status byte register are described as follows:

- *Operation Summary (OSB), Bit (7):* this bit is set when an enabled operation event has occurred.
- *Master Summary Status (MSS), Bit (6):* this bit is set when a summary bit and the summary bit's corresponding enable bit in the service request enable register are set. A *STB? will read the status of the MSS bit (along with all of the summary bits), but also will not clear it. To clear the MSS bit, either clear the event register that set the summary bit or disable the summary bit in the service request Enable register.

  In addition, in other instruments with a GPIB interface, this bit is also defined as the Request Service (RQS) bit. In this case, when the RQS/MSS bit would be set, the service request hardware line would go high, indicating to the controller on the bus to query the status byte. Since the M91 FastHall™ measurement controller does not have a GPIB interface, this bit is strictly referred to as the MSS bit.
- *Summary (ESB), Bit (5):* this bit is set when an enabled standard event has occurred.
- *Message Available (MAV), Bit (4):* this bit is set when a message is available in the output buffer.
- *Questionable Summary (QSB), Bit (3):* this bit is set when an enabled questionable event has occurred.

4.3.2.2 Service Request Enable Register

The service request enable register is programmed by the user and determines which summary bits of the status byte may set bit 6 (MSS). Enable bits are logically ANDed with the corresponding summary bits (FIGURE 4-2). Whenever a summary bit is set by an event register and its corresponding enable bit is set by the user, bit 6 will be set. The Service Request Enable command (*SRE) programs the Service Request Enable Register and the query command (*SRE?) reads it.
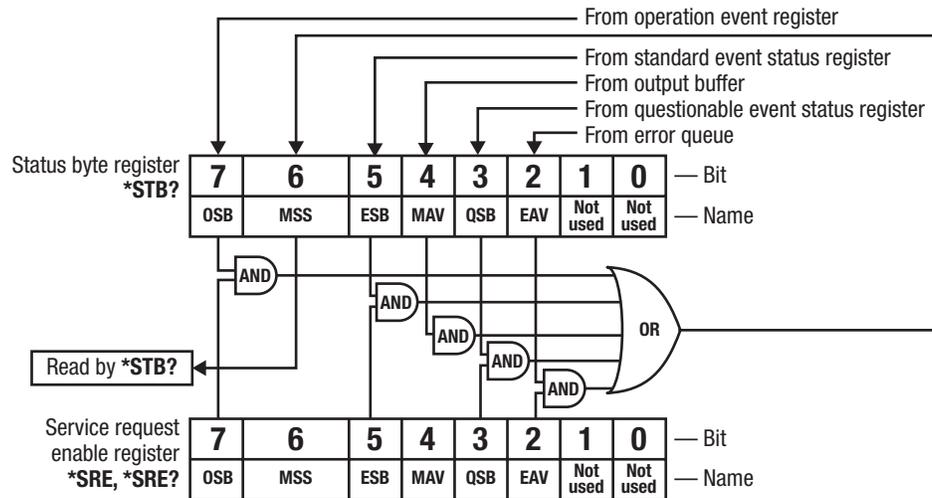
FIGURE 4-2 *Status byte register and service request enable register*

4.3.2.3 Standard Event Status Register Set

The standard event status register reports the following interface-elated instrument events: power on detected, command syntax errors, command execution errors, query errors, and operation complete. Any or all of these events may be reported in the standard event summary bit through the enable register (FIGURE 4-3). The standard event status enable command (*ESE) programs the enable register and the query command (*ESE?) reads it. *ESR? reads and clears the standard event status register.

The used bits of the standard event register are described as follows:
- *Power On (PON), Bit (7):* this bit is set to indicate an instrument off-on transition.
- *Command Error (CME), Bit (5):* this bit is set if a command error has been detected since the last reading. This means that the instrument could not interpret the command due to a syntax error, an unrecognized header, unrecognized terminators, or an unsupported command.
- *Execution Error (EXE), Bit (4):* this bit is set if an execution error has been detected. This occurs when the instrument is instructed to do something not within its capabilities. A typical example of this are command parameters that are outside the instrument's acceptable bounds.
- *Device Specific Error (DSE), Bit (3):* this bit is set if an error occurs that does not fall into another category defined as a standard event. Examples include if the M91 is unable to set its date/time, time zone, or if the peripherals throw an exception.
- *Query Error (QYE), Bit (2):* this bit indicates a query error. It occurs rarely and involves loss of data because the output queue is full.
- *Operation Complete (OPC), Bit (0):* when *OPC is sent, this bit will be set when the instrument has completed all pending operations. The operation of this bit is not related to the *OPC? command, which is a separate interface feature (section 4.2.8).
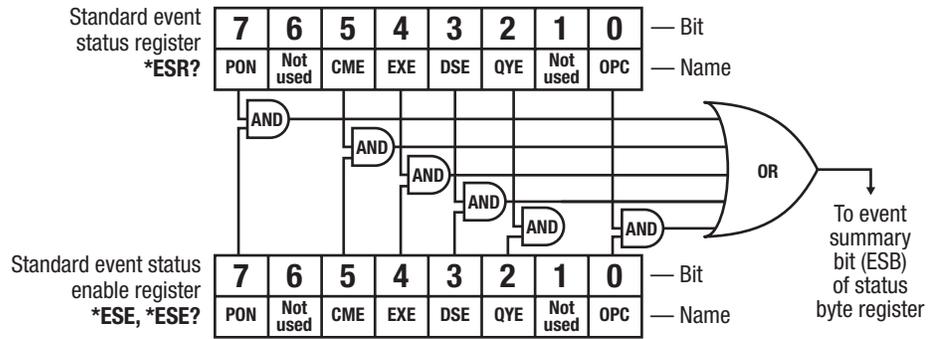
FIGURE 4-3 ***Standard event status register***

4.3.2.4 Operation Event Register Set

The operation event register reports the instrument events that are considered part of normal operation. Any or all of these events may be reported in the operation event summary bit through the enable register (FIGURE 4-4.) The operation event enable command (`STATus:OPERation:ENABle`) programs the enable register and the query command (`STATus:OPERation:ENABle?`) reads it.
`STATus:OPERation[:EVENt]?` reads and clears the operation event register.
`STATus:OPERation:CONDition?` reads the operation condition register.

The used bits of the operation event register are described as follows:

■   *Measuring Done (MEAS), Bit (4):* this bit is set when a measurement has finished running. Reset once a new measurement has started.
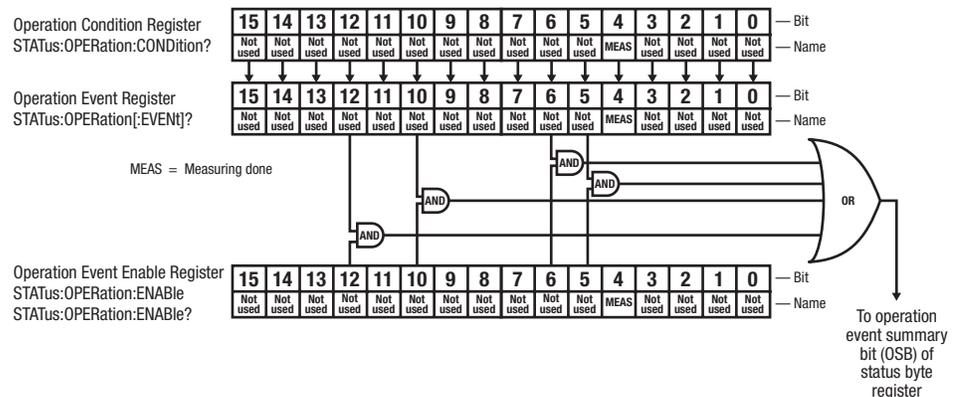
FIGURE 4-4 ***Operation event status register***

4.3.2.5 Questionable Status Register Set

The questionable status register reports various states of the instrument that could indicate the quality of the output signal may be compromised. Any or all of these events may be reported in the questionable event summary bit through the enable register (FIGURE 4-5). The questionable event enable command (**STATus:QUEStionable:ENABle**) programs the enable register and the query command (**STATus:QUEStionable:ENABle?**) reads it. **STATus:QUEStionable[:EVENt]?** reads and clears the operation event register. **STATus:QUEStionable:CONDition?** reads the operation condition register.

The used bits of the operation event register are described as follows:
- *Compliance Limit (CMPLIM), Bit (0):* when the compliance limit voltage or current limit has been reached, this bit will be set.
- *Resistivity (RES), Bit (1):* when the resistivity value is negative, this bit will be set.
- *Current Measurement Overload (COVLD), Bit (5):* when the current measurement is overloaded, this bit will be set.
- *Voltage Measurement Overload (VOVLD), Bit (6):* when the voltage measurement is overloaded, this bit will be set.
- *Inter-Processor Communication error (FCOM), Bit (9):* this bit is set if communications are lost between the main microprocessor and the analog board microprocessor.
- *Minimum R Squared Error (RSQR), Bit (12):* when the measured R^2 value is less than minimum user defined R^2 value, or negative, this bit will be set.
- *Calculated F value (FValue), Bit (13):* when the calculated F value is out of the acceptable range, this bit will be set.
- *Geometry (GEOM), Bit (14):* when the geometry is out of the acceptable range, this bit will be set.
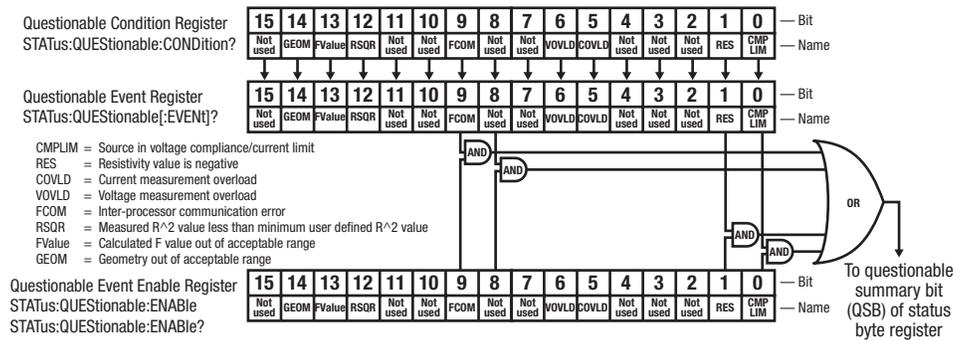
FIGURE 4-5 Questionable event status register

4.3.3 Error Messages

As called out in the SCPI-99 specification, the M91 FastHall™ measurement controller implements an error queue that contains coded error and status messages thrown during operation. SCPI-99 defines error messages with a negative (-) prefix as standard errors, common to all SCPI compliant instruments. Error messages with a positive prefix (+) are allocated to instrument manufacturers for instrument specific messages. Presently, the M91 does not implement any instrument specific messages. All M91 specific errors and status are captured in the status register system.

Coded error and status messages can be retrieved and cleared over the remote interface using the following commands:
SYSTem:ERRor:ALL?
SYSTem:ERRor:CLEar
SYSTem:ERRor:COUNt?
SYSTem:ERRor[:NEXT]?

The queue is implemented with a "First In, First Out" (FIFO) approach. This means, if the M91 adds multiple messages to the queue in a given period of time, issuing the **SYSTem:ERRor[:NEXT]?** query will return the message that was added to the queue first, and, subsequently remove it from the queue. For further details on these error query commands, see section 4.5.

SCPI-99 categorizes its standard errors into logical groups that match bit definitions in the standard event status register. When the M91 adds an error message to the queue, a bit in the standard event status register will be set as well. The error code range table shown below lists the error code ranges, title, and the corresponding bit in the standard event status register that gets set when the error or status is added to the queue.

Error code range	Description	Standard event register bit
-100 to -184	Command errors	5
-200 to -294	Execution errors	4
-300 to -365	Device specific errors	3
-400 to -440	Query errors	2

*TABLE 4-3 **Error code ranges***

A comprehensive list of standard SCPI error codes descriptions can be found in chapters 21.8.9 through 21.8.16 of the official SCPI-99 standard, located on the IVI foundation website: http://www.ivifoundation.org/docs/scpi-99.pdf.

NOTE   **The MeasureReady® M91 FastHall™ measurement controller does not implement every error code listed in the standard.**

4.4 Remote Interfaces

This section provides operational instructions for the remote interfaces for the Lake Shore MeasureReady® M91 FastHall™ measurement controller. Each of the three interfaces provided with the M91 permits remote operation.

4.4.1 USB

The USB interface provides a convenient way to connect to most modern computers. The USB interface is implemented as a virtual serial com port connection. This implementation provides a simple migration path for modifying existing RS-232 based remote interface software. It also provides a simpler means of communicating than a standard USB implementation.

4.4.1.1 Physical Connection

The M91 has a USB Type-B connector on the rear panel. This is the standard connector used on USB peripheral devices, and it allows the common USB Type-A to USB Type-B cable to be used to connect the M91 to a host PC. The pin assignments are shown in section 6.6. The maximum length of a USB cable, as defined by the USB 2.0 standard, is 5 m (16.4 ft). This length can be extended using USB hubs every 5 m (16.4 ft) up to five times, for a maximum total length of 30 m (98.4 ft).

4.4.1.2 Hardware Support

The USB interface emulates an RS-232 serial port at a fixed 921,600 baud rate, but with the physical connections of a USB. This programming interface requires a certain configuration to communicate properly with the M91. Serial port settings are listed in the table below.

Baud rate	921,600
Data bits	8
Parity	None
Stop bits	1
Flow control	RTS/CTS

TABLE 4-4 Host com port configuration

IP address	DHCP or Manual
Port	7777

TABLE 4-5 Ethernet settings

The USB hardware connection uses the full speed (12,000,000 bit/s) profile of the USB 2.0 standard; however, since the interface uses a virtual serial com port at a fixed data rate, the data throughput is still limited to a baud rate of 921,600 bit/s.

GPIB is also available for remote interface capability via an external adapter, which can be purchased from Lake Shore. Visit https://www.lakeshore.com/ for more information.

4.4.1.3 Installing the USB Driver

The USB driver is available through Windows® Update. This is the recommended method for installing the driver, as it will ensure that you always have the latest version of the driver installed. If you are unable to install the driver from Windows® Update, refer to section 4.4.1.3.2 to install the driver from the web. These procedures assume that you are logged into a user account that has administrator privileges.

4.4.1.3.1 Installing the Driver from Windows® Update

1. Connect the USB cable from the M91 to the computer.
2. Turn on the M91.
3. When the Found New Hardware wizard appears, select **Locate and install driver software (recommended)**.
4. The Found New Hardware wizard should automatically connect to Windows® Update and install the drivers.
5. When the Found New Hardware wizard finishes installing the driver, a confirmation message stating "the software for this device has been successfully installed" will appear. Click **Close** to complete the installation.

4.4.1.3.2 Installing the Driver from the Web

The USB driver is available on the Lake Shore website. To install the driver, it must be downloaded from the website and extracted. Use the procedures below to download, extract, and install the driver using Windows®.

Download the driver:

1. Locate the USB driver on https://www.lakeshore.com/software/.
2. Right-click on the USB driver download link, and select **Save as**.
3. Save the driver to a convenient place, and take note where the driver was downloaded.

Extract the driver:

The downloaded driver is in a ZIP compressed archive. The driver must be extracted from this file. Windows® provides built-in support for ZIP archives. If this support is disabled, a third-party application, such as WinZip™ or 7-Zip, must be used.

1. Right-click on the file and click **extract all.**
2. An Extract Compressed (Zipped) Folders dialog box will appear. It is recommended the default folder is not changed. Take note of this folder location.
3. Click to clear the **Show extracted files when complete** checkbox, and click **Extract**.

Manually install the driver:

The following section describes how to manually install the driver using Windows. To install the driver, you must be logged into a user account that has administrator privileges.

1. Connect the USB cable from the M91 to the computer.
2. Turn on the M91.
3. If the Found New Hardware wizard appears, click **Ask me again later**.
4. Open Device Manager. Use this procedure to open Device Manager.

    a. Type Device Manager in the Windows® Start Search box.
    b. Click the Device Manager link in the Search Results dialog box.
    c. If User Account Control is enabled, click **Continue** on the User Account Control prompt.

5. Click **View** and ensure that **Devices by Type** is selected.
6. In the main window of Device Manager, locate Ports (COM & LPT) in the list of device types. If the Ports (COM & LPT) item is not already expanded, click the ❯ icon. In many instances it will be listed after Network adapters.
   Lake Shore MeasureReady M91 should appear indented in the list. If it is not displayed as **Lake Shore MeasureReady M91**, it might be displayed as USB Device. If neither are displayed, click **Action** and then **Scan for hardware changes**, which may open the Found New Hardware wizard automatically. If the Found New Hardware wizard opens, click **Cancel**.
7. Right-click on **Lake Shore MeasureReady M91** and click **Update Driver Software**.

8. Click **Browse my computer for driver software**.
9. Click **Browse** and select the location of the extracted driver.
10. Ensure the **Include subfolders** checkbox is selected and click **Next**.
11. When the driver finishes installing a confirmation message stating "Windows has successfully updated your driver software" should appear. Click **Close** to complete the installation.

4.4.2 Ethernet

The Ethernet interface provides a means of connecting the MeasureReady® M91 FastHall™ measurement controller to a network. Networks provide the ability to communicate across large distances, often using existing equipment (the internet, pre-existing local networks). The Ethernet interface of the M91 provides the ability to use TCP socket connections (section 4.4.2.4) to send commands and queries to the instrument using the common command set detailed in section 4.5.2.

Configuration and status for these network configurations can be found from the front panel by tapping the Settings menu (top left corner of the screen). Ethernet settings can be found under the Connectivity tab. Touch either item to see further settings.

4.4.2.1 Ethernet Configuration

Configuration and status for the Ethernet connection can be found from the front panel by tapping the Settings menu (top left corner of the screen). Select Ethernet. A screen is displayed showing network status and IP settings. In the example below, the network is disconnected.
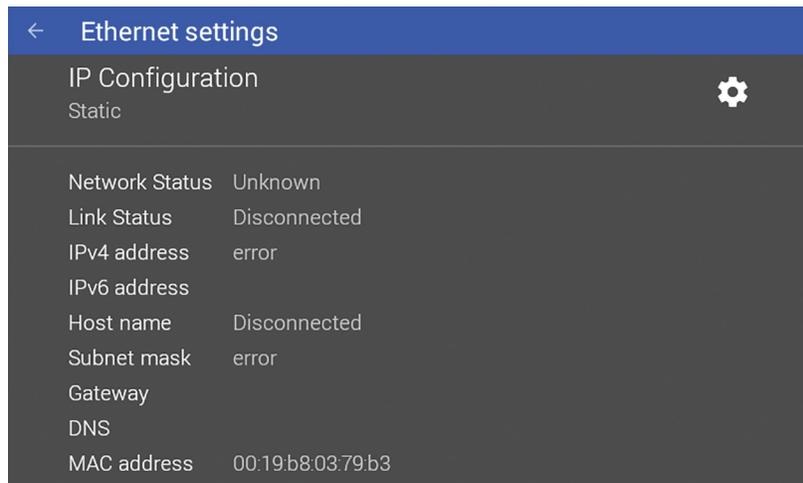
FIGURE 4-6 Ethernet settings

Touching the IP Configuration item allows the user to select DHCP or Static as the Ethernet configuration method. If static is selected, then the fields for IP address, gateway, subnet, and DNS are presented and can be entered at that time.

4.4.2.2 Network Address Parameters

Network address parameters include the IP address, the subnet mask, gateway address, and DNS address. The network address parameters of the M91 can be configured using one of two methods: DHCP or Static-IP.

■ *IP Address:* an IP address is required for a device to communicate using TCP/IP, which is the protocol generally used for Ethernet devices and the M91. The M91 supports both IPv4 and IPv6. However, for simplicity, references to the IP protocol from this point forward will be referring to IPv4.

An IP address is a 32-bit logical address used to differentiate devices on a network. It is most often given in dotted decimal notation, such as nnn.nnn.nnn.nnn where nnn is a decimal number from 0 to 255.

■ *Subnet Mask:* a sub network, or subnet, is a group of devices within a network that have a common, designated IP address routing prefix. A subnet mask is a 32-bit "bit mask" that signifies which part of the IP address represents the subnet routing prefix, and which part represents the device's address on the subnet. A subnet mask is most often given in dotted decimal notation, such as nnn.nnn.nnn.nnn where nnn is a decimal number from 0 to 255. When converted to a binary notation, the 32-bit subnet mask should consist of a contiguous group of ones, followed by a contiguous group of zeros. The ones represent which bits in the IP address refer to the subnet, and the zeros represent which bits refer to the device address. For example, the default Static-IP Address of the M91 is 192.168.0.128, and the default static subnet mask is 255.255.255.0. Converting this subnet mask to binary shows that the first 24 bits are ones, and the last 8 bits are zeros. This means that the first 24 bits of the Static-IP Address (192.168.0) represent the subnet, and the last 8 bits (12) represent the device.

■ *Gateway Address:* a gateway is a network traffic routing device that is used to route communication between networks. If a gateway is not used, then devices on a network can only communicate with other devices on that same network. A gateway address is the IP address of the gateway on a network. Contact the network administrator for the gateway address for your network.

■ *DNS Address:* a Domain Name System (DNS) is a service that translates names into IP addresses. This service allows for using human readable names for devices on a network. As an example, when a web browser attempts to retrieve the web page at www.lakeshore.com, the browser first performs a forward-lookup on the assigned DNS server to attempt to retrieve the IP address that is represented by the name www.lakeshore.com. If successful, the web browser then uses the retrieved IP address to communicate with the web server that hosts the website at www.lakeshore.com.

4.4.2.3 Network Address Configuration Methods

The network address parameters of the M91 can be configured using one of two methods: DHCP or Static-IP. DHCP is an automatic configuration method while Static-IP requires manual configuration. If supported by the server, DHCP can also be used to automatically configure DNS server addresses, as well as IP address parameters.

Dynamic Host Configuration Protocol (DHCP): DHCP is a method of automatically configuring the IP address, subnet mask, and gateway of Ethernet devices on a network. This method provides simple automatic configuration for users connecting to a network that provides a DHCP server. The network DHCP server will provide an IP address, subnet mask, and gateway address. Depending on the DHCP server configuration, it may also provide primary DNS and secondary DNS addresses as well. DHCP is the simplest method of IP configuration. DHCP does have the disadvantage of not necessarily preserving the IP address through a device reconfiguration, as well as the possibility of being automatically reconfigured when the DHCP "lease" expires. Contact your network administrator to find out the DHCP lease policy on your network.

Static-IP: Static-IP is a method of manually configuring the IP address, subnet mask, and gateway of network enabled devices. When using the Static-IP method, the IP address, subnet mask, and gateway must be configured appropriately for the connected network, or for the connected PC, in order to establish connection to the network. A major advantage to the Static-IP method is that the IP address will not change during device reconfiguration (power cycle). Disadvantages of using the Static-IP method include the requirement of knowing how your network is configured in order to choose the correct configuration parameters.

Domain Name: A domain is a collection of network devices that are managed according to some common characteristic of its members. Domains can contain subdomains, which are subsets within the domain. The hierarchy can contain several dot-separated levels which flow from right to left. For example, lakeshore.com contains the top-level-domain "com" and the subdomain "lakeshore". When using the Domain Name System (DNS) to connect to a specific host device on a network, the device's hostname is tacked onto the left of the domain name. For example, the "www"" in www.lakeshore.com refers to the Lake Shore web server, located within the internet domain "lakeshore.com."

4.4.2.4 TCP Socket Communication

A TCP socket connection interface is provided as the communication medium for the network interface of the M91 FastHall™ measurement controller. A TCP socket connection, or simply "socket connection", is a common connection protocol used by Ethernet devices. The Transmission Control Protocol (TCP) is commonly used for creating a communication channel between one program on one computer and one program on another computer, for example a web browser on a PC and a web server on the Internet.

In the case of the M91, the protocol is used to create a communication channel between one program on one computer and the command line interface of the M91. TCP uses error correction and collision avoidance schemes that make it a very reliable form of network communication, but has drawbacks of having nondeterministic timing, and can encounter relatively large delays depending on network conditions. These delays can be on the order of seconds. Sockets use port numbers to identify sending and receiving endpoints on network devices. This allows for multiple separate communication links to exist on each device.

NOTE

The port number used for TCP socket connections on the M91 is 8888.

4.4.3 SCPI over TCP

There may be scenarios where the user desires to have the M91 connected to the internet but does not want anyone to be able to connect to the M91 and start controlling it. The SCPI over TCP setting allows for this. If the setting is disabled then network connections are still allowed, allowing firmware or autodate time to still function. For example, remote control of the M91 will not be allowed even if another user knows the IP address and socket of the M91.

In order to issue SCPI commands over TCP and remotely control the instrument, this setting needs to be enabled. This can be done by touching the switch, as shown below.
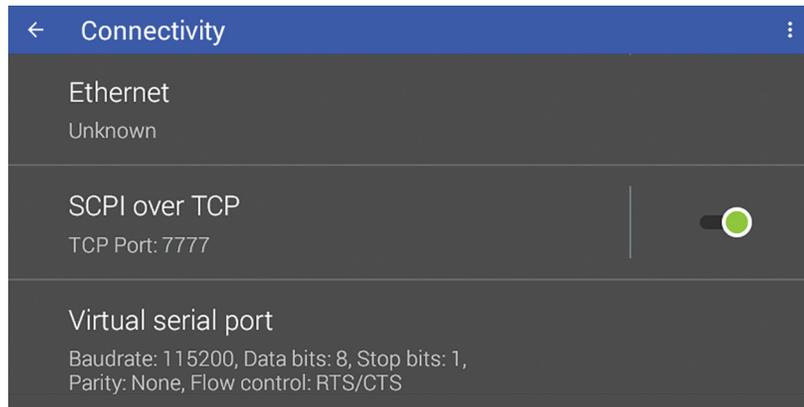
FIGURE 4-7 **SCPI over TCP**

4.5 Command Summary

This section lists the interface commands in alphabetical order.

bool	Boolean data type. Used to specify if a setting should be enabled or disabled. A "0" or "OFF" are valid for disable, while a "1" or "ON" are valid for enable.
NR1	Signed integer with no decimal point. Example: 77
NRf	A number that can be represented in one of three ways. Examples include an integer (77), a real number (77.325), or an exponential number (7732.5E02)
NAMED	A finite group of strings representing valid parameters. Examples include "TRIGger," and "MANual" as valid parameters for the **ANALog:OUTputFUNCtion?** command.
string	Character string enclosed in double quotes.
Number	Any numeric type. Can be an integer or a floating point number.

TABLE 4-6 Command parameter data types

> **NOTE** All command and query examples listed below are assumed to have a terminator included at the end of the string.

4.5.1 Common Commands

The following commands and queries are specified in both IEEE 488.2 and SCPI-99.

*CLS

Command Format	*CLS
Remarks	Clears the bits in the status byte register and the standard event status register, clears the error queue and terminates all pending operations. It does not clear the enable registers.

*ESE

Command Format	*ESE <data>	
Parameter	<data>	Decimal value that is the sum of the binary-weighted values for the desired bits. Data type is *NR1*
Query Format	*ESE?	
Return Parameter	<data>	(see above)
Examples		
Command	*ESE 48	Enables command error and execution error flags
Query	*ESE?	
Query Response	32	Indicates that the command error flag is set
Remarks	This command programs the standard event status enable register bits. Each bit is assigned a bit weighting and represents the enable/disable mask of the corresponding event flag bit in the standard event status register. To enable an event flag bit, send the command *ESE with the sum of the bit weighting for each desired bit. Refer to section 4.3.2.3 for a list of event flags.	

Bit	Bit weighting	Event name
0	1	OPC
2	4	QYE
3	8	DSE
4	16	EXE
5	32	CME
7	128	PON
Total:	189	

*IDN?

Query Format	*IDN?
Return Parameter	<manufacturer>,<model>,<serial number>,<firmware version>
	Each parameter is of type AARD
Examples	
Query	*IDN?
Query Response	LSCI, 155-DC, 155B23C, 1.1.2
Remarks	Returns the MeasureReady® 155 identification string. Each field in the return message is separated by a comma.

*OPC

Command Format	*OPC
Remarks	Generates an operation complete event in the event status register upon completion of all pending selected device operations. Send it as the last command in a command string. Unrelated to *OPC? See section 4.3.2.3 for more details.

*OPC?

Query Format	*OPC?
Return Parameter	1 Data type is *NR1*
Examples	
Query	*OPC?
Query Response	1
Remarks	Places a 1 in the 155 output buffer upon completion of all pending selected device operations. Send as the last command in a command string. See section 4.2.8 for more detail.

*RST

Command Format	*RST
Remarks	This command performs an instrument reset. This command resets the volatile memory of the instrument to the power-up settings.

*SRE

Command Format	*SRE <data>	
Parameter	<data>	Decimal value that is the sum of the binary-weighted values for the desired bits. Data type is *NR1*
Query Format	*SRE?	
Return Parameter	<data>	(see above)
Examples		
Command	*SRE 4	Enables error available flag
Query	*SRE?	
Query Response	136	Indicates that operation and questionable event enable flags are set
Remarks	This command programs the service request enable register bits. This register determines which bits from the status byte register are summed to set the Master Status Summary (MSS) bit. To enable a status flag bit, send the command *SRE with the sum of the bit weighting for each desired bit. Refer to section 4.3.2.2 for a list of status flags.	

Bit	Bit weighting	Event name
2	4	EAV
3	8	QSB
4	16	MAV
5	32	ESB
7	128	OSB
Total:	188	

*STB?

Query Format	*STB?	
Return Parameter	<data>	Data type is *NR1*
Examples		
Query	*OPC?	
Query Response	1	
Remarks	Reads the status byte register. Acts like a serial poll, but does not reset the register to all zeros. The integer returned represents the sum of the bit weighting of the status flag bits that are set in the Status Byte Register. Refer to section 4.3.2.1 for a list of status flags.	

*TST?

Query Format	*TST?	
Return Parameter	<status>	0 = no errors found, 1= errors found Data type is *NR1*
Examples		
Query	*TST?	
Query Response	0	Indicates no errors were found
Remarks	The report status based on test done at power up..	

*WAI

Command Format	*WAI	
Remarks	Causes the interface to hold off until all pending operations have been completed. This is the same function as the *OPC command, except that it does not set the operation complete event bit in the event status register.	

4.5.2 SCPI Subsystem Commands

The following commands and queries are derived from the SCPI 99 standard.

ANALog:INPut:FUNCtion?

Summary	Queries the available settable modes for the analog input.
Query Format	ANALog:INPut:FUNCtion?
Returns	The analog input function. MANUAL is the only supported function. Data type is *NAMED*
Example	ANALog:INPut:FUNCtion?

ANALog:INPut[:LEVel]?

Summary	Queries the analog input.
Query Format	ANALog:INPut[:LEVel]?
Returns	Voltage ranging from -10 to +10 V. Data type is *NRf*
Example	ANALog:INPut[:LEVel]?

ANALog:OUTPut:FUNCtion?

Summary	Queries the available settable functions for the analog output.
Query Format	ANALog:OUTPut:FUNCtion?
Returns	The analog output function. MANUAL is the only supported function. Data type is *NAMED*
Example	ANALog:OUTPut:FUNCtion?

ANALog:OUTPut:SETTing

Summary	Sets the level of the analog output.
Command Format	ANALog:OUTPut:SETTing <output>
Parameters	<output> -10 to +10 V Data type is *NRf*
Example	ANALog:OUTPut:SETTing 5.5

ANALog:OUTPut:SETTing?

Summary	Queries the analog output level setting.
Query Format	ANALog:OUTPut:SETTing?
Returns	Output level setting. Data type is *NRf*
Example	ANALog:OUTPut:SETTing?

CALibration:CLEAr

Summary	Clears all calibration values.
Command Format	CALibration:CLEAr
Example	CALibration:CLEAr

CALibration:CURRent:MEASurement:GAIN

Summary	Sets the current measurement gain.
Command Format	CALibration:CURRent:MEASurement:GAIN <range>,<gain>
Parameters	<range> 0 = 10 nA, 1 = 10 µA, 2 = 10 mA, 3 = 100 mA
	Data type is *NR1*
	<gain> Double
	Data type is *NRf*
Example	CALibration:CURRent:MEASurement:GAIN 0 1.234

CALibration:CURRent:MEASurement:GAIN?

Summary	Queries the current measurement gain.
Query Format	CALibration:CURRent:MEASurement:GAIN? <range>
Parameters	<range> 0 = 10 nA, 1 = 10 µA, 2 = 10 mA, 3 = 100 mA
	Data type is *NR1*
Returns	Current measurement gain as a double.
	Data type is *NRf*
Example	CALibration:CURRent:MEASurement:GAIN?

CALibration:CURRent:MEASurement:READ

Summary	Sets the current measurement range.
Command Format	CALibration:CURRent:MEASurement:READ <range>
Parameters	<range> 0 = 10 nA, 1 = 10 µA, 2 = 10 mA, 3 = 100 mA
	Data type is *NR1*
Example	CALibration:CURRent:MEASurement:READ 0

CALibration:CURRent:MEASurement:READ?

