The high power Model 2651A is the newest addition to the Series 2600A family of System SourceMeter instruments. Specifically designed to characterize and test high power electronics, these source measurement unit (SMU) instruments can help you improve productivity in applications across the R&D, reliability, and production spectrums, including high brightness LEDs, power semiconductors, DC-DC converters, batteries, and other high power materials, components, modules, and subassemblies.

The Model 2651A, like every Series 2600A SourceMeter instrument, offers a highly flexible, four-quadrant voltage and current source/load coupled with precision voltage and current meters. It can be used as:

- Semiconductor characterization instrument
- V or I waveform generator
- V or I pulse generator
- Precision power supply
- True current source
- Digital multimeter (DCV, DCI, ohms, and power with 6½-digit resolution)
- Precision electronic load

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**APPLICATIONS**

- Power semiconductor, HBLED, and optical device characterization and testing
- Characterization of GaN, SiC, and other compound materials and devices
- Semiconductor junction temperature characterization
- High speed, high precision digitization
- Electromigration studies
- High current, high power device testing

The Model 2651A can source or sink up to ±40V and ±50A.

**Two Measurement Modes: Digitizing or Integrating**

Precisely characterize transient and steady-state behavior, including rapidly changing thermal effects, with the two measurement modes in the Model 2651A. Each mode is defined by its independent analog-to-digital (A/D) converters.

The Digitizing Measurement mode enables 1μs per point measurements. Its 18-bit A/D converters allow you to precisely measure transient characteristics. For more accurate measurements, use its Integrating Measurement mode, which is based on 22-bit A/D converters. The Integrating Measurement mode is provided in all Series 2600A instruments.
50A, High Power System
SourceMeter® Instrument

Expansion Capabilities
Through TSP-Link® technology, multiple Model 2651As and other Series 2600A instruments can be combined to form a larger integrated system with up to 64 channels. Precision timing and tight channel synchronization are guaranteed with built-in 500ns trigger controllers. True SMU instrument-per-pin testing is assured with the fully isolated, independent channels of the SourceMeter instruments.

1µV measurement resolution and current sourcing up to 50A (100A with two units) enable low-level Rds measurements to support next-generation devices.

Standard Capabilities of
Series 2600A Instruments
Each Model 2651A includes all the features and capabilities provided in the other Series 2600A instruments, such as:

• Ability to be used as either a bench-top I-V characterization tool or as a building block component of multiple-channel I-V test systems
• TSP Express software to quickly and easily perform common I-V tests without programming or installing software
• ACS Basic Edition software for semiconductor component characterization (optional). ACS Basic now features a Trace mode for generating a suite of characteristic curves.
• Keithley’s Test Script Processor (TSP®), which enables creation of custom user test scripts to further automate testing, and also supports the creation of programming sequences that allow the instrument to operate asynchronously without direct PC control.
• Parallel test execution and precision timing when multiple Series 2600A instruments are connected together in a system
• LXI Class C compliance
• 14 digital I/O lines for direct interaction with probe stations, component handlers, or other automation tools
• USB port for extra data and test program storage via USB memory device

High Speed Pulsing
The Model 2651A minimizes the unwanted effects of self heating during tests by accurately sourcing and measuring pulses as short as 100µs. Additional control flexibility enables you to program the pulse width from 100µs to DC and the duty cycle from 1% to 100%. A single unit can pulse up to 50A; combine two units to pulse up to 100A.

The dual digitizing A/D converters sample at up to 1µs/point, enabling full simultaneous characterization of both current and voltage waveforms.

Precision measurements to 50A (100A with two units) enable a more complete and accurate characterization.
## Specification Conditions

This document contains specifications and supplemental information for the Model 2651A High Power System SourceMeter instrument. Specifications are the standards against which the Model 2651A is tested. Upon leaving the factory, the Model 2651A meets these specifications. Supplemental and typical values are non-warranted, apply at 23°C, and are provided solely as useful information.

Accuracy specifications are applicable for both normal and high-capacitance modes.

