MeasureReady™ M91 FastHall™ Measurement Controller

Lake Shore CRYOTRONICS

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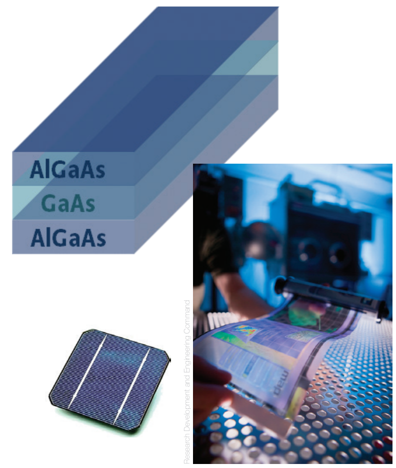
A new approach to Hall measurement

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

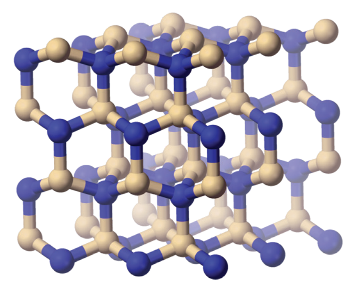
Featuring Lake Shore's patented* new FastHall measurement technique, the M91 fundamentally changes the way the Hall effect is measured by eliminating the need to switch the polarity of the applied magnetic field during the measurement. This breakthrough results in faster and more precise measurements,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

**Protected by US patent numbers 9797965 and 10073151. Other patents pending.*



Simpler and more convenient

- All-in-one instrument
- Automatically selects optimal excitation and measurement levels
- Automatically executes measurement steps
- Provides complete Hall analysis
- Easy to use, easy to integrate with existing lab systems



Makes better measurements, faster

- No need to reverse the magnetic field with FastHall
- Up to 100× faster for low mobility materials
- Improves accuracy by minimizing thermal drift

Cost effective

- Build a new Hall system or upgrade an existing one
- Add state-of-the-art Hall measurement capability to any lab
- Use with any type of magnet

Ideal for measuring low mobility materials

MeasureReady M91 FastHall measurement controller automatically checks sample contact quality and graphically displays results.

Executes a complete Hall measurement sequence:

Automatically Optimizes Parameters → Checks Contact Integrity → Measures Sample Resistivity → Field Applied to Sample → Measures Hall Voltage → Calculates Results → Outputs All Values

A convenient, single instrument

Traditional Hall effect measurement systems (HMS) provide basic electrical measurement instrumentation combined with a switching unit to measure sample resistivity and Hall voltages, but must rely on separate PC-based software to perform pre- and post-measurement calculations in order to ultimately derive the physical parameters that researchers need to know—resistivity, carrier type, carrier concentration, mobility, and Hall coefficient.

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 calculated parameters.

Typical HMS	HMS using MeasureReady™ M91
Magnet	Magnet
Sample holder	Sample holder
Switch mainframe with matrix card	MeasureReady™ M91
Data collection software	
Nanovoltmeter	
Current source	
Ohmic contact evaluation software	
Hall analysis software	
Charting software	MeasureLINK™-MCS software

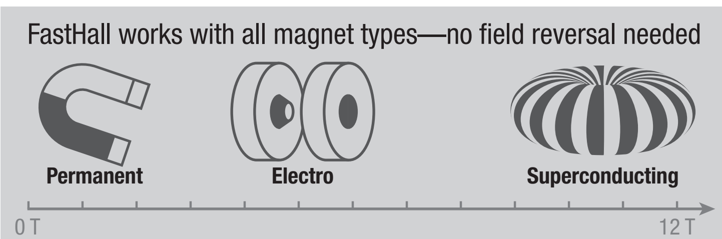
Adding HMS capabilities to any research platform has never been easier!

