A unique instrument architecture optimized to provide synchronous DC, AC, and mixed DC+AC source and measure to 100 kHz for low-level measurements.
The MeasureReady™ M81-SSM (Synchronous Source and Measure) system provides a confident and straightforward approach for advanced measurement applications. The M81 is designed to eliminate the complexity of multiple function-specific instrumentation setups, combining the convenience of DC and AC sourcing with DC and AC measurement, including a lock-in’s sensitivity and measurement performance.

This extremely low-noise simultaneous source and measure system ensures inherently synchronized measurements from 1 to 3 source channels and from 1 to 3 measure channels per half-rack instrument — while also being highly adaptable for a range of material and device research applications.

**Unique real-time sampling architecture for synchronous sourcing and measuring**

- MeasureSync™ technology for simultaneous source module update and measure module sampling timing across all channels
- DC/AC amplitude and phase detection is user-selectable on all measure channels
- Common DAC/ADC sampling clock ensures highly precise and consistent source/measure timing coordination between 3 sources and 3 measures

**The absolute precision of DC plus the detection sensitivity performance of AC instrumentation**

- All source and measure channels are capable of combined DC and AC to 100 kHz signals
- Optimized for fundamental, harmonic, and phase AC plus DC biased measurements
- Modularity allows for flexible, user-configured modules to suit a specific application

**Designed for scientific-grade low-level measurement applications**

- Linear module power supply architecture for lowest possible source/measure noise
- Fully analog signal paths between data converters, modules, and the device under test (DUT)
- Remote modules for the shortest possible signal path to the DUT, which separates sensitive analog circuits from digital circuits and unwanted sources of interference typical of traditional single-enclosure instrument designs

**Unique, flexible instrument/distributed module architecture**

- Remote-mountable amplifier modules are interchangeable between instruments
- Modules are dynamically recognized when the system is reconfigured
- Uses a clean, simple UI and a common programming API for fast setup and a shorter learning curve
Components of the M81-SSM system

- Connect up to three source modules and up to three measure modules
- Exchange modules and adapt the configuration for each measurement
- All modules are capable of measuring with DC and AC to 100 kHz
- All modules are optimized for highest precision with common amplitude and frequency references

Flexible measurement capabilities

The M81-SSM provides DC and AC stimulus and measurement capabilities for characterizing materials and devices in cryogenic, room temperature, and high-temperature environments.

Choose a combination of differential current source and voltage measurement modules for low-resistance applications requiring a precise stimulus current and the noise-cancellation benefits of balanced (floating) sample connections. Or mix and match with additional voltage source and current measurement modules for complex high-impedance or gate-biasing applications where precise voltage control and sweeping test regimes are required.

Unlike a narrow-bandwidth DC system, these modules operate from very low frequencies to 100 kHz. You can select a measurement bandwidth to avoid 1/f noise and other bands where test environment noise is highest.

The system’s MeasureSync™ technology samples all sourcing and measurement channels at precisely the same time, enabling multiple DUTs to be tested under identical conditions so you can obtain consistent data.

Lake Shore MeasureLINK™ software can provide configurable measurement scripts and loops to support a variety of applications. It facilitates easy integration with Lake Shore as well as third-party systems.

These combined capabilities make the M81-SSM a superior solution for characterizing several test structures, including nanostructures, single- and multilayer atomic structures, MEMs, quantum structures, organic semiconductors, and superconducting materials.
MeasureSync™ architecture explained

The MeasureReady M81-SSM uses patent-pending MeasureSync™ signal synchronization, enabling continuous data sampling on every channel (see full explanation on page 5). Noise and sensitivity are on par with the best scientific-grade source and measure instruments.

The M81-SSM simplifies the setup and operation of complex material characterization operations by reducing the number and types of instruments and software required. It unifies all configuration and experiment functions through a single interface. Measurements are conducted using the included powerful MeasureLINK™ software.

Traditional equipment setup for multiple devices

- Typical material and device characterization applications require a combination of both DC and AC instruments
- These experimental setups often involve physically large sample apparatus machinery, requiring long signal cables between the sample and instruments
- Many applications require multiple channels of source and measure capabilities, creating synchronization challenges
- ‘Rack and stack’ approaches to modularity have required high levels of operator skill for reliable results
- As source and measure channel counts increase, so does the need for redundant, separate instruments — which can add to the overall cost of implementation

The M81 simplifies these measurements by:

- Reducing the number of separate instruments for easier setup and operation and combining the capabilities of DC picoameters, voltmeters, and AC lock-in amplifiers
- Reducing the number of and lengths of signal cables between source, measure, and sample, minimizing parasitics (leakage, noise, resistance, and reactance)
- Increasing the number of channels and thus enabling synchronized or parallel sample/device testing
- Allowing for easy reconfiguration by simply swapping module configurations for various applications
- Being typically much less expensive than multiple-instrument configurations
Timing is everything.

Now it’s automatic.

MeasureSync architecture allows for tightly synchronized data collection from the remotely located modules. Amplitude and frequency signals are transmitted to/from the remote amplifier modules using a proprietary, real-time analog voltage method that minimizes noise and ground errors while ensuring tight synchronization of all modules. This analog interface keeps noisy digital circuitry away from the modules’ sensitive analog circuits. The signals are digitized by a dedicated converter for each channel, which are synchronized by the shared MeasureSync clock. Each rising edge of the clock triggers every ADC to take a reading and triggers each DAC to update its output. In between clock edges, all of the data is transferred from ADCs to the controller and each DAC is preloaded with a value that is applied on the next edge. Unlike multiplexed systems, this maintains total synchronization and continuous sampling of each channel. Digital signals are generated or processed by a configurable DSP core.

Each measure channel can be configured to perform DC, AC, or lock-in measurements. The core processes the individual readings collected at 375 kSa/s and produces fully processed and calibrated readings at up to 5 kSa/s. These readings can be observed on the front panel and collected via the remote interface.