Summary	Queries the current measurement reading.
Query Format	CALibration:CURRent:MEASurement:READ? <averagingTime>
Parameters	<averagingTime> Measurement averaging time in seconds, 10 e-3 to 1
	DEFault = 1/16
	MINimum = 10 e-6, MAXimum = 1
	Data type is *Number*
Returns	Current measurement reading as a double.
	Data type is *NRf*
Example	CALibration:CURRent:MEASurement:READ?

CALibration:CURRent:MEASurement:ZERO

Summary	Sets the current measurement offset.
Command Format	CALibration:CURRent:MEASurement:ZERO <range>,<offset>
Parameters	<range> 0 = 10 nA, 1 = 10 µA, 2 = 10 mA, 3 = 100 mA
	Data type is *NR1*
	<offset Double
	Data type is *NRf*
Example	CALibration:CURRent:MEASurement:ZERO 0, 1.234

CALibration:CURRent:MEASurement:ZERO?

Summary	Queries the current measurement offset.
Query Format	CALibration:CURRent:MEASurement:ZERO? <range>
Parameters	<range> 0 = 10 nA, 1 = 10 µA, 2 = 10 mA, 3 = 100 mA
	Data type is *NR1*
Returns	Current measurement offset as a double.
	Data type is *NRf*
Example	CALibration:CURRent:MEASurement:ZERO? 0

CALibration:CURRent:SOURce:GAIN

Summary	Sets the current source gain.
Command Format	CALibration:CURRent:SOURce:GAIN <range>,<gain>
Parameters	<range> 0 = 1 µA, 1 = 10 µA, 2 = 100 µA, 3 = 1 mA, 4 = 10 mA,
	5 = 100 mA
	Data type is *NR1*
	<gain> Double
	Data type is *NRf*
Example	CALibration:CURRent:SOURce:GAIN 0, 1.234

CALibration:CURRent:SOURce:GAIN?

Summary	Queries the current source gain.
Query Format	CALibration:CURRent:SOURce:GAIN? <range>
Parameters	<range> 0 = 1 µA, 1 = 10 µA, 2 = 100 µA, 3 = 1 mA, 4 = 10 mA,
	5 = 100 mA
	Data type is *NR1*
Returns	The current source gain as an integer.
	Data type is *NRf*
Example	CALibration:CURRent:SOURce:GAIN? 0

CALibration:CURRent:SOURce:ZERO

Summary	Sets the current source offset.
Command Format	CALibration:CURRent:SOURce:ZERO <range>,<offset>
Parameters	<range> 0 = 1 µA, 1 = 10 µA, 2 = 100 µA, 3 = 1 mA, 4 = 10 mA,
	5 = 100 mA
	Data type is *NR1*
	<offset> Double
	Data type is *NRf*
Example	CALibration:CURRent:SOURce:ZERO 0, 1.234

CALibration:CURRent:SOURce:ZERO?

Summary	Queries the current source offset.
Query Format	CALibration:CURRent:SOURce:ZERO? <range>
Parameters	<range> 0 = 1 µA, 1 = 10 µA, 2 = 100 µA, 3 = 1 mA, 4 = 10 mA,
	5 = 100 mA
	Data type is *NR1*
Returns	Offset as a double.
	Data type is *NRf*
Example	CALibration:CURRent:SOURce:ZERO? 0

CALibration:DATE

Summary	Sets the date of the calibration.
Command Format	CALibration:DATE <year>,<month>,<day>,<hour>,<minute>,<second>
Parameters	

<year>	The year	Data type is *NR1*
<month	The month	Data type is *NR1*
<day>	The day	Data type is *NR1*
<hour>	The hour	Data type is *NR1*
<minute>	The minute	Data type is *NR1*
<second>	The second	Data type is *NR1*

Example	CALibration:DATE 2018, 6, 12, 1, 20, 20

CALibration:DATE?

Summary	Queries the date of the calibration.
Query Format	CALibration:DATE?
Returns	Date in the form of year, month, day, hour, minute, second. Data type is *NRf*
Example	CALibration:DATE?

CALibration:MUX

Summary	Configures the instrument's MUX.
Command Format	CALibration:MUX <excitationPlus>,<excitationMinus>,<measurementPlus>, <measurementMinus>
Parameters	

<excitationPlus>	Integer 1-6 representing terminals 1-6 for excitation + Data type is *NR1*
<excitationMinus	Integer 1-6 representing terminals 1-6 for excitation +- Data type is *NR1*
<measurementPlus>	Integer 1-6 representing terminals 1-6 for measurement + Data type is *NR1*
<measurementMinus>	Integer 1-6 representing terminals 1-6 for measurement - Data type is *NR1*

Example	CALibration:MUX 0, 0, 0, 0, 0, 0

CALibration:SAVE

Summary	Saves the calibration.
Command Format	CALibration:SAVE <calibrationPassed>
Parameters	<calibrationPASSED> 1 = passed, 0 = failed Data type is *bool*
Example	CALibration:SAVE 1

CALibration:SNUMber

Summary	Sets the unit's serial number.
Command Format	CALibration:SNUMber <serialNumber>
Parameters	<serialNumber> The serial number as a string. Data type is *string*
Example	CALibration:SNUMber "foo"

CALibration:SNUMber?

Summary	Queries the unit's serial number.
Query Format	CALibration:SNUMber?
Returns	Serial number as a string. Data type is *string*
Example	CALibration:SNUMber?

CALibration:SOURce

Summary	Configures parameters for the instrument's source.	
Command Format	CALibration:SOURce	‹state›,‹mode›,‹range›,‹amplitude›,‹complianceLimit›
Parameters	‹state›	0 = enabled, 1 = disabled Data type is *NR1*
	‹mode›	0 = voltage, 1 = current Data type is *NR1*
	‹range›	Voltage: 0 = 10 mV, 1 = 100 mV, 2 = 1 V, 3 = 10 V Current: 0 = 1 µA, 1 = 10 µA, 2 = 100 µA, 3 = 1 mA, 4 = 10 mA, 5 = 100 mA Data type is *NR1*
	‹amplitude›	Source amplitude. Voltage between -10 V and 10 V. Current between -100 mA and 100 mA Data type is *NRf*
	‹complianceLimit›	Source compliance limit. Voltage source: 100 nA to 100 mA. Current source: 1 V to 10 V Data type is *NRf*
Example	CALibration:SOURce 0, 0, 3, 5, 10	

CALibration:STATe?

Summary	Queries the calibration state.
Query Format	CALibration:STATe?
Returns	0 = valid, 1 = corrupt, 2 = uninitialized, 3 = default. Data type is *NR1*
Example	CALibration:STATe?

CALibration:TEMPerature

Summary	Sets the temperature for the calibration.
Command Format	CALibration:TEMPerature
Example	CALibration:TEMPerature 275

CALibration:TEMPerature?

Summary	Queries the calibration temperature.
Query Format	CALibration:TEMPerature?
Returns	Temperature as a double. Data type is *NRf*
Example	CALibration:TEMPerature?

CALibration:VOLTage:MEASurement:GAIN

Summary	Sets the voltage measurement gain.
Command Format	CALibration:VOLTage:MEASurement:GAIN <range>,<gain>
Parameters	<range> 0 = 1 mV, 1 = 10 mV, 2 = 100 mV, 3 = 1 V, 4 = 10 V
	Data type is *NR1*
	<gain> Double
	Data type is *NRf*
Example	CALibration:VOLTage:MEASurement:GAIN 0, 1.234

CALibration:VOLTage:MEASurement:GAIN?

Summary	Queries the voltage measurement gain.
Query Format	CALibration:VOLTage:MEASurement:GAIN? <range>
Parameters	<range> 0 = 1 mV, 1 = 10 mV, 2 = 100 mV, 3 = 1 V, 4 = 10 V
	Data type is *NR1*
Returns	Voltage measurement gain as a double.
	Data type is *NRf*
Example	CALibration:VOLTage:MEASurement:GAIN? 0

CALibration:VOLTage:MEASurement:READ

Summary	Sets the voltage measurement range.
Command Format	CALibration:VOLTage:MEASurement:READ <range>
Parameters	<range> 0 = 1 mV, 1 = 10 mV, 2 = 100 mV, 3 = 1V, 4 = 10 V
	Data type is *NR1*
Example	CALibration:VOLTage:MEASurement:READ 0

CALibration:VOLTage:MEASurement:READ?

Summary	Queries the voltage measurement reading.
Query Format	CALibration:VOLTage:MEASurement:READ? <averagingTime>
Parameters	<averagingTime> Measurement averaging time in seconds, 10 e-3 to 1
	DEFault = 1/16
	MINimum = 10 e-6, MAXimum = 1
	Data type is *Number*
Returns	Voltage measurement reading as a double.
	Data type is *NRf*
Example	CALibration:VOLTage:MEASurement:READ?

CALibration:VOLTage:MEASurement:ZERO

Summary	Sets the voltage measurement offset.
Command Format	CALibration:VOLTage:MEASurement:ZERO <range>,<offset>
Parameters	<range> 0 = 1 mV, 1 = 10 mV, 2 = 100 mV, 3 = 1 V, 4 = 10 V
	Data type is *NR1*
	<offset> Double
	Data type is *NRf*
Example	CALibration:VOLTage:MEASurement:ZERO 0, 1.234

CALibration:VOLTage:MEASurement:ZERO?

Summary	Queries the voltage measurement offset.
Query Format	CALibration:VOLTage:MEASurement:ZERO? <range>
Parameters	<range> 0 = 1 mV, 1 = 10 mV, 2 = 100 mV, 3 = 1 V, 4 = 10 V
	Data type is *NR1*
Returns	Voltage measurement offset as a double.
	Data type is *NRf*
Example	CALibration:VOLTage:MEASurement:ZERO? 0

CALibration:VOLTage:SOURce:GAIN

Summary	Sets the voltage source gain.
Command Format	CALibration:VOLTage:SOURce:GAIN <range>,<gain>
Parameters	<range> 0 = 10 mV, 1 = 100 mV, 2 = 1 V, 3 = 10 V
	Data type is *NR1*
	<offset> Double
	Data type is *NRf*
Example	CALibration:VOLTage:SOURce:GAIN 0, 1.234

CALibration:VOLTage:SOURce:GAIN?

Summary	Queries the voltage source gain.
Query Format	CALibration:VOLTage:SOURce:GAIN? <range>
Parameters	<range> 0 = 10 mV, 1 = 100 mV, 2 = 1 V, 3 = 10 V
	Data type is *NR1*
Returns	Voltage source gain as a double.
	Data type is *NRf*
Example	CALibration:VOLTage:SOURce:GAIN?

CALibration:VOLTage:SOURce:ZERO

Summary	Sets the voltage source offset.
Command Format	CALibration:VOLTage:SOURce:ZERO <range>,<gain>
Parameters	<range> 0 = 10 mV, 1 = 100 mV, 2 = 1 V, 3 = 10 V
	Data type is *NR1*
	<offset> Double
	Data type is *NRf*
Example	CALibration:VOLTage:SOURce:ZERO 0, 1.234

CALibration:VOLTage:SOURce:ZERO?

Summary	Queries the voltage source offset.
Query Format	CALibration:VOLTage:SOURce:ZERO? <range>
Parameters	<range> 0 = 10 mV, 1 = 100 mV, 2 = 1 V, 3 = 10 V
	Data type is *NR1*
Returns	Voltage source offset as a double.
	Data type is *NRf*
Example	CALibration:VOLTage:SOURce:ZERO?

CCHeck:BLANKing:RESEt

Summary	Cancels any running blanking time calculations.
Command Format	CCHeck:BLANKing:RESEt

CCHeck:BLANKing:RESult:JSON?

Summary	Returns the results of calculating the optimal blanking time.
Query Format	CCHeck:BLANKing:RESult:JSON? <prettty>
Parameters	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized contact check optimization blanking time calculation data. Data type is *NAMED*

CCHeck:BLANKing:RUNNing?

Summary	Indicates if the standalone blanking time calculation is running.
Query Format	CCHeck:BLANKing:RUNNing?
Returns	The measurement is running. Data type is *bool*

CCHeck:BLANKing:STARt

Summary	Calculates the optimal blanking time for a contact check on this sample.
Command Format	CCHeck:BLANKing:STARt

CCHeck:HBAR:STARt

Summary	Performs a contact check measurement on contact pairs 5-6, 5-1, 5-2, 5-3, 5-4, and 6-1.
Command Format	CCHeck:HBAR:STARt <excitationType>,<excitationValueStart>, <excitationValueEnd>,<excitationRange>, <measurementRange>,<complianceLimit>, <numberOfPoints>,<minimumRSquared>,<blankingTime> <samplingTime>
Parameters	<excitationType> VOLTage, CURRent Data type is *ExcitationType*
	<excitationValueStart> The starting excitation value. For voltage excitation -10 to 10 V. For current excitation -100 e3 to 100 e-3 A. Data type is *NRf*
	<excitationValueEnd> The ending excitation value For voltage excitation -10 to 10 V For current excitation -100 e3 to 100 e-3 A Data type is *NRf*
	<excitationRange> For voltage excitation 0 to 10 V For current excitation 0 to 100 e-3 A AUTO sets the range to the best fit range for a given excitation value. **NOTE:** The hardware will be configured to best meet the desired range. Data type is *Number*
	<measurementRange> For voltage excitation, specify the current measurement range 0 to 100 e-3 A. For current excitation, specify the voltage measurement range 0 to 10 V. **NOTE:** The hardware will be configured to best meet the desired range. Data type is *Number*
	<complianceLimit> For voltage excitation, specify the current limit 100 e-9 to 100 e-3 A.

	For current excitation, specify the voltage compliance 1.0 to 10 V. Data type is *NRf*
<numberOfPoints>	The number of points to measure between the excitation start and end. 0 - 100. Data type is *NR1*
<minimumRSquared>	The minimum R^2 desired, DEFault = 0.9999. Data type is *Number*
<blankingTime>	The time in seconds to wait for the hardware to settle before gathering readings. 0.5 ms to 300 s with a resolution of 0.1 ms DEFault = 2 ms MINimum = 0.5 ms MAXimum = 300 s Data type is *Number*
<samplingTime>	The sampling time, in seconds, which measurements will be averaged over to get one sample. MINimum = 0.010 ms MAXimum = 1 s DEFault = 1/60 s Data type is *Number*

Example   CCHeck:HBAR:STARt CURRent,-10e-6,10e-6,10e-6,100e-3,1.5,20,0.9999,2.4e-3

CCHeck:RESet

Summary   Resets the measurement to a not run state, canceling any running measurement.
Command Format   CCHeck:RESet
Example   CCHeck:RESET

CCHeck:RESult:JSON:ALL:SUBstring?

Summary   Retrieves a substring of the last run contact check measurement results serialized as JSON.
Query Format   CCHeck:RESult:JSON:ALL:SUBstring? <startIndex>,<length>
Parameters

<startIndex>	The substring starting index, zero based. Data type is *NR1*
<length>	The number of characters to return. Data type is *NR1*

Returns   Substring of the JSON serialized contact check measurement result.
Data type is *NAMED*
Examples
```
Query CCHeck:RESult:JSON:ALL:SUBstring? 0, 42
Query response
{"Setup":{"ExcitationType":1,"ExcitationVa
```

CCHeck:RESult:JSON:ALL?

Summary   Retrieves the results of the last run contact check measurement, serialized as JSON.
Query Format   CCHeck:RESult:JSON:ALL? <pretty>
Parameters

<pretty>	Optional, pretty format JSON response. Defaults to False. Data type is *bool*

Returns   JSON serialized contact check measurement result.
Data type is *NAMED*
Examples
```
Query CCHeck:RESult:JSON:ALL? 1
Query response
        {
 "Setup": {
   "ExcitationType": 1,
   "ExcitationValueStart": 0.0001,
```

```
        "ExcitationValueEnd": -0.0001,
        "ExcitationAutoRange": false,
        "ExcitationRange": 0.0001,
        "MeasurementAutoRange": false,
        "MeasurementRange": 1.0,
        "ComplianceLimit": 10.0,
        "NumberOfPoints": 11,
        "MinimumRSquared": 0.9999,
        "BlankingTimeInSeconds": 0.002,
        "SamplingTimeInSeconds": 0.0.0166666666666667,
        "Guid": "14f0e82d-5be6-443c-bb28-3f31f77f4339"
    },
    "AutoSetup": {
        "MaxCurrentInAmps": 0.1,
        "MaxVoltageInVolts": 10.0,
        "NumberOfPoints": 11,
        "MinimumRSquared": 0.9999
    },
    "AutoModeDiagnostics": {
        "GeneratedSetup": {
            "ExcitationType": 1,
            "ExcitationValueStart": 0.0001,
            "ExcitationValueEnd": -0.0001,
            "ExcitationAutoRange": false,
            "ExcitationRange": 0.0001,
            "MeasurementAutoRange": false,
            "MeasurementRange": 1.0,
            "ComplianceLimit": 10.0,
            "NumberOfPoints": 11,
            "MinimumRSquared": 0.9999,
            "BlankingTimeInSeconds": 0.002,
            "Guid": "14f0e82d-5be6-443c-bb28-3f31f77f4339"
        },
        "ContactPairResults": [
            {
                "GeneratedSetup": {
                    "ExcitationType": 1,
                    "ExcitationValueStart": 0.0001,
                    "ExcitationValueEnd": -0.0001,
                    "ExcitationAutoRange": false,
                    "ExcitationRange": 0.0001,
                    "MeasurementAutoRange": true,
                    "MeasurementRange": 1.0,
                    "ComplianceLimit": 10.0,
                    "NumberOfPoints": 11,
                    "MinimumRSquared": 0.9999,
                    "BlankingTimeInSeconds": 0.002,
                    "Guid": "4a1be53d-85dc-4815-87c0-80bf078ed380"
                },
                "ContactPair": {
                    "Point1": 1,
                    "Point2": 2
                },
                "InCompliance": false,
                "CalculatedRSquared": 0.99996206145417155,
                "RSquaredPass": true,
                "Success": true
            }
            ...
        ],
        "Success": true
    },
    "SampleType": 0,
    "ContactPairIVResults": [
        {
            "ContactPair": {
                "Point1": 1,
                "Point2": 2
```

```
        },
        "Offset": 0.00070853406935334471,
        "Slope": 369.81494437493217,
        "RSquared": 0.99997701090807767,
        "RSquaredPass": true,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false,
        "IvCurvePoints": [
          {
            "Source": 0.0001,
            "ResistanceInOhms": 374.4813,
            "VoltageInVolts": 0.03733717,
            "CurrentInAmps": 9.970371E-05,
            "InCompliance": false,
            "VoltageOverload": false,
            "CurrentOverload": false
          },
          {
            "Source": 8E-05,
            "ResistanceInOhms": 378.0658,
            "VoltageInVolts": 0.03010416,
            "CurrentInAmps": 7.96268E-05,
            "InCompliance": false,
            "VoltageOverload": false,
            "CurrentOverload": false
          },
          ...
        ]
      }
    ],
    "ActualBlankingTimeInSeconds": 0.002,
    "ActualSamplingTimeInSeconds": 0.0166666666666667,
    "InCompliance": false,
    "VoltageOverload": false,
    "CurrentOverload": false,
    "IsRunning": false,
    "StartTime": "2019-04-23T12:35:56.154506+00:00",
    "EndTime": "2019-04-23T12:36:06.606348+00:00",
    "DurationInSeconds": 10.452
            }
```

CCHeck:RESult:JSON:DATA?

Summary	Retrieves the results of a single point in the contact check measurement IV curve for a given contact pair.
Query Format	CCHeck:RESult:JSON:DATA? <contactPoint1>,<contactPoint2>,<curvePoint>,<pretty>
Parameters	<contactPoint1> Contact pair point 1. Data type is *NR1*
	<contactPoint2> Contact pair point 2. Data type is *NR1*
	<curvePoint> IV curve point, zero indexed. Data type is *NR1*
	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized IV curve point for a given contact pair. Data type is *NAMED*

Examples

```
Query CCHeck:RESult:JSON:DATA? 1,2,2,1
Query response
{
    "Source": -7.894737E-06,
    "ResistanceInOhms": 80935.24,
    "VoltageInVolts": -0.25,
    "CurrentInAmps": -3.088889E-06,
    "InCompliance": true,
    "VoltageOverload": true,
    "CurrentOverload": false
}
```

CCHeck:RESult:JSON:DIAGnostics?

Summary	Retrieves optimization diagnostics of the last run contact check measurement serialized as JSON.
Query Format	CCHeck:RESult:JSON:DIAGnostics? <pretty>
Parameters	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized contact check measurement optimization diagnostics. Data type is *NAMED*

CCHeck:RESult:JSON[:SUMMary]?

Summary	Retrieves summary results of the last run contact check measurement, serialized as JSON.
Query Format	CCHeck:RESult:JSON[:SUMMary]? <pretty>
Parameters	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized contact check measurement result. Data type is *NAMED*

Examples

```
Query CCHeck:RESult:JSON? 1
Query response
{
 "Setup": {
   "ExcitationType": 1,
   "ExcitationValueStart": 0.0001,
   "ExcitationValueEnd": -0.0001,
   "ExcitationAutoRange": false,
   "ExcitationRange": 0.0001,
   "MeasurementAutoRange": false,
   "MeasurementRange": 1.0,
   "ComplianceLimit": 10.0,
   "NumberOfPoints": 11,
   "MinimumRSquared": 0.9999,
   "BlankingTimeInSeconds": 0.002,
```

```
                              "Guid": "53c4e26b-096e-4c3d-9225-73e23595b125"
                          },
                          "AutoSetup": {
                            "MaxCurrentInAmps": 0.1,
                            "MaxVoltageInVolts": 10.0,
                            "NumberOfPoints": 11,
                            "MinimumRSquared": 0.9999
                          },
                          "AutoModeDiagnostics": {
                            "GeneratedSetup": {
                              "ExcitationType": 1,
                              "ExcitationValueStart": 0.0001,
                              "ExcitationValueEnd": -0.0001,
                              "ExcitationAutoRange": false,
                              "ExcitationRange": 0.0001,
                              "MeasurementAutoRange": false,
                              "MeasurementRange": 1.0,
                              "ComplianceLimit": 10.0,
                              "NumberOfPoints": 11,
                              "MinimumRSquared": 0.9999,
                              "BlankingTimeInSeconds": 0.002,
                              "Guid": "53c4e26b-096e-4c3d-9225-73e23595b125"
                            },
                            "ContactPairResults": [
                              {
                                "GeneratedSetup": {
                                  "ExcitationType": 1,
                                  "ExcitationValueStart": 0.0001,
                                  "ExcitationValueEnd": -0.0001,
                                  "ExcitationAutoRange": false,
                                  "ExcitationRange": 0.0001,
                                  "MeasurementAutoRange": true,
                                  "MeasurementRange": 1.0,
                                  "ComplianceLimit": 10.0,
                                  "NumberOfPoints": 11,
                                  "MinimumRSquared": 0.9999,
                                  "BlankingTimeInSeconds": 0.002,
                                  "Guid": "8c4890b1-6248-4ab8-a95f-9f37cea0f5a3"
                                },
                                "ContactPair": {
                                  "Point1": 1,
                                  "Point2": 2
                                },
                                "InCompliance": false,
                                "CalculatedRSquared": 0.99993347328231341,
                                "RSquaredPass": true,
                                "Success": true
                              },
                              {
                                "GeneratedSetup": {
                                  "ExcitationType": 1,
                                  "ExcitationValueStart": 0.0001,
                                  "ExcitationValueEnd": -0.0001,
                                  "ExcitationAutoRange": false,
                                  "ExcitationRange": 0.0001,
                                  "MeasurementAutoRange": true,
                                  "MeasurementRange": 0.1,
                                  "ComplianceLimit": 10.0,
                                  "NumberOfPoints": 11,
                                  "MinimumRSquared": 0.9999,
                                  "BlankingTimeInSeconds": 0.002,
                                  "Guid": "46f8d1d8-9c63-40ea-9b7f-6deca5642f2e"
                                },
                                "ContactPair": {
                                  "Point1": 2,
                                  "Point2": 3
                                },
                                "InCompliance": false,
```

```
      "CalculatedRSquared": 0.999944844772935,
      "RSquaredPass": true,
      "Success": true
    },
    {
      "GeneratedSetup": {
        "ExcitationType": 1,
        "ExcitationValueStart": 0.0001,
        "ExcitationValueEnd": -0.0001,
        "ExcitationAutoRange": false,
        "ExcitationRange": 0.0001,
        "MeasurementAutoRange": true,
        "MeasurementRange": 0.1,
        "ComplianceLimit": 10.0,
        "NumberOfPoints": 11,
        "MinimumRSquared": 0.9999,
        "BlankingTimeInSeconds": 0.002,
        "Guid": "a058fa01-8f65-4acc-9492-956eba3703de"
      },
      "ContactPair": {
        "Point1": 3,
        "Point2": 4
      },
      "InCompliance": false,
      "CalculatedRSquared": 0.99995429808639591,
      "RSquaredPass": true,
      "Success": true
    },
    {
      "GeneratedSetup": {
        "ExcitationType": 1,
        "ExcitationValueStart": 0.0001,
        "ExcitationValueEnd": -0.0001,
        "ExcitationAutoRange": false,
        "ExcitationRange": 0.0001,
        "MeasurementAutoRange": true,
        "MeasurementRange": 0.1,
        "ComplianceLimit": 10.0,
        "NumberOfPoints": 11,
        "MinimumRSquared": 0.9999,
        "BlankingTimeInSeconds": 0.002,
        "SamplingTimeInSeconds": 0.0.0166666666666667,
        "Guid": "aedd62c0-9d17-4c9d-8a6a-b1adc020037c"
      },
      "ContactPair": {
        "Point1": 4,
        "Point2": 1
      },
      "InCompliance": false,
      "CalculatedRSquared": 0.99998119493700188,
      "RSquaredPass": true,
      "Success": true
    }
  ],
  "Success": true
},
"SampleType": 0,
"ContactPairIVResults": [
  {
    "ContactPair": {
      "Point1": 1,
      "Point2": 2
    },
    "Offset": 0.00073432332878914234,
    "Slope": 351.65899806878764,
    "RSquared": 0.99997037843103864,
    "RSquaredPass": true,
    "InCompliance": false,
```

```
              "VoltageOverload": false,
              "CurrentOverload": false
            },
            {
              "ContactPair": {
                "Point1": 2,
                "Point2": 3
              },
              "Offset": 0.00091293629123161916,
              "Slope": 322.45801602324741,
              "RSquared": 0.99997942216190217,
              "RSquaredPass": true,
              "InCompliance": false,
              "VoltageOverload": false,
              "CurrentOverload": false
            },
            {
              "ContactPair": {
                "Point1": 3,
                "Point2": 4
              },
              "Offset": 0.00064834521512294446,
              "Slope": 125.38136891935942,
              "RSquared": 0.9999540757056905,
              "RSquaredPass": true,
              "InCompliance": false,
              "VoltageOverload": false,
              "CurrentOverload": false
            },
            {
              "ContactPair": {
                "Point1": 4,
                "Point2": 1
              },
              "Offset": 0.00077756298505080783,
              "Slope": 157.92911795843915,
              "RSquared": 0.99998213223135157,
              "RSquaredPass": true,
              "InCompliance": false,
              "VoltageOverload": false,
              "CurrentOverload": false
            }
          ],
          "ActualBlankingTimeInSeconds": 0.002,
          "ActualSamplingTimeInSeconds": 0.0.0166666666666667,
          "InCompliance": false,
          "VoltageOverload": false,
          "CurrentOverload": false,
          "IsRunning": false,
          "StartTime": "2019-04-23T12:58:50.538058+00:00",
          "EndTime": "2019-04-23T12:58:59.667846+00:00",
          "DurationInSeconds": 9.13
        }
```

Remarks	This is similar to the CCHeck:RESult:JSON:ALL? query with the IV curve points omitted for each pair.

CCHeck:RESult[:STANdard]:DATA?

Summary	Retrieves the results of a single point in the contact check measurement IV curve for a given contact pair.
Query Format	CCHeck:RESult[:STANdard]:DATA? <contactPoint1>,<contactPoint2>,<curvePoint>
Parameters	<contactPoint1> Contact pair point 1. Data type is *NR1*
	<contactPoint2> Contact pair point 2. Data type is *NR1*

	<curvePoint>	IV curve point, zero indexed. Data type is *NR1*
Returns	<excitationType>,<excitationValue>,<voltage>,<current>,<resistance>	
	<excitationType>	The excitation type used for the measurement, VOLTage or CURRent. Data type is *NAMED*
	<excitationValue>	The excitation output value. Data type is *NRf*
	<voltage>	The measured voltage. Data type is *NRf*
	<current>	The measured current. Data type is *NRf*
	<resistance>	The measured resistance. Data type is *NRf*

CCHeck:RESult[:STANdard][:SUMMary]:ASETup?

Summary	Retrieves the last run contact check measurement's auto optimization Setup.
Query Format	CCHeck:RESult[:STANdard][:SUMMary]:ASETup?
Returns	<autoEnabled>,<maxCurrent>,<maxVoltage>,<maxPoints>,<minimumRSquared> <samplingTimeInSeconds>

<autoEnabled>	Indicates if the measurement's auto mode was used. Data type is *bool*
<maxCurrent>	Maximum output current, independent of the excitation type. Data type is *NRf*
<maxVoltage>	IMaximum output voltage, independent of the excitation type. Data type is *NRf*
<maxPoints>	The number of points to measure between the excitation start and end. Data type is *NRf*
<minimumRSquared>	The minimum desired R^2. Data type is *NRf*
<samplingTimeInSeconds>	The time, in seconds, which measurements will be averaged over to get one sample. Data type is *NRf*

CCHeck:RESult[:STANdard][:SUMMary]?

Summary	Retrieves the results of the last run contact check measurement.
Query Format	CCHeck:RESult[:STANdard][:SUMMary]?
Returns	<startDateTime>,<durationOfTest>,<excitationType>,<excitationValueStart>, <excitationValueEnd>,<excitationRange>,<measurementRange>, <complianceLimit>,<numberOfPoints>,<minimumRSquared>, <blankingTimeInSeconds>,<samplingTimeInSeconds>,<contactPairAOffset>, <contactPairASlope>,<contactPairARSquared>,<contactPairARSquaredPassed>, <contactPairBOffset>,<contactPairBSlope>,<contactPairBRSquared>, <contactPairBRSquaredPassed>,<contactPairCOffset>,<contactPairCSlope>, <contactPairCRSquared>,<contactPairCRSquaredPassed>,<contactPairDOffset>, <contactPairDSlope>,<contactPairDRSquared>,<contactPairDRSquaredPassed>, <contactPairEOffset>,<contactPairESlope>,<contactPairERSquared>, <contactPairERSquaredPassed>,<contactPairFOffset>,<contactPairFSlope>, <contactPairFRSquared>,<contactPairFRSquaredPassed>

<startDateTime>	UTC date and time when the measurement was started in

	ISO 8601 format.
	Data type is *string*
‹durationOfTest›	Duration of the test in seconds.
	Data type is *NR1*
‹excitationType›	The excitation type used for the measurement, VOLTage or CURRent.
	Data type is *NAMED*
‹excitationValueStart›	The starting excitation value.
	Data type is *NRf*
‹excitationValueEnd›	The ending excitation value.
	Data type is *NRf*
‹excitationRange›	The excitation range.
	Data type is *NRf*
‹measurementRange›	The measurement range.
	Data type is *NRf*
‹complianceLimit›	For voltage excitation, the current limit. For current excitation, the voltage compliance.
	Data type is *NRf*
‹numberOfPoints›	The number of points measured between the excitation start and end.
	Data type is *NR1*
‹minimumRSquared›	The minimum R^2 desired.
	Data type is *NRf*
‹blankingTimeInSeconds›	The time in seconds to wait for hardware to settle before changing the state of the hardware again.
	Data type is *NRf*
‹samplingTimeInSeconds›	The time, in seconds, which measurements will be averaged over to get one sample.
	Data type is *NRf*
‹contactPairAOffset›	The measured offset for contact pair 1-2 if sample is van der Pauw, 5-6 if sample is Hall bar.
	Data type is *NRf*
‹contactPairASlope›	The measured slope for contact pair 1-2 if sample is van der Pauw, 5-6 if sample is Hall bar.
	Data type is *NRf*
‹contactPairARSquared	The measured R^2 for contact pair 1-2 if sample is van der Pauw, 5-6 if sample is Hall bar.
	Data type is *NRf*
‹contactPairARSquaredPassed›	If measured R^2 was less than or equal to desired R^2 for contact pair 1-2 if sample is van der Pauw, 5-6 if sample is Hall bar.
	Data type is *bool*
‹contactPairBOffset›	The measured offset for contact pair 2-3 if sample is van der Pauw, 5-1 if sample is Hall bar.
	Data type is *NRf*
‹contactPairBSlope›	The measured slope for contact pair 2-3 if sample is van der Pauw, 5-1 if sample is Hall bar.
	Data type is *NRf*
‹contactPairBRSquared	The measured R^2 for contact pair 2-3 if sample is van der Pauw, 5-1 if sample is Hall bar.
	Data type is *NRf*
‹contactPairBRSquaredPassed›	If measured R^2 was less than or equal to desired R^2 for contact pair 2-3 if sample is van der Pauw, 5-1 if sample is Hall bar.
	Data type is *bool*

<contactPairCOffset>	The measured offset for contact pair 3-4 if sample is van der Pauw, 5-2 if sample is Hall bar. Data type is *NRf*
<contactPairCSlope>	The measured slope for contact pair 3-4 if sample is van der Pauw, 5-2 if sample is Hall bar. Data type is *NRf*
<contactPairCRSquared	The measured R^2 for contact pair 3-4 if sample is van der Pauw, 5-2 if sample is Hall bar. Data type is *NRf*
<contactPairCRSquaredPassed>	If measured R^2 was less than or equal to desired R^2 for contact pair 3-4 if sample is van der Pauw, 5-2 if sample is Hall bar. Data type is *bool*
<contactPairDOffset>	The measured offset for contact pair 4-1 if sample is van der Pauw, 5-3 if sample is Hall bar. Data type is *NRf*
<contactPairDSlope>	The measured slope for contact pair 4-1 if sample is van der Pauw, 5-3 if sample is Hall bar. Data type is *NRf*
<contactPairDRSquared	The measured R^2 for contact pair 4-1 if sample is van der Pauw, 5-3 if sample is Hall bar. Data type is *NRf*
<contactPairDRSquaredPassed>	If measured R^2 was less than or equal to desired R^2 for contact pair 4-1 if sample is van der Pauw, 5-3 if sample is Hall bar. Data type is *bool*
<contactPairEOffset>	The measured offset for contact pair 5-4 (field present for Hall bar only). Data type is *NRf*
<contactPairESlope>	The measured slope for contact pair 5-4 (field present for Hall bar only). Data type is *NRf*
<contactPairERSquared	The measured R^2 for contact pair 5-4 (field present for Hall bar only). Data type is *NRf*
<contactPairERSquaredPassed>	If measured R^2 was less than or equal to desired R^2 for contact pair 5-4 (field present for Hall bar only). Data type is *bool*
<contactPairFOffset>	The measured offset for contact pair 6-1 (field present for Hall bar only). Data type is *NRf*
<contactPairFSlope>	The measured slope for contact pair 6-1 (field present for Hall bar only). Data type is *NRf*
<contactPairFRSquared	The measured R^2 for contact pair 6-1 (field present for Hall bar only). Data type is *NRf*
<contactPairFRSquaredPassed>	If measured R^2 was less than or equal to desired R^2 for contact pair 6-1 (field present for Hall bar only). Data type is *bool*

CCHeck:RUNNing?