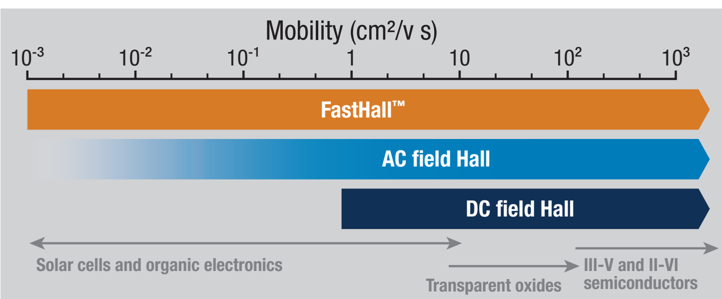
Better measurements in less time

Lake Shore's patented new FastHall technology eliminates the need to reverse the field, significantly reducing the time to make measurements without reducing measurement quality. In fact, a shorter measurement window lessens the opportunity for sample parameters to drift due to self-heating or ambient temperature change.

A unidirectional field also removes potential sources of measurement bias due field alignment errors, further improving the quality of the result.

With FastHall, any type of magnet can be used. For research platforms with high field superconducting magnets, the elimination of field reversal is especially beneficial.



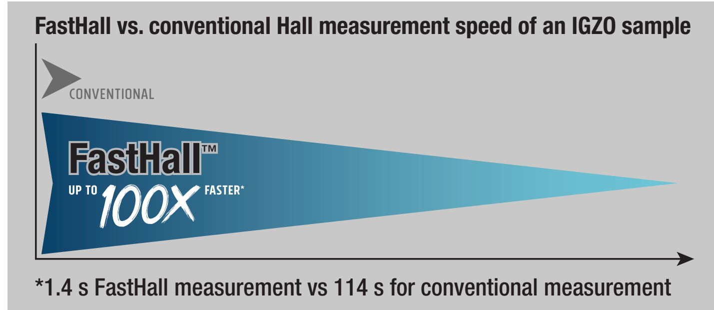


Ideal for low mobility materials

Traditional DC field Hall effect measurement is relatively straightforward and reliable for simpler materials with higher mobilities. Measurement difficulty increases and accuracy decreases as carrier mobilities decrease. This is often the case in promising new semiconductor materials such as photovoltaics, thermoelectrics, and organics.

AC field techniques using advanced lock-in amplifiers and longer measurement windows can extract smaller Hall voltage signals and are commonly used today to explore low mobility materials. Extended measurement intervals can also add error from thermal drift effects and results take longer to get—sometimes many hours.

The FastHall technique eliminates both of these issues — it precisiely measures even extremely low mobility materials in seconds.



The DC field Hall effect process requires taking voltage measurements with the magnetic field set in one direction, followed by reversal of the field polarity and repetition of the voltage measurements. The type of magnet used and the number of measurement samples needed for satisfactory data impact the overall measurement time.

Comparison of HMS techniques

	FastHall™	AC field	DC field
Eliminates field reversal	✓	✗ AC field (sinusoidal)	✗
Can be used with permanent magnets	✓ FAST	✗	✓ MANUAL
Can be used with electromagnets	✓ FAST	✓ SLOWER WITH LOWER MOBILITIES	✓ SLOWER WITH LARGE ELECTROMAGNETS
Can be used with superconducting magnets	✓ FASTER THAN DC FIELD	✗	✓ SLOW
Measurement capability	Lower mobility: ~10^{-3} cm²/V s and up	Lower mobility: ~10^{-3} cm²/V s and up	Higher mobility: ~1 cm²/V s and up

FastHall measurement requires Van der Pauw sample configurations (Hall bar configurations measured with DC field)

AC field measurement not currently supported in the M91—contact Lake Shore for more information

Materials

Solar cells

OPVs, a:Si, µc-Si, 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

Elemental semiconductors

Ge, Si on insulator devices (SOI), SiC, doped diamond
SiGe based devices: HBTs and FETs