### VOLTAGE ACCURACY SPECIFICATIONS

<table>
<thead>
<tr>
<th>Range</th>
<th>Programming Resolution</th>
<th>Accuracy</th>
<th>Noise (typical)</th>
<th>Noise (Vpp) (typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.00nA</td>
<td>2 nA</td>
<td>±0.1%</td>
<td>50 nA</td>
<td>100 µA</td>
</tr>
<tr>
<td>1.0000 µA</td>
<td>20 nA</td>
<td>±0.01%</td>
<td>500 nA</td>
<td>1 µV</td>
</tr>
<tr>
<td>10.0000 µA</td>
<td>200 nA</td>
<td>±0.001%</td>
<td>5000 nA</td>
<td>10 µV</td>
</tr>
<tr>
<td>100.0000 µA</td>
<td>2 µA</td>
<td>±0.01%</td>
<td>50000 nA</td>
<td>100 µV</td>
</tr>
<tr>
<td>1.000000 µA</td>
<td>20 µA</td>
<td>±0.001%</td>
<td>500000 nA</td>
<td>1 µA</td>
</tr>
</tbody>
</table>

### CURRENT ACCURACY SPECIFICATIONS

<table>
<thead>
<tr>
<th>Range</th>
<th>Programming Resolution</th>
<th>Accuracy</th>
<th>Noise (typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.00 nA</td>
<td>2 nA</td>
<td>±0.1%</td>
<td>50 nA</td>
</tr>
<tr>
<td>1.0000 µA</td>
<td>20 nA</td>
<td>±0.01%</td>
<td>500 nA</td>
</tr>
<tr>
<td>10.0000 µA</td>
<td>200 nA</td>
<td>±0.001%</td>
<td>5000 nA</td>
</tr>
<tr>
<td>100.0000 µA</td>
<td>2 µA</td>
<td>±0.01%</td>
<td>50000 nA</td>
</tr>
<tr>
<td>1.000000 µA</td>
<td>20 µA</td>
<td>±0.001%</td>
<td>500000 nA</td>
</tr>
</tbody>
</table>

### NOTES

1. Add 50µV to source accuracy specifications per volt of HI lead drop.
2. For temperatures 0° to 18°C and 28° to 50°C, accuracy is degraded by ±(0.15 × accuracy specification)/°C.
3. Derate accuracy specification for NPLC setting <1 by increasing error term.
4. Add appropriate typical percent of range term for resistive loads using the table below.
5. 18-bit ADC. Average of 1000 samples taken at 1µs intervals.
6. 50A range accessible only in pulse mode.
7. 100A range accuracy measurements are taken at 0.008 NPLC.
8. Average of 100 samples taken at 1µs intervals.
DC POWER SPECIFICATIONS

MAXIMUM OUTPUT POWER: 202W maximum.

SOURCE/SINK LIMITS:

Voltage: ±10.1V at ±20.0A, ±20.2V at ±10.0A, ±40.4V at ±5.0A. Four-quadrant source or sink operation.

Current: ±5.05A at ±40V, ±10.2A at ±20V, ±20.4A at ±10V. Four-quadrant source or sink operation.

CAUTION: Carefully consider and configure the appropriate output-off state and source and compliance levels before connecting the Model 2651A to a device that can deliver energy. Failure to consider the output-off state and source and compliance levels may result in damage to the instrument or to the device under test.

PULSE SPECIFICATIONS

MINIMUM PROGRAMMABLE PULSE WIDTH: 100µs. Note: Minimum pulse width for settled source at a given I/V output and load can be longer than 100µs.

PULSE WIDTH PROGRAMMING RESOLUTION: 1µs.

PULSE WIDTH PROGRAMMING ACCURACY: ±5µs.

PULSE WIDTH JITTER: 1µs (typical).