The multiple parameter query structure allows a single data query to return multiple readings in one query, which maintains synchronization. Additionally, the configurable data streaming interface can be used to provide a continuous stream of synchronized data at a fixed, regular time interval, or a burst of high-speed collection. This combination of an analog interface to the distributed modules, a centralized simultaneous acquisition clock, and a unified remote interface provides end-to-end signal synchronization that cannot be easily achieved with separate instrumentation.
Modules using patent-pending signal technology

The M81-SSM system provides DC to 100 kHz precision electrical source and measure capabilities with 375 kHz (2.67 μs) source/measure digitization rates across up to 3 source and 3 measurement front-end modules.

All modules are designed with linear circuitry powered by highly isolated linear power supply designs for the lowest possible voltage/current noise performance — rivaling modern lock-in amplifiers and research lab-grade source and measure instruments.

These quick-swappable modules with embedded calibration data enable quick measurement reconfiguration during and between experimental setups. Compact and well shielded, the modules can be remote, rack, or benchtop mounted depending on application requirements and user preference. For interconnection to the main instrument, the modules come standard with 2 m cables, but you can also order optional 8 m extender cables for making connections up to 10 m in length.

**Built-in patent-pending capabilities include:**

- Dual AC and DC range sourcing — allowing for precise, full control of DC and AC amplitude signals with a single module and sample/device connection (VS-10 module)
- Seamless range change measuring — for significantly reducing or eliminating the typical range change-induced measurement discontinuities in signal sweeping applications that require numerous range changes (VM-10 module)

**The integration of both AC and DC into single source and measurement modules:**

- Simplifies connections to the device under test
- Simplifies ground return connection schemes
- Simplifies test programming by allowing DC and AC signals to be sourced and measured under program control and without changing hardware or connections
- Enables AC modulation with a DC bias and allows a high degree of signal flexibility and measurement resolution options

Dual AC and DC range source settings on the VS-10 module enable better control of DC and AC amplitude signals.

Seamless range change measuring is provided with the VM-10 module, as demonstrated by this voltage vs. time sweep.
As easy to use as your smartphone

The M81 instrument front display has an easy independent setup of each module’s output or input parameters, including range, amplitudes, frequencies, and filters. Each module has a full screen of controls on the M81, similar to the VM-10 screen shown here. The output settings or measure input data of each module are easy to manipulate (S1, S2, S3, M1, M2, or M3). The result is an easy setup to make and see measurement results. To collect several measurements over time as a source is ramped or an environment parameter is changed like temperature or field, Lake Shore created MeasureLINK software to control environmental or source parameters over time and capture the measurement data.

Made for the way you work today, the M81 features an uncluttered touch display with a unique TiltView™ screen, presenting a natural and engaging user interface.

With no confusing buttons or long learning curves, the M81 is intuitive and straightforward to operate. You’ll quickly recognize the icons, gestures, and menu styles that follow familiar smartphone technology standards.
M81-SSM and Lake Shore MeasureLINK™ software

The Lake Shore MeasureLINK™ PC software is an easy, non-programming way to coordinate sophisticated electrical measurements as source or environment parameters change over time.

- Install application packs
  - They provide access to temperature, field, and electrical instrumentation drivers
- Build a system configuration that includes all of the instruments in the experiment
  - Monitor and control the instruments from the Monitor pane
- Build a sequence using drag-and-drop components to control temperature, field, and electrical parameter sweeps
- Collect data from the experiment and export it to your favorite analysis tool
- Need to build an experiment that isn’t fully supported? No problem, simply make a similar drag-and-drop sequence and export it to a custom programming environment for final customizations. No problem is too complex to handle.

The MeasureLINK interface
MeasureLINK™ measurement sequence example

In a temperature-dependent electrical measurement, Step 1 would be to set up a discrete temperature loop with start, end, and step temperature values.

Step 2: Configure the electrical source sweep, which includes specifying the instrument, source mode (voltage or current, source shape [DC or AC]), followed by the loop configuration parameters, such as sweep variable (amplitude, frequency, or offset) and related start, end, and step parameters.

Step 3: Add an electrical measurement step. Start execution and then collect the data in a table for easy export to your favorite analysis program.
The heart of the M81-SSM is the instrument. Depending on the model ordered, the instrument supports a total of 2, 4, or 6 channels comprising 1, 2, or 3 sources and 1, 2, or 3 measures, respectively, as shown here:

<table>
<thead>
<tr>
<th>Instrument model</th>
<th>Maximum channel capacity</th>
<th>Number of source channels</th>
<th>Number of measure channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>M81-SSM-2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>M81-SSM-4</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>M81-SSM-6</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Each M81 instrument can manage from 1 to 3 source channels and from 1 to 3 measure channels per half-rack for testing of multiple DUTs during a single test sequence without adding complexity and signal degradation from signal switching.

More than one instrument can also be combined to increase source and measure channel capabilities without degradation of analog performance while utilizing MeasureSync™ timing synchronization across all signal channels within the system.