Dilute magnetic semiconductors

GaMnAs, MnZnO

Half -Heusler compounds

TiNiSn, ZrNiSn, GdPtBi

Topological semi-metals

TaAs, WTe_2, $MoTe_2$

Topological insulators

Bi_2Te_3, Bi_2Se_3, Sb_2Te_3

Transition-metal Di-chalcogenides (TMDC)

WS_2, WSe_2, MoS_2, HfS_2

Other 2D materials

BN, graphene structures

Other conducting materials

Metal oxides
Organic and inorganic conductors

High temperature superconductors

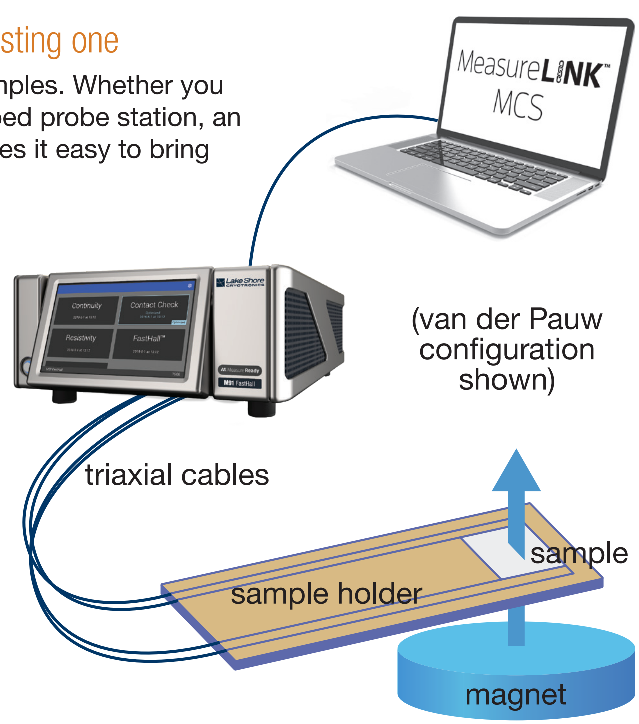
Key features

- Hall analysis including calculation of derived parameters for van der Pauw and Hall bar samples
- FastHall technology eliminates the need for magnetic field reversal when measuring van der Pauw samples—extends mobility range down to 0.001 $cm^2/V\ s$
- Traditional DC field Hall measurement mode for both Hall bar and van der Pauw samples
- Automated operation for maximum convenience—includes automatic optimization of excitation values and measurement range
- Manual step-by-step mode for full parameter control
- High-resistance option—enables measurement of samples to 200 GΩ
- Outputs all measured values plus derived parameters
- 1-year calibration

A cost effective way to build a new Hall system or upgrade an existing one

A few simple connections and you're ready to begin analyzing your samples. Whether you choose to use a simple benchtop holder and magnet, a magnet-equipped probe station, an electromagnet platform, or a more specialized apparatus, the M91 makes it easy to bring state-of-the-art Hall measurement capability to your lab.

Lake Shore's versatile MeasureLINK-MCS software, included with each M91, gives you a simple way to customize, start, and step-through your measurement sequences, as well as chart, log and organize the results. MeasureLINK also enables automated control of field, management of sample temperature, and coordinated integration with other instrumentation and measurement protocols. With MeasureLINK, the M91 FastHall measurement controller becomes an even more powerful component to support your advanced semiconductor research.