PULSE RISE TIME (TYPICAL):

<table>
<thead>
<tr>
<th>Current Range</th>
<th>R_load</th>
<th>Rise Time (typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 A</td>
<td>0.05 Ω</td>
<td>26 µs</td>
</tr>
<tr>
<td>50 A</td>
<td>0.2 Ω</td>
<td>57 µs</td>
</tr>
<tr>
<td>50 A</td>
<td>0.4 Ω</td>
<td>85 µs</td>
</tr>
<tr>
<td>20 A</td>
<td>0.5 Ω</td>
<td>99 µs</td>
</tr>
<tr>
<td>20 A</td>
<td>1 Ω</td>
<td>180 µs</td>
</tr>
<tr>
<td>10 A</td>
<td>2 Ω</td>
<td>330 µs</td>
</tr>
<tr>
<td>5 A</td>
<td>8.2 Ω</td>
<td>400 µs</td>
</tr>
</tbody>
</table>

NOTES

1. Full power source operation regardless of load to 30°C ambient. Above 30°C or power sink operation, refer to “Operating Boundaries” in the Model 2651A Reference manual for additional power derating information.

2. Quadrants 2 and 4 power envelope is trimmed at 36V and 4.5A.

3. Times measured from the start of pulse to the start off-time; see figure below.

4. Thermally limited in sink mode (quadrants 2 and 4) and ambient temperatures above 30°C. See power equations in the Model 2651A Reference Manual for more information.

# Model 2651A Specifications

## ADDITIONAL SOURCE SPECIFICATIONS

### NOISE (10Hz to 20MHz)

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Peak-Peak</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>10V</td>
<td>&lt;100mV</td>
<td>&lt;5mV</td>
</tr>
<tr>
<td>20V</td>
<td>&lt;200mV</td>
<td>&lt;10mV</td>
</tr>
</tbody>
</table>

**Overshoot:**

- Voltage: ±0.1% + 10mV
- Current: ±0.1% + 10mV

**Settling Time:**

- Voltage: Time required to reach within 0.1% of final value after source level command is processed.
- Current: Time required to reach within 0.1% of final value after source level command is processed.

### RANGE CHANGE OVERSHOOT

- Voltage: ±5% of larger range + 50mV (for >1mA ranges)
- Current: ±5% of larger range + 360mV/R_{load} (for >10µA ranges)

### VOLTAGE SOURCE OUTPUT SETTLING TIME

- Time required to reach within 0.1% of final value after source level command is processed. Values below for I_{out} × R_{load}:

<table>
<thead>
<tr>
<th>Range</th>
<th>Setting Time (typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20A</td>
<td>&lt;195 µs</td>
</tr>
<tr>
<td>10A</td>
<td>&lt;560 µs</td>
</tr>
<tr>
<td>5A</td>
<td>&lt;80 µs</td>
</tr>
<tr>
<td>1A</td>
<td>&lt;80 µs</td>
</tr>
<tr>
<td>100mA</td>
<td>&lt;10 µs</td>
</tr>
<tr>
<td>1mA</td>
<td>&lt;300 µs</td>
</tr>
<tr>
<td>1µA</td>
<td>&lt;500 µs</td>
</tr>
<tr>
<td>10µA</td>
<td>&lt;15 ms</td>
</tr>
<tr>
<td>1µA</td>
<td>&lt;35 ms</td>
</tr>
<tr>
<td>10nA</td>
<td>&lt;110 ms</td>
</tr>
</tbody>
</table>

### CURRENT SOURCE OUTPUT SETTLING TIME

- Time required to reach within 0.1% of final value after source level command is processed. Values below for I_{out} × R_{load}:

<table>
<thead>
<tr>
<th>Current Range</th>
<th>R_{load} Setting Time (typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20A</td>
<td>5 Ω 0.5 Ω</td>
</tr>
<tr>
<td>10A</td>
<td>1.5 Ω 0.5 Ω</td>
</tr>
<tr>
<td>5A</td>
<td>5 Ω 1 Ω</td>
</tr>
<tr>
<td>1A</td>
<td>1 Ω 0.5 Ω</td>
</tr>
<tr>
<td>100mA</td>
<td>10 Ω 5 Ω</td>
</tr>
<tr>
<td>1mA</td>
<td>100 Ω 2 Ω</td>
</tr>
<tr>
<td>1µA</td>
<td>1000 Ω 2 Ω</td>
</tr>
<tr>
<td>10µA</td>
<td>10000 Ω 2 Ω</td>
</tr>
</tbody>
</table>