Built on the Lake Shore MeasureReady™ instrument platform, the instrument features a graphical, touchscreen interface for both programming control and monitoring. Its ergonomically designed front panel features a TiltView™ display for best visibility, whether on a bench or mounted in a rack. It also supports standard LAN, USB, and GPIB communications.
M81 instrument specifications

Specifications are subject to change

Source channels

Source channel functions
- DC, sine, triangle (up to 5 kHz), square (up to 5 kHz)

Source sync functions
- Synchronize to another channel or internal or external reference in frequency range
- 100 µHz to 100 kHz (or module bandwidth, whichever is lesser)

Frequency range
- Greater of 100 µHz, 6 digits

Frequency resolution
- 0.06%

Frequency accuracy
- 100 ms time constant, 12 dB/oct:
  - Internal reference: <0.0001° RMS at 10 kHz
  - External reference: <0.002° RMS at 10 kHz

Phase noise
- >120 dB (typical, see manual)

Dynamic reserve
- >120 dB (typical, see manual)

Measure channels

Measure channel functions
- DC, AC (RMS, peak), or lock-in (X and Y, R and Θ)

Lock-in reference
- Any source channel, or external reference input

Reference in
- BNC: sine ≥1 V p – p ≥200 Hz; square ≥1 V p – p ≥ 10 mHz

Reference out
- BNC: 3.3 V square

Monitor out
- BNC: M1 monitor, M2 monitor, M3 monitor, manual output

Digital inputs
- 6-pin 3.5 mm detachable terminal block:
  - 2 TTL compatible inputs:
    - $V_{\text{high}}$ nominal: 3.3 V; $V_{\text{low}}$ nominal: 0 V

Digital outputs
- 6-pin 3.5 mm detachable terminal block:
  - 2 TTL compatible outputs:
    - $3.3 V_{\text{high}}$ nominal at 1 mA

Total harmonic distortion
- <0.1% from DC to 100 kHz, typical

Sample rate
- 375 kSa/s

Warm-up time
- 60 min to achieve specified accuracy

Isolation
- Measure common isolated from chassis ground

Front panel display
- 5 in capacitive touch, color TFT-LCD WVGA (800 × 480) with LED back-light

System speeds

<table>
<thead>
<tr>
<th>Data streaming maximum reading rate (records/s)</th>
<th>USB</th>
<th>GPIB</th>
<th>Ethernet</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data streaming maximum data throughput1 (kB/s)</th>
<th>USB</th>
<th>GPIB</th>
<th>Ethernet</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>20</td>
<td>40</td>
<td>80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typical SCPI query response time2 (ms)</th>
<th>USB</th>
<th>GPIB</th>
<th>Ethernet</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>20</td>
<td>40</td>
<td>60</td>
</tr>
</tbody>
</table>

1. Host PC dependent; speeds measured using PyVISA and Python 3 on Windows® 10 Intel® Core™ i7-8700 2.4-GHz CPU PC with 16 GB RAM
2. 99% of queries are serviced faster than this interval

Interface

IEEE-488.2 (GPIB)
- Function: IEEE-488 command and control
- Capabilities: SH1, AH1, T5, L4, SR1, RL1, PP0, DC1, DT0, CO, E1
- Data throughput: Limited by 3 megabit internal bus rate

USB host
- Type: USB 3.0 MSC device
- Function: Firmware updates, flash drive support
- 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 Bd
- Connector: USB Type-B
- Software support: LabVIEW™, Python, MeasureLINK, IVI.NET

Ethernet
- Function: TCP/IP command and control, mobile app
- App layer protocol: Standard commands for programmable instruments (SCPI)
- Connector: RJ-45
- Speed: 1 Gb/s
- Software support: LabVIEW, Python, MeasureLINK, IVI.NET

General

Ambient temperature
- Rated accuracy ±5 °C of calibration temperature; 5 °C to 40 °C at reduced accuracy

Power requirement
- 100 V, 120 V, 220 V, 240 V, ±10%, 50 or 60 Hz, 140 VA

Size
- 216 mm W × 87 mm H × 369 mm D (8.5 in × 3.4 in × 14.5 in), half rack

Weight
- 5.7 kg (12.6 lb)

Approval
- CE mark

Available BNC adapter specifications

When used with S1, S2, or S3 source connections
- Range: 10 V, fixed
- Noise: <1 µV/√Hz at 1 kHz
- Output impedance: 25 Ω
- Raw converter resolution: 18 bits (76 µV/LSB)
- Temperature coefficient: 50 ppm/°C
- Accuracy (typical): 0.25% + 1 mV (1 year, ±5 °C from calibration temperature, after self calibration of instrument and within 24 h and ±1 °C, no calibration applicable to the cable itself)

When used with M1, M2, or M3 measure connections
- Range: 10 V, fixed
- Noise: <1 µV/√Hz at 1 kHz
- Input impedance: 10 MΩ
- Raw converter resolution: 20 bits (19 µV/LSB)
- Temperature coefficient: 50 ppm/°C
- Accuracy (typical): 0.25% + 1 mV (1 year, ±5 °C from calibration temperature, after self calibration of instrument and within 24 h and ±1 °C, no calibration applicable to the cable itself)

USB GPIB Ethernet
VM-10 voltage measure module

This module provides voltage measurements with resolution from low nanovolts up to 10 V from DC to 100 kHz, including amplitude, phase, and harmonic detection capabilities. Proprietary seamless ranging technology allows continuous measurements when increasing or decreasing ranges.

Voltage noise performance is on par with modern AC lock-in amplifier instruments but packaged in a compact, easy-to-use, remote-mountable module that can be located next to the sample or DUT to minimize cabling signal losses and noise pickup.

In addition, the module offers two configurable hardware low-pass and high-pass filters, which enable highly sensitive low-level measurements to be made in the presence of significant interfering signals. The inclusion of user-configurable hardware filters combined with the high-gain, low-noise front-end module amplifier design can eliminate the need for additional pre-amplifiers often required with traditional lock-in amplifiers. It also offers user-selectable single-ended or differential input connections providing additional options for minimizing noise and ground loop interference without the use of external converters or adapters.