The MeasureReady M91 FastHall measurement controller offers the ultimate in HMS speed, convenience, and precision

Measurement applications

The M91 is capable of running a wide array of Hall analysis functions including:

Hall voltage

- Resolution = 1 µV
- Noise = 0.1 µV (RMS), averaged over 1 power line cycle

Resistance/resistivity (four-contact in-line probe and van der Pauw)

- Calculated by instrument
- Resistance range 10 mΩ to 10 MΩ standard
- Up to 200 GΩ with high-resistance option

Magnetoresistance

- System provides field control to measure resistance as a function of magnetic field

Hall coefficient

- Calculated by instrument
- Derived from Hall voltage, magnetic field, and current

Hall mobility

- Calculated by instrument
- 10^{-3} to 10^{6} cm^2/V s

Anomalous Hall effect (AHE)

- System provides field control to measure Hall voltage as a function of magnetic field

Carrier type/concentration/density

- Sheet or volume carrier concentration calculated
- Typical sheet carrier density $\leq 10^{17}$ cm^{-2} (carrier density depends on measurement parameters)

More science, less time

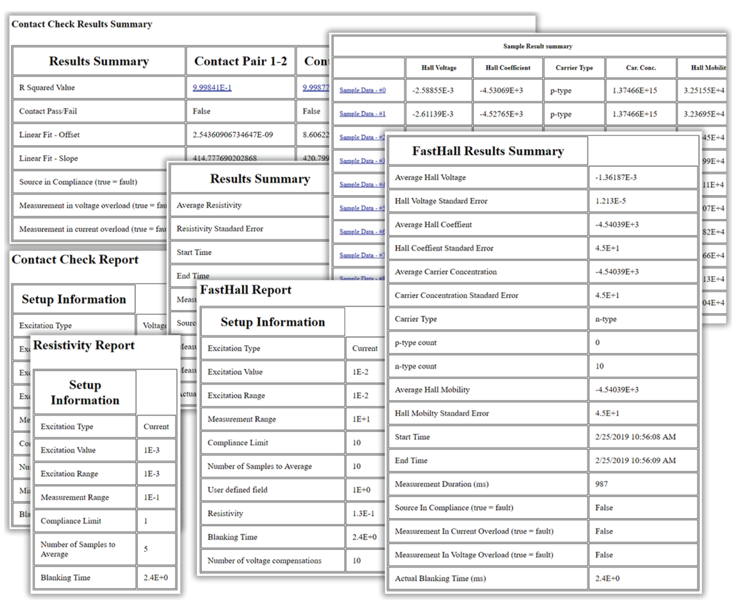
The M91 significantly reduces analysis time, in some cases by a factor of 100. Materials with resistances less than 1 MΩ can be analyzed in under a minute. Even extremely high resistances—up to 200 GΩ—can be measured quickly, although analysis time will increase. For resistances over 1 MΩ, the measurement time will depend on the time required for the voltages to stabilize.

Get all the data

Analysis of low mobility or high resistance materials faces challenges due to very low signal-to-noise ratios. Imprecise measurements are likely unless sophisticated techniques and/or larger measurement samples are used.

With some HMS solutions, the researcher often has little chance to double check the intermediate results of the analysis, and can therefore be easily misled as to the validity of the reported results.

The M91 collects all the data. In addition to performing the complete Hall analysis and outputting the usual measured and derived mobility values, the M91 can also generate detailed reports including all of the supporting intermediate data, so the researcher can readily confirm the integrity of the final results.

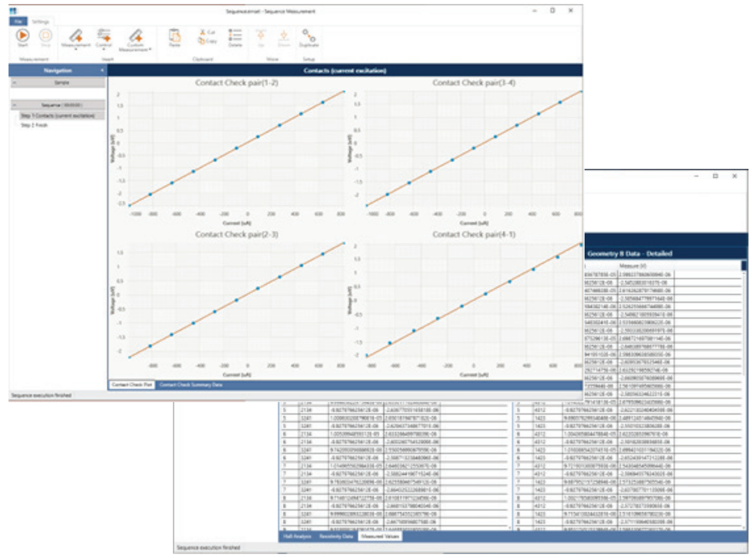


Built for science, designed for people

The M91 is a powerful research instrument that incorporates Lake Shore's decades of experience in Hall effect measurement. It's also really easy to work with.