Summary	Indicates if the contact check measurement is running.
Query Format	CCHeck:RUNNing?
Returns	The measurement is running. Data type is *bool*

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CCHeck[:VDP]:STARt:MANual

Summary		Performs a contact check measurement on contact pairs 1-2, 2-3, 3-4, and 4-1 for a van der Pauw sample.
Command Format		CCHeck[:VDP]:STARt:MANual ‹excitationType›,‹excitationValueStart›, ‹excitationValueEnd›,‹excitationRange›, ‹measurementRange›,‹complianceLimit›, ‹numberOfPoints›,‹minimumRSquared›,‹blankingTime›
Parameters	‹excitationType›	VOLTage, CURRent
		Data type is *NAMED*
	‹excitationValueStart›	The starting excitation value
		For voltage excitation -10 to 10 V
		For current excitation -100 e3 to 100 e-3 A
		Data type is *NRf*
	‹excitationValueEnd›	The ending excitation value
		For voltage excitation -10 to 10 V
		For current excitation -100 e3 to 100 e-3 A
		Data type is *NRf*
	‹excitationRange›	For voltage excitation 0 to 10 V
		For current excitation 0 to 100 e-3 A
		AUTO sets the range to the best fit range for a given excitation value
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	‹measurementRange›	For voltage excitation, specify the current measurement range 0 to 100 e-3 A
		For current excitation, specify the voltage measurement range 0 to 10 V
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	‹complianceLimit›	For voltage excitation, specify the current limit 100 e-9 to 100 e-3 A
		For current excitation, specify the voltage compliance 1.0 to 10 V
		Data type is *NRf*
	‹numberOfPoints›	The number of points to measure between the excitation start and end. 0 - 100
		Data type is *NR1*
	‹minimumRSquared›	The minimum R^2 desired, DEFault = 0.9999.
		Data type is *Number*
	‹blankingTime›	The time in seconds to wait for the hardware to settle before gathering readings.
		0.5 ms to 300 s with a resolution of 0.1 ms
		DEFault = 2 ms
		MINimum = 0.5 ms
		MAXimum = 300 s
		Data type is *Number*
	‹samplingTime›	The sampling time, in seconds, which measurements will be averaged over to get one sample.
		MINimum = 0.010 ms
		MAXimum = 1 s
		DEFault = 1/60 s
		Data type is *Number*
Example		CCHeck:STARt:MANual CURRent,-10e-6,10e-6,10e-6,100e-3,1.5,20,0.9999,2.4e-3

CCHeck[:VDP]:STARt[:OPTimize]

Summary	Automatically determines excitation value and ranges. Then runs contact check on all 4 pairs for a van der Pauw sample.
Command Format	CCHeck[:VDP]:STARt[:OPTimize] <maxCurrent>,<maxVoltage>,<numberOfPoints>, <minimumRSquared>,<samplingTime>
Parameters	<maxCurrent> A 'not to exceed' output current value for the auto algorithm to use. MINimum = 1 µA MAXimum = 100 mA DEFault = 100 mA Data type is *Number*
	<maxVoltage> A 'not to exceed' output voltage value for the auto algorithm to use. MINimum = 1 V MAXimum = 10 V DEFault = 10 V Data type is *Number*
	<numberOfPoints> The number of points to measure between the excitation start and end. MINimum = 2 MAXimum = 100 DEFault = 11 Data type is *Number*
	<minimumRSquared> The minimum R^2 desired, DEFault = 0.9999. Data type is *Number*
	<samplingTime> The sampling time, in seconds, which measurements will be averaged over to get one sample. MINimum = 0.010 ms MAXimum = 1 s DEFault = 1/60 s Data type is *Number*
Example	CCHeck:STARt 10e-3,10,11,0.9999

DIGital:IDATa?

Summary	Returns the bit-wise representation of the input states.
Query Format	DIGital:IDATa?
Returns	Data type is *NRf*
Example	DIGital:IDATa?

DIGital:OSETting?

Summary	Returns the bit-wise representation of the output states.
Query Format	DIGital:OSETting?
Returns	Data type is *NRf*
Example	DIGital:OSETting?

DIGital:OSETting

Summary	Configures the output states.
Command Format	DIGital:OSETting?
Returns	Data type is *NRf*
Example	DIGital:OSETting 4

DISPlay:BRIGhtness

Command Format	DISPlay:BRIGhtness <brightness>	
Parameter	<brightness>	0 (OFF), 25, 50, 75, 100
		Data type is NR1
Query Format	DISPlay:BRIGhtness?	
Return Parameter	<brightness>	(see above)
Examples		
Command	DISP:BRIG 50	Sets the display brightness to 50
Query	DIG:BRIG?	
Query Response	100	Indicates that the display brightness is set to 100
Remarks	This command controls the intensity of the display on the device.	

DISPlay:ENABle

Command Format	DISPlay:ENABle <on/off>	
Parameter	<on/off>	0 = OFF, 1 = ON
		Data type is bool
Query Format	DISPlay:ENABle?	
Return Parameter	<on/off>	(see above)
Examples		
Command	DISP:ENAB 1	Turns on the display
Query	DISP:ENAB?	
Query Response	0	Indicates that the display is off
Remarks	This command controls whether the display is turned on or off.	

FASThall:RESet

Summary	Resets the measurement to a not run state, canceling any running measurement.
Command Format	FASThall:RESet
Example	FASThall:RESET

FASThall:RESult:JSON:ALL:SUBstring?

Summary	Retrieves a substring of the last run FastHall™ measurement results serialized as JSON.	
Query Format	FASThall:RESult:JSON:ALL:SUBstring? <startIndex>,<length>	
Parameters	<startIndex>	The substring starting index, zero based.
		Data type is *NR1*
	<length>	The number of characters to return.
		Data type is *NR1*
Returns	Substring of the JSON serialized FastHall™ measurement result.	
	Data type is *NAMED*	
Examples	`Query FASThall:RESult:JSON:ALL:SUBstring? 0, 42`	
	`Query response`	
	`{"Setup":{"ExcitationType":1,"ExcitationVa`	

FASThall:RESult:JSON:ALL?

Summary	Retrieves the results of the last run FastHall™ measurement, serialized as JSON.	
Query Format	FASThall:RESult:JSON:ALL? <pretty>	
Parameters	<pretty>	Optional, pretty format JSON response. Defaults to False.
		Data type is *bool*
Returns	JSON serialized FastHall™ measurement result.	
	Data type is *NAMED*	
Examples	`Query FASThall:RESult:JSON:ALL? 1`	
	`Query response`	

```
{
  "Setup": {
    "ExcitationType": 1,
    "ExcitationValue": 0.01,
    "ExcitationAutoRange": false,
    "ExcitationRange": 0.1,
    "ExcitationMeasurementRange": 0.1,
    "MeasurementAutoRange": false,
    "MeasurementRange": 0.1,
    "ComplianceLimit": 10.0,
    "MinimumHallVoltageSnr": 30.0,
    "MaxNumberOfSamples": 10,
    "UserDefinedFieldReadingInTesla": 0.9313,
    "Resistivity": 0.26,
    "BlankingTimeInSeconds": 0.002,
    "NumberOfVoltageCompensationSamplesToAverage": 1,
    "SampleThicknessInMeters": null,
    "Guid": "c02c4a82-c116-4c3f-8207-0a73e4bfd6a7"
  },
  "HallVoltageSnr": 33665.326111799768,
  "HallVoltageAverageInVolts": -0.00178542105,
  "HallVoltageStandardErrorInVolts": 5.3034420164853415E-08,
  "HallCoefficientAverageInMetersCubedPerCoulomb": "NaN",
  "HallCoefficientStandardErrorInMetersCubedPerCoulomb": "NaN",
  "SheetHallCoefficientAverageInMetersSquaredPerCoulomb":
19.197745754863831,
  "SheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb":
0.000570252778514894,
  "CarrierType": 2,
  "PTypeCount": 0,
  "NTypeCount": 10,
  "CarrierConcentrationAveragePerMetersCubed": "NaN",
  "CarrierConcentrationStandardErrorPerMetersCubed": "NaN",
  "SheetCarrierConcentrationAveragePerMetersSquared":
3.2511677197404589E+17,
  "SheetCarrierConcentrationStandardErrorPerMetersSquared":
9657318360569.5645,
  "MobilityAverageInMetersSquaredPerVoltSecond": 73.837483672553191,
  "MobilityStandardErrorInMetersSquaredPerVoltSecond":
0.0021932799173649768,
  "ActualBlankingTimeInSeconds": 0.002,
  "ActualSamplingTimeInSeconds": 0.0166666666666667,
  "InCompliance": false,
  "VoltageOverload": false,
  "CurrentOverload": false,
  "NumberOfSamples": 10,
  "FastHallSamples": [
    {
      "HallVoltageInVolts": -0.00178504225,
      "HallCoefficientInMetersCubedPerCoulomb": "NaN",
      "SheetHallCoefficientInMetersSquaredPerCoulomb": 19.193712492447734,
      "CarrierType": 2,
      "CarrierConcentrationPerMetersCubed": "NaN",
      "SheetCarrierConcentrationPerMetersSquared": 3.251850902453424E+17,
      "MobilityInMetersSquaredPerVoltSecond": 73.821971124798978,
      "FieldReadingInTesla": 0.9313,
      "CurrentAverageInAmps": 0.009986192,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false,
      "ActualBlankingTimeInSeconds": 0.002,
      "ActualSamplingTimeInSeconds": 0.0166666666666667,
      "PositiveFieldConfiguration": {
        "PositiveExcitation": {
          "VoltageInVolts": -0.001704974,
          "CurrentInAmps": 0.009987975,
          "ExcitationSetpoint": 0.01,
          "InCompliance": false,
```

```
                              "VoltageOverload": false,
                              "CurrentOverload": false
                        },
                        "NegativeExcitation": {
                              "VoltageInVolts": 0.001870144,
                              "CurrentInAmps": -0.009984306,
                              "ExcitationSetpoint": -0.01,
                              "InCompliance": false,
                              "VoltageOverload": false,
                              "CurrentOverload": false
                        }
                  },
                  "NegativeFieldConfiguration": {
                        "PositiveExcitation": {
                              "VoltageInVolts": 0.001868397,
                              "CurrentInAmps": 0.00998818,
                              "ExcitationSetpoint": 0.01,
                              "InCompliance": false,
                              "VoltageOverload": false,
                              "CurrentOverload": false
                        },
                        "NegativeExcitation": {
                              "VoltageInVolts": -0.001696654,
                              "CurrentInAmps": -0.009984307,
                              "ExcitationSetpoint": -0.01,
                              "InCompliance": false,
                              "VoltageOverload": false,
                              "CurrentOverload": false
                        }
                  }
            },
            ...
      ],
   "IsRunning": false,
   "StartTime": "1970-01-02T01:54:54.722693-05:00",
   "EndTime": "1970-01-02T01:54:56.680644-05:00",
   "DurationInSeconds": 1.959
}
```

FASThall:RESult:JSON:DATA?

Summary	Retrieves data from a given sample taken during the last run FastHall™ measurement
Query Format	FASThall:RESult:JSON:DATA? <sampleIndex>,<pretty>
Parameters	<sampleIndex> Sample index, zero based. Data type is *NR1*
	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized FastHall™ measurement sample data. Data type is *NAMED*

Examples

```
Query FASThall:RESult:JSON:DATA? 4,1
Query response
{
 "HallVoltageInVolts": -0.001785474,
 "HallCoefficientInMetersCubedPerCoulomb": "NaN",
 "SheetHallCoefficientInMetersSquaredPerCoulomb": 19.198509657073764,
 "CarrierType": 2,
 "CarrierConcentrationPerMetersCubed": "NaN",
 "SheetCarrierConcentrationPerMetersSquared": 3.2510383568758234E+17,
 "MobilityInMetersSquaredPerVoltSecond": 73.840421757976017,
 "FieldReadingInTesla": 0.9313,
 "CurrentAverageInAmps": 0.0099861115,
 "InCompliance": false,
 "VoltageOverload": false,
 "CurrentOverload": false,
 "ActualBlankingTimeInSeconds": 0.002,
 "ActualSamplingTimeInSeconds": 0.0166666666666667,
 "PositiveFieldConfiguration": {
   "PositiveExcitation": {
     "VoltageInVolts": -0.001712573,
     "CurrentInAmps": 0.009987764,
     "ExcitationSetpoint": 0.01,
     "InCompliance": false,
     "VoltageOverload": false,
     "CurrentOverload": false
   },
   "NegativeExcitation": {
     "VoltageInVolts": 0.001864178,
     "CurrentInAmps": -0.009984493,
     "ExcitationSetpoint": -0.01,
     "InCompliance": false,
     "VoltageOverload": false,
     "CurrentOverload": false
   }
 },
 "NegativeFieldConfiguration": {
   "PositiveExcitation": {
     "VoltageInVolts": 0.001867327,
     "CurrentInAmps": 0.009987842,
     "ExcitationSetpoint": 0.01,
     "InCompliance": false,
     "VoltageOverload": false,
     "CurrentOverload": false
   },
   "NegativeExcitation": {
     "VoltageInVolts": -0.001697818,
     "CurrentInAmps": -0.009984347,
     "ExcitationSetpoint": -0.01,
     "InCompliance": false,
     "VoltageOverload": false,
     "CurrentOverload": false
   }
 }
```

FASThall:RESult:JSON[:SUMMary]?

Summary	Retrieves summary results of the last run FastHall™ measurement, serialized as JSON.
Query Format	FASThall:RESult:JSON[:SUMMary]? <pretty>
Parameters	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized FastHall™ measurement result. Data type is *NAMED*

Examples

```
Query FASThall:RESult:JSON? 1
Query response
{
  "Setup": {
    "ExcitationType": 0,
    "ExcitationValue": "NaN",
    "ExcitationAutoRange": false,
    "ExcitationRange": "NaN",
    "ExcitationMeasurementRange": "NaN",
    "MeasurementAutoRange": false,
    "MeasurementRange": "NaN",
    "ComplianceLimit": "NaN",
    "MinimumHallVoltageSnr": 0.0,
    "MaxNumberOfSamples": 0,
    "UserDefinedFieldReadingInTesla": "NaN",
    "Resistivity": "NaN",
    "BlankingTimeInSeconds": 2.0,
    "NumberOfVoltageCompensationSamplesToAverage": 0,
    "SampleThicknessInMeters": null,
    "SamplingTimeInSeconds": 0.0166666666666667,
    "Guid": "d75b6abd-6dc5-444c-b43d-f4b2dce61bc8"
  },
  "HallVoltageSnr": 0.0,
  "HallVoltageAverageInVolts": 0.0,
  "HallVoltageStandardErrorInVolts": 0.0,
  "HallCoefficientAverageInMetersCubedPerCoulomb": 0.0,
  "HallCoefficientStandardErrorInMetersCubedPerCoulomb": 0.0,
  "SheetHallCoefficientAverageInMetersSquaredPerCoulomb": 0.0,
  "SheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb": 0.0,
  "CarrierType": 0,
  "PTypeCount": 0,
  "NTypeCount": 0,
  "CarrierConcentrationAveragePerMetersCubed": 0.0,
  "CarrierConcentrationStandardErrorPerMetersCubed": 0.0,
  "SheetCarrierConcentrationAveragePerMetersSquared": 0.0,
  "SheetCarrierConcentrationStandardErrorPerMetersSquared": 0.0,
  "MobilityAverageInMetersSquaredPerVoltSecond": 0.0,
  "MobilityStandardErrorInMetersSquaredPerVoltSecond": 0.0,
  "ActualBlankingTimeInSeconds": 0.0,
  "ActualSamplingTimeInSeconds": 0.0166666666666667,
  "InCompliance": false,
  "VoltageOverload": false,
  "CurrentOverload": false,
  "NumberOfSamples": 0,
  "IsRunning": false,
  "StartTime": "0001-01-01T00:00:00",
  "EndTime": "0001-01-01T00:00:00",
  "DurationInSeconds": 0.0
}
```

FASThall:RESult[:STANdard]:DATA?

Summary
Retrieves data from a given sample taken during the last run FastHall™ measurement.

Query Format
FASThall:RESult[:STANdard]:DATA? <sampleIndex>

Parameters
<sampleIndex>   Sample index, zero based.
                      Data type is *NR1*

Returns
<HallVoltageInVolts>,<HallCoefficientInMetersCubedPerCoulomb>, <SheetHallCoefficientInMetersSquaredPerCoulomb>,<carrierType>, <CarrierConcentrationPerMetersCubed>,<SheetConcentrationPerMetersSquared>, <MobilityInMetersSquaredPerVoltSecond>,<FieldReadingInTesla>, <CurrentAverageInAmps>

<HallVoltageInVolts>   The Hall voltage, in units of volts.
                         Data type is *NRf*
<HallCoefficientInMetersCubedPerCoulomb>
                         The bulk Hall coefficient, in units of meters cubed per coulomb.
                         Data type is *NRf*
<SheetHallCoefficientInMetersSquaredPerCoulomb>
                         The sheet Hall coefficient, in units of meters squared per coulomb.
                         Data type is *NRf*
<carrierType>   The carrier type. P, N, or Unknown.
                         Data type is *NAMED*
<CarrierConcentrationPerMetersCubed>
                         The bulk carrier concentration, in units of per meters cubed.
                         Data type is *NRf*
<SheetCarrierConcentrationPerMetersSquared>
                         The sheet carrier concentration, in units of per meters squared.
                         Data type is *NRf*
<MobilityInMetersSquaredPerVoltSecond>
                         The mobility in units of meters squared per volt second.
                         Data type is *NRf*
<FieldReadingInTesla>   The field, in units of Tesla, the sample is being subjected to.
                         Data type is *NRf*
<CurrentAverageInAmps>   The average current, in amperes, that is being applied to the sample.
                         Data type is *NRf*

Examples
```
Query FASThall:RESult:DATA? 4
Query response
3.8853575E-07,nan,0.00777387216383254,P,nan,8.02882913104489E+20,
0.0777387216383254,0.5,0.00999593875,0,0,0
```

FASThall:RESult[:STANdard]:POINts?

Summary
Retrieves the number of points in the results list. Use in conjunction with FASThall:RESult[:STANdard]:DATA? and FASThall:RESult[:STANdard]:RAW? queries.

Query Format
FASThall:RESult[:STANdard]:POINts?

Returns
The number of points in the results list.
Data type is *NR1*

Examples
```
Query FASThall:RESult:POINts?
Query response
42
```

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FASThall:RESult[:STANdard]:RAW?

Summary

Retrieves the excitation setpoint, measured current, measured voltage, and compliance status for negative and positive excitations in both negative and positive field configurations from a given sample taken during the last run FastHall™ measurement.

Query Format

FASThall:RESult[:STANdard]:RAW? <sampleIndex>

Parameters

<sampleIndex>   Sample index, zero based.
                        Data type is *NR1*

Returns

<negativeFieldConfigurationNegativeExcitationSetpoint>,
<negativeFieldConfigurationNegativeExcitationCurrent>,
<negativeFieldConfigurationNegativeExcitationVoltage>,
<negativeFieldConfigurationPositiveExcitationSetpoint>,
<negativeFieldConfigurationPositiveExcitationCurrent>,
<negativeFieldConfigurationPositiveExcitationVoltage>,
<positiveFieldConfigurationNegativeExcitationSetpoint>,
<positiveFieldConfigurationNegativeExcitationCurrent>,
<positiveFieldConfigurationNegativeExcitationVoltage>,
<positiveFieldConfigurationPositiveExcitationSetpoint>,
<positiveFieldConfigurationPositiveExcitationCurrent>,
<positiveFieldConfigurationPositiveExcitationVoltage>,

<negativeFieldConfigurationNegativeExcitationSetpoint>
      The excitation setpoint for negative field configuration's negative excitation.
      Data type is *NRf*
<negativeFieldConfigurationNegativeExcitationCurrent>
      The measured current for negative field configuration's negative excitation.
      Data type is *NRf*
<negativeFieldConfigurationNegativeExcitationVoltage>
      The measured voltage for negative field configuration's negative excitation.
      Data type is *NRf*
<negativeFieldConfigurationPositiveExcitationSetpoint>
      The excitation setpoint for negative field configuration's positive excitation.
      Data type is *NRf*
<negativeFieldConfigurationPositiveExcitationCurrent>
      The measured current for negative field configuration's positive excitation.
      Data type is *NRf*
<negativeFieldConfigurationPositiveExcitationVoltage>
      The measured voltage for negative field configuration's positive excitation.
      Data type is *NRf*
<positiveFieldConfigurationNegativeExcitationSetpoint>
      The excitation setpoint for positive field configuration's negative excitation.
      Data type is *NRf*
<positiveFieldConfigurationNegativeExcitationCurrent>
      The measured current for positive field configuration's negative excitation.
      Data type is *NRf*

<positiveFieldConfigurationNegativeExcitationVoltage>

    The measured voltage for positive field configuration's negative excitation.

    Data type is *NRf*

<positiveFieldConfigurationPositiveExcitationSetpoint>

    The excitation setpoint for positive field configuration's positive excitation.

    Data type is *NRf*

<positiveFieldConfigurationPositiveExcitationCurrent>

    The measured current for positive field configuration's positive excitation.

    Data type is *NRf*

<positiveFieldConfigurationPositiveExcitationVoltage>

    The measured voltage for positive field configuration's positive excitation.

    Data type is *NRf*

Example

```
Query FASThall:RESult:RAW? 4
Query response
-0.01,-0.009995845,-1.088518E-05,0,0,0,0.01,0.009996215,-2.473091E-
06,0,0,0,-0.01,-0.009995703,-1.279248E-05,0,0,0,0.01,0.009995992,-
2.826248E-06,0,0,0
```

FASThall:RESult[:STANdard][:SUMMary]?

Summary   Retrieves the results of the last run FastHall™ measurement.

Query Format   FASThall:RESult[:STANdard][:SUMMary]?

Returns   <startDateTime>,<durationOfTest>,<excitationType>,<excitationValue>, <excitationRange>,<excitationMeasurementRange>,<measurementRange>, <complianceLimit>,<userDefinedFieldReadingInTesla>,<maxNumberOfSamples>, <resistivity>,<blankingTimeInSeconds>,<numberOfVoltageCompensation SamplesToAverage>,<sampleThicknessInMeters>,<minimumHallVoltageSnr>, <samplingTimeInSeconds>,<hallVoltageAverageInVolts>,<hallVoltageSnr>, <carrierType>,<pTypeCount>,<nTypeCount>, <carrierConcentrationAveragePerMetersCubed>, <sheetCarrierConcentrationAveragePerMetersSquared>, <carrierConcentrationStandardErrorPerMetersCubed>, <sheetCarrierConcentrationStandardErrorPerMetersSquared>, <hallCoefficientAverageInMetersCubedPerCoulomb>, <sheetHallCoefficientAverageInMetersSquaredPerCoulomb>, <HallCoefficient StandardErrorInMetersCubedPerCoulomb>, <sheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb>, <mobilityAverageInMetersSquaredPerVoltSecond>, <mobilityStandardErrorInMetersSquaredPerVoltSecond>

<startDateTime>	UTC date and time when the measurement was started in ISO 8601 format. Data type is *string*
<durationOfTest>	Duration of the test in milliseconds. Data type is *NRf*
<excitationType>	The excitation type used for the measurement, VOLTage or CURRent. Data type is *NAMED*
<excitationValue>	The excitation value. Data type is *NRf*
<excitationRange>	The excitation range. Data type is *NRf*
<excitationMeasurementRange>	

	The full scale range used to measure the excitation signal, dependent on excitationType. Data type is *NRf*
<measurementRange>	The full scale range of the measurement. For example, if excitation type is current, this is the full scale voltage range. Data type is *NRf*
<complianceLimit>	For voltage excitation, the current limit. For current excitation, the voltage compliance. Data type is *NRf*
<userDefinedFieldReadingInTesla>	The field, in units of Tesla, that the sample is being subjected to. Data type is *NRf*
<maxNumberOfSamples>	The setup's number of samples. When minimumSnr is omitted or INFinity (9.9E+37), this is the total number of samples. When minimumSnr is specified, this is the maximum number of samples. The FASThall:RESult[:STANDARD]:POINts? command can be used to retrieve the actual number of points in the results list. Data type is *NR1*
<resistivity>	The resistivity of the sample in units of ohm*meters (bulk) or ohms per square (sheet) Data type is *NRf*
<blankingTimeInSeconds>	The time in seconds to wait for the hardware to settle before making measurements. Data type is *NRf*
<numberOfVoltageCompensationSamplesToAverage>	The number of voltage compensation samples to average. Only applied for excitation type voltage. Data type is *NR1*
<sampleThicknessInMeters>	Thickness of the sample in meters. Data type is *NRf*
<minimumHallVoltageSnr>	The desired signal-to-noise ratio of the Hall voltage measurement. Data type is *NRf*
<samplingTimeInSeconds>	The sampling time in seconds which measurements were averaged over to get one sample. Data type is *NRf*
<hallVoltageAverageInVolts>	The average Hall voltage measured, in volts. Data type is *NRf*
<hallVoltageStandardErrorInVolts>	The standard error of the Hall voltage, in volts. Data type is *NRf*
<hallVoltageSnr>	The signal-to-noise ratio of the Hall voltage. measurement. Data type is *NRf*
<carrierType>	The carrier type of the sample. P, N, or Unknown. Data type is *NAMED*
<pTypeCount>	The number of samples that were measured as P carrier type. Data type is *NR1*
<nTypeCount>	The number of samples that were measured as N carrier type. Data type is *NR1*
<carrierConcentrationAveragePerMetersCubed>	The average bulk carrier concentration measured in units of

per meters cubed.
Data type is *NRf*

<sheetCarrierConcentrationAveragePerMetersSquared>

The average sheet carrier concentration measured in units of per meters squared.
Data type is *NRf*

<carrierConcentrationStandardErrorPerMetersCubed>

The standard error of the bulk carrier concentration in units of per meters cubed.
Data type is *NRf*

<sheetCarrierConcentrationStandardErrorPerMetersSquared>

The standard error of the sheet carrier concentration in units of per meters squared.
Data type is *NRf*

<hallCoefficientAverageInMetersCubedPerCoulomb>

The average bulk Hall coefficient measured in units of meters cubed per coulomb.
Data type is *NRf*

<sheetHallCoefficientAverageInMetersSquaredPerCoulomb>

The average sheet Hall coefficient measured in units of meters squared per coulomb.
Data type is *NRf*

<hallCoefficient StandardErrorInMetersCubedPerCoulomb>

The standard error of the bulk Hall coefficient in units of meters cubed per coulomb.
Data type is *NRf*

<sheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb>

The standard error of the sheet Hall coefficient in units of meters squared per coulomb.
Data type is *NRf*

<mobilityAverageInMetersSquaredPerVoltSecond>

The average mobility measured in units of meters squared per volt second.
Data type is *NRf*

<mobilityStandardErrorInMetersSquaredPerVoltSecond>

The standard deviation of the mobility in meters squared per volt second.
Data type is *NRf*

FASThall:RUNNing?

Summary   Indicates if the FastHall™ measurement is running.
Query Format   FASThall:RUNNing?
Returns   The measurement is running.
Data type is *bool*

FASThall[:VDP]:STARt

Summary   Performs a FastHall™ measurement for a van der Pauw sample.
Command Format   FASThall[:VDP]:STARt   <excitationType>,<excitationValue>,<excitationRange>,
<excitationMeasurementRange>,<measurementRange>,
<complianceLimit>,<userDefinedFieldReadingInTesla>,
<maxNumberOfSamples>,<resistivity>,<blankingTime>,
<numberOfVoltageCompensationSamplesToAverage>,
<sampleThickness>,<minimumHallVoltageSnr>,
<samplingTime>

Parameters		
	\<excitationType\>	VOLTage, CURRent
		Data type is *NAMED*
	\<excitationValue\>	For voltage excitation -10 to 10 V
		For current excitation -100 e3 to 100 e-3 A
		Data type is *NRf*
	\<excitationRange\>	For voltage excitation 0 to 10 V
		For current excitation 0 to 100 e-3 A
		AUTO sets the range to the best fit range for a given excitation value.
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	\<excitationmeasurementRange\>	For voltage excitation 0 to 10 V
		For current excitation 0 to 100 e-3 A
		AUTO sets the measurement range to the best fit range for a given excitation value.
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	\<measurementRange\>	For voltage excitation, specify the current measurement range 0 to 100 e-3 A
		For current excitation, specify the voltage measurement range 0 to 10 V
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	\<complianceLimit\>	For voltage excitation, specify the current limit 100 e-9 to 100 e-3 A
		For current excitation, specify the voltage compliance 1 to 10 V
		Data type is *NRf*
	\<userDefinedFieldReadingInTesla\>	The field, in units of Tesla, that the sample is being subjected to. Used for calculations.
		Data type is *NRf*
	\<maxNumberOfSamples\>	When minimumSnr is omitted or INFinity (9.9 e+37), the total number of samples to average 1 to 1000.
		When minimumSnr is specified, the maximum number of samples to average 10 to 1000.
		DEFault = 100
		Data type is *Number*
	\<resistivity\>	The resistivity of the sample in units of ohm*meters (bulk) of ohms per square (sheet). Used for calculations. Measure this value using the RESistivity SCPI subsystem. Defaults to not a number which will propagate through calculated values.
		DEFault = NaN (9.91 e+37)
		NOTE: When the resistivity is omitted or NaN (9.91 e+37), mobility is not calculated.
		Data type is *Number*
	\<blankingTime\>	The time, in seconds, to wait for hardware to settle before gathering readings.
		0.5 ms to 300 s with a resolution of 0.1 ms
		DEFault = 2 ms
		MINimum = 0.5 ms
		MAXimum = 300 s
		Data type is *Number*

<numberOfVoltageCompensationSamplesToAverage>	The number of voltage compensation samples to average. Only applied for excitation type voltage. 1 to 120 DEFault = 60 Data type is *Number*
<sampleThickness>	Thickness of the sample in meters. 0 to 10 e-3 m DEFault = 0 m Data type is *Number*
<minimumHallVoltageSnr>	The desired signal-to-noise ratio of the measurement calculated using average Hall voltage/error of mean 1 to 1000, or INFinity (9.9 e+37) DEFault = 30
<samplingTime>	The sampling time, in seconds, which measurements will be averaged over to get one sample. MINimum = 0.010 ms MAXimum = 1 s DEFault = 1/60 s Data type is *Number*

Example	FASThall:STARt CURRent,10E-3,10E-3,AUTO,1.0,10.0,0.5,12,0.1,2.4e-3,10,0,30

FASThall[:VDP]:STARt:LINk

Summary	Performs a FastHall™ measurement (for a van der Pauw sample) that uses the last run contact check measurement's excitation type, compliance limit, blanking time, excitation range, and the largest absolute value of the start and end excitation values along with the last run resistivity measurement's resistivity average and sample thickness.
Command Format	FASThall[:VDP]:STARt:LINk <userDefinedFieldReadingInTesla>,<measurementRange>, <maxNumberOfSamples>,<minimumHallVoltageSnr, <numberOfVoltageCompensationSamplesToAverage>, <sampleThickness>

Parameters		
	<userDefinedFieldReadingInTesla>	The field, in units of Tesla, that the sample is being subjected to. Used for calculations. Data type is *NRf*
	<measurementRange>	For voltage excitation 0 to 10 V For current excitation 0 to 100 e-3 A AUTO sets the measurement range to the best fit range for a given excitation value. DEFault= AUTO **NOTE:** The hardware will be configured to best meet the desired range. Data type is *Number*
	<MaxNumberOfSamples>	When minimumSnr is omitted or INFinity (9.9 e+37), the total numberof samples to average 1 - 1000. When minimumSnr is specified, the maximum number of samples to average 10 - 1000. DEFault = 100 Data type is *Number*
	<minimumHallVoltageSnr>	The desired signal-to-noise ratio of the measurement calculated using average Hall voltage/error of mean 1 - 1000, or INFinity (9.9 e+37) DEFault = 30 Data type is *Number*

	<numberOfVoltageCompensationSamplesToAverage> The number of voltage compensation samples to average. Only applied for excitation type voltage. 1 - 120 DEFault = 60 Data type is *Number*
	<sampleThickness> Thickness of the sample in meters. 0 to 10 e-3 m DEFault = 0 m if resistivity measurement was NOT run DEFault = resistivity from last run resistivity measurement, if one was run Data type is *Number*

Example   FASThall:STARt:LINk 0.5

FWIRe:RESet

Summary   Resets the measurement to a not run state, canceling any running measurement.
Command Format FWIRe:RESet
Example   FWIRe:RESET

FWIRe:RESult:JSON:ALL:SUBstring?