Up to three simultaneously connected VM-10 modules can be used with each M81 instrument. Each module can be independently configured to perform DC, AC, or lock-in measurements.
VM-10 specifications

Specifications are subject to change

Input configuration  Single-ended (A) or differential (A-B)
Input coupling  DC or AC (0.1 Hz)
Ranges  10 V, 1 V, 100 mV, 10 mV; seamless, automatic transitions
Best sensitivity  <1 nV
Hardware filters  LP: 10 Hz, 30 Hz, 100 Hz, 300 Hz, 1 kHz, 3 kHz, 10 kHz; 20 dB or 40 dB/decade
                   HP: 10 Hz, 30 Hz, 100 Hz, 300 Hz, 1 kHz, 3 kHz; 20 dB or 40 dB/decade
Modes: High reserve, Low-noise

Input impedance  >10 GΩ, 120 pF (DC coupled)
Leakage current  <15 pA
CMRR  80 dB up to 1 kHz
Magnetic field exposure  Operational up to 8 mT DC
Size  142 mm W × 39 mm H × 89 mm D (5.6 in × 1.5 in × 3.5 in)

Bandwidth/accuracy

<table>
<thead>
<tr>
<th>Range</th>
<th>Bandwidth (-3 dB, typical)</th>
<th>DC^2 ±(%rdg + V)</th>
<th>Lock-in^2,3,4 ±%rdg</th>
<th>Temperature coefficient^2,3 ±(ppm rdg/°C + V/°C)</th>
<th>DC^2 ±(%rdg + V)</th>
<th>Lock-in^2,3,4 ±%rdg</th>
<th>Temperature coefficient^2,3 ±(ppm rdg/°C + V/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 V</td>
<td>&gt;100 kHz</td>
<td>0.025% + 600 µV</td>
<td>0.025%</td>
<td>6 ppm/°C + 24 µV/°C</td>
<td>0.025% + 150 µV</td>
<td>0.025%</td>
<td>6 ppm/°C + 6 µV/°C</td>
</tr>
<tr>
<td>1 V</td>
<td>&gt;100 kHz</td>
<td>0.025% + 21 µV</td>
<td>0.025%</td>
<td>6 ppm/°C + 20 µV/°C</td>
<td>0.025% + 5 µV</td>
<td>0.025%</td>
<td>6 ppm/°C + 2 µV/°C</td>
</tr>
<tr>
<td>100 mV</td>
<td>75 kHz</td>
<td>0.1% + 20 µV</td>
<td>0.1%</td>
<td>120 ppm/°C + 20 µV/°C</td>
<td>0.05% + 3 µV</td>
<td>0.05%</td>
<td>6 ppm/°C + 1 µV/°C</td>
</tr>
<tr>
<td>10 mV</td>
<td>75 kHz</td>
<td>0.1% + 20 µV</td>
<td>0.1%</td>
<td></td>
<td>0.05% + 3 µV</td>
<td>0.05%</td>
<td></td>
</tr>
</tbody>
</table>

Noise (typical)

Current noise at 1 kHz: 20 fA/√Hz
Voltage noise measured with filters off, inputs shorted

<table>
<thead>
<tr>
<th>Range</th>
<th>Single-ended operation at 1 kHz</th>
<th>Voltage noise at 0.1 Hz to 10 Hz</th>
<th>Differential operation at 1 kHz</th>
<th>Voltage noise at 0.1 Hz to 10 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 V</td>
<td>170 nV/√Hz</td>
<td>4 µV RMS; 20 µV p-p</td>
<td>170 nV/√Hz</td>
<td>4 µV RMS; 20 µV p-p</td>
</tr>
<tr>
<td>1 V</td>
<td>50 nV/√Hz</td>
<td>400 nV RMS; 2 µV p-p</td>
<td>50 nV/√Hz</td>
<td>500 nV RMS; 2.5 µV p-p</td>
</tr>
<tr>
<td>100 mV</td>
<td>3.8 nV/√Hz</td>
<td>50 nV RMS; 250 nV p-p</td>
<td>4.5 nV/√Hz</td>
<td>60 nV RMS; 300 nV p-p</td>
</tr>
<tr>
<td>10 mV</td>
<td>3.2 nV/√Hz</td>
<td>25 nV RMS; 125 nV p-p</td>
<td>4.1 nV/√Hz</td>
<td>30 nV RMS; 150 nV p-p</td>
</tr>
</tbody>
</table>

1 Lock-in measurement, 10 mV range, 10 s time constant, 24 dB rolloff, 95% confidence interval
2 Total system accuracy, 95% confidence, 1 year and ±5 °C from Lake Shore calibration, 24 h and ±1 °C from self-calibration, filters off
3 DC to 1 kHz
4 Add 0.1% of reading when AC coupled
BCS-10 balanced current source module

This module provides programmable currents from 1 pA to 100 mA with a ±10 V maximum compliance output from DC to 100 kHz sinusoidal output. Derived from Lake Shore’s industry-leading Model 372 AC resistance bridge, the BCS-10 employs a differential or balanced design that helps reduce or eliminate ground loops often encountered in cryostats and other research apparatus. It expands on Model 372 balanced source capability, adding variable frequency and amplitude programmability for enhanced flexibility while maintaining excellent noise performance.

The inclusion of a virtual center-point ground connection further enhances noise performance by allowing the user to determine optimal center-point tie points within given apparatus or equipment setups. The BCS-10 is designed to be paired with the VM-10 module, which provides both single-ended and differential (balanced) input connection and modes.