Easy to get started

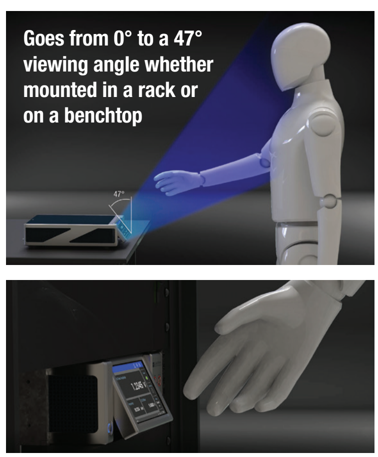
- Begin using the M91 right out of the box with the included MeasureLINK-MCS application software
- Install MeasureLINK on your laptop and easily enter measurement parameters
- MeasureLINK enables you to easily initiate Hall measurement sequences and view graphical results
- Measurement sequences can be readily customized and adapted to your research needs

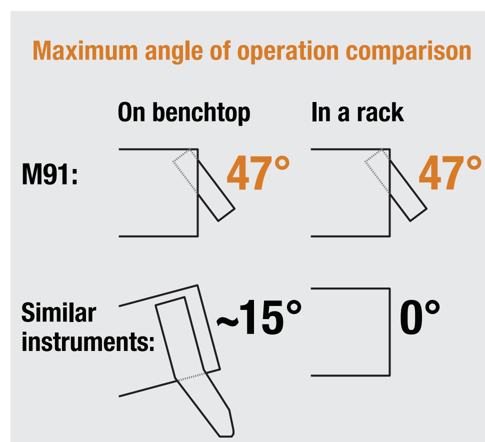


Easy to use

- Onboard touchscreen UI displays measurement process steps as they execute in real time, and provides quick access to view high-level measurement results
- Ergonomically designed package features TiltView™ display for best visibility, whether on a bench or mounted in a rack