Summary   Retrieves a substring of the last run four wire measurement results serialized as JSON.
Query Format FWIRe:RESult:JSON:ALL:SUBstring? <startIndex>,<length>
Parameters   <startIndex>   The substring starting index, zero based.
                                     Data type is *NR1*
                  <length>   The number of characters to return.
                                     Data type is *NR1*
Returns   Substring of the JSON serialized four wire measurement result.
                  Data type is *NAMED*
Examples   `Query FWIRe:RESult:JSON:ALL:SUBstring? 1`
                  `Query response`
                  `{"Setup":{"ContactPairSense":{"Point1":1,"Point`

FWIRe:RESult:JSON:ALL?

Summary   Retrieves ALL the results, including individual samples, of the last run four wire measurement, serialized as JSON.
Query Format FWIRe:RESult:JSON:ALL? <pretty>
Parameters   <pretty>   Optional, pretty format JSON response. Defaults to False.
                                     Data type is *bool*
Returns   JSON serialized four wire measurement result.
                  Data type is *NAMED*
Examples   `Query FWIRe:RESult:JSON:ALL? 1`
                  `Query response`

```
{
  "Setup": {
    "ContactPairExcitation": {
      "Point1": 1,
      "Point2": 4
    },
    "ContactPairSense": {
      "Point1": 1,
      "Point2": 4
    },
    "ExcitationType": 1,
    "ExcitationValue": 0.0005,
    "ExcitationAutoRange": false,
    "ExcitationRange": 0.001,
    "MeasurementAutoRange": false,
```

```
        "MeasurementRange": 1.0,
        "ExcitationMeasurementRange": 0.01,
        "ComplianceLimit": 1.5,
        "BlankingTimeInSeconds": 0.003,
        "MaximumNumberOfSamples": 3,
        "MinimumResistanceSnr": "Infinity",
        "UseExcitationReversal": true,
        "SamplingTimeInSeconds": 0.0.0166666666666667,
        "Guid": "2f4db56f-8ec0-48a7-aa18-1807b579ecb8"
    },
    "ResistanceSnr": 1320.0135758769798,
    "ResistanceAverageInOhms": 166.57247082481206,
    "ResistanceStandardErrorInOhms": 0.12618996794343271,
    "VoltageAverageInVolts": 0.083259233333333335,
    "VoltageStandardErrorInVolts": 6.4466840141094486E-05,
    "CurrentAverageInAmps": 0.00049983788333333339,
    "CurrentStandardErrorInAmps": 1.0765544317146766E-08,
    "InCompliance": false,
    "VoltageOverload": false,
    "CurrentOverload": false,
    "ActualBlankingTimeInSeconds": 0.003,
    "ActualSamplingTimeInSeconds": 0.0166666666666667,
    "FourWireMeasurementSamples": [
      {
        "Excitations": [
          {
            "VoltageInVolts": 0.08025881,
            "CurrentInAmps": 0.0004990022,
            "ExcitationSetpoint": 0.0005,
            "InCompliance": false,
            "CurrentOverload": false,
            "VoltageOverload": false
          },
          {
            "VoltageInVolts": -0.08643671,
            "CurrentInAmps": -0.0005007162,
            "ExcitationSetpoint": -0.0005,
            "InCompliance": false,
            "CurrentOverload": false,
            "VoltageOverload": false
          }
        ],
        "VoltageInVolts": 0.083347759999999993,
        "CurrentInAmps": 0.00049985919999999992,
        "ResistanceInOhms": 166.74247468087015,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false,
        "ActualBlankingTimeInSeconds": 0.003,
        "ActualSamplingTimeInSeconds": 0.0166666666666667,
      },
      {
        "Excitations": [
          {
            "VoltageInVolts": 0.08022177,
            "CurrentInAmps": 0.0004990204,
            "ExcitationSetpoint": 0.0005,
            "InCompliance": false,
            "CurrentOverload": false,
            "VoltageOverload": false
          },
          {
            "VoltageInVolts": -0.08637053,
            "CurrentInAmps": -0.0005006393,
            "ExcitationSetpoint": -0.0005,
            "InCompliance": false,
            "CurrentOverload": false,
            "VoltageOverload": false
```

```
          }
        ],
        "VoltageInVolts": 0.08329615,
        "CurrentInAmps": 0.00049982985,
        "ResistanceInOhms": 166.64901065832703,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false,
        "ActualBlankingTimeInSeconds": 0.003,
        "ActualSamplingTimeInSeconds": 0.0166666666666667,
      },
      {
        "Excitations": [
          {
            "VoltageInVolts": 0.08016813,
            "CurrentInAmps": 0.0004990384,
            "ExcitationSetpoint": 0.0005,
            "InCompliance": false,
            "CurrentOverload": false,
            "VoltageOverload": false
          },
          {
            "VoltageInVolts": -0.08609945,
            "CurrentInAmps": -0.0005006108,
            "ExcitationSetpoint": -0.0005,
            "InCompliance": false,
            "CurrentOverload": false,
            "VoltageOverload": false
          }
        ],
        "VoltageInVolts": 0.08313379,
        "CurrentInAmps": 0.0004998246,
        "ResistanceInOhms": 166.32592713523903,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false,
        "ActualBlankingTimeInSeconds": 0.003,
        "ActualSamplingTimeInSeconds": 0.0166666666666667,
      }
    ],
    "IsRunning": false,
    "StartTime": "1970-01-02T02:16:08.441601-05:00",
    "EndTime": "1970-01-02T02:16:08.68956-05:00",
    "DurationInSeconds": 0.247
  }
```

FWIRe:RESult:JSON[:SUMMary]?

Summary	Retrieves summary results of the last run four wire measurement, serialized as JSON.
Query Format	FWIRe:RESult:JSON[:SUMMary]? <pretty>
Parameters	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized four wire measurement result. Data type is *NAMED*

Examples

```
Query FWIRe:RESult:JSON? 1
Query response
{
  "Setup": {
    "ContactPairExcitation": {
      "Point1": 1,
      "Point2": 4
    },
    "ContactPairSense": {
      "Point1": 1,
      "Point2": 4
    },
    "ExcitationType": 1,
    "ExcitationValue": 0.0005,
    "ExcitationAutoRange": false,
    "ExcitationRange": 0.001,
    "MeasurementAutoRange": false,
    "MeasurementRange": 1.0,
    "ExcitationMeasurementRange": 0.01,
    "ComplianceLimit": 1.5,
    "BlankingTimeInSeconds": 0.003,
    "MaximumNumberOfSamples": 10,
    "MinimumResistanceSnr": 30.0,
    "SamplingTimeInSeconds": 0.0166666666666667,
    "UseExcitationReversal": true,
    "Guid": "79893bed-0324-4f3c-afc7-7787bb7e2b14"
  },
  "ResistanceSnr": 19581.809718361535,
  "ResistanceAverageInOhms": 166.04548854988784,
  "ResistanceStandardErrorInOhms": 0.008479578289139934,
  "VoltageAverageInVolts": 0.0829870805,
  "VoltageStandardErrorInVolts": 3.7480418924799673E-06,
  "CurrentAverageInAmps": 0.00049978522,
  "CurrentStandardErrorInAmps": 1.4462273142375665E-08,
  "InCompliance": false,
  "VoltageOverload": false,
  "CurrentOverload": false,
  "ActualBlankingTimeInSeconds": 0.003,
  "ActualSamplingTimeInSeconds": 0.0166666666666667,
  "IsRunning": false,
  "StartTime": "1970-01-02T02:05:09.367824-05:00",
  "EndTime": "1970-01-02T02:05:10.366021-05:00",
  "DurationInSeconds": 0.998
}
```

FWIRe:RESult[:STANdard][:SUMMary]?

Summary	Retrieves the results of the last run four wire measurement.
Query Format	FWIRe:RESult[:STANdard][:SUMMary]?
Returns	<startDateTime>,<durationInSeconds>,<contactPairPoint1>,<contactPairPoint2>, <contactPairPoint3>,<contactPairPoint4>,<excitationType>,<excitationValue>, <excitationRange>,<measurementRange>,<excitationMeasurementRange>, <complianceLimit>,<blankingTimeInSeconds>,<maximumNumberOfSamples>, <minimumResistanceSnr>,<useExcitationReversal>,<samplingTimeInSeconds>, <resistanceAverageInOhms>,<resistanceStandardErrorInOhms>, <voltageAverageInVolts>,<voltageStandardErrorInAmps>,<currentAverageInAmps>, <currentStandardErrorInAmps>

<startDateTime>	UTC date and time when the measurement was started in ISO 8601 format. Data type is *string*
<durationInSeconds>	Duration of the test in seconds. Data type is *NRf*
<contactPairPoint1>	The contact point assigned to excitation +. Data type is *NAMED*
<contactPairPoint2>	The contact point assigned to excitation -. Data type is *NAMED*
<contactPairPoint3>	The contact point assigned to voltage measurement /sense +. Data type is *NAMED*
<contactPairPoint4>	The contact point assigned to voltage measurement/ sense -. Data type is *NAMED*
<excitationType>	The excitation type used for the measurement, VOLTage or CURRent. Data type is *NAMED*
<excitationValue>	The excitation output value Data type is *NRf*
<excitationRange>	The excitation range. Data type is *NRf*
<measurementRange>	The full scale range of the measurement. For example, if excitation type is current, this is the full scale voltage range. Data type is *NRf*
<excitationMeasurementRange>	The full scale range used to measure the excitation signal, dependent on excitationType. Data type is *NRf*
<complianceLimit>	For voltage excitation, the current limit. For current excitation, the voltage compliance. Data type is *NRf*
<blankingTimeInSeconds>	The time in seconds to wait for the hardware to settle before making measurements. Data type is *NRf*
<maximumNumberOfSamples>	The number of samples to average. Data type is *NR1*
<minimumResistanceSnr>	The desired signal-to-noise ratio of the measured resistance, calculated using measurement average/ error of mean. Data type is *NRf*
<useExcitationReversal>	Indicates whether or not excitation reversal was used. 1 = excitation reversal 0 = no excitation reversal.

Data type is *bool*

<samplingTimeInSeconds>The time, in seconds, which measurements were averaged
over to get one sample.
Data type is *NRf*

<resistanceAverageInOhms> The average measured resistance, in ohms.
Data type is *NRf*

<resistanceStandardErrorInOhms>
The measured resistance standard error, in ohms.
Data type is *NRf*

<voltageAverageInVolts> The average measured voltage, in volts.
Data type is *NRf*

<voltageStandardErrorInVolts>The measured voltage standard error, in volts.
Data type is *NRf*

<currentAverageInAmps> The averaged measured current, in amperes.
Data type is *NRf*

<currentStandardErrorInAmps>The measured current standard error, in amperes.
Data type is *NRf*

FWIRe:RUNNing?

Summary Indicates if the four wire measurement is running.
Query Format FWIRe:RUNNing?
Returns The measurement is running.
Data type is *bool*

FWIRe:STARt

Summary Performs a four wire measurement. Excitation is sourced from contact point 1 to contact point 2. Voltage is measured/senses between contact point 3 and contact point 4.

Command Format FWIRe:STARt <contactPoint1>,<contactPoint2>,<contactPoint3>,<contactPoint4>,
<excitationType>,<excitationValue>,<excitationRange>,<measurementRange>,
<excitationMeasurementRange>,<complianceLimit>,<blankingTime>,
<MaximumNumberOfSamples>,<MinimumSnr>,<samplingTimeInSeconds>,
<ExcitationReversal>,<samplingTime>

Parameters <contactPoint1> Excitation +. Valid contact points are: 1, 2, 3, 4, 5, or 6.
Cannot be the same as Contact Point 2.
Data type is *NR1*

<contactPoint2> Excitation -. Valid contact points are: 1, 2, 3, 4, 5, or 6.
Cannot be the same as Contact Point 1.
Data type is *NR1*

<contactPoint3> Voltage measure/sense +. Valid contact points are: 1, 2, 3, 4,
5, or 6. Cannot be the same as Contact Point 4.
Data type is *NR1*

<contactPoint4> Voltage measure/sense -. Valid contact points are: 1, 2, 3, 4,
5, or 6. Cannot be the same as Contact Point 3.
Data type is *NR1*

<excitationType> VOLTage, CURRent
Data type is *NAMED*

<excitationValue> For voltage excitation, -10 to 10 V
For current excitation 0 to 100 e-3 A
Data type is *NRf*

<excitationRange> For voltage excitation 0 to 10 V
For current excitation 0 to 100 e-3 A
AUTO sets the range to the best fit range for a given
excitation value.

	NOTE: The hardware will be configured to best meet the desired range.
	Data type is *Number*
<measurementRange>	For voltage excitation, specify the current measurement range 0 to 100 e-3 A
	For current excitation, specify the voltage measurement range 0 to 10 V
	NOTE: The hardware will be configured to best meet the desired range.
	Data type is *Number*
<excitationMeasurementRange>	For current excitation, specify the current excitation measurement range 0 to 100 e-3 A
	For voltage excitation, specify the voltage excitation measurement range 0 to 10 V
	AUTO sets the measurement range to the best fit range for a given excitation value.
	NOTE: The hardware will be configured to best meet the desired range.
	Data type is *Number*
<complianceLimit>	For voltage excitation, specify the current limit 100 e-9 to 100 e-3 A
	For current excitation, specify the voltage compliance 1 to 10 V
	Data type is *NRf*
<blankingTime>	The time, in seconds, to wait for the hardware to settle before gathering readings.
	0.5 to 300 s with a resolution of 0.1 ms
	DEFault = 2 ms
	MINimum = 0.5 ms
	MAXimum = 300 s
	Data type is *Number*
<MaximumNumberOfSamples>	When minimumSnr is omitted or INFinity (9.9 e+37), the total number of samples to average 1 to 1000.
	When minimumSnr is specified, the maximum number of samples to average 10 to 1000.
	DEFault = 100
	Data type is *Number*
<MinimumSnr>	The desired signal-to-noise ratio of the measured resistance, calculated using measurement average/ error of mean 1 - 1000, or INFinity (9.9 e+37).
	DEFault = 30
	Data type is *Number*
<excitationReversal>	1 = Reverse the excitation to generate the resistance
	0 = no excitation reversal
	Data type is *bool*
<samplingTime>	The sampling time, in seconds, which measurements will be averaged over to get one sample.
	MINimum = 0.010 ms
	MAXimum = 1 s
	DEFault = 1/60 s
	Data type is *Number*
Example	FWIRe:STARt 5,6,3,1,CURRent,500e-6,1e-3,1.0,1e-3,1.5,2.4e-3,100,30,1

HALl:HBAR[:DC]:STARt

Summary	Performs a DC Hall measurement for a Hall bar sample.
Command Format	HALl:HBAR[:DC]:STARt <excitationType>,<excitationValue>,<excitationRange>, <excitationMeasurementRange>,<measurementRange>,<complianceLimit>, <maxNumberOfSamples>,<userDefinedFieldReadingInTesla>, <withFieldReversal>,<resistivity>,<blankingTime>,<sampleThickness>, <minimumSnr>,<samplingTime>

Parameters

<excitationType>	VOLTage, CURRent Data type is *NAMED*
<excitationValue>	For voltage excitation, -10 to 10 V For current excitation, -100 e-3 to 100 e-3 A Data type is *NRf*
<excitationRange>	For voltage excitation 0 to 10 V For current excitation 0 to 100 e-3 A AUTO sets the range to the best fit range for a given excitation value. **NOTE:** The hardware will be configured to best meet the desired range. Data type is *Number*
<excitationMeasurementRange>	For voltage excitation 0 to 10 V For current excitation 0 to 100 e-3 A AUTO sets the measurement range to the best fit range for a given excitation range. **NOTE:** The hardware will be configured to best meet the desired range. Data type is *Number*
<measurementRange>	For voltage excitation, specify the current measurement range 0 to 100 e-3 A For current excitation, specify the voltage measurement range 0 to 10 V **NOTE:** The hardware will be configured to best meet the desired range. Data type is *Number*
<complianceLimit>	For voltage excitation, specify the current limit 100 e-9 to 100 e-3 A For current excitation, specify the voltage compliance 1 to 10 V Data type is *NRf*
<maxNumberOfSamples>	When minimumSnr is omitted or INFinity (9.9 e+37), the total number of samples to average is 1-1000. When minimumSnr is specified, the maximum number of samples to average is 10-1000. Data type is *Number*
<userDefinedFieldReadingsInTesla>	The field, in units of Tesla, the sample is being subjected to. Used for calculations. Data type is *NRf*
<withFieldReversal>	Specifies whether or not to apply reversal field. DEFault = true Data type is *bool*
<resistivity>	The resistivity of the sample in units of ohm*meters (bulk) of ohms per square (sheet). Used for calculations. Measure this value using the RESistivity SCPI subsystem. Defaults to not a number which will propagate through calculated values. DEFault = NaN (9.91 e+37)

NOTE: When the resistivity is omitted or NaN (9.91 e+37), mobility is not calculated.

	Data type is *Number*
<blankingTime>	The time, in seconds, to wait for the hardware to settle before gathering readings.
	0.5 to 300 s with a resolution of 0.1 ms
	DEFault = 2 ms
	MINimum = 0.5 ms
	MAXimum = 300 s
	Data type is *Number*
<sampleThickness>	Thickness of the sample in meters.
	0 to 10 e-3 m
	DEFault = 0 m
	Data type is *Number*
<MinimumSnr>	The desired signal-to-noise ratio of the measured resistance, calculated using measurement average/ error of mean 1 - 1000, or INFinity (9.9 e+37).
	DEFault = Infinity
	Data type is *Number*
<samplingTime>	The sampling time, in seconds, which measurements will be averaged over to get one sample.
	MINimum = 0.010 ms
	MAXimum = 1 s
	DEFault = 1/60 s
	Data type is *Number*

Example   HAL:HBAR:DC:START Current,10E-3,10E-3,10E-3,1.0,10,10,0.6,1,0.216,100e-3, 1e-3,30

HALl[:DC]:CONTinue
Continues the DC Hall measurement if it's in a waiting state.

Command Format   HALl[:DC]:CONTinue

HALl[:DC]:RESet
Summary   Resets the measurement to a not run state, canceling any running measurement.
Command Format   HALl[:DC]:RESet
Example   HALl[:DC]:RESET

HALl[:DC]:RESult:JSON:ALL:SUBstring?
Retrieves a substring of the last run DC Hall measurement results, serialized as JSON.

Query Format   HALl[:DC]:RESult:JSON:ALL:SUBstring? <startIndex>,<length>
Parameters

<startIndex>	The substring starting index, zero based.
	Data type is *NR1*
<length>	The number of characters to return.
	Data type is *NR1*

Returns   Substring of the JSON serialized DC Hall measurement result.
Data type is *NAMED*

Examples
```
Query HALl:DC::RESult:JSON:ALL:SUBstring? 0, 42
Query response
{"Setup":{"ExcitationType":1,"ExcitationVa
```

HALl[:DC]:RESult:JSON:ALL?

Summary	Retrieves the results of the last run DC Hall measurement, serialized as JSON.
Query Format	HALl[:DC]:RESult:JSON:ALL? <pretty>
Parameters	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	None
Examples	

```
Query HALl:DC:RESult:JSON:ALL? 1
Query response
{
    "Setup": {
    "ExcitationType": 1,
    "ExcitationValue": 0.01,
    "ExcitationAutoRange": false,
    "ExcitationRange": 0.01,
    "ExcitationMeasurementRange": 0.01,
    "MeasurementAutoRange": false,
    "MeasurementRange": 1.0,
    "ComplianceLimit": 10.0,
    "MaxNumberOfSamples": 10,
    "UserDefinedFieldReadingInTesla": 0.6,
    "WithFieldReversal": true,
    "Resistivity": 0.216,
    "BlankingTimeInSeconds": 0.1,
    "SampleThicknessInMeters": 0.01,
    "MinimumSnr": 30.0,
    "SamplingTimeInSeconds": 0.0166666666666667,
    "Guid": "e910b1b4-e844-4953-bdbb-667928177ba6"
  },
  "SampleType": 0,
  "DcHallSnr": 1.02614910287,
  "HallVoltageAverageInVolts": -8.5571230446485356E-07,
  "HallVoltageStandardErrorInVolts": 8.3390640022026488E-07,
  "HallCoefficientAverageInMetersCubedPerCoulomb": 0.00014268465591413487,
  "HallCoefficientStandardErrorInMetersCubedPerCoulomb":
0.00013904865824552416,
  "SheetHallCoefficientAverageInMetersSquaredPerCoulomb":
1.1414901714091761,
  "SheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb":
0.031870422976452206,
  "CurrentAverageInAmps": 0.009995378725,
  "CarrierType": 2,
  "PTypeCount": 2,
  "NTypeCount": 3,
  "CarrierConcentrationAveragePerMetersCubed": 4.3743380036293484E+22,
  "CarrierConcentrationStandardErrorPerMetersCubed": 4.262867834107526E+22,
  "SheetCarrierConcentrationAveragePerMetersSquared":
5.4678605960265032E+18,
  "SheetCarrierConcentrationStandardErrorPerMetersSquared":
1.5266275114442029E+17,
  "MobilityAverageInMetersSquaredPerVoltSecond": 0.00066057711071358736,
  "MobilityStandardErrorInMetersSquaredPerVoltSecond":
0.00064374378817372291,
  "GeometryCSummaryResults": {
    "HallVoltageAverageInVolts": -2.4550420634878181E-06,
    "HallVoltageStandardErrorInVolts": 2.0285597091312204E-06,
    "CurrentAverageInAmps": 0.00999564805,
    "HallCoefficientAverageInMetersCubedPerCoulomb": 0.0004093518251155009,
    "HallCoefficientStandardErrorInMetersCubedPerCoulomb":
0.00033824048542325721,
    "SheetHallCoefficientAverageInMetersSquaredPerCoulomb":
0.040935182511550088,
    "SheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb":
0.033824048542325721,
    "CarrierConcentrationAveragePerMetersCubed": 1.5247297669281664E+22,
    "CarrierConcentrationStandardErrorPerMetersCubed": 1.259858402633378E+22,
```

```
    "SheetCarrierConcentrationAveragePerMetersSquared":
1.5247297669281667E+20,
    "SheetCarrierConcentrationStandardErrorPerMetersSquared":
1.259858402633378E+20,
    "PositiveFieldResultsSummary": {
       "PositiveExcitationHallVoltageAverageInVolts": 0.008500096,
       "PositiveExcitationHallVoltageStandardErrorInVolts":
2.1517319630938939E-05,
       "PositiveExcitationCurrentAverageInAmps": 0.0099954841999999981,
       "PositiveExcitationInCompliance": false,
       "PositiveExcitationVoltageOverload": false,
       "PositiveExcitationCurrentOverload": false,
       "NegativeExcitationHallVoltageAverageInVolts": -0.008281223,
       "NegativeExcitationHallVoltageStandardErrorInVolts":
1.2025488817507728E-05,
       "NegativeExcitationCurrentAverageInAmp": 0.009995947199999999,
       "NegativeExcitationInCompliance": false,
       "NegativeExcitationVoltageOverload": false,
       "NegativeExcitationCurrentOverload": false
    },
    "NegativeFieldResultsSummary": {
       "PositiveExcitationHallVoltageAverageInVolts": 0.0084890608,
       "PositiveExcitationHallVoltageStandardErrorInVolts":
2.0779260177879121E-05,
       "PositiveExcitationCurrentAverageInAmps": 0.0099954822,
       "PositiveExcitationInCompliance": false,
       "PositiveExcitationVoltageOverload": false,
       "PositiveExcitationCurrentOverload": false,
       "NegativeExcitationHallVoltageAverageInVolts": -0.0082916978000000009,
       "NegativeExcitationHallVoltageStandardErrorInVolts":
1.1644247512828007E-05,
       "NegativeExcitationCurrentAverageInAmp": 0.0099957796,
       "NegativeExcitationInCompliance": false,
       "NegativeExcitationVoltageOverload": false,
       "NegativeExcitationCurrentOverload": false
    },
    "CarrierType": 2,
    "PTypeCount": 0,
    "NTypeCount": 5,
    "InCompliance": false,
    "VoltageOverload": false,
    "CurrentOverload": false

  },
  "GeometryDSummaryResults": {
    "HallVoltageAverageInVolts": 7.4361745455811071E-07,
    "HallVoltageStandardErrorInVolts": 3.8239779048063621E-07,
    "CurrentAverageInAmps": 0.0099951093999999987,
    "HallCoefficientAverageInMetersCubedPerCoulomb": 0.00012399688434260839,
    "HallCoefficientStandardErrorInMetersCubedPerCoulomb":
6.3764149575097243E-05,
    "SheetHallCoefficientAverageInMetersSquaredPerCoulomb":
0.012399688434260838,
    "SheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb":
0.0063764149575097238,
    "CarrierConcentrationAveragePerMetersCubed": 5.0336015796608495E+22,
    "CarrierConcentrationStandardErrorPerMetersCubed":
2.5884789422620135E+22,
    "SheetCarrierConcentrationAveragePerMetersSquared":
5.0336015796608493E+20,
    "SheetCarrierConcentrationStandardErrorPerMetersSquared":
2.5884789422620135E+20,
    "PositiveFieldResultsSummary": {
       "PositiveExcitationHallVoltageAverageInVolts": -0.0082725954,
       "PositiveExcitationHallVoltageStandardErrorInVolts":
2.82548400455577E-06,
       "PositiveExcitationCurrentAverageInAmps": 0.0099950376000000011,
       "PositiveExcitationInCompliance": false,
```

```
                "PositiveExcitationVoltageOverload": false,
                "PositiveExcitationCurrentOverload": false,
                "NegativeExcitationHallVoltageAverageInVolts": 0.0082348906,
                "NegativeExcitationHallVoltageStandardErrorInVolts":
1.4553178896724013E-06,
                "NegativeExcitationCurrentAverageInAmp": 0.0099953324,
                "NegativeExcitationInCompliance": false,
                "NegativeExcitationVoltageOverload": false,
                "NegativeExcitationCurrentOverload": false
            },
            "NegativeFieldResultsSummary": {
                "PositiveExcitationHallVoltageAverageInVolts": -0.0082633413999999988,
                "PositiveExcitationHallVoltageStandardErrorInVolts":
4.4750247105464231E-06,
                "PositiveExcitationCurrentAverageInAmps": 0.0099949398,
                "PositiveExcitationInCompliance": false,
                "PositiveExcitationVoltageOverload": false,
                "PositiveExcitationCurrentOverload": false,
                "NegativeExcitationHallVoltageAverageInVolts": 0.0082451744,
                "NegativeExcitationHallVoltageStandardErrorInVolts":
2.2773556727048522E-06,
                "NegativeExcitationCurrentAverageInAmp": 0.0099951196,
                "NegativeExcitationInCompliance": false,
                "NegativeExcitationVoltageOverload": false,
                "NegativeExcitationCurrentOverload": false
            },
            "CarrierType": 1,
            "PTypeCount": 5,
            "NTypeCount": 0,
            "InCompliance": false,
            "VoltageOverload": false,
            "CurrentOverload": false
        },
        "ActualBlankingTimeInSeconds": 0.1,
        "ActualSamplingTimeInSeconds": 0.0.0166666666666667,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false,
    },
    "DcHallSamples": [
    {
    "HallVoltageInVolts": -1.2479799698861455E-07,
    "GeometryCHallVoltageInVolts": -3.0194351555753589E-07,
    "GeometryDHallVoltageInVolts": 5.2347521580306795E-08,
    "CurrentAverageInAmps": 0.0099953415000000011,
    "GeometryCCurrentAverageInAmps": 0.00999557775,
    "GeometryDCurrentAverageInAmps": 0.00999510525,
    "CarrierType": 1,
    "PositiveFieldGeometryCData": {
        "ContactConfiguration": "V3142",
        "PositiveExcitation": {
            "VoltageInVolts": 0.008414321,
            "CurrentInAmps": 0.00999526,
            "ExcitationSetpoint": 0.01,
            "InCompliance": false,
            "VoltageOverload": false,
            "CurrentOverload": false
        },
        "NegativeExcitation": {
            "VoltageInVolts": -0.008328633,
            "CurrentInAmps": -0.00999577,
            "ExcitationSetpoint": -0.01,
            "InCompliance": false,
            "VoltageOverload": false,
            "CurrentOverload": false
        }
    },
    "PositiveFieldGeometryDData": {
```

```
            "ContactConfiguration": "V4213",
            "PositiveExcitation": {
               "VoltageInVolts": -0.008263264,
               "CurrentInAmps": 0.009994991,
               "ExcitationSetpoint": 0.01,
               "InCompliance": false,
               "VoltageOverload": false,
               "CurrentOverload": false
            },
            "NegativeExcitation": {
               "VoltageInVolts": 0.008235818,
               "CurrentInAmps": -0.00999531,
               "ExcitationSetpoint": -0.01,
               "InCompliance": false,
               "VoltageOverload": false,
               "CurrentOverload": false
            }
         },
         "NegativeFieldGeometryCData": {
            "ContactConfiguration": "V3142",
            "PositiveExcitation": {
               "VoltageInVolts": 0.008406538,
               "CurrentInAmps": 0.009995479,
               "ExcitationSetpoint": 0.01,
               "InCompliance": false,
               "VoltageOverload": false,
               "CurrentOverload": false
            },
            "NegativeExcitation": {
               "VoltageInVolts": -0.008337834,
               "CurrentInAmps": -0.009995802,
               "ExcitationSetpoint": -0.01,
               "InCompliance": false,
               "VoltageOverload": false,
               "CurrentOverload": false
            }
         },
         "NegativeFieldGeometryDData": {
            "ContactConfiguration": "V4213",
            "PositiveExcitation": {
               "VoltageInVolts": -0.008245957,
               "CurrentInAmps": 0.009994914,
               "ExcitationSetpoint": 0.01,
               "InCompliance": false,
               "VoltageOverload": false,
               "CurrentOverload": false
            },
            "NegativeExcitation": {
               "VoltageInVolts": 0.008253185,
               "CurrentInAmps": -0.009995206,
               "ExcitationSetpoint": -0.01,
               "InCompliance": false,
               "VoltageOverload": false,
               "CurrentOverload": false
            }
         },
         "InCompliance": false,
         "VoltageOverload": false,
         "CurrentOverload": false,
         "ActualBlankingTimeInSeconds": 0.1,
         "ActualSamplingTimeInSeconds": 0.0166666666666667,
         "HasReverseFieldData": true
      },
      ...
      ],
      "IsWaiting": false,
      "IsRunning": false,
      "StartTime": "1970-01-01T19:32:27.629879-05:00",
```

```
"EndTime": "1970-01-01T19:32:33.88998-05:00",
"DurationInSeconds": 6.217
}
```

_____

HALl[:DC]:RESult:JSON:DATA?