A typical application of the balanced current source involves low-resistance measurements, where the resistance of the wires connecting the current source to a sensor may be significant. Any unbalance in lead wire resistance results in a common-mode voltage that complicates the measurement of the desired parameter, the voltage across the sensor. The external CMR feature is unique in that it allows the BCS-10 to force some remote node (such as a VM-10 input) to circuit common potential and thus mitigate the effect of unbalanced lead wire resistance.
BCS-10 specifications

Specifications are subject to change

Ranges  
100 mA, 10 mA, 1 mA, 100 μA, 10 μA, 1 μA, 100 nA, 10 nA; automatic selection

Compliance  
20 V differential, 10 V single-ended (non-settable)

Maximum power  
1 W, 4-quadrant operation

CMR modes  
Off, internal, external

Coupling  
DC or AC (1 Hz)

Guard drive  
Enable or disable

Rise time  
<25 μs, 10% to 90%, zero to full scale, <1 Ω impedance load, 1 μA and above ranges

Settle time  
<60 μs to 0.1% of final value, zero to full scale, <1 Ω impedance load, 1 μA and above ranges

Load impedance  
Stability maintained with reactive loads up to 50 μF or 1 mH (with 100 Ω damping)

Magnetic field exposure  
Operational up to 11 mT DC

Size  
142 mm W × 39 mm H × 89 mm D (5.6 in × 1.5 in × 3.5 in)

Bandwidth/accuracy

<table>
<thead>
<tr>
<th>Range</th>
<th>Bandwidth (typical)</th>
<th>DC¹</th>
<th>Lock-in²</th>
<th>Temperature coefficient¹,²</th>
<th>Settable resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum frequency</td>
<td>Full accuracy maximum frequency</td>
<td>(% rdg + A)</td>
<td>±% rdg</td>
<td>±(ppm rdg/°C + A/°C)</td>
</tr>
<tr>
<td>100 mA</td>
<td>100 kHz</td>
<td>1 kHz</td>
<td>0.03% + 5 μA</td>
<td>0.15%</td>
<td>2 ppm/°C + 100 nA/°C</td>
</tr>
<tr>
<td>10 mA</td>
<td>100 kHz</td>
<td>1 kHz</td>
<td>0.03% + 500 nA</td>
<td>0.15%</td>
<td>2 ppm/°C + 10 nA/°C</td>
</tr>
<tr>
<td>1 mA</td>
<td>100 kHz</td>
<td>1 kHz</td>
<td>0.03% + 50 nA</td>
<td>0.15%</td>
<td>2 ppm/°C + 500 pA/°C</td>
</tr>
<tr>
<td>100 μA</td>
<td>100 kHz</td>
<td>1 kHz</td>
<td>0.03% + 5 nA</td>
<td>0.15%</td>
<td>0.2 ppm/°C + 200 pA/°C</td>
</tr>
<tr>
<td>10 μA</td>
<td>100 kHz</td>
<td>1 kHz</td>
<td>0.03% + 1 nA</td>
<td>0.15%</td>
<td>0.2 ppm/°C + 10 pA/°C</td>
</tr>
<tr>
<td>1 μA</td>
<td>10 kHz</td>
<td>1 kHz</td>
<td>0.5% + 120 pA</td>
<td>0.5%</td>
<td>5 ppm/°C + 2 pA/°C</td>
</tr>
<tr>
<td>100 nA</td>
<td>1 kHz</td>
<td>100 Hz</td>
<td>0.5% + 60 pA</td>
<td>0.5%</td>
<td>5 ppm/°C + 2 pA/°C</td>
</tr>
<tr>
<td>10 nA</td>
<td>100 Hz</td>
<td>30 Hz</td>
<td>0.5% + 30 pA</td>
<td>0.5%</td>
<td>5 ppm/°C + 2 pA/°C</td>
</tr>
</tbody>
</table>

Noise (typical)

<table>
<thead>
<tr>
<th>Range</th>
<th>Noise density</th>
<th>Noise at 0.1 Hz to 10 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mA</td>
<td>1.2 nA/Hz at 1 kHz</td>
<td>10 nA RMS (50 nA p-p)</td>
</tr>
<tr>
<td>10 mA</td>
<td>200 pA/Hz at 1 kHz</td>
<td>2 nA RMS (10 nA p-p)</td>
</tr>
<tr>
<td>1 mA</td>
<td>20 pA/Hz at 1 kHz</td>
<td>400 pA RMS (2 nA p-p)</td>
</tr>
<tr>
<td>100 μA</td>
<td>2.5 pA/Hz at 1 kHz</td>
<td>50 pA RMS (250 pA p-p)</td>
</tr>
<tr>
<td>10 μA</td>
<td>450 fA/Hz at 1 kHz</td>
<td>1.5 pA RMS (7.5 pA p-p)</td>
</tr>
<tr>
<td>1 μA</td>
<td>150 fA/Hz at 1 kHz</td>
<td>600 fA RMS (3 pA p-p)</td>
</tr>
<tr>
<td>100 nA</td>
<td>50 fA/Hz at 100 Hz</td>
<td>200 fA RMS (1 pA p-p)</td>
</tr>
<tr>
<td>10 nA</td>
<td>20 fA/Hz at 10 Hz</td>
<td>150 fA RMS (750 fA p-p)</td>
</tr>
</tbody>
</table>

DC output impedance

<table>
<thead>
<tr>
<th>Range</th>
<th>Magnitude output impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mA</td>
<td>&gt;500 kΩ</td>
</tr>
<tr>
<td>10 mA</td>
<td>&gt;1 MΩ</td>
</tr>
<tr>
<td>1 mA</td>
<td>&gt;10 MΩ</td>
</tr>
<tr>
<td>100 μA</td>
<td>&gt;100 μΩ</td>
</tr>
<tr>
<td>10 μA</td>
<td>&gt;1 GΩ</td>
</tr>
<tr>
<td>1 μA</td>
<td>&gt;1 GΩ</td>
</tr>
<tr>
<td>100 nA</td>
<td>&gt;1 GΩ</td>
</tr>
<tr>
<td>10 nA</td>
<td>&gt;1 GΩ</td>
</tr>
</tbody>
</table>

¹ Total system, 1 year and ±5 °C from Lake Shore calibration, 24 h and ±1 °C from self-calibration, 95% confidence
² DC to full accuracy frequency
This module provides current measurements with near-zero input offset voltage from fA levels up to 100 mA from DC to 100 kHz, including amplitude, phase, and harmonic detection capabilities. The module also has configurable hardware and software filtering.