### TRANSIENT RESPONSE TIME

- 10V: <70µs
- 20V: <70µs
- 20A: <110µs

### OVERTEMPERATURE PROTECTION

- Maximum: 250V DC
- COMMON MODE ISOLATION: >1GΩ, <4500pF

### MAXIMUM LOAD IMPEDANCE

- Normal Mode: 10mΩ (typical), 3µH (typical)
- High-Capacitance Mode: 50µH (typical), 3µH (typical)

### MEASURE INPUT IMPEDANCE

- >10GΩ

### SENSE INPUT IMPEDANCE

- >10GΩ

### MAXIMUM SENSE LEAD RESISTANCE

- 1kΩ for rated accuracy

### OVERRANGE

- 10% of source range, 10% of measure range

### ADDITIONAL METER SPECIFICATIONS

### MAXIMUM MEASUREMENT SPECIFICATIONS

<table>
<thead>
<tr>
<th>Speed</th>
<th>Maximum Measurement Speed to Memory</th>
<th>Accuracy (1 Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast</td>
<td>1.1 ms (1.2 ms)</td>
<td>±5% + 15 Ω</td>
</tr>
<tr>
<td>Medium</td>
<td>4.1 ms (5 ms)</td>
<td>±5% + 5 Ω</td>
</tr>
<tr>
<td>Slow</td>
<td>36 ms (12 ms)</td>
<td>±5% + 3 Ω</td>
</tr>
</tbody>
</table>

### ADDITIONAL MEASUREMENT SPECIFICATIONS

#### MODE CHANGE DELAY

- 100 µA Current Range and Above:
  - Delay into High-Capacitance Mode: 11ms.
  - Delay out of High-Capacitance Mode: 11ms.
- 1 µA and 10 µA Current Ranges:
  - Delay into High-Capacitance Mode: 250ms.
  - Delay out of High-Capacitance Mode: 11ms.

### MEASURE INPUT IMPEDANCE

- >10GΩ in parallel with 25nF

### VOLTAGE SOURCE RANGE CHANGE OVERSHOOT

- ±0.1% of larger range (typical)
- Overshoot into a 100kΩ load, 20MHz bandwidth.

### NOTES

1. Includes measurement of SENSE HI to HI and SENSE LO to LO contact resistances.
2. High-capacitance mode specifications are for DC measurements only and use locked ranges. Autorange is disabled.
3. 200mA range is not available in high-capacitance mode.
4. Add an additional 2nA to the source current accuracy and measure current accuracy offset for the 1µA range.
5. With measure and compliance set to the maximum current for the specified voltage range.

---

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### MEASUREMENT SPEED SPECIFICATIONS 1, 2