Summary	Retrieves data from a given sample taken during the last run DC Hall measurement.
Query Format	HALl[:DC]:RESult:JSON:DATA? <sampleIndex>,<pretty>
Parameters	<sampleIndex> Sample index, zero based.
	Data type is *NR1*
	<pretty> Optional, pretty format JSON response. Defaults to False.
	Data type is *bool*
Returns	JSON serialized DC Hall measurement sample data
	Data type is *NAMED*
Examples	

```
Query HALl:DC:RES:JSON:DATA? 0,1
Query response
{
  "HallVoltageInVolts": -1.2479799698861455E-07,
  "GeometryCHallVoltageInVolts": -3.0194351555753589E-07,
  "GeometryDHallVoltageInVolts": 5.2347521580306795E-08,
  "CurrentAverageInAmps": 0.0099953415000000011,
  "GeometryCCurrentAverageInAmps": 0.00999557775,
  "GeometryDCurrentAverageInAmps": 0.00999510525,
  "CarrierType": 1,
  "PositiveFieldGeometryCData": {
    "ContactConfiguration": "V3142",
    "PositiveExcitation": {
      "VoltageInVolts": 0.008414321,
      "CurrentInAmps": 0.00999526,
      "ExcitationSetpoint": 0.01,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    },
    "NegativeExcitation": {
      "VoltageInVolts": -0.008328633,
      "CurrentInAmps": -0.00999577,
      "ExcitationSetpoint": -0.01,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    }
  },
  "PositiveFieldGeometryDData": {
    "ContactConfiguration": "V4213",
    "PositiveExcitation": {
      "VoltageInVolts": -0.008263264,
      "CurrentInAmps": 0.009994991,
      "ExcitationSetpoint": 0.01,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    },
    "NegativeExcitation": {
      "VoltageInVolts": 0.008235818,
      "CurrentInAmps": -0.00999531,
      "ExcitationSetpoint": -0.01,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    }
  },
  "NegativeFieldGeometryCData": {
    "ContactConfiguration": "V3142",
    "PositiveExcitation": {
      "VoltageInVolts": 0.008406538,
```

```
          "CurrentInAmps": 0.009995479,
          "ExcitationSetpoint": 0.01,
          "InCompliance": false,
          "VoltageOverload": false,
          "CurrentOverload": false
        },
        "NegativeExcitation": {
          "VoltageInVolts": -0.008337834,
          "CurrentInAmps": -0.009995802,
          "ExcitationSetpoint": -0.01,
          "InCompliance": false,
          "VoltageOverload": false,
          "CurrentOverload": false
        }
      },
      "NegativeFieldGeometryDData": {
        "ContactConfiguration": "V4213",
        "PositiveExcitation": {
          "VoltageInVolts": -0.008245957,
          "CurrentInAmps": 0.009994914,
          "ExcitationSetpoint": 0.01,
          "InCompliance": false,
          "VoltageOverload": false,
          "CurrentOverload": false
        },
        "NegativeExcitation": {
          "VoltageInVolts": 0.008253185,
          "CurrentInAmps": -0.009995206,
          "ExcitationSetpoint": -0.01,
          "InCompliance": false,
          "VoltageOverload": false,
          "CurrentOverload": false
        }
      },
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false,
      "ActualBlankingTimeInSeconds": 0.1,
      "ActualSamplingTimeInSeconds": 0.0166666666666667,
      "HasReverseFieldData": true
    }
```

HALl[:DC]:RESult:JSON[:SUMMary]?

Summary	Retrieves summary results of the last run DC Hall measurement, serialized as JSON.
Query Format	HALl[:DC]:RESult:JSON[:SUMMary]? <pretty>,<includeGeometries>
Parameters	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
	<includeGeometries> Optional, include summary data for C and D geometries. Defaults to False. Data type is *bool*
Returns	JSON serialized DC Hall measurement result. Data type is *NAMED*

Examples

```
Query HALl:DC:RESult:JSON? 1,0
Query response
```

```
{
 "Setup": {
   "ExcitationType": 1,
   "ExcitationValue": 0.01,
   "ExcitationAutoRange": false,
   "ExcitationRange": 0.01,
   "ExcitationMeasurementRange": 0.01,
   "MeasurementAutoRange": false,
   "MeasurementRange": 1.0,
   "ComplianceLimit": 10.0,
   "MaxNumberOfSamples": 10,
   "UserDefinedFieldReadingInTesla": 0.6,
   "WithFieldReversal": true,
   "Resistivity": 0.216,
   "BlankingTimeInSeconds": 0.1,
   "SampleThicknessInMeters": 0.01,
   "MinimumSnr": 30.0,
   "Guid": "e910b1b4-e844-4953-bdbb-667928177ba6"
 },
 "SampleType": 0,
 "DcHallSnr": 1.02614910287,
 "HallVoltageAverageInVolts": -8.5571230446485356E-07,
 "HallVoltageStandardErrorInVolts": 8.3390640022026488E-07,
 "HallCoefficientAverageInMetersCubedPerCoulomb": 0.00014268465591413487,
 "HallCoefficientStandardErrorInMetersCubedPerCoulomb":
0.00013904865824552416,
 "SheetHallCoefficientAverageInMetersSquaredPerCoulomb":
1.1414901714091761,
 "SheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb":
0.031870422976452206,
 "CurrentAverageInAmps": 0.009995378725,
 "CarrierType": 2,
 "PTypeCount": 2,
 "NTypeCount": 3,
 "CarrierConcentrationAveragePerMetersCubed": 4.3743380036293484E+22,
 "CarrierConcentrationStandardErrorPerMetersCubed": 4.262867834107526E+22,
 "SheetCarrierConcentrationAveragePerMetersSquared":
5.4678605960265032E+18,
 "SheetCarrierConcentrationStandardErrorPerMetersSquared":
1.5266275114442029E+17,
 "MobilityAverageInMetersSquaredPerVoltSecond": 0.00066057711071358736,
 "MobilityStandardErrorInMetersSquaredPerVoltSecond":
0.00064374378817372291,
 "ActualBlankingTimeInSeconds": 0.1,
 "ActualSamplingTimeInSeconds": 0.0166666666666667,
 "InCompliance": false,
 "VoltageOverload": false,
 "CurrentOverload": false,
 "IsWaiting": false,
 "IsRunning": false,
 "StartTime": "1970-01-01T19:32:27.629879-05:00",
 "EndTime": "1970-01-01T19:32:33.88998-05:00",
 "DurationInSeconds": 6.217}
```

HALl[:DC]:RESult[:STANdard]:DATA?

Summary	Retrieves data from a given sample taken during the last run DC Hall measurement.
Query Format	HALl[:DC]:RESult[:STANdard]:DATA? <sampleIndex>
Parameters	<sampleIndex> Sample index, zero based.
	Data type is *NR1*

Returns <hallVoltage>,<geometryCHallVoltage>,<geometryDHallVoltage>,<currentAverage>, <geometryCCurrentAverage>,<geometryDCurrentAverage>,<carrierType>

<hallVoltage>	The Hall voltage.
	Data type is *NRf*
<geometryCHallVoltage>	Geometry C Hall voltage.
	Data type is *NRf*
<geometryDHallVoltage>	Geometry D Hall voltage.
	Data type is *NRf*
<currentAverage>	The average current through the sample, in amperes.
	Data type is *NRf*
<geometryCCurrentAverage>	Geometry C average current.
	Data type is *NRf*
<geometryDCurrentAverage>	Geometry D average current.
	Data type is *NRf*
<carrierType>	The Hall voltage.
	Data type is *LakeShore.FastHall.Instrument.Models. Measurement.FastHall.CarrierType.*

HALl[:DC]:RESult:[:STANdard]:POINts?

	Retrieves the number of points in the results list. Use in conjunction with HALl[:DC]:RESult[:STANdard]:DATA? and HALl[:DC]:RESult[:STANdard]:RAW? queries.
Query Format	HALl[:DC]:RESult:[:STANdard]:POINts?
Returns	The number of points in the results list.
	Return type is *NR1*

Examples	`Query HALl:DC:RESult:POINts?`
	`Query response`
	`42`

HALl[:DC]:RESult[:STANdard]:RAW?

Summary	Retrieves the measured current, measured voltage, and compliance status for negative and positive excitations in both negative and positive field configurations from a given sample taken during the last run DC Hall measurement.
	NOTE: If the measurement did not include field reversal, then 'negative field' parameters will not be returned.
Query Format	HALl[:DC]:RESult[:STANdard]:RAW? <sampleIndex>,<geometry>
Parameters	<sampleIndex> Sample index, zero based.
	Data type is *NR1*
	<geometry> The geometry, C or D
	Data type is *DcHallGeometry*

Returns <positiveFieldConfigurationNegativeExcitationCurrent>,
<positiveFieldConfigurationNegativeExcitationSetpoint>,
<positiveFieldConfigurationNegativeExcitationVoltage>,
<positiveFieldConfigurationPositiveExcitationInCurrent>,
<positiveFieldConfigurationPositiveExcitationSetpoint>,
<positiveFieldConfigurationPositiveExcitationVoltage>,
<negativeFieldConfigurationNegativeExcitationCurrent>,
<negativeFieldConfigurationNegativeExcitationSetpoint>,
<negativeFieldConfigurationNegativeExcitationVoltage>,
<negativeFieldConfigurationPositiveExcitationInCurrent>,

<negativeFieldConfigurationPositiveExcitationSetpoint>,
<negativeFieldConfigurationPositiveExcitationVoltage>
<positiveFieldConfigurationNegativeExcitationCurrent>
> The measured current for positive field configuration's negative excitation.
> Data type is *NRf*

<positiveFieldConfigurationNegativeExcitationSetpoint>
> The excitation setpoint for positive field configuration's negative excitation.
> Data type is *NRf*

<positiveFieldConfigurationNegativeExcitationVoltage>
> The measured voltage for positive field configuration's negative excitation.
> Data type is *NRf*

<positiveFieldConfigurationPositiveExcitationCurrent>
> The measured current for positive field configuration's positive excitation.
> Data type is *NRf*

<positiveFieldConfigurationPositiveExcitationSetpoint>
> The excitation setpoint for positive field configuration's positive excitation.
> Data type is *NRf*

<positiveFieldConfigurationPositiveExcitationVoltage>
> The measured voltage for positive field configuration's positive excitation.
> Data type is *NRf*

<negativeFieldConfigurationNegativeExcitationCurrent>
> The measured current for negative field configuration's negative excitation.
> Data type is *NRf*

<negativeFieldConfigurationNegativeExcitationSetpoint>
> The excitation setpoint for negative field configuration's negative excitation.
> Data type is *NRf*

<negativeFieldConfigurationNegativeExcitationVoltage>
> The measured voltage for negative field configuration's negative excitation.
> Data type is *NRf*

<negativeFieldConfigurationPositiveExcitationCurrent>
> The measured current for negative field configuration's positive excitation.
> Data type is *NRf*

<negativeFieldConfigurationPositiveExcitationSetpoint>
> The excitation setpoint for negative field configuration's positive excitation.
> Data type is *NRf*

<negativeFieldConfigurationPositiveExcitationVoltage>
> The measured voltage for negative field configuration's positive excitation.
> Data type is *NRf*

Example

```
Query HALl:DC:RESult:RAW? 4, C
Query response (with field reversal):
        -0.009996027,-0.01,0.008274896,0,0,0,0.009995508,0.01,
0.008519672,0,0,0,-0.009995925,-0.01,0.008281359,0,0,0,0.009995515,0.01,
0.008510619,0,0,0
Query response (with NO field reversal):
        -0.009995706,-0.01,-0.008277785,0,0,0,0.009995279,0.01,
0.008519675,0,0,0
```

HALl[:DC]:RESult[:STANdard][:SUMMary]?

Summary

Retrieves the results of the last run DC Hall measurement.

Query Format

HALl[:DC]:RESult[:STANdard][:SUMMary]?

Returns

<startDateTime>,<durationOfTestInSeconds>,<excitationType>,<excitationValue>, <excitationRange>,<excitationMeasurementRange>,<measurementRange>, <complianceLimit>,<maxNumberOfSamples>,<userDefinedFieldReadingInTesla>, <withFieldReversal>,<resistivity>,<blankingTimeInSeconds>, <sampleThicknessInMeters>,<minimumSnr>,<samplingTimeInSeconds>, <hallVoltageAverageInVolts>,<hallVoltageStandardErrorInVolts>, <hallCoefficientAverageInMetersCubedPerCoulomb>, <sheetHallCoefficientAverageInMetersSquaredPerCoulomb>, <hallCoefficientStandardErrorInMetersCubedPerCoulomb>, <sheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb>,<dcHallSnr>, <carrierType>,<pTypeCount>,<nTypeCount>, <carrierConcentrationAveragePerMetersCubed>, <sheetCarrierConcentrationAveragePerMetersSquared>, <carrierConcentrationStandardErrorPerMetersSquared>, <sheetCarrierConcentrationStandarErrorPerMetersSquared>, <mobilityAverageInMetersSquaredPerVoltSecond>, <mobilityStandardErrorInMetersSquaredPerVoltSecond>

<startDateTime>	UTC date and time when the measurement was started in ISO 8601 format. Data type is *string*
<durationOfTestInSeconds>	Duration of the test in seconds. Data type is *NRf*
<excitationType>	The excitation type used for the measurement, VOLTage or CURRent. Data type is *NAMED*
<excitationValue>	The excitation value. Data type is *NRf*
<excitationRange>	The excitation range. Data type is *NRf*
<excitationMeasurementRange>	The full scale range used to measure the excitation signal, dependent on excitationType. Data type is *NRf*
<measurementRange>	The full scale range of the measurement. For example, if excitation type is current, this is the full scale voltage range. Data type is *NRf*
<complianceLimit>	For voltage excitation, the current limit. For current excitation, the voltage compliance. Data type is *NRf*
<maxNumberOfSamples>	The setup's number of samples. When minimumSnr is omitted or INFinity (9.9E+37), this is the total number of samples. When minimumSnr is specified, this is the maximum number of samples. The HALl[:DC]:RESult[:STANDARD]:POINts? command can be used to retrieve the actual number of points in the results list. Data type is *NR1*
<userDefinedFieldReadingInTesla>	The field, in units of Tesla, that the sample is being subjected to. Data type is *NRf*

\<withFieldReversal\>	Specifies whether or not reversal field was applied. Data type is *bool*
\<resistivity\>	The resistivity of the sample in units of ohm*meters (bulk) or ohms per square (sheet). Data type is *NRf*
\<blankingTimeInSeconds\>	The time, in seconds, to wait for the hardware to settle before making measurements. Data type is *NRf*
\<sampleThicknessInMeters\>	Thickness of the sample, in meters. Data type is *NRf*
\<minimumSnr\>	The desired signal-to-noise ratio of the DC Hall measurement. Data type is *NRf*
\<samplingTimeInSeconds\>	The time, in seconds, which measurements were averaged over to get one sample. Data type is *NRf*
\<hallVoltageAverageInVolts\>	The average Hall voltage measured, in volts. Data type is *NRf*
\<hallVoltageStandardErrorInVolts\>	The standard deviation of the Hall voltage. Data type is *NRf*
\<hallCoefficientAverageInMetersCubedPerCoulomb\>	The average bulk Hall coefficient measured in units of meters cubed per coulomb. Data type is *NRf*
\<sheetHallCoefficientAverageInMetersSquaredPerCoulomb\>	The average sheet Hall coefficient measured in units of meters squared per coulomb. Data type is *NRf*
\<hallCoefficient StandardErrorInMetersCubedPerCoulomb\>	The standard error of the bulk Hall coefficient in units of meters cubed per coulomb. Data type is *NRf*
\<sheetHallCoefficientStandardErrorInMetersSquaredPerCoulomb\>	The standard error of the sheet Hall coefficient in units of meters squared per coulomb. Data type is *NRf*
\<dcHallSnr\>	The signal-to-noise ratio of the DC Hall measurement. Data type is *NRf*
\<carrierType\>	The carrier type of the sample. P, N, or Unknown. Data type is *NAMED*
\<pTypeCount\>	The number of samples that were measured as P carrier type. Data type is *NR1*
\<nTypeCount\>	The number of samples that were measured as N carrier type. Data type is *NR1*
\<carrierConcentrationAveragePerMetersCubed\>	The average bulk carrier concentration measured in units of per meters cubed. Data type is *NRf*
\<sheetCarrierConcentrationAveragePerMetersSquared\>	The average sheet carrier concentration measured in units of per meters squared. Data type is *NRf*
\<carrierConcentrationStandardErrorPerMetersCubed\>	The standard error of the bulk carrier concentration in

units per meters cubed.
Data type is *NRf*

<sheetCarrierConcentrationStandarErrorPerMetersSquared>

The standard error of the sheet carrier concentration in units of per meters squared.
Data type is *NRf*

<mobilityAverageInMetersSquaredPerVoltSecond>

The average mobility measured in units of meters squared per volt second.
Data type is *NRf*

<mobilityStandardErrorInMetersSquaredPerVoltSecond>

The standard error of the mobility in meters squared per volt second.
Data type is *NRf*

HALl[:DC]:RUNNing?

Summary	Indicates if the DC Hall measurement is running.
Query Format	HALl[:DC]:RUNNing?
Returns	The measurement is running.
	Data type is *bool*

HALl[:DC]:WAITing?

Summary	Indicates if the DC Hall measurement is waiting.
Query Format	HALl[:DC]:WAITing?
Returns	The measurement is waiting.
	Data type is *bool*

HALl[:VDP][:DC]:STARt

Summary	Performs a DC Hall measurement for a van der Pauw sample.	
Command Format	HALl[:VDP][:DC]:STARt	<excitationType>,<excitationValue>,<excitationRange>, <excitationMeasurementRange>,<measurementRange>, <complianceLimit>,<maxNumberOfSamples>, <userDefinedFieldReadingInTesla>,<withFieldReversal>, <resistivity>,<blankingTime>,<sampleThickness>, <MinimumSnr>,<samplingTime>
Parameters	<excitationType>	VOLTage, CURRent
		Data type is *ExcitationType*
	<excitationValue>	For voltage excitation -10 to 10 V
		For current excitation -100 e3 to 100 e-3 A
		Data type is *NRf*
	<excitationRange>	For voltage excitation 0 to 10 V
		For current excitation 0 to 100 e-3 A
		AUTO sets the range to the best fit range for a given excitation value.
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	<excitationmeasurementRange>	For voltage excitation 0 to 10 V
		For current excitation 0 to 100 e-3 A
		AUTO sets the measurement range to the best fit range for a given excitation value.
		NOTE: The hardware will be configured to best meet the

	desired range.
	Data type is *Number*
‹measurementRange›	For voltage excitation, specify the current measurement range 0 to 100 e-3 A
	For current excitation, specify the voltage measurement range 0 to 10 V
	NOTE: The hardware will be configured to best meet the desired range.
	Data type is *Number*
‹complianceLimit›	For voltage excitation, specify the current limit 100 e-9 to 100 e-3 A
	For current excitation, specify the voltage compliance 1 to 10 V
	Data type is *NRf*
‹maxNumberOfSamples›	When minimumSnr is omitted or INFinity (9.9 e+37), the total number of samples to average is 1-1000.
	When minimumSnr is specified, the maximum number of samples to average is 10-1000.
	Data type is *Number*
‹userDefinedFieldReadingInTesla›	The field, in units of Tesla, the sample is being subjected to. Used for calculations.
	Data type is *NRf*
‹withFieldReversal›	Specifies whether or not to apply reversal field.
	DEFault = true
	Data type is *bool*
‹resistivity›	The resistivity of the sample in units of ohm*meters (bulk) of ohms per square (sheet). Used for calculations. Measure this value using the RESistivity SCPI subsystem. Defaults to not a number which will propagate through calculated values.
	DEFault = NaN (9.91 e+37)
	NOTE: When the resistivity is omitted or NaN (9.91 e+37), mobility is not calculated.
	Data type is *Number*
‹blankingTime›	The time, in seconds, to wait for hardware to settle before gathering readings.
	0.5 ms to 300 s with a resolution of 0.1 ms
	DEFault = 2 ms
	MINimum = 0.5 ms
	MAXimum = 300 s
	Data type is *Number*
‹sampleThickness›	Thickness of the sample in meters.
	0 to 10 e-3 m
	DEFault = 0 m
	Data type is *Number*
‹MinimumSnr›	The desired signal-to-noise ratio of the measured resistance, calculated using measurement average voltage/ error of mean 1 - 1000, or INFinity (9.9e+37).
	DEFault = Infinity
	Data type is *Number*
‹samplingTime›	The sampling time, in seconds, which measurements will be averaged over to get one sample.
	MINimum = 0.010 ms
	MAXimum = 1 s
	DEFault = 1/60 s
	Data type is *Number*
Example	HAL:DC:START Current,10E-3,10E-3,10E-3,1.0,10,5,0.6,1,0.216,100e-3,1e-2,30

RESistivity:HBAR:STARt

Summary	Performs a resistivity measurement on a Hall bar sample.
Command Format	RESistivity:HBAR:STARt ‹excitationType›,‹excitationValue›,‹excitationRange›, ‹excitationMeasurementRange›,‹measurementRange›,‹complianceLimit›,‹width›, ‹separation›,‹maxNumberOfSamples›, ‹blankingTime›,‹sampleThickness›, ‹minimumSnr›,‹samplingTime›

Parameters

‹excitationType›	VOLTage, CURRent
	Data type is *NAMED*
‹excitationValue›	For voltage excitation -10 to 10 V
	For current excitation -100 e3 to 100 e-3 A
	Data type is *NRf*
‹excitationRange›	For voltage excitation 0 to 10 V
	For current excitation 0 to 100 e-3 A
	AUTO sets the range to the best fit range for a given excitation value.
	NOTE: The hardware will be configured to best meet the desired range.
	Data type is *Number*
‹excitationMeasurementRange›	For voltage excitation 0 to 10 V
	For current excitation 0 to 100 e-3 A
	AUTO sets the range to the best fit range for a given excitation value.
	NOTE: The hardware will be configured to best meet the desired range.
	Data type is *Number*
‹measurementRange›	For voltage excitation, specify the current measurement range 0 to 100 e-3 A
	For current excitation, specify the voltage measurement range 0 to 10 V
	AUTO sets the range to the best fit range for a given excitation value.
	NOTE: The hardware will be configured to best meet the desired range.
	Data type is *Number*
‹complianceLimit›	For voltage excitation, specify the current limit 100 e-9 to 100 e-3 A
	For current excitation, specify the voltage compliance 1 to 10 V
	Data type is *NRf*
‹width›	The width of the sample in meters. Greater than 0.
	Data type is *NRf*
‹separation›	The distance between the sample's arms in meters. Greater than 0.
	Data type is *NRf*
‹MaxNumberOfSamples›	When minimumSnr is omitted or INFinity (9.9 e+37), the total number of samples to average 1 to 1000.
	When minimumSnr is specified, the maximum number of samples to average 10 to 1000.
	DEFault = 100
	Data type is *Number*
‹blankingTime›	The time in seconds to wait for hardware to settle before gathering readings.
	0.5 to 300 s with a resolution of 0.1 ms
	DEFault = 2 ms
	MINimum = 0.5 ms

	MAXimum = 300 s
	Data type is *Number*
<sampleThickness>	Thickness of the sample in meters.
	0 to 10 e-3 m
	DEFault = 0 m
	Data type is *Number*
<minimumSnr>	The desired signal to noise ratio of the measurement calculated using average resistivity / error of mean 1 - 1000, or INFinity (9.9 e+37).
	DEFault = 30
	Data type is *Number*
<samplingTime>	The sampling time, in seconds, which measurements will be averaged over to get one sample.
	MINimum = 0.010 ms
	MAXimum = 1 s
	DEFault = 1/60 s
	Data type is *Number*

Example   RESistivity:HBAR:STARt CURRent,10e-6,10e-6,AUTO,100e-3,1.5,1E-3,2E-3,30, 2.4e-3,0,30

RESistivity:RESet

Summary   Resets the measurement to a not run state, canceling any running measurement.
Command Format   RESistivity:RESet
Example   RESistivity:RESET

RESistivity:RESult:JSON:ALL:SUBstring?

Summary   Retrieves a substring of the last run resistivity measurement results, serialized as JSON.
Query Format   RESistivity:RESult:JSON:ALL:SUBstring? <startIndex>,<length>
Parameters

<startIndex>	The substring starting index, zero based.
	Data type is *NR1*
<length>	The number of characters to return.
	Data type is *NR1*

Returns   Substring of the JSON serialized resistivity measurement result.
Data type is *NAMED*
Examples
```
Query RESistivity:RESult:JSON:ALL:SUBstring? 1
Query response
{"Setup":{"ExcitationType":1,"ExcitationVa
```

RESistivity:RESult:JSON:ALL?

Summary   Retrieves all of the results of the last run resistivity measurement, serialized as JSON, including raw samples. Van der Pauw results are shown in this example.
Query Format   RESistivity:RESult:JSON:ALL? <pretty>
Parameters   <pretty>   Optional, pretty format JSON response. Defaults to False.
Data type is *bool*
Returns   JSON serialized resistivity measurement result
Data type is *Named*
Examples
```
Query RESistivity:RESult:JSON:ALL? 1
Query response
    {
"Setup": {
  "ExcitationType": 1,
  "ExcitationValue": 1E-05,
  "ExcitationAutoRange": false,
  "ExcitationRange": 1E-05,
```

```
                    "ExcitationMeasurementRange": 1E-05,
                    "MeasurementAutoRange": false,
                    "MeasurementRange": 0.1,
                    "ComplianceLimit": 1.5,
                    "SampleWidthInMeters": null,
                    "SampleArmSeparationInMeters": null,
                    "MaxNumberOfSamples": 25,
                    "BlankingTimeInSeconds": 0.0024,
                    "SampleThicknessInMeters": 0.001,
                    "MinimumSnr": 30.0,
                    "Guid": "2860ada9-4c68-45fd-87ea-a734aa8c9b44"
            },
            "ResistivitySnr": 31.487073734504811,
            "ResistivityAverageInOhmMeters": 0.00088881560980731949,
            "SheetResistivityAverageInOhmsPerSquare": 0.88881560980731933,
            "ResistivityStandardErrorInOhmMeters": 2.8227952120978436E-05,
            "SheetResistivityStandardErrorInOhmsPerSquare": 0.028227952120978436,
            "GeometryAResistivityAverageInOhmMeters": 0.00088921656986532308,
            "GeometryASheetResistivityAverageInOhmsPerSquare": 0.88921656986532316,
            "GeometryAResistivityStandardErrorInOhmMeters": 3.1424935834095014E-05,
            "GeometryASheetResistivityStandardErrorInOhmsPerSquare":
            0.031424935834095023,
            "GeometryAFValueAverage": 0.47295516582624647,
            "GeometryBResistivityAverageInOhmMeters": 0.00088841464974931568,
            "GeometryBSheetResistivityAverageInOhmsPerSquare": 0.88841464974931572,
            "GeometryBResistivityStandardErrorInOhmMeters": 3.948699771072754E-05,
            "GeometryBSheetResistivityStandardErrorInOhmsPerSquare":
            0.039486997710727542,
            "GeometryBFValueAverage": 0.47607532383092671,
            "ActualBlankingTimeInSeconds": 0.0024,
            "InCompliance": false,
            "VoltageOverload": false,
            "CurrentOverload": false,
            "NumberOfSamples": 19,
            "ResistivitySamples": [
             {
             "ResistivityInOhmMeters": 0.00075449768840567537,
             "SheetResistivityInOhmsPerSquare": 0.75449768840567533,
             "GeometryAResistivityInOhmMeters": 0.000917269343714799,
             "GeometryASheetResistivityInOhmsPerSquare": 0.917269343714799,
             "GeometryAFValue": 0.48031151820901091,
             "GeometryBResistivityInOhmMeters": 0.00059172603309655175,
             "GeometryBSheetResistivityInOhmsPerSquare": 0.5917260330965517,
             "GeometryBFValue": 0.3086672481272571,
             "Measurements": [
               {
                 "ContactConfiguration": "R2134",
                 "PositiveExcitation": {
                   "VoltageInVolts": 7.887944E-05,
                   "CurrentInAmps": 1.000049E-05,
                   "InCompliance": false,
                   "VoltageOverload": false,
                   "CurrentOverload": false
                 },
                 "NegativeExcitation": {
                   "VoltageInVolts": 7.852261E-05,
                   "CurrentInAmps": -9.990846E-06,
                   "InCompliance": false,
                   "VoltageOverload": false,
                   "CurrentOverload": false
                 },
                 "ResistanceInOhms": 0.01784945,
                 "InCompliance": false,
                 "VoltageOverload": false,
                 "CurrentOverload": false
               },
               {
                 "ContactConfiguration": "R3241",
```

```
      "PositiveExcitation": {
        "VoltageInVolts": 8.840124E-05,
        "CurrentInAmps": 1.000684E-05,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "NegativeExcitation": {
        "VoltageInVolts": 7.190482E-05,
        "CurrentInAmps": -9.992138E-06,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "ResistanceInOhms": 0.8248631,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    },
    {
      "ContactConfiguration": "R4312",
      "PositiveExcitation": {
        "VoltageInVolts": 8.063428E-05,
        "CurrentInAmps": 1.000026E-05,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "NegativeExcitation": {
        "VoltageInVolts": 8.059134E-05,
        "CurrentInAmps": -9.993138E-06,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "ResistanceInOhms": 0.0021477,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    },
    {
      "ContactConfiguration": "R1423",
      "PositiveExcitation": {
        "VoltageInVolts": 8.801011E-05,
        "CurrentInAmps": 1.000285E-05,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "NegativeExcitation": {
        "VoltageInVolts": 7.113639E-05,
        "CurrentInAmps": -9.994808E-06,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "ResistanceInOhms": 0.8437848,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    }
  ],
  "InCompliance": false,
  "VoltageOverload": false,
  "CurrentOverload": false,
  "ActualBlankingTimeInSeconds": 0.0024
},
 ...
```

```
    ],
    "IsRunning": false,
    "StartTime": "1970-01-02T03:03:42.290236-05:00",
    "EndTime": "1970-01-02T03:03:46.064352-05:00",
    "DurationInSeconds": 3.773
}
```

RESistivity:RESult:JSON:DATA?

Summary	Retrieves the resistivity and F value of both geometries A and B along with all measurements for a given sample. Van der Pauw results are shown in this example.
Query Format	RESistivityl:RESult:JSON:DATA? <sampleIndex>,<pretty>
Parameters	<sampleIndex> Sample index, zero based Data type is *NR1* <pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized resistivity measurement sample data. Data type is *NAMED*
Examples	

```
Query RESistivity:RESult:JSON:DATA? 4,1
Query response
{
  "ResistivityInOhmMeters": 0.00083849203674707482,
  "SheetResistivityInOhmsPerSquare": 0.83849203674707473,
  "GeometryAResistivityInOhmMeters": 0.00089504567597727147,
  "GeometryASheetResistivityInOhmsPerSquare": 0.89504567597727147,
  "GeometryAFValue": 0.48411577862915228,
  "GeometryBResistivityInOhmMeters": 0.00078193839751687817,
  "GeometryBSheetResistivityInOhmsPerSquare": 0.7819383975168781,
  "GeometryBFValue": 0.43807298616439694,
  "Measurements": [
    {
      "ContactConfiguration": "R2134",
      "PositiveExcitation": {
        "VoltageInVolts": 7.875055E-05,
        "CurrentInAmps": 9.994036E-06,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "NegativeExcitation": {
        "VoltageInVolts": 7.839359E-05,
        "CurrentInAmps": -9.994946E-06,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "ResistanceInOhms": 0.01785782,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    },
    {
      "ContactConfiguration": "R3241",
      "PositiveExcitation": {
        "VoltageInVolts": 8.848818E-05,
        "CurrentInAmps": 1.000711E-05,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "NegativeExcitation": {
        "VoltageInVolts": 7.251695E-05,
        "CurrentInAmps": -1.000757E-05,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
```

```
      },
      "ResistanceInOhms": 0.7979757,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    },
    {
      "ContactConfiguration": "R4312",
      "PositiveExcitation": {
        "VoltageInVolts": 8.006728E-05,
        "CurrentInAmps": 1.000784E-05,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "NegativeExcitation": {
        "VoltageInVolts": 8.09014E-05,
        "CurrentInAmps": -1.000535E-05,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "ResistanceInOhms": -0.04167845,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    },
    {
      "ContactConfiguration": "R1423",
      "PositiveExcitation": {
        "VoltageInVolts": 8.756496E-05,
        "CurrentInAmps": 9.995517E-06,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "NegativeExcitation": {
        "VoltageInVolts": 7.097688E-05,
        "CurrentInAmps": -1.000636E-05,
        "InCompliance": false,
        "VoltageOverload": false,
        "CurrentOverload": false
      },
      "ResistanceInOhms": 0.8293255,
      "InCompliance": false,
      "VoltageOverload": false,
      "CurrentOverload": false
    }
  ],
  "InCompliance": false,
  "VoltageOverload": false,
  "CurrentOverload": false,
  "ActualBlankingTimeInSeconds": 0.0024,
  "ActualSamplingTimeInSeconds": 0.0166666666666667,
}
```

Remarks   This command is similar to the standard SCPI DATA and RAW queries combined.