See and operate more easily with TiltView™

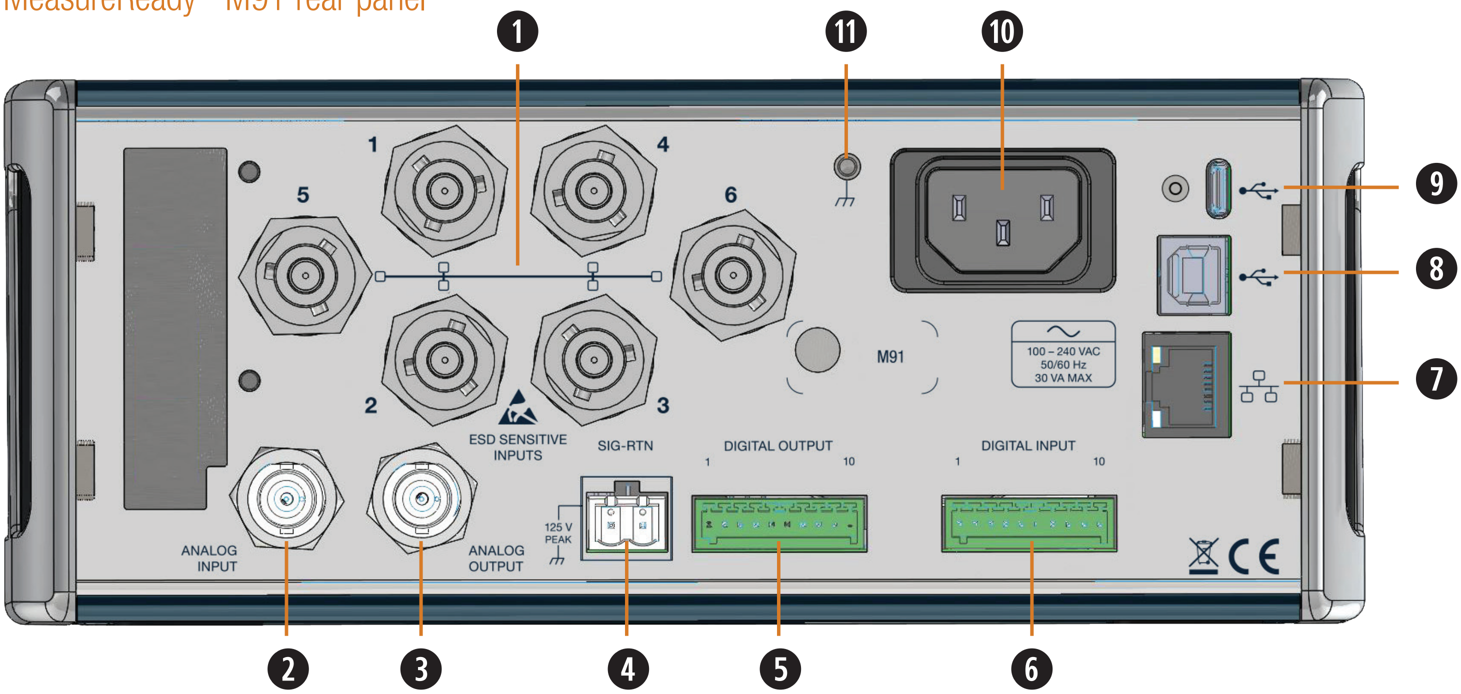




Easy to integrate

- Simple SCPI command interface
- MeasureLINK software facilitates integration with third party instruments and software
- Hardware digital and analog I/O for OEM system interfaces

MeasureReady™ M91 rear panel



1. Triaxial sample connectors
2. Analog input
3. Analog output
4. Signal RTN
5. Digital output
6. Digital input
7. RJ-45 Ethernet interface
8. USB communications interface
9. USB thumb drive interface
10. Line input assembly
11. Chassis ground connection

Be future-ready with MeasureReady

With free online firmware updates, your instrument can always have the most current capabilities. And as Lake Shore introduces new options in the future, you can purchase and download them to your instrument. This allows the controller to grow as your measurement needs evolve.

M91 specifications

Hall measurement
FastHall™ method (no physical field reversal) — van der Pauw samples
Traditional DC method — Hall bar and van der Pauw samples

Derived parameters
Hall coefficient, Hall mobility, resistivity, carrier concentration

Sheet resistance
Lowest range: 10 mΩ
Highest range: up to 10 MΩ
Highest range with M9-ADD-HR high resistance option: up to 200 GΩ

Hall mobility range
0.001 to 10^6 $cm^2/V\,s$

Programmable limits
I out: compliance voltage; **V out:** current limit

Positive output:	±5% of setting (when setting is >10% of its full-scale range)
Negative output:	±5% of setting (when setting is >10% of its full-scale range)
Programming resolution current limit:	0.1% of full-scale current range (auto selected)
Programming resolution voltage limit:	10 mV

Analog input
Analog input raw signal accuracy:	±300 mV of reading
Raw analog input voltage range:	±11 V
Safe input voltage range:	±15 V
Compliance voltage (typical):	≤10 V
Current limit (typical):	≤0.1 A

Analog output
Analog output raw signal accuracy:	±300 mV of setting
Raw analog output voltage range:	±11 V rails, ±15 V max during overload