Current noise performance is on par with modern TIA and DC picoammeters, and the module also includes a programmable ±10 V voltage bias offset feature for materials or devices that require biased current measurements or operation, such as a photodiode.
CM-10 specifications

Specifications are subject to change

Ranges

100 mA, 10 mA, 1 mA, 100 μA, 10 μA, 1 μA, 100 nA, 10 nA, 1 nA; automatic transitions

Input offset voltage

<150 μV

Settable bias voltage

±10 V

Bias voltage settable resolution

320 μV

Best sensitivity

<10 fA

Hardware filters

LP: 10 Hz, 30 Hz, 100 Hz, 300 Hz, 1 kHz, 3 kHz, 10 kHz; 20 dB or 40 dB/decade

HP: 10 Hz, 30 Hz, 100 Hz, 300 Hz, 1 kHz, 3 kHz; 20 db or 40 db/decade

Modes: High reserve, Low-noise

Magnetic field exposure

Operational up to 3 mT DC

Size

142 mm W × 39 mm H × 89 mm D (5.6 in × 1.5 in × 3.5 in)

Bandwidth/accuracy

<table>
<thead>
<tr>
<th>Range</th>
<th>Bandwidth (-3 dB, typical)</th>
<th>Full accuracy</th>
<th>DC² ±(% rdg + A)</th>
<th>Lock-in²,³ ±% rdg</th>
<th>Temperature coefficient²,³ ±(% rdg/°C + A/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mA</td>
<td>&gt;100 kHz</td>
<td>1 kHz</td>
<td>0.05% + 1 μA</td>
<td>0.05%</td>
<td>5 ppm/°C + 10 nA/°C</td>
</tr>
<tr>
<td>10 mA</td>
<td>&gt;100 kHz</td>
<td>1 kHz</td>
<td>0.05% + 100 nA</td>
<td>0.05%</td>
<td>2 ppm/°C + 5 nA/°C</td>
</tr>
<tr>
<td>1 mA</td>
<td>&gt;100 kHz</td>
<td>1 kHz</td>
<td>0.05% + 10 nA</td>
<td>0.05%</td>
<td>2 ppm/°C + 20 nA/°C</td>
</tr>
<tr>
<td>100 μA</td>
<td>40 kHz</td>
<td>1 kHz</td>
<td>0.05% + 1 nA</td>
<td>0.05%</td>
<td>2 ppm/°C + 1 nA/°C</td>
</tr>
<tr>
<td>10 μA</td>
<td>8 kHz</td>
<td>500 Hz</td>
<td>0.05% + 500 pA</td>
<td>0.05%</td>
<td>5 ppm/°C + 1 nA/°C</td>
</tr>
<tr>
<td>1 μA</td>
<td>2.2 kHz</td>
<td>100 Hz</td>
<td>0.05% + 500 pA</td>
<td>0.1%</td>
<td>5 ppm/°C + 5.0 ppm/°C</td>
</tr>
<tr>
<td>100 nA</td>
<td>450 Hz</td>
<td>20 Hz</td>
<td>0.05% + 10 pA</td>
<td>0.1%</td>
<td>5 ppm/°C + 0.5 ppm/°C</td>
</tr>
<tr>
<td>10 nA</td>
<td>80 Hz</td>
<td>10 Hz</td>
<td>0.1% + 5 pA</td>
<td>0.5%</td>
<td>50 ppm/°C + 0.5 ppm/°C</td>
</tr>
<tr>
<td>1 nA</td>
<td>80 Hz</td>
<td>10 Hz</td>
<td>0.1% + 5 pA</td>
<td>0.5%</td>
<td>50 ppm/°C + 0.5 ppm/°C</td>
</tr>
</tbody>
</table>

Noise (typical)

<table>
<thead>
<tr>
<th>Range</th>
<th>Noise density⁴</th>
<th>Noise at 0.1 Hz to 10 Hz⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mA</td>
<td>2.6 nA/√Hz at 1 kHz</td>
<td>35 nA RMS (175 nA p-p)</td>
</tr>
<tr>
<td>10 mA</td>
<td>250 pA/√Hz at 1 kHz</td>
<td>4 nA RMS (20 nA p-p)</td>
</tr>
<tr>
<td>1 mA</td>
<td>30 pA/√Hz at 1 kHz</td>
<td>350 pA RMS (1.75 nA p-p)</td>
</tr>
<tr>
<td>100 μA</td>
<td>3.5 pA/√Hz at 1 kHz</td>
<td>30 pA RMS (150 nA p-p)</td>
</tr>
<tr>
<td>10 μA</td>
<td>500 fA/√Hz at 1 kHz</td>
<td>4 pA RMS (20 pA p-p)</td>
</tr>
<tr>
<td>1 μA</td>
<td>70 fA/√Hz at 1 kHz</td>
<td>400 fA RMS (2 pA p-p)</td>
</tr>
<tr>
<td>100 nA</td>
<td>13 fA/√Hz at 100 Hz</td>
<td>60 fA RMS (300 fA p-p)</td>
</tr>
<tr>
<td>10 nA</td>
<td>4.3 fA/√Hz at 77 Hz</td>
<td>16 fA RMS (80 fA p-p)</td>
</tr>
<tr>
<td>1 nA</td>
<td>4.3 fA/√Hz at 77 Hz</td>
<td>16 fA RMS (80 fA p-p)</td>
</tr>
</tbody>
</table>