RESistivity:RESult:JSON[:SUMMary]?

Summary	Retrieves summary results of the last run resistivity measurement, serialized as JSON. Van der Pauw results are shown in this example.
Query Format	RESistivity:RESult:JSON[:SUMMary]? <pretty>
Parameters	<pretty> Optional, pretty format JSON response. Defaults to False. Data type is *bool*
Returns	JSON serialized resistivity measurement result. Data type is *NAMED*

Examples

```
Query RESistivity:RESult:JSON? 1
Query response
{
  "Setup": {
    "ExcitationType": 1,
    "ExcitationValue": 1E-05,
    "ExcitationAutoRange": false,
    "ExcitationRange": 1E-05,
    "ExcitationMeasurementRange": 1E-05,
    "MeasurementAutoRange": false,
    "MeasurementRange": 0.1,
    "ComplianceLimit": 1.5,
    "SampleWidthInMeters": null,
    "SampleArmSeparationInMeters": null,
    "MaxNumberOfSamples": 25,
    "BlankingTimeInSeconds": 0.0024,
    "SampleThicknessInMeters": 0.001,
    "MinimumSnr": 30.0,
    "ActualSamplingTimeInSeconds": 0.0166666666666667,
    "Guid": "2860ada9-4c68-45fd-87ea-a734aa8c9b44"
  },
  "ResistivitySnr": 31.487073734504811,
  "ResistivityAverageInOhmMeters": 0.00088881560980731949,
  "SheetResistivityAverageInOhmsPerSquare": 0.88881560980731933,
  "ResistivityStandardErrorInOhmMeters": 2.8227952120978436E-05,
  "SheetResistivityStandardErrorInOhmsPerSquare": 0.028227952120978436,
  "GeometryAResistivityAverageInOhmMeters": 0.00088921656986532308,
  "GeometryASheetResistivityAverageInOhmsPerSquare": 0.88921656986532316,
  "GeometryAResistivityStandardErrorInOhmMeters": 3.1424935834095014E-05,
  "GeometryASheetResistivityStandardErrorInOhmsPerSquare":
0.031424935834095023,
  "GeometryAFValueAverage": 0.47295516582624647,
  "GeometryBResistivityAverageInOhmMeters": 0.00088841464974931568,
  "GeometryBSheetResistivityAverageInOhmsPerSquare": 0.88841464974931572,
  "GeometryBResistivityStandardErrorInOhmMeters": 3.948699771072754E-05,
  "GeometryBSheetResistivityStandardErrorInOhmsPerSquare":
0.039486997710727542,
  "GeometryBFValueAverage": 0.47607532383092671,
  "ActualBlankingTimeInSeconds": 0.0024,
  "ActualSamplingTimeInSeconds": 0.0166666666666667,
  "InCompliance": false,
  "VoltageOverload": false,
  "CurrentOverload": false,
  "NumberOfSamples": 19,
  "IsRunning": false,
  "StartTime": "1970-01-02T03:03:42.290236-05:00",
  "EndTime": "1970-01-02T03:03:46.064352-05:00",
  "DurationInSeconds": 3.773
}
```

RESistivity:RESult[:STANdard]:DATA?

Summary	Retrieves the resistivity and F value of both geometries A and B for a given sample.
Query Format	RESistivity:RESult[:STANdard]:DATA? <sampleIndex>
Parameters	<sampleIndex> Sample index, zero based
	Data type is *NR1*
Returns	<ResistivityInOhmMeters>,<SheetResistivityInOhmsPerSquare>,
	<GeometryAResistivityInOhmMeters>,
	<GeometryASheetResistivityInOhmsPerSquare>,<geometryAFValue>,
	<GeometryBResistivityInOhmMeters>,
	<GeometryBSheetResistivityInOhmsPerSquare>,<geometryBFValue>

<ResistivityInOhmMeters>Bulk resistivity
Data type is *NRf*

<SheetResistivityInOhmsPerSquare> Sheet resistivity
Data type is *NRf*

<GeometryAResistivityInOhmMeters>
Bulk resistivity for geometry A with contact configurations R2134 (0°) and R3241 (90°)
Data type is *NRf*

<GeometryASheetResistivityInOhmsPerSquare>
Sheet resistivity for geometry A with contact configurations R2134 (0°) and R3241 (90°)
Data type is *NRf*

<geometryAFValue> F value for geometry A
Data type is *NRf*

<GeometryBResistivityInOhmMeters>
Resistivity for geometry B with contact configurations R4312 (0°) and R1423 (90°)
Data type is *NRf*

<GeometryBSheetResistivityInOhmsPerSquare>
Sheet resistivity for geometry B with contact configurations R4312 (0°) and R1423 (90°)
Data type is *NRf*

<geometryBFValue> F value for geometry B
Data type is *NRf*

Examples	`Query RESistivity:RESult:DATA? 4`
	`Query response`
	`0.000107824489134878,0.107824489134878,0.0001321692503,0.132169250305947,0.`
	`9973639678955,8.34797279638077E-05,0.0834797279638,0.993738479614258,0,0,0`

RESistivity:RESult[:STANdard]:POINts?

Summary	Retrieves the number of points in the results list. Use in conjunction with RESistivity:RESult[:STANdard]:DATA? and RESistivity:RESult[:STANdard]:RAW? queries.
Query Format	RESistivity:RESult[:STANdard]:POINts?
Returns	The number of points in the results list.
	Data type is *NR1*
Example	`Query RESistivity:RESult:POINts?`
	`Query response`
	`42`

RESistivity:RESult[:STANdard]:RAW?

Summary	Retrieves the measured voltage, current, and calculated current reversed resistance for a given contact configuration and sample.
Query Format	RESistivity:RESult[:STANdard]:RAW? <sampleIndex>,<contactConfiguration>

Parameters

<sampleIndex>	Sample index, zero based
	Data type is *NR1*
<contactConfiguration>	van der Pauw: R2134, R3241, R4312, or R1423
	Hall bar: R5614 or R5623
	Data type is *ContactConfiguration*

Returns   <measuredVoltagePositive>,<measuredCurrentPositive>, <measuredVoltageNegative>,<measuredCurrentNegative>, <CurrentReversedResistance>,<inCompliance>,<voltageOverload>,<currentOverload>

<measuredVoltagePositive>	Measured voltage with positive excitation, V+
	Data type is *NRf*
<measuredCurrentPositive>	Measured current with positive excitation, I+
	Data type is *NRf*
<measuredVoltageNegative>	Measured voltage with negative excitation, V-
	Data type is *NRf*
<measuredCurrentNegative>	Measured current with negative excitation, I-
	Data type is *NRf*
<CurrentReversedResistance>	Calculated current reversed resistance.
	Data type is *NRf*
<inCompliance>	The specified voltage compliance or current limit was reached.
	Data type is *bool*
<voltageOverload>	Indicates if, during the measurement, the sample was in a voltage overload condition.
	Data type is *bool*
<currentOverload>	Indicates if, during the measurement, the sample was in a current overload condition.
	Data type is *bool*

Examples

```
Van der Pauw query: RESistivity:RESult:RAW? 4,R3241
Van der Pauw result: 7.504676E-05,9.997895e-06,7.441112e-05,-9.99955e-06,
0.03178598,0,0,0
Hall Bar Query: RESistivity:RESult:RAW? 4,R5614
Hall Bar Result: 7.397222E-05,-7.685482e-10,7.364797e-05,3.068916e-09,
-84.49669,1,0,0
```

RESistivity:RESult[:STANdard][:SUMMary]?

Summary
Query Format
Returns

Retrieves the results of the last run resistivity measurement.
RESistivity:RESult[:STANdard][:SUMMary]?
‹startDateTime›,‹durationOfTest›,‹excitationType›,‹excitationValue›,
‹excitationRange›,‹excitationMeasurementRange›,‹measurementRange›,
‹complianceLimit›,‹maxNumberOfSamples›,‹blankingTimeInSeconds›,
‹sampleThicknessInMeters›,‹minimumSnr›,‹samplingTimeInSeconds›,
‹resistivityAverageInOhmMeters›,‹sheetResistivityAverageInOhmsPerSquare›,
‹resistivityStandardErrorInOhmMeters›,‹sheetResistivityStandardErrorInOhmsPerS
quare›,‹resistivitySnr›,‹geometryAResistivityAverageInOhmMeters›,
‹geometryASheetResistivityAverageInOhmsPerSquare›,
‹geometryAResistivityStandardErrorInOhmMeters›,
‹geometryASheetResistivityStandardErrorInOhmsPerSquare›,
‹geometryAFValueAverage›,‹geometryBResistivityAverageInOhmMeters›,
‹geometryBSheetResistivityAverageInOhmsPerSquare›,
‹geometryBResistivityStandardErrorInOhmMeters›,
‹geometryBSheetResistivityStandardErrorInOhmsPerSquare›,
‹geometryBFValueAverage›

‹startDateTime›	UTC date and time when the measurement was started in ISO 8601 format Data type is *string*
‹durationOfTest›	Duration of the test in seconds Data type is *NRf*
‹excitationType›	The excitation type used for the measurement, VOLTage or CURRent. Data type is *NAMED*
‹excitationValue›	The excitation value Data type is *NRf*
‹excitationRange›	The excitation range Data type is *NRf*
‹excitation MeasurementRange›	The full scale range used to measure the excitation signal, dependent on excitationType. Data type is *NRf*
‹measurementRange›	The full scale range of the measurement. For example, if excitation type is current, this is the full scale voltage range. Data type is *NRf*
‹complianceLimit›	For voltage excitation, the current limit. For current excitation, the voltage compliance. Data type is *NRf*
‹maxNumberOfSamples›	The setup's number of samples. When minimumSnr is omitted or INFinity (9.9 e+37), this is the total number of samples. When minimumSnr is specified, this is the maximum number of samples. The RESistivity:RESult[:STANDARD]:POINts? command can be used to retrieve the actual number of points in the results list. Data type is *NR1*
‹blankingTimeInSeconds›	The time in seconds to wait for hardware to settle before making measurements. Data type is *NRf*
‹sampleThicknessInMeters›	Thickness of the sample in meters. Data type is *NRf*
‹minimumSnr›	The desired signal-to-noise ratio of the measurement. Data type is *NRf*
‹samplingTimeInSeconds›	The sampling time in seconds which measurements were

averaged over to get one sample.

Data type is *NRf*

<resistivityAverageInOhmMeters>Average bulk resistivity, in units of Ohm * Meters.

Data type is *NRf*

<sheetResistivityAverageInOhmsPerSquare>

Average sheet resistivity, in units of ohms per square.

Data type is *NRf*

<resistivityStandardErrorInOhmMeters>Standard error of the bulk resistivity,
in units of ohm*meters

Data type is *NRf*

<sheetResistivityStandardErrorInOhmsPerSquare>

Standard error of the sheet resistivity, in units of
ohms per square

Data type is *NRf*

<resistivitySnr>   Signal-to-noise ratio of the resistivity measurement.

Data type is *NRf*

<geometryAResistivityAverageInOhmMeters>Average bulk resistivity for geometry A
with contact configurations R2134 (0°) and R3241 (90°).

Data type is *NRf*

<geometryASheetResistivityAverageInOhmsPerSquare>

Average sheet resistivity for geometry A with contact
configurations R2134 (0°) and R3241 (90°).

Data type is *NRf*

<geometryAResistivityStandardErrorInOhmMeters>

Standard error of the bulk resistivity measurements for
geometry A.

Data type is *NRf*

<geometryASheetResistivityStandardErrorInOhmsPerSquare>

Standard error of the sheet resistivity measurements for
geometry A.

Data type is *NRf*

<geometryAFValueAverage>The F value for geometry A.

Data type is *NRf*

<geometryBResistivityAverageInOhmMeters>

Average bulk resistivity for geometry B with contact
configurations R4312 (0°) and R1423 (90°)..

Data type is *NRf*

<geometryBSheetResistivityAverageInOhmsPerSquare>

Average sheet resistivity for geometry B with contact
configurations R4312 (0°) and R1423 (90°)

Data type is *NRf*

<geometryBResistivityStandardErrorInOhmMeters>

Standard error of the bulk resistivity measurements for
geometry B.

Data type is *NRf*

<geometryBSheetResistivityStandardErrorInOhmsPerSquare>

Standard error of the sheet resistivity measurements for
geometry B.

Data type is *NRf*

<geometryBFValueAverage>The F value for geometry B.

Data type is *NRf*

RESistivity:RUNNing?

Summary   Indicates if the resistivity measurement is running.

Query Format   RESistivity:RUNNing?

| Returns | The measurement is running |
| | Data type is *bool* |

RESistivity[:VDP]:STARt

Summary	Performs a resistivity measurement for a van der Pauw sample.
Command Format	RESistivity[:VDP]:STARt	‹excitationType›,‹excitationValue›,‹excitationRange›, ‹excitationMeasurementRange›,‹measurementRange›, ‹complianceLimit›,‹maxNumberOfSamples›, ‹blankingTime›,‹sampleThickness›,‹minimumSnr›, ‹samplingTime›
Parameters	‹excitationType›	VOLTage, CURRent
		Data type is *NAMED*
	‹excitationValue›	For voltage excitation -10 to 10 V
		For current excitation -100 e3 to 100 e-3 A
		Data type is *NRf*
	‹excitationRange›	For voltage excitation 0 to 10 V
		For current excitation 0 to 100 e-3 A
		AUTO sets the range to the best fit range for a given excitation value.
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	‹excitationmeasurementRange›	For voltage excitation 0 to 10 V
		For current excitation 0 to 100 e-3 A
		AUTO sets the measurement range to the best fit range for a given excitation value.
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	‹measurementRange›	For voltage excitation, specify the current measurement range 0 to 100 e-3 A
		For current excitation, specify the voltage measurement range 0 to 10 V
		AUTO sets the measurement range to the best fit range for a given excitation value.
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	‹complianceLimit›	For voltage excitation, specify the current limit 100 e-9 to 100 e-3 A
		For current excitation, specify the voltage compliance 1 to 10 V
		Data type is *NRf*
	‹MaxNumberOfSamples›	When minimumSnr is omitted or INFinity (9.9 e+37), the total number of samples to average 1 to 1000.
		When minimumSnr is specified, the maximum number of samples to average 10 to 1000.
		DEFault = 100
		Data type is *Number*
	‹blankingTime›	The time, in seconds, to wait for hardware to settle before gathering readings.
		0.5 ms to 300 s with a resolution of 0.1 ms
		DEFault = 2 ms
		MINimum = 0.5 ms
		MAXimum = 300 s

		Data type is *Number*
	<sampleThickness>	Thickness of the sample in meters.
		0 to 10 e-3 m
		DEFault = 0 m
		Data type is *Number*
	<minimumSnr>	The desired signal to noise ratio of the measurement calculated using average resistivity / error of mean
		1 to1000, or INFinity (9.9 e+37).
		DEFault = 30
		Data type is *Number*
	<samplingTime>	The sampling time, in seconds, which measurements will be averaged over to get one sample.
		MINimum = 0.010 ms
		MAXimum = 1 s
		DEFault = 1/60 s
		Data type is *Number*
Example		RESistivity:STARt CURRent,10e-6,10e-6,AUTO,100e-3,1.5,25,2.4e-3,0,30

RESisitivity[:VDP]:STARt:LINk

Summary   Performs a resistivity measurement (for a van der Pauw sample) that uses the last run contact check measurement's excitation type, compliance limit, blanking time, excitation range, and the largest absolute value of the start and end excitation values.

Command Format   RESistivity[:VDP]:STARt:LINk<measurementRange>,<sampleThickness>, <minimumSnr>,<maxNumberOfSamples>

Parameters	<measurementRange>	For voltage excitation, specify the current measurement range 0 to 100 e-3 A
		For current excitation, specify the voltage measurement range 0 to 10 V
		AUTO sets the range to the best fit range
		DEFault = AUTO
		NOTE: The hardware will be configured to best meet the desired range.
		Data type is *Number*
	<sampleThickness>	Thickness of the sample in meters.
		0 to 10 e-3 m
		DEFault = 0 m
		Data type is *Number*
	<minimumSnr>	The desired signal-to-noise ratio of the measurement calculated using average resistivity/error of mean
		1 to 1000, or INFinity (9.9 e+37)
		DEFault = 30
		Data type is *Number*
	<MaxNumberOfSamples>	When minimumSnr is omitted or INFinity (9.9 e+37), the total numberof samples to average 1 to 1000.
		When minimumSnr is specified, the maximum number of samples to average 10 to 1000.
		DEFault = 100
		Data type is *Number*
Example		RESistivity:STARt:LINk

STATus:OPERation

Remarks
This group of commands, known as the Operation Status Register, contains informative conditions which are part of the normal operation of the M91. The following table provides the bit definitions for the operation status register.

Bit(s)	Description
0-3	Not used
4	Measuring done
5-15	Not used

:CONDition?

Query Format	STATus:OPERation:CONDition?	
Return Parameter	<value>	Sum of the binary-weighted values for the set bits
		Data type is NR1
Examples		
Query	STAT:OPER:COND?	
Query Response	5120	Indicates that the interlock is not present and the trigger model is in the IDLE state (bits 10 and 12 are set)
Remarks	Returns the "real-time" status of the operation status register. This information is non-latching. The register contents are not altered by issuing this query.	

:ENABle

Command Format	STATus:OPERation:ENABle <mask>	
Parameter	<mask>	Sum of the binary-weighted values for the set bits
		Both data types are NR1
Query Format	STATus:OPERation:ENABle?	
Return Parameter	<mask>	(see above)
Examples		
Command	STAT:OPER:ENAB 4096	Enables interlock not present
Query	STAT:OPER:ENAB?	
Query Response	5120	Indicates that interlock not present and IDLE are enabled
Remarks	This command specifies the enable mask, allowing true conditions in the operation event register to be reported in the operation summary bit, located in the status byte register. If a bit is set in the enable register and its associated event bit transitions to true, the operation summary bit will be set.	

[:EVENt]?

Query Format	STATus:OPERation[:EVENt]?	
Return Parameter	<value>	Sum of the binary-weighted values for the set bits
		Data type is NR1
Examples		
Query	STAT:OPER:EVEN?	
Query Response	1024	Indicates that instrument is in trigger idle mode
	Returns the contents of the operation status register since the last time the event register was read. Reading the register will clear its contents.	

STATus:PRESet

Command Format	STATus:PRESet	
Parameter	None	
Examples		
Command	STAT:PRES	
Remarks	Resets the operation and questionable event enable registers to 0.	

STATus:QUEStionable

Remarks   This group of commands, known as the Questionable Status Register, contain informative conditions which can indicate that the quality of the output signal of the MeasureReady® M91 FastHall™ measurement controller might be compromised. The following table provides the bit definitions for the questionable status register.

Bit(s)	Description
0	Source in voltage compliance/current limit
1	Resistivity value is negative
2-4	Not used
5	Current measurement overload
6	Voltage measurement overload
7-8	Unused
9	Inter-processor communication error
10-11	Not used
12	Measured R^2 value less than minimum user defined R^2 value
13	Calculated F value out of acceptable range
14	Geometry out of acceptable range
15	Not used

:CONDition?

Query Format   STATus:QUEStionable:CONDition?
Return Parameter   <value>   Sum of the binary-weighted values for the set bits
                                             Data type is NR1

Examples
   Query   STAT:QUES:COND?
   Query Response   2   Indicates that the current source is in voltage compliance
Remarks   Returns the "real-time" status of the questionable status register. This information is non-latching. The register contents are not altered by issuing this query.

:ENABle

Command Format   STATus:QUEStionable:ENABle <mask>
Parameter   <mask>   Sum of the binary-weighted values for the set bits
                                             Both data types are NR1

Query Format   STATus:QUEStionable:ENABle?
Return Parameter   <mask>   (see above)
Examples
   Command   STAT:QUES:ENAB 3   Enables current limit and voltage compliance
   Query   STAT:QUES:ENAB?
   Query Response   512   Indicates that internal communication error is enabled
Remarks   This command specifies the enable mask, allowing true conditions in the questionable event register to be reported in the questionable summary bit, located in the status byte register. If a bit is set in the enable register and its associated event bit transitions to true, the questionable summary bit will be set.

[:EVENt]?

Query Format   STATus:QUEStionable[:EVENt]?
Return Parameter   <value>   Sum of the binary-weighted values for the set bits
                                             Data type is NR1

Examples
   Query   STAT:QUES:EVEN?
   Query Response   256   Indicates that the instrument's calibration is questionable
Returns the contents of the questionable status register since the last time the event register was read. Reading the register will clear its contents.

SYSTem:AUTODATETIME

Command Format	SYSTem:AUTODATETIME <on/off>	
Parameter	<on/off>	0 = auto date/time disabled. 1 = auto date/time enabled
		Data type is bool
Query Format	SYSTem:AUTODATETIME?	
Return Parameter	<on/off>	
Examples		
Command	SYST:AUTODATETIME 1	Enables auto date/time
Query	SYST:AUTODATETIME?	
Remarks	This command will automatically set the date and time for the user. The instrument must be connected to the internet for this feature to work properly.	

SYSTem:BEEPer:VOLume

Command Format	SYSTem:BEEPer:VOLume <volume>	
Parameter	<volume>	0 to 100
		Data type is NR1
Query Format	SYSTem:BEEPer:VOLume?	
Return Parameter	<volume>	(see above)
Examples		
Command	SYST:BEEP:VOL 100	Sets the instrument volume to max volume
Query	SYST:BEEP:VOL?	
Query Response	50	Indicates that the instrument volume is set to mid-scale
Remarks	This command sets the volume of audible tones.	

SYSTem:DATE

Command Format	SYSTem:DATE <year>,<month>,<day>	
Parameter	<year>	####
	<month>	1 to 12
	<day)	1 to 31
		All three parameters are data type is NR1
Query Format	SYSTem:DATE?	
Return Parameter	<year>,<month>,<day>	(see above)
Examples		
Command	SYST:DATE 2017, 5, 15	Sets the date to May 15, 2017
Query	SYST:DATE?	
Query Response	2018,2,23	Indicates that the date is set to February 23, 2018
Remarks	This command sets the date of the instrument.	

SYSTem:ERRor

Remarks	The group of command and queries below are related to the reading and control of the error/event queue.

:ALL?

Query Format	SYSTem:ERRor:ALL?	
Return Parameter	<code>,<error message>	code is the error event code
		Data type is NR1
		error message is a description of the error
		Data type is string
Examples		
Query	SYST:ERR:ALL?	
Query Response	-113,"Undefined header;asdf",221,"Settings conflict";-221,"Data out of range"	

Remarks	Queries the error/event queue for all the unread items and removes them from the queue. If there are multiple errors queued, the response returns a comma separated list of code, error message pairs, in FIFO order. If the queue is empty, the response code is 0 and the error message is "No error".

:CLEar

Command Format	SYSTem:ERRor:CLEar
Parameter	None
Examples	
Command	SYST:ERR:CLE
Remarks	This command removes all errors from the error/event queue.

:COUNt?

Query Format	SYSTem:ERRor:COUNt?	
Return Parameter	<count>	Number of errors in the queue
		Data type is NR1
Examples		
Query	SYST:ERR:COUN?	
Query Response	4	Indicates there are 4 unread errors in the queue
Remarks	Returns the number of unread items in the error/event queue for the number of unread items. If the queue is empty, the response is 0.	

[:NEXT]?

Query Format	SYSTem:ERRor[:NEXT]?	
Return Parameter	<code>,<error message>	code is the error event code
		Data type is NR1
		error message is a description of the error
		Data type is string
Examples		
Query	SYST:ERR?	
Query Response	-113,"Undefined header;qwerty"	
Remarks	Queries error/event queue for the next item and removes it from queue.	

SYSTem:FACTORYRESET

Format	SYSTem:FACTORYRESET
Examples	SYST:FACTORYRESET
Remarks	This command resets the instrument settings to its factory defaults.

SYSTem:KLOCk

Command Format	SYSTem:KLOCk <on/off>	
Parameter	<on/off>	0 = unlocked, 1 = locked
		Data type is bool
Query Format	SYSTem:KLOCk?	
Return Parameter	<on/off>	
Examples		
Command	SYST:KLOC 1	Locks the front panel from being used
Query	SYST:KLOC?	
Query Response	0	Indicates that the front panel is unlocked
Remarks	This command locks the front panel controls of the instrument.	

SYSTem:PRESet

Command Format	SYSTem:PRESet
Parameter	None
Examples	
Command	SYST:PRES
Remarks	This command sets the device to the same state as the front-panel reset instrument settings key.

SYSTem:TIME

Command Format	SYSTem:TIME <hour>,<minute>,<second>	
Parameter	<hour>	0 to 23
	<minute>	0 to 59
	<second>	0 to 59
		All three parameters are data type NR1
Query Format	SYSTem:TIME?	
Return Parameter	<hour>,<minute>,<second> (see above)	
Examples		
Command	SYST:TIME 13,34,00	Sets the time to 1:34 PM
Query	SYST:TIME?	
Query Response	4,5,4	Indicates that the time is set to 4:05:04 AM
Remarks	This command sets the clock of the instrument. If any parameter exceeds the range specified above, it shall be rippled up through the date. For example, if SYST:TIME 9,30,126 is sent, the time will be set to 9:32:06 AM.	

SYSTem:TZONE

Command Format	SYSTem:TZONE <hour>,<minute>	
Parameter	<hour>	-12 to 12
	<minute>	0, 30, 45
		Both data types are NR1
Query Format	SYSTem:TZONE?	
Return Parameter	<hour>,<minute>	(see above)
Examples		
Command	SYST:TZONE -5,00	Sets the time zone to UTC -05:00
Query	SYST:TZONE?	
Query Response	9,0	Indicates that the time zone is set to UTC +09:00
Remarks	This command sets the time zone of the instrument. When each field is subtracted from the value of the TIME command, the result is the correct universal coordinated time (also known as UCT).	

SYSTem:VERSion?

Query Format	SYSTem:VERSion?	
Return Parameter	<version>	Version of the SCPI standard that the instrument adheres to Data type is NR2
Examples		
Query	SYST:VERS?	
Query Response	1999.0	Indicates that this instrument adheres to SCPI version 1999
Remarks	None	

TESLameter:FETCh:FIELd?

Summary	Gets a field reading.
Query Format	TESLameter:FETCh:FIELd?
Returns	Field reading.
	Data type is *NRf*

TESLameter:SOURce:FIELd:MODE

Summary	Sets the current field control mode.
Command Format	TESLameter:SOURce:FIELd:MODE ‹fieldControlMode›
Parameters	‹fieldControlMode› OPLOOP for open loop, CLLOOP for closed loop.
	Data type is *FieldControlMode*

TESLameter:SOURce:FIELd:MODE?

Summary	Gets the current field control mode.
Query Format	TESLameter:SOURce:FIELd:MODE?
Returns	OPLOOP for open loop, CLLOOP for closed loop.
	Data type is *NAMED*

TESLameter:SOURce:FIELd:OPLoop:VOLTage

Summary	Sets the open loop field control voltage.
Command Format	TESLameter:SOURce:FIELd:OPLoop:VOLTage ‹voltage›
Parameters	‹voltage› The voltage.
	Data type is *NRf*
Example	TESLameter:SOURce:FIELd:OPLoop:VOLTage 1.23

TESLameter:SOURce:FIELd:OPLoop:VOLTage?

Summary	Gets the current open loop field control voltage.
Command Format	TESLameter:SOURce:FIELd:OPLoop:VOLTage?
Returns	The voltage.
	Data type is *NRf*

TESLameter:SOURce:FIELd:STATe

Summary	Sets the field control state.
Command Format	TESLameter:SOURce:FIELd:STATe ‹fieldControlState›
Parameters	‹fieldControlState› 1 for enabled, 0 for disabled.
	Data type is *bool*

TESLameter:SOURce:FIELd:STATe?

Summary	Gets the current field control state.
Command Format	TESLameter:SOURce:FIELd:STATe?
Returns	1 for enabled, 0 for disabled.
	Data type is *bool*

Chapter 5: Options and Accessories

5.1 General

This chapter provides information on the models, options, and accessories available for the MeasureReady® M91 FastHall™ measurement controller.

5.2 Models and Kits

The list of M91 source model numbers and kits follows:

Model	Description
M91	Standard MeasureReady® M91 FastHall™ measurement controller
M91-HR	MeasureReady® M91 FastHall™ measurement controller with high resistance firmware upgrade

TABLE 5-1 **Model description**

5.3 Accessories

Accessories are devices that perform a secondary duty as an aid or refinement to the primary unit. Refer to https://www.lakeshore.com/M91/ for details. A list of accessories available for the M91 is provided in the table below.

Model	Description
843-076	Triaxial cable, 3 m
P12379	Triaxial to BNC adapter
RM-1/2	Half rack mount kit
RM-2	Dual half rack mount kit

TABLE 5-2 **Accessories**

5.4 Options

A high resistance firmware upgrade is available for high resistance samples. Contact Lake Shore to purchase this option.

Model	Description
M9-ADD-HR	Upgrade for MeasureReady® M91 FastHall™ measurement controller for high resistance measurements, >10 MΩ *

Only for M91 standard model. M91-HR includes this firmware upgrade pre-installed.

TABLE 5-3 **Options**

5.5 Rack Mounting

The MeasureReady® M91 FastHall™ measurement controller can be installed into a half rack or dual half rack mount using the optional Lake Shore rack mount kits. The kits contain the necessary parts to mount one instrument with the provided blank, or two instruments side by side in a rack mount space, 483 mm (19 in) wide by 88.9 mm (3.5 in) high.

> **NOTE** ►
>
> **Ensure that there is a 25 mm (1 in) clearance on both sides of the instrument after rack mounting.**

5.5.1 Half Rack Mounting

Refer to the figure below for half rack installation details.

Item	Description	Qty
❶	Rack mount panel	1
❷	Rack mount ear	2
❸	Screw, M4 × 8 mm FHM Phillips	2
❹	Screw, M4 × 16 mm FHM Phillips (original touchscreen instrument screws)	4
	-- OR --	
	Screw, 6-32 × 0.5 in FHM Phillips	4

1. Remove instrument feet.
2. Attach the blank to the rack ear using the supplied screws.
3. *For dark blue touchscreen instruments:*

   Remove the front screws from the side panels and use these M4 screws to attach the rack ears.

   For beige keypad instruments:

   a. Remove the front screws from the sides of the instrument and retain for future use, if the rack kit is ever removed.

   b. Use the 6-32 screws ❹ to attach the rack ears.
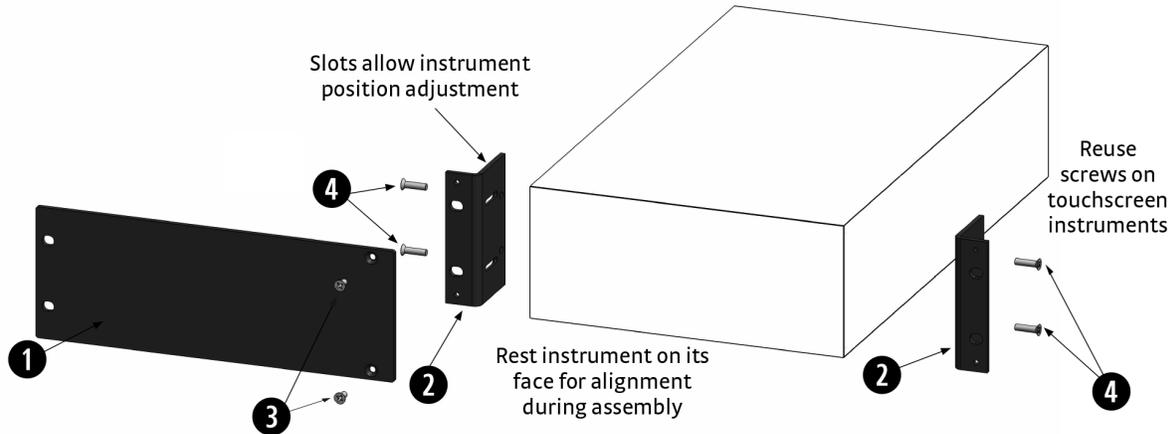
FIGURE 5-1 **Half rack mounting**

5.5.2 Dual Half Rack Mounting

Refer to the figure below for dual half rack installation details.
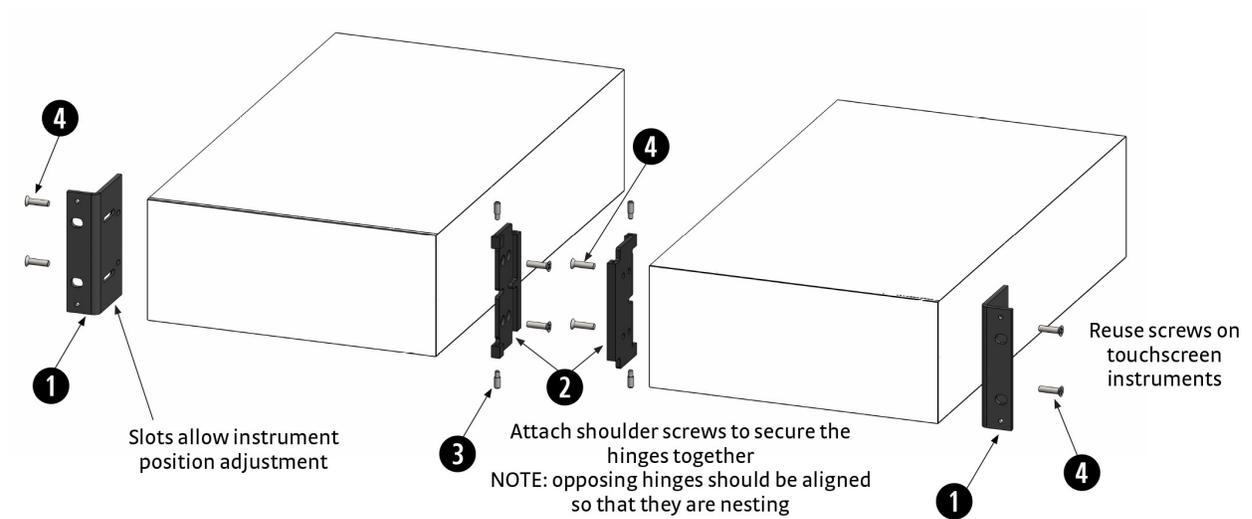
Item	Description	Qty
❶	Dual rack mount ears	2
❷	Dual rack mount hinges	2
❸	Screw, headless shoulder	4
❹	Screw, M4 × 16 mm FHM Phillips (original touchscreen instrument screws	8
	-- OR --	
❹	Screw, 6-32 × 0.5 in FHM Phillips	8

1. Remove instrument feet.

2. *For dark blue touchscreen instruments:*

   Remove the front screws from the side panels and use the M4 screws to attach the rack ears and hinges to the sides of each instrument.