#### MAXIMUM SWEEP OPERATION RATES (operations per second) FOR 60Hz (50Hz):

<table>
<thead>
<tr>
<th>A/D Converter Speed</th>
<th>Trigger Origin</th>
<th>Measure To Memory Using User Scripts</th>
<th>Measure To GPIB Using User Scripts</th>
<th>Source Measure To Memory Using User Scripts</th>
<th>Source Measure To GPIB Using User Scripts</th>
<th>Source Measure To Memory Using Sweep API</th>
<th>Source Measure To GPIB Using Sweep API</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001 NPLC Internal</td>
<td>2000 (2000)</td>
<td>9800 (9800)</td>
<td>7000 (7000)</td>
<td>6200 (6200)</td>
<td>12000 (12000)</td>
<td>5900 (5900)</td>
<td></td>
</tr>
<tr>
<td>0.001 NPLC Digital I/O</td>
<td>8100 (8100)</td>
<td>7100 (7100)</td>
<td>5500 (5500)</td>
<td>5100 (5100)</td>
<td>11200 (11200)</td>
<td>5700 (5700)</td>
<td></td>
</tr>
<tr>
<td>0.01 NPLC Internal</td>
<td>4900 (4000)</td>
<td>3900 (3400)</td>
<td>3400 (3000)</td>
<td>3200 (2900)</td>
<td>4200 (3700)</td>
<td>4600 (3500)</td>
<td></td>
</tr>
<tr>
<td>0.01 NPLC Digital I/O</td>
<td>3500 (3100)</td>
<td>3400 (3000)</td>
<td>3000 (2700)</td>
<td>2800 (2600)</td>
<td>4150 (3650)</td>
<td>3800 (3400)</td>
<td></td>
</tr>
<tr>
<td>0.1 NPLC Internal</td>
<td>500 (3400)</td>
<td>500 (3400)</td>
<td>500 (3400)</td>
<td>500 (3400)</td>
<td>500 (3400)</td>
<td>545 (460)</td>
<td></td>
</tr>
<tr>
<td>0.1 NPLC Digital I/O</td>
<td>550 (460)</td>
<td>550 (460)</td>
<td>540 (450)</td>
<td>540 (450)</td>
<td>540 (450)</td>
<td>545 (460)</td>
<td></td>
</tr>
<tr>
<td>1.0 NPLC Internal</td>
<td>59 (49)</td>
<td>59 (49)</td>
<td>59 (49)</td>
<td>59 (49)</td>
<td>59 (49)</td>
<td>59 (49)</td>
<td></td>
</tr>
<tr>
<td>1.0 NPLC Digital I/O</td>
<td>58 (48)</td>
<td>58 (48)</td>
<td>58 (48)</td>
<td>58 (48)</td>
<td>58 (48)</td>
<td>58 (48)</td>
<td></td>
</tr>
<tr>
<td>HS ADC Internal</td>
<td>38500 (38500)</td>
<td>18000 (18000)</td>
<td>10000 (10000)</td>
<td>9500 (9500)</td>
<td>14500 (14500)</td>
<td>6300 (6300)</td>
<td></td>
</tr>
<tr>
<td>HS ADC Digital I/O</td>
<td>12500 (12500)</td>
<td>11500 (11500)</td>
<td>7500 (7500)</td>
<td>7000 (7000)</td>
<td>15200 (15200)</td>
<td>6000 (6000)</td>
<td></td>
</tr>
</tbody>
</table>

#### HIGH SPEED ADC BURST MEASUREMENT RATES 3

<table>
<thead>
<tr>
<th>Burst Length (readings)</th>
<th>Readings per Second</th>
<th>Bursts per Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1000,000</td>
<td>40</td>
</tr>
<tr>
<td>500</td>
<td>1000,000</td>
<td>80</td>
</tr>
<tr>
<td>1000</td>
<td>1000,000</td>
<td>40</td>
</tr>
<tr>
<td>2500</td>
<td>1000,000</td>
<td>16</td>
</tr>
<tr>
<td>5000</td>
<td>1000,000</td>
<td>8</td>
</tr>
</tbody>
</table>

#### MAXIMUM SINGLE MEASUREMENT RATES (operations per second) FOR 60Hz (50Hz)

<table>
<thead>
<tr>
<th>A/D Converter Speed</th>
<th>Trigger Origin</th>
<th>Measure To GPIB</th>
<th>Source Measure To GPIB</th>
<th>Source Measure Pass/Fail To GPIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001 NPLC Internal</td>
<td>1900 (1800)</td>
<td>1400 (1400)</td>
<td>1400 (1400)</td>
<td></td>
</tr>
<tr>
<td>0.01 NPLC Internal</td>
<td>1450 (1400)</td>
<td>1200 (1100)</td>
<td>1100 (1100)</td>
<td></td>
</tr>
<tr>
<td>0.1 NPLC Internal</td>
<td>450 (390)</td>
<td>425 (370)</td>
<td>425 (375)</td>
<td></td>
</tr>
<tr>
<td>1.0 NPLC Internal</td>
<td>58 (48)</td>
<td>57 (48)</td>
<td>57 (48)</td>
<td></td>
</tr>
</tbody>
</table>

#### TRIGGERING AND SYNCHRONIZATION SPECIFICATIONS

- **TRIGGERING:**
  - Trigger In to Trigger Out: 0.5μs (typical).
  - Trigger In to Source Change: 1μs (typical).
  - Trigger Timer Accuracy: ±2μs (typical).
- **SOURCE CHANGE** 3 After LXI Trigger: 20μs (typical).
- **SYNCHRONIZATION:**
  - Single-Node Synchronized Source Change: <0.5μs (typical).
  - Multi-Node Synchronized Source Change: <0.5μs (typical).