Digital input
Number of independent inputs:	4
Input isolation:	Optical
Maximum low-level input voltage:	1 V
Minimum high-level input voltage:	4 V
Safe input voltage range:	-5 V to 32 V

Digital output
Number of independent outputs:	4
Relay type:	Solid state
Digital output relay max current:	1.5 A
Digital output relay max voltage:	32 V

Rear panel test connectors
Sample connections: 6 individual 3-lug socket triaxial connectors
Analog input BNC
Analog output BNC
10-pin Phoenix connector for digital output
10-pin Phoenix connector for digital input
2-pin Phoenix connector for signal return

Front panel
Display:	5 in capacitive touch, color TFT-LCD WVGA (800 × 480) with LED backlight

Interface
USB host

Type	USB 3.0, mass storage class (MSC) device
Function	Firmware updates, flash drive support
Location	Rear panel
Connector	USB Type-C™

USB device

Type	USB 2.0
Function	Emulates a standard RS-232 serial port
Protocol	Standard commands for programmable instruments (SCPI)
Baud rate	921,600
Connector	USB Type-B
Software support	LabVIEW™ and IVI.NET drivers (see www.lakeshore.com)

Ethernet

Function	TCP/IP command and control
Application layer protocol	Standard commands for programmable instruments (SCPI)
Connector	RJ-45
Speed	1 Gb/s
Software support	LabVIEW™ and IVI.NET drivers (see www.lakeshore.com)

General
Operating conditions:	23°C ±5°C at rated accuracy; 10°C to 35°C at reduced accuracy, <70% RH non-condensing
Instrument maximum field exposure:	Operational limit <10 mT DC, 1 mT RMS; Guaranteed performance <2 mT RMS
Power requirement:	100 V to 240 V (universal input), 50 to 60 Hz, 30 VA
Size:	216 mm W × 87 mm H × 369 mm D (8.5 in × 3.4 in × 14.5 in), half rack
Weight:	3.2 kg
Approval:	CE mark
Warm-up time:	30 min
Power consumption:	35 W maximum

Measurement performance

Current excitation range			Voltage measurement range				
			1 mV	10 mV	100 mV	1 V	10 V
1 µA	Resistance at maximum voltage		1 kΩ	10 kΩ	100 kΩ	1 MΩ	10 MΩ
1 µA	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]		0.2%	0.06%	0.06%	**	**
1 µA	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)		0.001%	0.001%	0.001%	**	**
10 µA	Resistance at maximum voltage		100 Ω	1 kΩ	10 kΩ	100 kΩ	1 MΩ
10 µA	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]		0.2%	0.06%	0.06%	0.06%	**
10 µA	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)		0.001%	0.001%	0.001%	0.001%	**
100 µA	Resistance at maximum voltage		10 Ω	100 Ω	1 kΩ	10 kΩ	100 kΩ
100 µA	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]		0.2%	0.2%	0.06%	0.06%	0.06%
100 µA	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)		0.001%	0.001%	0.001%	0.001%	0.5%
1 mA	Resistance at maximum voltage		1 Ω	10 Ω	100 Ω	1 kΩ	10 kΩ
1 mA	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]		0.2%	0.2%	0.2%	0.06%	0.06%
1 mA	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)		0.001%	0.001%	0.001%	0.001%	0.5%
10 mA	Resistance at maximum voltage		0.1 Ω	1 Ω	10 Ω	100 Ω	1 kΩ
10 mA	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]		0.5%	0.2%	0.2%	0.2%	0.2%
10 mA	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)		0.001%	0.001%	0.001%	0.001%	0.5%
100 mA	Resistance at maximum voltage		0.01 Ω	0.1 Ω	1 Ω	10 Ω	100 Ω
100 mA	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1,2]		2.0%	0.2%	0.2%	0.2%	**
100 mA	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)		0.001%	0.001%	0.001%	0.001%	**