   For beige keypad instruments:

   a. Remove the front screws from the sides of the instrument and retain for future use, if the rack kit is ever removed.

   b. Use the supplied 6-32 screws ❹ to attach the rack ears and hinges to the sides of each instrument.

3. Nest the two hinges together and install all four ❸ screws to lock instruments together.

*FIGURE 5-2 **Dual half rack mounting***

Chapter 6: Service

6.1 Overview

This chapter provides basic service information for the MeasureReady® M91 FastHall™ measurement controller. Customer service of the product is limited to the information presented in this chapter. Lake Shore trained service personnel should be consulted if the instrument requires repair.

6.2 USB Troubleshooting

This section provides USB interface troubleshooting for issues that arise with new installations, existing installations, and intermittent lockups.

6.2.1 New Installation

1. Check that the instrument's interface is set to USB.
2. Check that the USB driver is installed properly and that the device is functioning. In Microsoft Windows®, the device status can be checked using Device Manager by right-clicking **Lake Shore Instrument** under Ports (COM & LPT) or Other Devices and then clicking **Properties**. Refer to section 4.4.1.3 for details on installing the USB driver.
3. Check that the correct com port is being used. In Microsoft Windows®, the com port number can be checked using Device Manager under Ports (COM & LPT).
4. Check that the correct settings are being used for communication. Refer to section 4.4.1.3 for details on installing the USB driver.
5. Check cable connections and length.
6. Send the message terminator.
7. Send the entire message string at one time including the terminator. (Many terminal emulation programs do not.)
8. Send only one simple command at a time until communication is established.
9. Be sure to spell commands correctly and use proper syntax.

6.2.2 Existing Installation No Longer Working

1. Power the instrument off, then on again to see if it is a soft failure.
2. Power the computer off, then on again to see if communication port is locked up.
3. Check all cable connections.
4. Check that the com port assignment has not been changed. In Microsoft Windows®, the com port number can be checked using Device Manager under Ports (COM & LPT).
5. Check that the USB driver is installed properly and that the device is functioning. In Microsoft Windows®, the device status can be checked using Device Manager by right-clicking **Lake Shore Instrument** under Ports (COM & LPT) or Other Devices and then clicking Properties.

6.2.3 Intermittent Lockups

1. Check cable connections and length.
2. Increase the delay between all commands to 100 ms to make sure the instrument is not being overloaded.
3. Ensure that the USB cable is not unplugged and that the M91 is not powered down while the com port is open. The USB driver creates a com port when the USB connection is detected, and removes the com port when the USB connection is no longer detected. Removing the com port while in use by software can cause the software to lock up or crash.

6.3 System Troubleshooting

6.3.1 Factory Reset

It is sometimes necessary to reset instrument parameter values to factory defaults. System settings are stored in nonvolatile memory, and can be cleared without affecting instrument calibration. To reset the instrument to the factory defaults:
1. Tap the Settings menu (top left corner of the screen).
2. Tap System settings.
3. Tap **Reset**, then tap **Reset instrumentation settings**.
4. A confirmation message will appear. Tap **Reset** to confirm the action.

Measurement data is not stored in non-volatile memory. Issuing a `*RST` command to the M91 will clear all measurement data and cancel any running measurement.

6.3.2 Calibration Errors

The M91 FastHall™ measurement controller contains calibration constants, programmed into the instrument during assembly and test, that are stored in non-volatile memory (NOVRAM). This memory is checked on power up, and if the calibration constants are determined to be invalid, they are reported on the front panel. In addition, bit 8 of the questionable event status register is set.

In these cases, the instrument cannot be guaranteed to be within published specifications and the default calibration constants are applied to guarantee the M91 will function. The user is allowed to continue operation of the M91, despite it being out of calibration.

Default
In this case, the NOVRAM contains default gain and offset calibration constants.
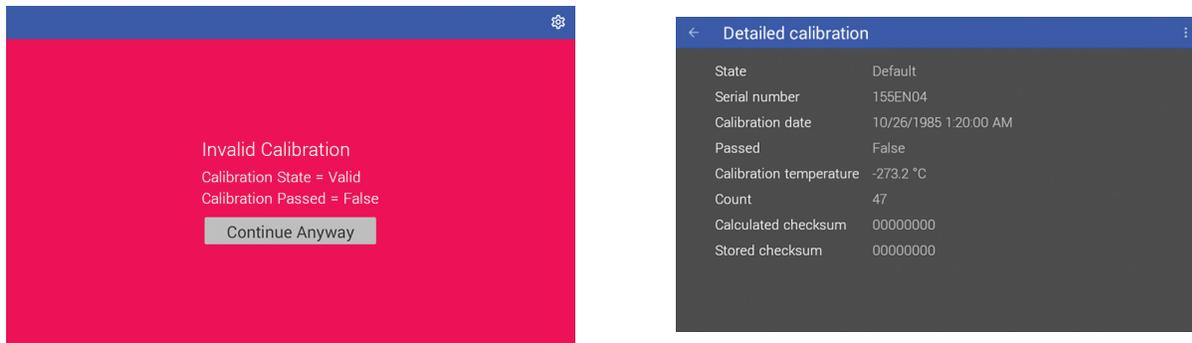
FIGURE 6-1   Calibration error: default

Uninitialized
The Calibration NOVRAM is in an uninitialized/blank state.
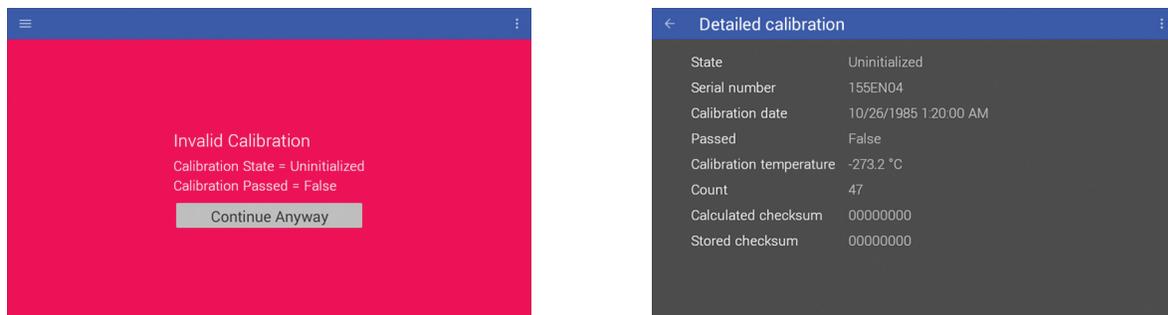
FIGURE 6-2   Calibration error: uninitialized

Corrupt

In this state, one or more of the calibration constants is invalid, resulting in a mismatch of the calculated and stored checksums.
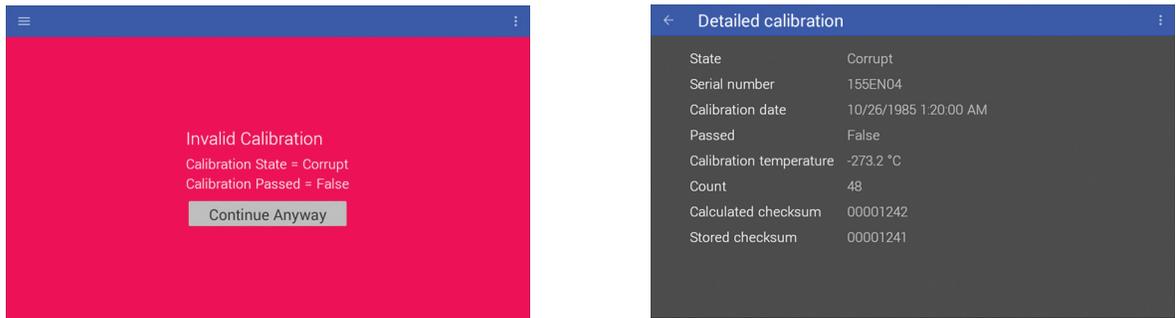
FIGURE 6-3 **Calibration error: corrupt**

Not Passed

In this case, the calibration data is not corrupt, default or uninitialized and is therefore considered valid, from a data integrity standpoint. However, despite running through the full calibration process, the M91 did not pass calibration.
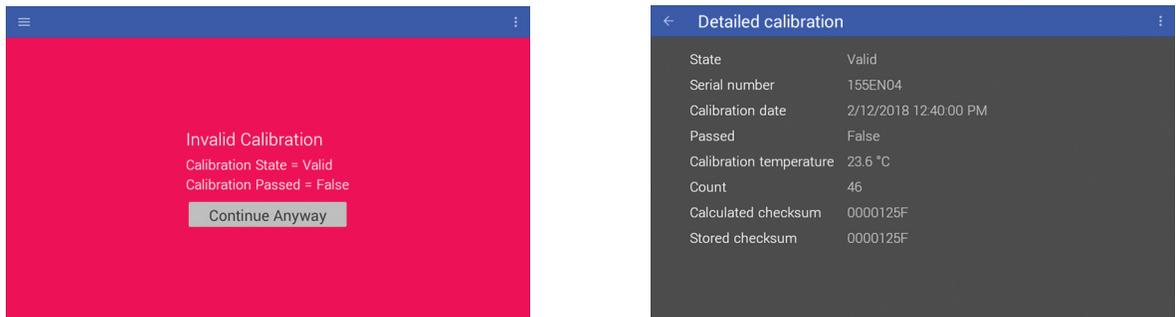
FIGURE 6-4 **Calibration error: not passed**

6.3.3 Firmware Updates

6.3.3.1 Overview

This section provides instructions on updating your firmware. The M91 FastHall™ measurement controller can update its firmware manually by attaching a USB Type-C™ stick to the rear panel, or by downloading and installing updates from Lake Shore with an M91 connected to the internet. However, the easiest method is to connect the instrument to the internet via Ethernet, and update directly from the Lake Shore firmware server.

Firmware comprises many files, aggregated together to form a Lake Shore Firmware (LSFW) package. The M91 stores versions of its LSFW packages in its internal memory. This local memory location is called the "local repository". This allows you to downgrade firmware should you choose, since older versions will still remain on the M91 in the local repository. In addition, Lake Shore maintains LSFW packages on a network server that allows us to deploy those packages to all M91 customers. This is called the "remote repository".

Firmware update information can be found via the M91 front panel:
1. Tap the Settings menu (top left corner of the screen).
2. Tap **Update**. Lake Shore recommends enabling the "Notify when updates are available" setting to ensure your firmware is up-to-date with the latest features and updates.
3. If used with a valid network connection, the M91 will display a notification on the notification bar as soon as an update is available.
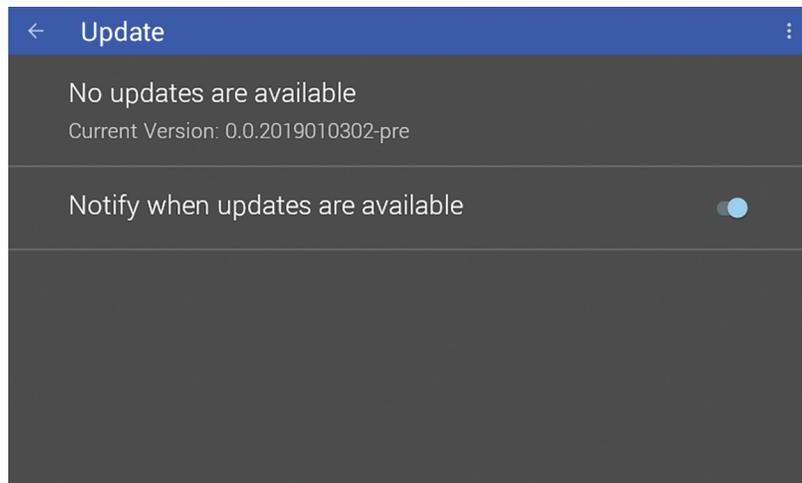
FIGURE 6-5 ***Firmware updates***

If the M91 notifies you that a firmware update is available, tap "Update available". A pop-up notification will appear, prompting you to install. Click **Install** and follow any on-screen instructions.
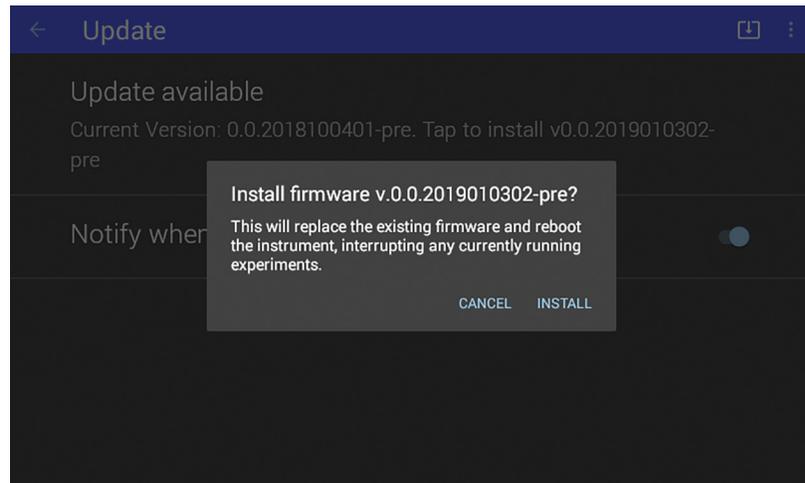
FIGURE 6-6 **Firmware updates**

6.3.3.2 Manual Update Procedure Using USB Type-C™

Firmware can be downloaded from the lake shore website and manually installed on the M91 using a USB Type-C™ stick:
1. To download the firmware, go to the Downloads tab at https://www.lakeshore.com/m91/.
2. Enter your name and e-mail address so that we can keep you updated on any new firmware for your instrument.
3. Insert the USB stick into your computer and copy the downloaded M91 LSFW package to the root directory of the USB stick.
4. Remove the stick from the computer and insert it into the USB Type-C™ port of the M91.
5. On the M91 front panel, tap the Settings menu (top left corner of the screen), then select Update.
6. Click "Updates are available. Click here to install" and follow the on-screen instructions to update the firmware.

6.3.3.3 High Resistance Option Upgrade

The M9-ADD-HR upgrade option enables the high resistance capability for measurements over 10 MΩ. This option enables the ability to source voltage and measure current, and is field upgradeable. Contact Lake Shore to purchase this option. A license key is required to enable the option.

To enter license information:
1. Use the **SYSTEM:LICENSE:ADD "<feature key>"** command. The feature key must be enclosed in quotation marks. For example:
   SYSTEM:LICENSE:ADD "D7A2700C38844B577BED44101B72744CD1DD0865"
2. Use the **SYSTEM:LICENSE?** query to verify that the license was installed. The M91 will return the high resolution license code.

6.4 Error and Status Messages

The following are error and status messages that may be displayed by the M91 during operation.

Message	Description
Voltage range of 100 V and current limit › 10 mA cannot be applied simultaneously	1. An attempt was made to set the voltage range to 100 V while the DC current limit was set to a value greater than 10 mA. Set the DC current limit to 10 mA or less first. 2. An attempt was made to set the DC current limit to a value greater than 10 mA while the voltage range was set to 100 V. Set the voltage range to 10 V or less first.
Current range of 100 mA and voltage compliance limit of › 10 V cannot be applied simultaneously	1. An attempt was made to set the DC compliance voltage setting to a value greater than 10 V while the current range is set to 100 mA. Set the current range to 10 mA or less first. 2. An attempt was made to set the current range to 100 mA while the DC compliance voltage was set to a value greater than 10 V. Set the DC compliance voltage to 10 V or less first.
Internal communication interrupted	The main microprocessor has lost communication with the analog board microprocessor. The output is automatically disabled as a result of this event.
Invalid calibration	See section 6.3.2.

TABLE 6-1 **Error messages**

6.5 Calibration Procedure

Instrument calibration can be obtained through Lake Shore Service. Refer to section 6.8 for technical inquiries and contact information.

6.6 Rear Panel Connector Definition

The connectors on the rear panel are defined below.
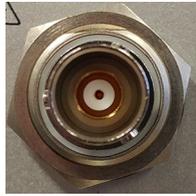
FIGURE 6-7 **Triaxial sample connectors**

Pin	Description
Center conductor	Output high
Inner shield	Driven guard voltage output
Outer shield	Output low (source common)

TABLE 6-2 **Triaxial sample connectors settings**

FIGURE 6-8 **Analog input**

Pin	Description
Center conductor	Output high
Outer shield	Output low (source common)

TABLE 6-3 **Analog input settings**

FIGURE 6-9 **Analog output**

Pin	Description
Center conductor	Voltage output high
Outer shield	Reference return (chassis ground)

TABLE 6-4 **Analog output settings**

Lake Shore
CRYOTRONICS | www.lakeshore.com
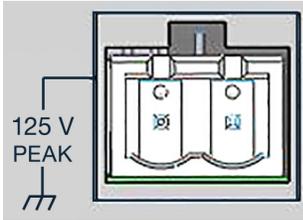
FIGURE 6-10 **Signal return**

Pin	Description
1	Signal return
2	Signal return

TABLE 6-5 **Signal return settings**

FIGURE 6-11 **Digital I/O port**

Pin	Digital input description
1	Ground
2	+5 V
3	Digital input 4 low
4	Digital input 4 high
5	Digital input 3 low
6	Digital input 3 high
7	Digital input 2 low
8	Digital input 2 high
9	Digital input 1 low
10	Digital input 1 high

TABLE 6-6 **Digital input pinouts**
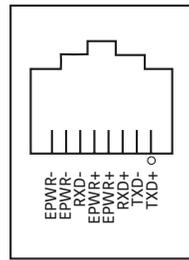
FIGURE 6-12 *Ethernet pin and connector*

Pin	Symbol	Description
1	TXD+	Transmit data+
2	TXD-	Transmit data-
3	RXD+	Receive data+
4	EPWR+	Power from switch+ (not used)
5	EPWR+	Power from switch+ (not used)
6	RXD-	Receive data-
7	EPWR-	Power from switch- (not used)
8	EPWR-	Power from switch- (not used)

TABLE 6-7 *Ethernet pin and connector details*
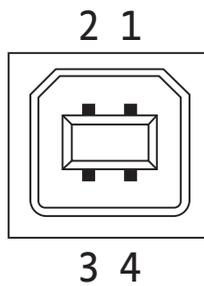
FIGURE 6-13 *USB pin and connector*

Pin	Name	Description
1	VCC	+5 VDC
2	D-	Data −
3	D+	Data +
4	GND	Ground

TABLE 6-8 *USB pin and connector details*
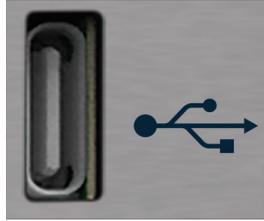
FIGURE 6-14 ***USB Type-C™ connector***

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	TX1+	TX1-	VBUS	CC1	D+	D-	SBU1	VBUS	RX2-	RX2+	GND

GND	RX1+	RX1-	VBUS	SBU2	D-	D+	CC2	VBUS	TX2-	TX2+	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1
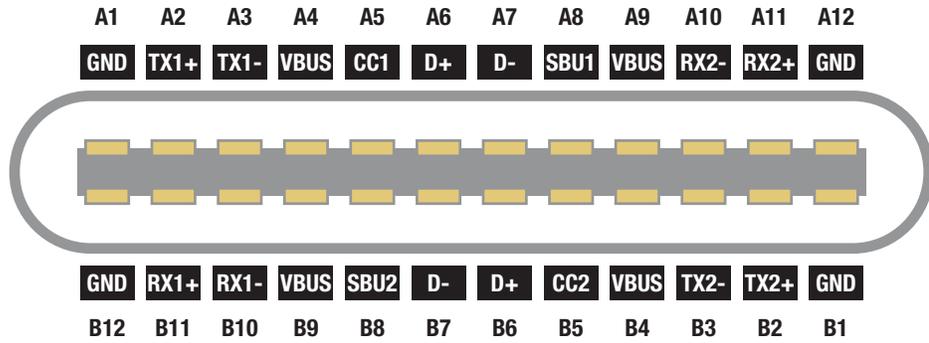
FIGURE 6-15 ***USB Type-C™ connector***

Pin	Name	Description	Pin	Name	Description
A1	GND	Ground return	B12	GND	Ground return
A2	SSTXp1	SuperSpeed differential pair #1, TX, positive	B11	SSRXp1	SuperSpeed differential pair #2, RX, positive
A3	SSTXn1	SuperSpeed differential pair #1, TX, negative	B10	SSRXn1	SuperSpeed differential pair #2, RX, negative
A4	V_{BUS}	Bus power	B9	V_{BUS}	Bus power
A5	CC1	Configuration channel	B8	SBU2	Sideband use (SBU)
A6	Dp1	Non-SuperSpeed differential pair, position 1, positive	B7	Dn2	Non-SuperSpeed differential pair, position 2, negative
A7	Dn1	Non-SuperSpeed differential pair, position 1, negative	B6	Dp2	Non-SuperSpeed differential pair, position 2, positive
A8	SBU1	Sideband use (SBU)	B5	CC2	Configuration channel
A9	V_{BUS}	Bus power	B4	V_{BUS}	Bus power
A10	SSRXn2	SuperSpeed differential pair #4, RX, negative	B3	SSTXn2	SuperSpeed differential pair #3, TX, negative
A11	SSRXp2	SuperSpeed differential pair #4, RX, positive	B2	SSTXp2	SuperSpeed differential pair #3, TX, positive
A12	GND	Ground return	B1	GND	Ground return

TABLE 6-9 ***USB Type-C™ connector details***

6.7 Summary of Internal Memory Devices

This section outlines the internal memory devices used inside the MeasureReady® M91 FastHall™ measurement controller, and provides an explanation of the types of data they contain.

Printed circuit board	Manufacturer	Part number	Description	Location	Function	Volatility	Field modifiable
Analog	Atmel/Microchip	ATSAME70Q21A	Microprocessor	U1	Microprocessor code	Non-volatile	No
Analog	Cypress	FM24V10	Microprocessor	U2	Calibration data, license files	Non-volatile	No
Digital	Kingston	EMMC04G-S100-A08U	4 GB eMMC Flash	U31	Operating system, firmware repository, app service, and instrument settings	Non-volatile	No
Digital	SK Hynix	H5TC2G83GFR--PBA	1 GB (256 MB x 4) DDR3L SRAM	U2, U3, U4, U5	Run-time data storage	Volatile	No
Digital	Microchip	SST25VF016B-50-4C	16 Mbit serial flash	U17	Bootloader	Non-volatile	No

TABLE 6-10 **Internal memory devices**

1. The Atmel/Microchip ATSAME70Q21A is a microprocessor with 2048 KB of onboard programmable flash memory. The code is loaded by initiating a firmware update over the remote interface.
2. The Cypress FM24V10 is a 128 KB I2C FRAM. It is used to store calibration constants and feature license files. The memory is programmed at Lake Shore.
3. The Kingston EMMC04G-S100-A08U is a 4 GB eMMC flash memory used to store the instrument operating system. It also contains the local firmware repository and app service, and instrument settings. Presently the instrument settings stored in this memory are not resettable in the field, but will be in a future firmware update.
4. The SK Hynix H5TC2G63GFR-PBA memories are comprised of four 256 MBDDR3L SRAM chips, totaling 1 GB of volatile memory. This memory is used by the operating system and applications during runtime as temporary data storage. Data is lost on a power cycle.
5. The Microchip SST25VF016B-50-4C is a 16 Mbit SPI flash. It is used to store bootloader firmware. The memory is programmed at Lake Shore.

6.8 Technical Inquiries

Refer to the following sections when contacting Lake Shore for application assistance or product service. Questions regarding product applications, price, availability and shipments should be directed to sales. Questions regarding instrument calibration or repair should be directed to instrument service. Do not return a product to Lake Shore without a Return Material Authorization (RMA) number (section 6.8.2).

6.8.1 Contacting Lake Shore

The Lake Shore Service Department is staffed Monday through Friday between the hours of 8:00 AM and 5:00 PM EST, excluding holidays and company shut down days.

Contact Lake Shore Service through any of the means listed below. However, the most direct and efficient means of contacting is to complete the online service request form at https://www.lakeshore.com/Service/. Provide a detailed description of the problem and the required contact information. You will receive a response within 24 hours or the next business day in the event of weekends or holidays.

If you wish to contact Service or Sales by mail or telephone, use the following:

Mailing address	Lake Shore Cryotronics Instrument Service Department 575 McCorkle Blvd. Westerville, Ohio USA 43082-8888	
E-mail address	sales@lakeshore.com support@lakeshore.com	Sales Instrument Service
Telephone	614-891-2244 614-891-2243 option 6	Sales Instrument Service
Fax	614-818-1600 614-818-1609	Sales Instrument Service
Web service request	https://www.lakeshore.com/Service/	Instrument Service

TABLE 6-11 ***Contact information***

6.8.2 Return of Equipment

The MeasureReady® M91 FastHall™ measurement controller is packaged to protect it during shipment.

The user should retain any shipping carton(s) in which equipment is originally received, in the event that any equipment needs to be returned.

If the original packaging is not available, a minimum of 76 mm (3 in) of shock absorbent packing material should be placed snugly on all sides of the instrument in a sturdy corrugated cardboard box. After receiving your M91, please use reasonable care when removing the temperature controller from its protective packaging and inspect it carefully for damage. If it shows any sign of damage, please file a claim with the carrier immediately. Do not destroy the shipping container; it will be required by the carrier as evidence to support claims. Call Lake Shore for return and repair instructions.

All equipment returns must be approved by a member of the Lake Shore Service Department. The service engineer will use the information provided in the service request form and will issue an RMA. This number is necessary for all returned equipment. It must be clearly indicated on both the shipping carton(s) and any correspondence relating to the shipment. Once the RMA has been approved, you will receive appropriate documents and instructions for shipping the equipment to Lake Shore.

6.8.3 RMA Valid Period

RMAs are valid for 60 days from issuance; however, we suggest that equipment needing repair be shipped to Lake Shore within 30 days after the RMA has been issued. You will be contacted if we do not receive the equipment within 30 days after the RMA is issued. The RMA will be canceled if we do not receive the equipment after 60 days.

6.8.4 Shipping Charges   All shipments to Lake Shore are to be made prepaid by the customer. Equipment serviced under warranty will be returned prepaid by Lake Shore. Equipment serviced out-of-warranty will be returned FOB Lake Shore.

6.8.5 Restocking Fee   Lake Shore reserves the right to charge a restocking fee for items returned for exchange or reimbursement.

◤Appendix: MeasureReady® FastHall™ Station

A.1 Overview

The MeasureReady® FastHall™ station is the industry's first high-performance table-top Hall measurement system to provide fast, accurate Hall analysis. For full details, see: https://www.lakeshore.com/FHS.

A.1.1 Features

- Van der Pauw and Hall bar geometries supported
- Excitation parameter optimization for one-button operation
- High performance for measuring mobilities down to 0.01 cm^2/V s and sample resistances of 10 mΩ to 1 GΩ
- Triax connections with driven guard all the way to sample
- Fully enclosed electrically shielded measurement
- Light-tight measurement space
- Sample space purge fitting for controlled measurement space
- Automatically creates data files; software development kit allows for full measurement customization
- Uses the same sample cards as Lake Shore's premium electromagnet-based 8400 Series Hall measurement system
- 2-year standard warranty

A.1.2 Measurement Options

- LN$_2$ option
- Vacuum option
- Gate bias option

A.1.3 Components

This convenient, all-in-one solution combines Lake Shore's patented M91 FastHall™ measurement controller with a Windows® 10 PC, 1 T permanent magnet, high precision sample holder, and the necessary software and cabling to provide a range of measurement capabilities in a compact package. The automatic optimization function makes running Hall analysis as simple as pushing a button, or you can set parameters independently for complete control over the Hall setup.

FIGURE A-1 **MeasureReady® FastHall™ station**

A.1.4 Patented FastHall™ Technology

The station contains all the sourcing, measurement, and switching instrumentation plus firmware needed to execute a complete measurement sequence. Key to its speed is the M91 controller provided. Using Lake Shore's patented FastHall™ technology, the instrument automatically executes measurement steps and provides better measurements faster, especially when working with low-mobility materials – up to 100 times faster in many cases. Most commonly measured materials can be analyzed in a few seconds.

It also provides a simple way to customize, start, and step through your measurement sequences, as well as chart, log, and organize the results. For further analysis, .csv data files are output and automatically saved.

A.1.5 Measurement Environment

A durable, light-tight system, the FastHall™ station features an electronically shielded, low-noise sample space with guarded contacts, resulting in far superior measurements as compared to most similar solutions—whether you want to derive carrier type, carrier concentration, mobility, or Hall coefficient properties of the sample.

The sample card starter kit includes both solder and prober pin style sample cards. The prober pin style cards allow you to mount your samples without requiring contact pad soldering. Load your sample and begin running van der Pauw or Hall bar measurements using the included PC loaded with MeasureLINK™-MCS software. It supports high resistivity measurements up to 1 GΩ.
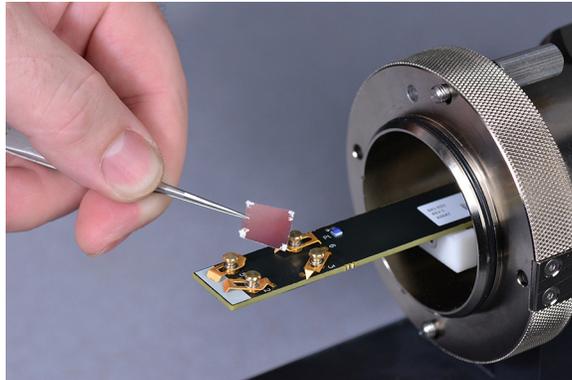
FIGURE A-2 **Sample and sample holder**

A.1.6
MeasureLINK™-MCS
Software

The FastHall™ station uses MeasureLINK™-MCS software, which is pre-loaded on the system computer. The software can also be downloaded at no charge from https://www.lakeshore.com/software/. The FastHall station includes the latest version of the scripting development license (ML-SDL), which allows users to edit the standard experiments and create new ones.

MeasureLINK software requires activation. An activation code (located on the computer desktop in a file named "MeasureLINK activation code") is required to register the product and to receive an annual license. MeasureLINK software and the scripting development license need to be reactivated annually (no annual fee, except when upgrading to the new version).

The software allows the user to combine environmental and electrical instrumentation into a coordinated measurement system. The software provides a simple software driver connection for Lake Shore instruments, and a generic driver for third-party instruments. MeasureLINK™ has a built in Visual Basic interpreter that permits simple user Interfaces and measurements, including the ability to construct, save and run data tables, charts and output files.