DC input impedance

<table>
<thead>
<tr>
<th>Range</th>
<th>DC input impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mA</td>
<td>30 Ω</td>
</tr>
<tr>
<td>10 mA</td>
<td>40 Ω</td>
</tr>
<tr>
<td>1 mA</td>
<td>100 Ω</td>
</tr>
<tr>
<td>100 μA</td>
<td>1 Ω</td>
</tr>
<tr>
<td>10 μA</td>
<td>6 Ω</td>
</tr>
<tr>
<td>1 μA</td>
<td>60 Ω</td>
</tr>
<tr>
<td>100 nA</td>
<td>500 Ω</td>
</tr>
<tr>
<td>10 nA</td>
<td>5 kΩ</td>
</tr>
<tr>
<td>1 nA</td>
<td>80 kΩ</td>
</tr>
</tbody>
</table>

¹ 1 nA range, 10 s, 95% confidence interval
² Total system accuracy, 1 year and ±5 °C from Lake Shore calibration; 24 h, ±1 °C from self-calibration, 95% confidence, filters off
³ DC to full accuracy frequency
⁴ In Low noise mode; High reserve mode will have the noise of the next higher current range
This module provides programmable voltages from ±1 nV to ±10 V with a maximum of 100 mA compliance from DC to 100 kHz sinusoidal output. The VS-10 is useful for gate biasing, voltage sweep I-V curve profiling, and applications that require highly stable voltages in combination with current, resistance/conductance, and other material or electronic device measurements.

Patent-pending circuitry enables separate ranges and amplitude settings for DC and AC signal components. This allows for simultaneous DC biasing and sweeping as well as combined AC signals to be superimposed for sample and device stimulus and selective measurement by corresponding and synchronized VM-10 modules. This hybrid DC+AC signal capability can reduce or eliminate the need and complexity for dedicated DC and AC sources while providing enhanced characterization capabilities and richer measurement data and sample insights.
VS-10 specifications
Specifications are subject to change

Ranges
V: 10 V, 1 V, 100 mV, 10 mV; AC and DC ranges can be independently set; automatic selection

Current limit
Settable up to 100 mA (DC only)

Maximum power
1 W, 4-quadrant operation

Output impedance
<150 mΩ

Rise time
<5 µs, 10% to 90%, negative to positive full scale, >10 MΩ impedance load, all ranges

Settle time
<10 µs to 0.1% of final value, negative to positive full scale, >10 MΩ impedance load, all ranges

Load impedance
Stability maintained with reactive loads up to 50 µF or 1 mH (with 100 Ω damping)

Magnetic field exposure
Operational up to 50 mT DC

Size
142 mm W × 39 mm H × 89 mm D (5.6 in × 1.5 in × 3.5 in)

Bandwidth/accuracy

<table>
<thead>
<tr>
<th>Range</th>
<th>Bandwidth (-3 dB, typical)</th>
<th>DC</th>
<th>Lock-in</th>
<th>Temperature coefficient</th>
<th>DC settable resolution</th>
<th>AC settable resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 V</td>
<td>95 kHz</td>
<td>0.025% + 450 µV</td>
<td>0.025%</td>
<td>5 ppm/°C + 5 µV/°C</td>
<td>3 µV</td>
<td>100 µV</td>
</tr>
<tr>
<td>1 V</td>
<td>95 kHz</td>
<td>0.05% + 450 µV</td>
<td>0.05%</td>
<td>5 ppm/°C + 5 µV/°C</td>
<td>1 µV</td>
<td>10 µV</td>
</tr>
<tr>
<td>100 mV</td>
<td>95 kHz</td>
<td>0.1% + 450 µV</td>
<td>0.1%</td>
<td>5 ppm/°C + 5 µV/°C</td>
<td>1 µV</td>
<td>1 µV</td>
</tr>
<tr>
<td>10 mV</td>
<td>95 kHz</td>
<td>0.15% + 450 µV</td>
<td>0.15%</td>
<td>5 ppm/°C + 5 µV/°C</td>
<td>1 µV</td>
<td>100 nV</td>
</tr>
</tbody>
</table>

Noise (typical)

<table>
<thead>
<tr>
<th>Range</th>
<th>Voltage noise at 1 kHz</th>
<th>Voltage noise at 0.1 Hz to 10 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 V</td>
<td>80 nV/√Hz</td>
<td>1 µV RMS (5 µV p-p)</td>
</tr>
<tr>
<td>1 V</td>
<td>30 nV/√Hz</td>
<td>500 nV RMS (2.5 µV p-p)</td>
</tr>
<tr>
<td>100 mV</td>
<td>30 nV/√Hz</td>
<td>350 nV RMS (1.75 µV p-p)</td>
</tr>
<tr>
<td>10 mV</td>
<td>30 nV/√Hz</td>
<td>350 nV RMS (1.75 µV p-p)</td>
</tr>
</tbody>
</table>

Wideband noise (DC to 100 MHz): 2 mV RMS

Output impedance

<table>
<thead>
<tr>
<th>Range</th>
<th>Absolute resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 V</td>
<td>&lt;0.1 Ω</td>
</tr>
<tr>
<td>1 V</td>
<td>&lt;0.1 Ω</td>
</tr>
<tr>
<td>100 mV</td>
<td>&lt;0.1 Ω</td>
</tr>
<tr>
<td>10 mV</td>
<td>&lt;0.1 Ω</td>
</tr>
</tbody>
</table>

1 Both DC and AC range less than or equal to the range
2 Total system accuracy, 1 year and ±5 °C from Lake Shore calibration, 24 h and ±1 °C from self-calibration, 95% confidence
3 DC to 1 kHz
4 Averaging over 60 NPLCs
Top material research applications and the M81 modules used

**DC transport**

**I-V curves, 4-wire**  
(VS module + CM module, primarily)  
**Ideal for:** 2D materials, nanowires, organic semiconductors  
**M81-SSM advantages:** Low-voltage source noise, low-current measure noise

**AC transport**

**AC resistance, sheet resistance, and AC current Hall**  
(BCS module + VM module)  
**Ideal for:** Metal-insulator transitions, 2D materials, superconducting materials  
**M81-SSM advantages:** AC current Hall: synchronous measurement of resistance and Hall voltages; and simultaneous measurement of up to three devices in a cryostat at different frequencies