*** Range available, not specified*
[1] *Calibration temperature is the ambient temperature during factor calibration; typically, 23 °C; reported by the instrument*
[2] *Guaranteed when lead resistance is 0.1 Ω or less*
All accuracies based on current reversal measurements

With high resistance option only

Voltage excitation range		Current measurement range			
		10 nA	100 µA	10 mA	100 mA
10 mV	Resistance at maximum current	1 MΩ	1 kΩ	1 Ω	0.1 Ω
10 mV	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]	0.5%	**	**	**
10 mV	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)	0.001%	**	**	**
100 mV	Resistance at maximum current	10 MΩ	10 kΩ	10 Ω	1 Ω
100 mV	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]	0.5%	**	**	**
100 mV	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)	0.001%	**	**	**
1 V	Resistance at maximum current	100 MΩ	100 kΩ	100 Ω	10 Ω
1 V	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]	0.8%	0.5%	**	**
1 V	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)	0.001%	0.001%	**	**
10 V	Resistance at maximum current	1 GΩ	1 MΩ	1 kΩ	100 Ω
10 V	Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]	0.5%	0.5%	**	**
10 V	Temperature coefficient/°C 10 °C to 35 °C ≤ 65% RH non-condensing ± % reading (typical)	0.001%	0.001%	**	**

*** Range available, not specified*
[1] *Calibration temperature is the ambient temperature during factor calibration; typically, 23 °C; reported by the instrument*
All accuracies based on voltage reversal measurements.

Current measurement range	DC Accuracy (1 year) calibration temperature °C ± 5 °C ± % reading[1]
10 mA	0.3%
100 mA	0.3%

[1] *Calibration temperature is the ambient temperature during factor calibration; typically, 23 °C; reported by the instrument*

Voltage and current excitation specifications

Voltage excitation range	Programming resolution (0.001%)	Temperature coefficient/°C 10 °C to 35 °C ± (% setting + offset), typical
10 mV	100 nV	0.06% + 4 µV
100 mV	1 µV	0.005% + 4 µV
1 V	10 µV	0.0004% + 20 µV
10 V	100 µV	0.0004% + 200 µV
Current excitation range	**Programming resolution (0.001%)**	**Temperature coefficient/°C 10 °C to 35 °C ± (% setting + offset), typical**
1 µA	10 pA	0.002% + 9 pA
10 µA	100 pA	0.0004% + 20 pA
100 µA	1 nA	0.0004% + 90 pA
1 mA	10 nA	0.0004% + 40 pA
10 mA	100 nA	0.0004% + 4 nA
100 mA	1 µA	0.0004% + 40 nA

Voltage and current measurement specifications

Voltage measurement range	Temperature coefficient/°C 10 °C to 35 °C ± offset (typical)
1 mV	50 nV
10 mV	50 nV
100 mV	200 nV
1 V	2 µV
10 V	20 µV
Current measurement range	**Temperature coefficient/°C 10 °C to 35 °C ± offset (typical)**
10 nA	2 pA
10 µA	7 pA
10 mA	7 nA
100 mA	70 nA

Ordering information

M91	MeasureReady® M91 FastHall™ controller with accessory kit (M91-ACC-KIT)
M91-HR	MeasureReady M91 FastHall controller with high resistance option and accessory kit (M91-ACC-KIT)
M9-ADD-HR	M91 firmware upgrade to include high resistance samples to 200 GΩ
MR-GPIB-USB	GPIB to USB adapter for XIP instruments
RM-1/2	Kit for mounting a single half-rack instruments in a 483 mm (19 in) rack
RM-2	Kit for mounting two adjacent half-rack instruments in a 483 mm (19 in) rack
843-076	Low noise triaxial cable, 3-slot, 1 m (3 ft)
843-062	Low noise triaxial cable, 3-slot, 3.7 m (12 ft)
P12379	BNC female to triaxial adapter, TRB male, 3 lug, isolated, 50 Ω

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Questions? Answers?

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and become part of the conversation!