See the integrated Help files within the MeasureLINK™-MCS software for more details.
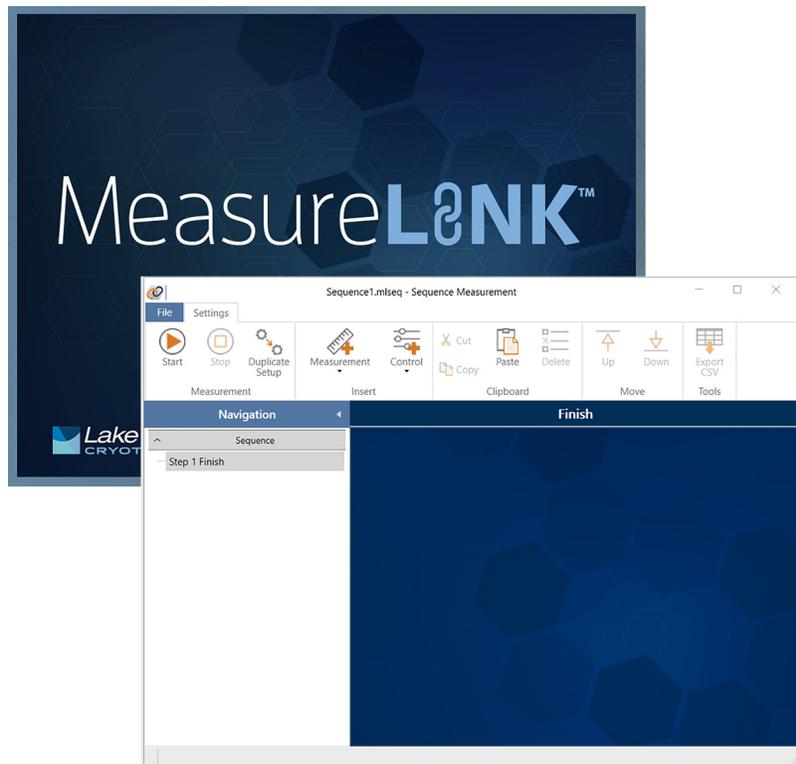
FIGURE A-3 **MeasureLINK™-MCS software interface**

A.2
Specifications

For full specifications, see: https://www.lakeshore.com/FHS/

Feature	Description
Ambient temperature	23 °C to ± 5 °C at rated accuracy 10 °C to 35 °C at reduced accuracy
Power requirement	100 V to 240 V (universal input), 50 Hz or 60 Hz, 30 VA
Size	
MeasureReady® M91 FastHall™ measurement controller	216 mm wide × 87 mm high × 369 mm deep (8.5 in × 3.4 in × 14.5 in), half rack
Measurement platform with magnet and insert	254 mm wide × 330.2 mm high × 457.2 mm deep (10 in × 13 in × 18 in)
LN_2 option with 0.75 T magnet and stand	140 mm wide × 235 mm high × 209.6 mm deep (5.5 in × 9.25 in × 8.25 in)
Model 155 precision I/V source (gate bias option)	216 mm wide × 87 mm high × 369 mm deep (8.5 in × 3.4 in × 14.5 in), half rack
Weight	
MeasureReady® M91 FastHall™ measurement controller	3.2 kg (7 lb)
Measurement platform with magnet and insert	9.1 kg (20 lb)
LN_2 option with 0.75 T magnet and stand	5.4 kg (12lb)
Model 155 precision I/V source (gate bias option)	3.2 kg (7 lb)

TABLE A-1 ***Key specifications***

A.3 Equipment Safety Symbols

⎓	Direct current (power line)
∿	Alternating current (power line)
≂	Alternating or direct current (power line)
3∿	Three-phase alternating current (power line)
⏚	Earth (ground) terminal
⏦	Protective conductor terminal
⏛	Frame or chassis terminal
		On (supply)
○	Off (supply)
	CAUTION: Electrostatic discharge sensitive (ESD) components
	CAUTION: High voltages; danger of electric shock; background color: yellow; symbol and outline: black
	CAUTION: Hot surface
⚠	CAUTION or WARNING: See included documentation; background color: yellow; symbol and outline: black
⧈	Equipment protected throughout by double insulation or reinforces insulation (equivalent to Class II of IEC 536—see Annex H)
	WARNING: people with implanted medical devices should avoid contact without previously consulting their doctor.
	WARNING: Contains high field magnets. Proper handling must be followed at all times to prevent accident and injury.
	WARNING: Clear workspace and personal space of ferrous (iron/steel) objects before starting. Be aware that magnetic fields can turn objects into flying projectiles.
	CAUTION: Electronic devices and magnetic media may be damaged by magnetic fields.
	WARNING: Crush hazard. Keep hands clear at all times.

FIGURE A-4 **Safety symbols**

A.4 Installation

A.4.1 Inspection and Unpacking

Inspect shipping containers for external damage before opening them. Photograph any container that has significant damage before opening it. Inspect all items for both visible and hidden damage that occurred during shipment. If there is visible damage to the contents of the container, contact the shipping company and Lake Shore immediately, preferably within five days of receipt of goods, for instructions on how to file a proper insurance claim. Lake Shore products are insured against damage during shipment, but a timely claim must be filed before Lake Shore will take further action. Procedures vary slightly with shipping companies. Keep all damaged shipping materials and contents until instructed to either return or discard them.

Open the shipping containers and keep the container and shipping materials until all contents have been accounted for. Check off each item on the packing list as it is unpacked. Instruments themselves may be shipped as several parts. The items included with the FastHall™ station are listed below. Contact Lake Shore immediately if there is a shortage of parts or accessories. Lake Shore is not responsible for any missing items if not notified within 60 days of shipment.

If the instrument must be returned for recalibration, replacement or repair, a Return Authorization (RMA) number must be obtained from a factory representative before it is returned. Refer to section 6.8.3 for the Lake Shore RMA procedure.

Items Included with the MeasureReady® FastHall™ station:
- MeasureReady® M91 FastHall™ measurement controller with high resistance option (M91-HR)
- Measurement platform with high performance sample holder and 1 T permanent magnet
- Windows® 10 computer
- MeasureLINK-MCS™ software with scripting development license and FastHall™ application pack:
  - Fully automated Hall measurement data collection and analysis
  - Data table, charts, and reports
  - Creates .csv data file output for further analysis
- Sample card starter kit (includes both solder and prober cards)
- One set of triaxial cables

FIGURE A-5 **Unpacking**

A.4.1.1 Unpacking

1. Unpack the measurement platform.
2. Unpack the M91 FastHall™ measurement .
3. Unpack the computer and monitor: The system computer and monitor are packed in the original manufacturer's packaging. Remove the packaging. Set these components aside in preparation for completing the system setup and assembly.

A.4.2 Cable Connections

Use the following procedures to connect the cables.
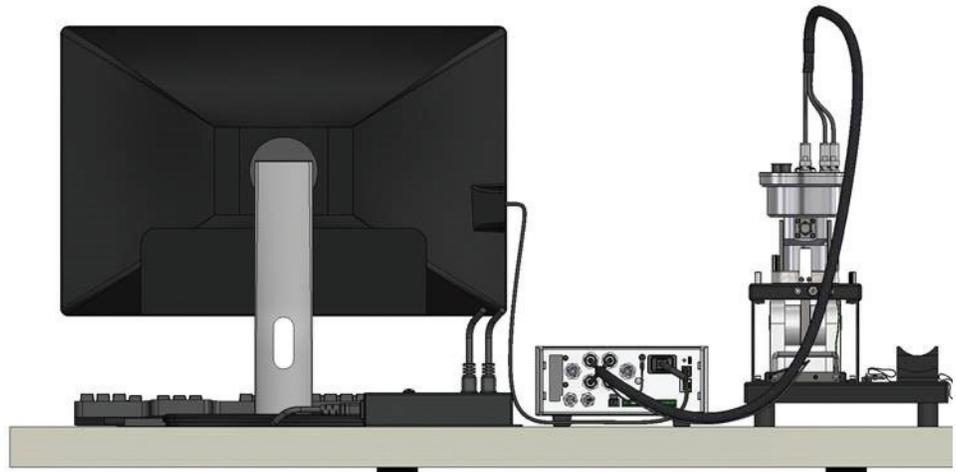
FIGURE A-6   Cabling connections: standard setup

FIGURE A-7   Cabling connections: full setup with additional equipment

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

- *Power:* connects the power.
- *Cable, digital ground:* connects the MeasureReady® M91 FastHall™ measurement controller to the power supply.
- *Cable, triax:* connects the M91 input/output to the sample holder.
- *Cable, multi function:* connects the power supply to the sample holder and the M91.

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

CAUTION ▷ **Installing other software may cause conflicts with the operation of the FastHall™ station and can have unintended consequences. Lake Shore assumes no responsibility for damage to the system as the result of unauthorized software installation**

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

NOTE ▷ **The system is designed for single-phase 3-wire AC power. Make sure to ground equipment when plugged into a 3-wire receptacle.**

A.4.3 Connecting the Components

Use the following procedures to connect the components of the FastHall™ station.

FIGURE A-8   Connections

1. Connect the computer, monitor and peripherals: the FastHall™ station comes with an integrated computer and monitor. A USB Type-B cable is provided to connect the computer to the USB connector on the M91.

FIGURE A-9   Computer and monitor connections

2. Connect the M91 FastHall™ measurement controller.

3. Connect the ground wire from the measurement platform to the M91 using a Phillips screwdriver.
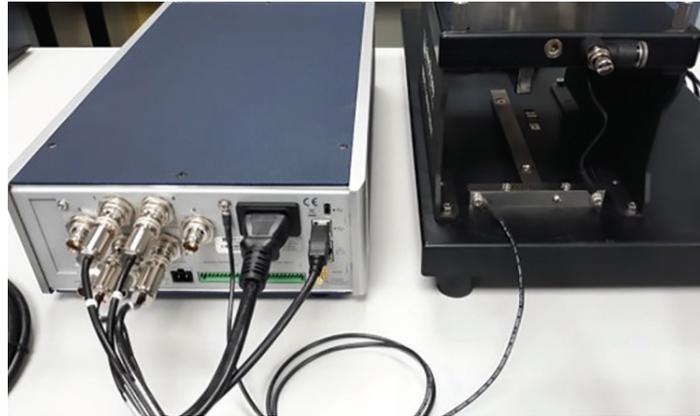
FIGURE A-10 **Ground wire**

4. Mount the sample insert onto the standard light-tight option body.

FIGURE A-11 **Sample insert**

5. Connect the triaxial cables. The ends marked with warning labels attach to the insert. The sample insert cable consists of a multifunction cable with a 22-pin connector, bundled with four primary triaxial cables. This connector provides access to:
   - RTD temperature sensor
   - Safety interlock (tells you the sample head is not engaged. This is needed for the gate bias option, but is not required for the standard M91 operation (V<10 V).

⚠WARNING

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

6. Connect the instrument AC power cord to the back of the M91 FastHall™ measurement controller.
7. Connect the computer and instrument power cords to the supplied IEC outlet strip.
8. Using the supplied country-specific AC power cord, connect the IEC outlet strip to the wall.

A.4.4 Optional Components

A.4.4.1 Connecting the Gate Bias

For applications requiring a gate bias signal, the voltage source is connected as follows:

■ V_{low} = source holder pin 7
■ V_{hi} = source holder pin 8
■ SIG-RTN: generally required to connect the signal common connectors of the M91 and gate bias source together. In this case, the following connection is provided on the M91.
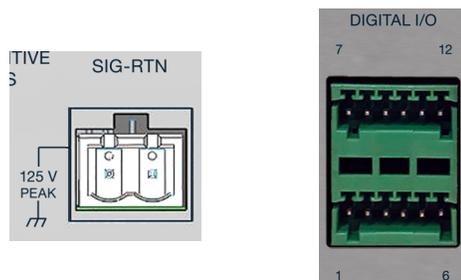
FIGURE A-12   *Gate bias connections*

A.4.5 Gas Connections

A.4.5.1 Purge Gas Fitting

A flow control valve is provided on the back of the light tight option body to allow users to connect to the sample space for inert gas purge. The fitting is sized for 8 mm or 5/16 in tubing. The sample space includes a 0.5 PSI pressure relief valve. The user is responsible for providing regulated inert gas.
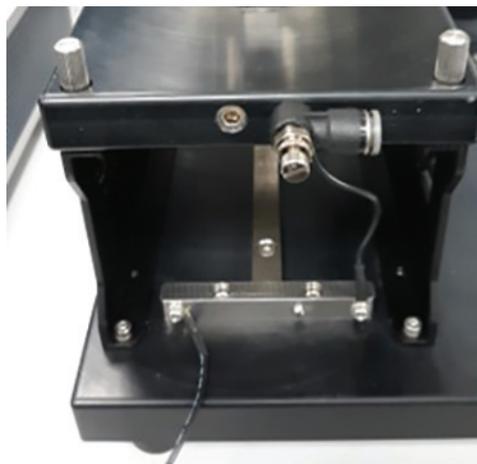
FIGURE A-13   *Purge gas fitting*

A.4.5.2 Liquid Nitrogen Option

■ Replace top-plate assembly
■ Install wider gap magnet
■ Details on how to fill the reservoir
■ Be sure to update the field value in the script when changing between the two magnet field values.
■ Pumping the vacuum jacket:
    ■ When this is necessary
    ■ How to determine that the jacket needs to be pumped
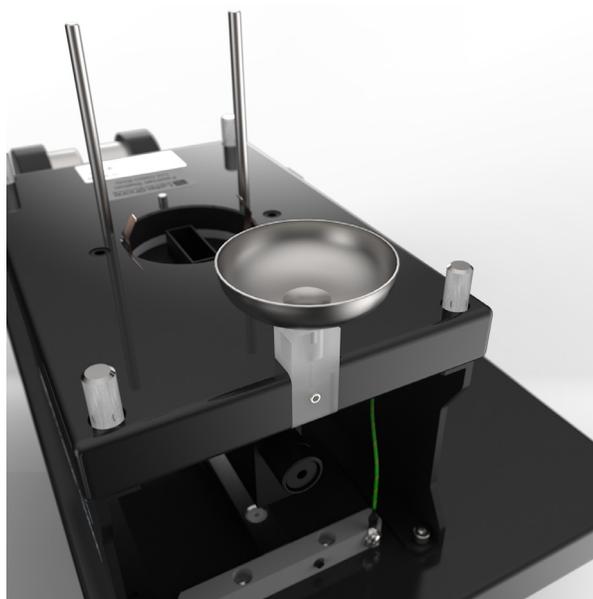
FIGURE A-14 **Liquid nitrogen option**

A.5 Operation

The following section explains basic operation of the MeasureReady® FastHall™ station.

A.5.1 Overview

The FastHall™ station is a complete Hall measurement system utilizing a permanent magnet. It automates the process of making the measurement, and provides an easy way to determine important transport properties such as material resistivity, carrier concentration, mobility and the Hall coefficient. The system is based on the M91 FastHall™ measurement controller, and a high precision sample holder and permanent magnet system.

A.5.2 Magnet Assembly

The standard FastHall™ station is provided with a nominal 1 T permanent magnet. The N-S orientation is marked directly on the base of the magnet. The magnet is mounted to a base palette with guide assembly, which aligns to a guide track mounted to the measurement platform. The magnet assembly can be moved back and forth along the track. There is a mechanical detent on each end of the track to positively identify the magnet placement with respect to the sample. This ensures the placement of the magnet, and therefore the magnetic field, is repeatable. To reverse the field, the magnet can be slid past the detent, rotated 180° and replaced on the track. Labels on the option bodies and magnet assemblies explain how to orient the magnets to create the desired fields.

FIGURE A-15 **Magnet assembly**

A.5.2.1 Magnet Orientation

It is important to make sure the correct orientation is observed per the specific Hall measurement routine. Since the sample holder is keyed, the sample always has the same orientation. This leads to a positive orientation and a negative orientation with respect to the keyed sample alignment. The positive and negative orientation is marked on top of the sample assembly. Therefore, comparing the magnet orientation with the positive/negative guide marks ensures the correct orientation for the magnetic field.

■ To place the sample in a 0 T field, manually pull the magnet to the end of the assembly as shown. This ensures a 0 T field and is independent of the orientation of the magnet orientation.
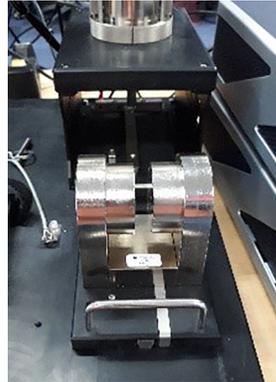
FIGURE A-16   Magnet orientation: 0 T

■ To place the sample in a +1 T (positive orientation) field, ensure the field arrow on the magnet is aligned with the positive orientation marking on the sample holder, and slide the magnet assembly in to position around the sample until the detent is engaged.

FIGURE A-17   Magnet orientation: +1 T

■ To place the sample in a -1 T (negative orientation) field, ensure the field arrow on the magnet is aligned with the negative orientation marking on the sample holder, and slide the magnet assembly in to position around the sample until the detent is engaged.
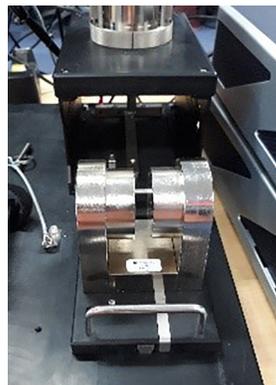
FIGURE A-18   Magnet orientation: -1 T

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NOTE ▷ **Reversing the magnet inadvertently will cause the Hall voltage to be the opposite polarity and therefore, the carrier type determination will be incorrect (for example, an actual n-type semiconductor sample will report to be a p-type).**

A.5.2.2 Locking the Magnet for Transport

A locking pin is included in the sample holder assembly to ensure that the magnet is secured before transporting the FastHall™ station. Lock the magnet before transporting so that the magnet will not shift or fall off of the base assembly in transport. The locking pin is not required for normal use.

A.5.3 Sample Insert

Samples for Hall measurement have either four (van der Pauw geometry) or six (Hall bar geometry) connections. Four triaxial cables are included and connect the M91 to the top of the sample card. Additional cables may be purchased from Lake Shore.

A.5.3.1 Connect the Sample Insert

The sample insert is intended to be easily removable to gain access to the sample. Two thumb screws are located on each side of the sample insert. When the screws are loosened, the holder can be lifted off of the magnet assembly. Two guide posts are provided to ensure that the sample aligns properly and does not touch the sides of the electrical shield when being inserted or removed. Additionally, the guide posts ensure that the sample card cannot be reversed.
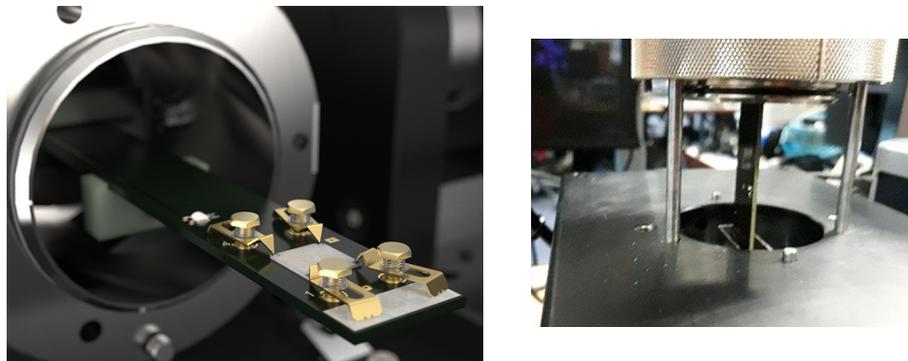
FIGURE A-19   Left: Sample insert
Right: Guide posts

A.5.3.2 To Install a Sample Card into the Sample Insert

Hold the card firmly and push into the card guide until it engages. Push into the sample holder.

A.5.3.3 To Remove a Sample Card

1. Hold the card firmly and pull out of the holder.
2. Once the card disengages from the connector, lift if from the card guide.

After the sample holder is removed, it can be placed in the cradle on the left side of the magnet assembly. A Velcro® hold down strap is provided to secure the sample holder when it is not mounted to the top of the assembly.

NOTE ▷ **The card inserts only in one orientation.**

A.5.4 Exchanging a Sample

The FastHall™ station uses a high precision sample card with plug-in sample cards. The sample cards are available in two basic varieties, prober cards and solder pad cards.

The prober card has four, spring-loaded contacts to implement a van der Pauw geometry sample with maximum dimensions of 10 x 10 mm.

The solder connection sample card has 8 connection pads in the sample area. Connections labeled 1 – 6 are intended for the connection of either a van der Pauw geometry (pins 1-4), or a Hall bar geometry (pins 1-6) sample with maximum dimensions of 10 x 10 mm. Two additional connection pads are located between connections 2 and 3. These pads are connected to the top of sample card. Connections 7 and 8 are intended to provide a gate bias capability as needed.
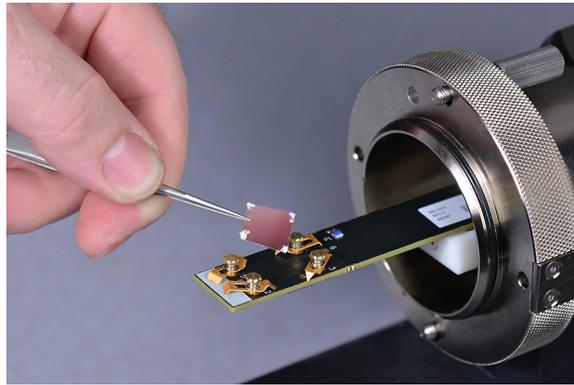
FIGURE A-20 **Sample and sample holder**

FIGURE A-21 **Sample holder**

A.5.5 Making a Measurement

The basic Hall measurement consists of three steps:
1. Checking the sample contacts to ensure they are ohmic (i.e. linear).
2. Measuring the resistivity. These first two steps are performed at 0 T field.
3. Placing the sample into a known magnetic field and measuring the Hall voltage.

After the completion of these measurements, the derived parameters can be calculated. The FastHall™ station automates the process of entering the required input parameters, collecting the measurement data, and reporting the output results.

The steps for completing a standard measurement are shown below. For more details, see *Hall Measurements with MeasureLINK™-MCS Software*, available from the Downloads page at https://www.lakeshore.com/FHS.

A.5.5.1 Making Static Hall Measurements with MeasureLINK-MCS™ Software

Scripts for fixed point Hall measurements are included in the MeasureLINK-MCS™ software. This script completes a Hall measurement at a single field for a van der Pauw sample. To use this script, open the software and follow the steps below.
1. Click **Sequence**.
2. In the Sequence window, click **Measurement**.
3. Click **M91 FastHall™**.
4. Click **Hall measurement**.
5. Fill out the fields in each section of the screen:
   - **Preferences:** defines where and how data will be stored, and the units for displaying data.
   - **Measurement Setup:** defines the sample parameters of the measurement.
   - **Optimization:** determines excitation type and values, and blanking time.
   - **Contact Check:** when selected, the measurement will complete a contact check.
   - **Resistivity:** when selected, the measurement will complete a resistivity measurement.
   - **Hall:** when selected, the measurement will include a Hall measurement.

Included in the sample card kit is one card with InAs mounted on the card. This is a n-type material. To run this sample, insert the card into the sample card and mount the sample card onto the light tight box. Set the MeasureLINK software to these parameters:
   - **Preferences:** choose your desired settings, or use the defaults settings.
   - **Measurement Setup:** set the sample thickness to 250 microns. Use the default values for the rest of the settings in this section.
   - **Optimization:** click Full optimization, then use the default values.
   - **Resistivity:** click Include resistivity, then use the default values.
   - **Hall:** click Include Hall, Enter the Magnetic field value on the magnet label. Use the default values for the rest of the selections.

After setting the parameters, click **Start**. The software will tell you when to move the magnet. When complete, the carrier type should be n type and the mobility about 24000 cm^2/(V s).

A.6 Maintenance and Troubleshooting

This section covers maintenance and troubleshooting. Customer service of the product is limited to the information presented in this chapter. Factory trained service personnel should be consulted if the instrument requires further repair. Damage to the system can result if these procedures are not done properly. Instructions for contacting Lake Shore and arranging product service are in section 6.8.

A.6.1 Preventive Maintenance Schedule

Use this table as a foundation in developing a time table for component maintenance. Tailor the schedule to fit your own system use.

Maintenance	Every use	3 months	6 months	12 months	As needed
Maintain a safe, clean work space	×				
Clean the sample holder		×			
Standard insert middle wiring board replacement					×
Sample card retainer replacement					×
Prober pin replacement					×
Clean the sample card					×
Clean the electromagnet surface				×	
Replace fuses					×
Lubricate o-rings					×

TABLE A-2 ***Preventive maintenance schedule***

A.6.2 Sample Card Retainer Replacement

This procedure assumes that the standard insert has been removed from the body, and the sample card has been removed according to section A.5.3.3. When the sample card retainer replacement is shipped to you, it is shipped attached to the card alignment guide. To replace the guide, follow this procedure.

1. Align the card alignment guide (with stem) to the connector on the middle wiring board, so that the line on the side of the guide aligns with the line on the insert outer tube.
2. Using a 2.5 mm hex key, screw in the two M3 screws onto either side of the card alignment guide to secure the guide and stem to the connector on the middle wiring board.

A.6.3 Sample Card Maintenance

This section describes maintenance procedures for the sample card.

A.6.3.1 Prober Pin Replacement

Follow these procedures to replace the prober pin on the prober pin sample card. You will need a number 1 Phillips screwdriver and the 10 mm prober pin sample card replacement kit.

1. Lay the sample card on the card fixture with the prober pins facing up.
2. Using a number 1 Phillips screwdriver, unscrew the four screws attaching the prober pins to the card.
3. Remove the four old prober pins.
4. Obtain the new prober pins and appropriate screws from the prober pin replacement kit.
5. Place the prober pin on the card, and screw it in. Do this to all four prober pins.

6.3.1.1 Cleaning Sample Cards

> **NOTE**
>
> **Wear gloves while performing any procedures dealing with the sample cards to avoid contaminating the sample card or other internal components with oils.**

To remove a sample mounted to a sample card with rubber cement, gently push the side of the sample with a wooden stick or other soft object to shear it from the adhesive.

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

We recommend cleaning sample cards between uses. Considering the many possible methods used to mount samples onto the sample cards, a variety of methods are necessary to clean them.

Chemical solvents are recommended over mechanical removal methods. The top surface of many sample cards is delicate and will not hold up to abrasives, scrubbing or scratching.

Be sure that all chemicals are compatible with the materials in the sample card. Sample cards also contain G-10/FR-4, copper.

A.6.4 Fuse Replacement

Fuses are installed in each instrument. When the fuse fails, before replacing it, first determine the cause for the failure. When replacing the fuse, it is important to replace it with the value and type indicated on the rear panel for the line voltage setting.

WARNING

To avoid potentially lethal shocks, turn off the controller and disconnect it from AC power before performing these procedures.

CAUTION

For continued protection against fire hazard, replace only with the same fuse type and rating specified for the line voltage selected.

NOTE

Test the fuse with an ohmmeter. Do not rely on visual inspection of the fuse.

1. Locate the line input assembly on the instrument rear panel.
2. Turn the power switch Off (O).
3. Remove the instrument power cord.
4. With a small screwdriver, release the drawer holding the line voltage selector and fuse.
5. Remove existing fuse(s).
6. Replace with the proper fuse with proper ratings. Refer to the manual for the specific instrument to determine the proper fuse rating.
7. Re-assemble the line input assembly in reverse order.
8. Verify the voltage indicator in the line input assembly window, and set it to the appropriate voltage.
9. Connect the instrument power cord.
10. Turn the power switch On (l).

When the fuse needs to be replaced, please read the particular instrument manual for instruction.

A.6.5 Measurement Troubleshooting

This section provides troubleshooting for measurements.

A.6.5.1 DC Calibration Troubleshooting

When performing DC calibration, you may confront two types of issues: those that materialize when attempting to run a calibration, and those that materialize in the data of the calibration.

If you attempt to run a calibration, and the software will not allow it, there may be a safety interlock condition. In this case, perform the following checks.

- Verify that the standard insert is fully engaged in the light tight body and the screws are fully tightened.
- Verify that the standard insert cable is fully attached. Check both the multifunction cable and all triaxial cables.

If you run a calibration, and you discover anomalies in the data, perform the following checks.

- Verify that the actual air gap matches the field platform parameters you set in the Toolbox.
- Verify that the pole cap size matches the field platform parameters you set in the Toolbox.
- Verify that the sample card was properly inserted with the retainer fully engaged.
- Verify that the field calibration card has not been damaged.
- If you recently changed the air gap, verify that the pole adjuster screws are fully tightened.
- If you recently changed the air gap, verify that the screws that hold the pole caps on the pole are fully tightened.

A.6.5.2 DC Measurement Verification Troubleshooting

During DC measurement verification, which is performed by the installer using the steps in Chapter 3, a test is made on an InAs sample, and a test is made on two resistors. The following sections provide troubleshooting for each of these tests.

A 6.5.2.1 InAs Sample Test Troubleshooting

If results show that the carrier type is p rather than n, check the contact of the triaxial cables and check the magnet wiring, and then re-run the magnetic field calibration.

If the InAs material values (resistivity, carrier density or mobility) have changed significantly from previous tests, inspect the InAs for cracks or other damage.

A 6.5.2.2 Resistor Troubleshooting

If the 10 MΩ or 0.01 Ω resistor test fails, perform the following checks.

- If current source is in compliance, check for broken cables or cables not connected.
- If the 10 MΩ resistor is in current compliance, ensure the current is less than 10 µA for 100 V compliance and less than 2 µA for 20 V compliance.
- If the value of resistances measured with the 8400 Series HMS is not within specifications, have the individual instruments re-calibrated.

A.6.5.3 AC Noise Troubleshooting

If the AC noise is unacceptably large, perform the following checks.

- Ensure that all wires on the sample are as short as possible and do not have unnecessary loops.

■ Ensure that the temperature of the sample is as stable as possible. Insert the sample into the magnet, wait 1 h, then re-run the test.

A.6.5.4 InAs Measurement Troubleshooting

If the InAs test shows up as p type in the AC mode, but n type in the DC mode, perform the following checks.

■ If the InAs material values (resistivity, carrier density or mobility) have changed significantly from previous tests, inspect the InAs for cracks or other damage.
■ Recalibrate the AC magnetic field.

A.6.5.5 AC/DC Comparison Troubleshooting

An AC/DC comparison should be made between the carrier density, mobility, and Hall coefficient. Do not directly compare Hall voltage since this depends on the magnetic field. The AC and DC test may be done at different fields. The calculation of Hall coefficient, density and mobility take into account the different magnetic fields. If the AC and DC Hall values do not agree, perform the following checks, and then re-run the field calibration.

■ Make sure all wires on the sample are as short as possible and do not have unnecessary loops.
■ Make sure the temperature of the sample is as stable as possible. Insert the sample into the magnet, wait 1 h, then re-run the test.

A.7 Service Reference

This section provides information for line voltage selection, electrical ground connection, ESD and safety information.

A.7.1 Line Voltage Selection

The instrument chassis and cabinets are grounded for safety. The safety ground provides a true ground path for electrical circuitry and, in the event of internal electrical faults such as shorts, it carries the entire fault current to ground to protect users from electrical shock. If the earth ground connection is impaired, render the system inoperative and secure it against any unintended operation. The ground connection is likely impaired if the equipment exhibits any of these conditions:

- Shows visible damage
- Fails to perform the intended measurement
- Has been subjected to prolonged storage under unfavorable conditions
- Has been subjected to severe transport stresses
- Has been serviced by unqualified personnel

NOTE: Do not use an apparatus exhibiting any of these conditions until qualified service personnel verify its safety.

When the instrument or equipment is removed from the system for service, make a note of its line voltage setting. When the item is returned, verify its line voltage setting with the voltage on the note before incorporating it into the system.

When the system is moved to a new location, before connecting the input power cord, verify that the system voltage setting is the same as the facility line voltage. When it's necessary, adjust each instrument in the console to the correct voltage. Read each instrument manual provided for detail on voltage adjustment.

A.7.2 Electrical Ground Connection

All instrument cases are grounded to the ground lead of the power distribution strip through its input power cable.

There is a safety ground cable built into the 22-pin connector on the multifunction cable for connection to the outer case of the sample insert to the instrument console chassis. Low impedance connections are maintained for safety purposes. This safety ground connection should be reestablished and maintained if any service is performed on the cable or measurement insert.

WARNING: A protective earth terminal is present on the electronic console's rear rack mounting rail. Do not disturb or remove any wires connected to this terminal.

A.7.3 Electrostatic Discharge

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

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

A.7.4 Identification of Electrostatic Discharge Sensitive Components

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

FIGURE 5-22 ***Symbols indicating ESD sensitivity***

A.7.5 Handling Electrostatic Discharge Sensitive Components

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

■ De-energize or disconnect all power and signal sources and loads used with unit.
■ Place unit on a grounded conductive work surface.
■ Technician should be grounded through a conductive wrist strap (or other device) using 1 M series resistor to protect operator.
■ Ground any tools, such as soldering equipment, that will contact unit. Contact with operator's hands provides a sufficient ground for tools that are otherwise electrically isolated.
■ Place ESD sensitive devices and assemblies removed from a unit on a conductive work surface or in a conductive container. An operator inserting or removing a device or assembly from a container must maintain contact with a conductive portion of the container. Use only plastic bags approved for storage of ESD material.
■ Do not handle ESD sensitive devices unnecessarily or remove them from the packages until they are actually used or tested.

A.8 Calibration Procedure

Instrument calibration can be obtained through Lake Shore Service. Refer to section 6.8 for technical inquiries and contact information.