#### NOTES

1. Fixed source range with no polarity change.

---

1. Tests performed with a Model 2651A on channel A using the following equipment: Computer hardware (Intel® Pentium® 4 2.4GHz, 2GB RAM, National Instruments™ PCI-GPIB). Driver (NI-488.2 Version 2.2 PCI-GPIB). Software (Microsoft® Windows® XP, Microsoft Visual Studio® 2010, VISA™ version 4.1).
2. Exclude current measurement ranges less than 1mA.
3. `smua.measure.adc` has to be enabled and the `smua.measure.count` set to the burst length.

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**SMU INSTRUMENTS**
SUPPLEMENTAL INFORMATION

FRONT PANEL INTERFACE: Two-line vacuum fluorescent display (VFD) with keypad and navigation wheel.

DISPLAY:
- Show error messages and user defined messages
- Display source and limit settings
- Show current and voltage measurements (6½-digit format)
- View measurements stored in dedicated reading buffers

KEYPAD OPERATIONS:
- Change host interface settings
- Save and restore instrument setups
- Load and run factory and user defined test scripts that prompt for input and send results to the display
- Store measurements into dedicated reading buffers

PROGRAMMING: Embedded Test Script Processor (TSP®) scripting engine is accessible from any host interface.
- Responds to individual instrument control commands.
- Responds to high speed test scripts comprised of instrument control commands and Test Script Language (TSL) statements (for example, branching, looping, and math).
- Able to execute high speed test scripts stored in memory without host intervention.

MINIMUM USER MEMORY AVAILABLE: 16MB (approximately 250,000 lines of TSP code).

TEST SCRIPT BUILDER: Integrated development environment for building, running, and managing TSP scripts. Includes an instrument console for communicating with any TSP enabled instrument in an interactive manner. Requires:
- VISA (NI-VISA included on CD)
- Microsoft® .NET Framework (included on CD)
- Keithley I/O Layer (included on CD)
- Intel® Pentium III 800MHz or faster personal computer
- Personal Computer Windows® 2000, XP, Vista®, or 7

TSP EXPRESS (embedded): Tool that allows users to quickly and easily perform common I/V tests without programming or installing software. To run TSP Express, you need:
- Java™ Platform, Standard Edition 6
- Microsoft Internet Explorer®, Mozilla® Firefox®, or another Java-compatible web browser

SOFTWARE INTERFACE: TSP Express (embedded), direct GPIB/VISA, read/write with Microsoft Visual Basic®, Visual C/C++, Visual C#, LabVIEW™, CEC TestPoint™ Data Acquisition Software Package, NI LabWindows™/CVI, etc.

READING BUFFERS: Nonvolatile memory uses dedicated storage areas reserved for measurement data. Reading buffers are arrays of measurement elements. Each element can hold the following items:
- Measurement
- Source setting (at the time the measurement was taken)
- Measurement status
- Range information
- Timestamp

Two reading buffers are reserved for each Model 2651A channel. Reading buffers can be filled using the front panel STORE key and retrieved using the RECALL key or host interface.

Buffer Size, without timestamp and source setting: >60,000 samples.

Buffer Size, with timestamp and source setting: >140,000 samples.

SYSTEM EXPANSION: The TSP-Link expansion interface allows TSP-enabled instruments to trigger and communicate with each other. See figure below.

Each Model 2651A has two TSP-Link connectors to make it easier to connect instruments together in sequence.
- Once source-measure instruments are interconnected through the TSP-Link expansion interface, a computer can access all of the resources of each source-measure instrument through the host interface of any Model 2651A.
- A maximum of 32 TSP-Link nodes can be interconnected. Each source-measure instrument consumes one TSP-Link node.

TIMER: Free-running 47-bit counter with 1MHz clock input. Resets each time instrument power is turned on. If the instrument is not turned off, the timer is reset to zero every 4 years.

Resolution: 1µs

Timestamp Accuracy: ±100ppm.

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