**Photodiodes and phototransistors**  
(CM module + occasionally VS module)  
**Ideal for:** IR sensitive materials, solar-blind materials, 2D materials  
**M81-SSM advantages:** Programmable offset voltage source

**Spin transport**  
(DC/AC: BCS module + VM module)  
**Ideal for:** Spin orbit torque (SOT), non-local resistance, spin valves  
**M81-SSM advantages:** SOT: synchronous measurement of resistance, Hall voltages, and harmonic Hall voltages

**Differential conductance**  
(VS module + CM module)  
**Ideal for:** MIS junctions, Josephson junctions, defect characterization in transistors  
**M81-SSM advantages:** Junctions: dual DAC AC and DC sourcing (source at appropriate range)

**Thermal transport**  
(AC, BCS module + VM module)  
**Ideal for:** Thermoelectric materials, 1D materials  
**M81-SSM advantages:** Phase-correlated current sources, synchronous harmonic detection
Application focus — M81 and Hall bar measurements

Magnetotransport and harmonic Hall effect measurements are primary characterization methodologies for a wide variety of materials — high mobility 2DEGs, graphene, magnetic semiconductors, and spin-orbit torque heterostructures. For low resistance materials in particular, samples are often etched or milled into a Hall bar geometry and a current source drives a uniform current through the long axis of the bar. The voltage drop along the current channel, $V_R$, is measured using narrow legs or taps along the current direction. Deflection of the current due to applied and internal magnetic fields manifests as a Hall voltage, $V_H$, detected in the legs perpendicular to the current flow. In certain applications, the measured voltages are exceedingly small and need to be extracted using lock-in techniques. The M81-SSM offers key advantages in these scenarios for both sourcing and detection.

AC current source

Conventionally, single-ended current sources are employed in Hall bar measurements. These single-ended sources drive current into the positive terminal of the Hall bar, which is returned to ground. In the single-ended configuration, there is a different impedance on each end of the Hall bar load and common mode voltage fluctuations, such as line pickup, are more easily coupled into the measurement circuit. With these common mode fluctuations, longer lock-in averaging times may be necessary in order to achieve an acceptable signal to noise ratio. Minimizing common mode fluctuations in Hall bar applications, the M81-SSM is configured with a balanced current source (BCS) for AC current excitation of the device. Configured as a differential source, the BCS module sources and sinks the prescribed current with two coordinated voltage-controlled source circuits. A common mode rejection connection on the source module is attached to a Hall bar’s shared leg and provides active feedback to reduce common mode voltage on the load.

Voltage detection

In AC current Hall bar measurements, two lock-in amplifiers are typically used in order to simultaneously measure $V_R$ and $V_H$ as a function of magnetic field or temperature. Due to cost considerations, a single lock-in could be switched between the two voltage measurement configurations; however, waiting for the lock-in to resettle after a configuration change is time-consuming. As the two measurements are acquired at different times, system drift can skew measurement results. For typical Hall bar measurements, the M81-SSM can be configured with two voltage measure (VM) modules — one for $V_H$ and one for $V_R$. For harmonic Hall measurements, the second harmonic of the oscillating Hall voltage characterizes the strength and nature of the spin-orbit interaction. In this case, a third VM module, configured to measure the second harmonic, is added in parallel to the $V_H$ legs. Whether configured with two or three VM modules, the M81-SSM platform can be queried to return synchronous lock-in results from all connected measurement modules.
Positioning and mounting accessories

Included mounting plates

Included with each module: a top clip for module-to-module stacking and a bottom clip for surface mounting (shown attached underneath).

Optional module rack mount panel (M81-RMK-2)

Optional module rack mount kit (M81-RMP-3)

Two optional module rack mount kits (M81-RMP-3) paired with an optional rack mount kit for two MeasureReady instruments (RM-2)

Optional probe station mounting kit (M81-PMK-1)

Includes shelf for mounting M81-SSM modules on Lake Shore probe stations adjacent to a DUT.
Ordering information

**M81 instruments**

- **M81-SSM-2**: M81 synchronous source measure system instrument with 1 source and 1 measure channel
- **M81-SSM-4**: M81 synchronous source measure system instrument with 2 source and 2 measure channels
- **M81-SSM-6**: M81 synchronous source measure system instrument with 3 source and 3 measure channels

**M81-SSM source and measure modules**

- **M81-BCS-10**: 100 mA/10 V balanced current source module
- **M81-VS-10**: 10 V/100 mA voltage source module
- **M81-VM-10**: 10 V voltage measure module
- **M81-CM-10**: 100 mA/10 V current measure module

**Accessories**

- **112-811**: Instrument LEMO to module extender cable, 8 m (26.3 ft)
- **112-812**: Instrument LEMO to BNC adapter cable, 2 m (6.6 ft)
- **843-076**: Low noise triaxial cable, 3-slot, 1 m (3 ft)
- **P12379**: BNC female to triaxial adapter, TRB male, isolated, 50 Ω, 3-lug
- **117-017**: 1 m (3.3 ft) long IEEE-488 (GPIB) computer interface cable assembly
- **RM-2**: Rack mount kit—two adjacent half-rack instruments
- **RM-1/2**: Rack mount kit—single half-rack instrument
- **M81-RMK-2**: Rack mount kit for M81 instrument and 2 modules (2U)
- **M81-RMP-3**: Rack mount kit for 3 M81-SSM modules (1U)
- **M81-PMK-1**: Mounting kit for mounting M81-SSM modules on a Lake Shore probe station
- **M81-MODULE-CLIPS**: Mating pair of 2 stacking/mounting clips for M81-SSM modules including rubber feet and mounting screws