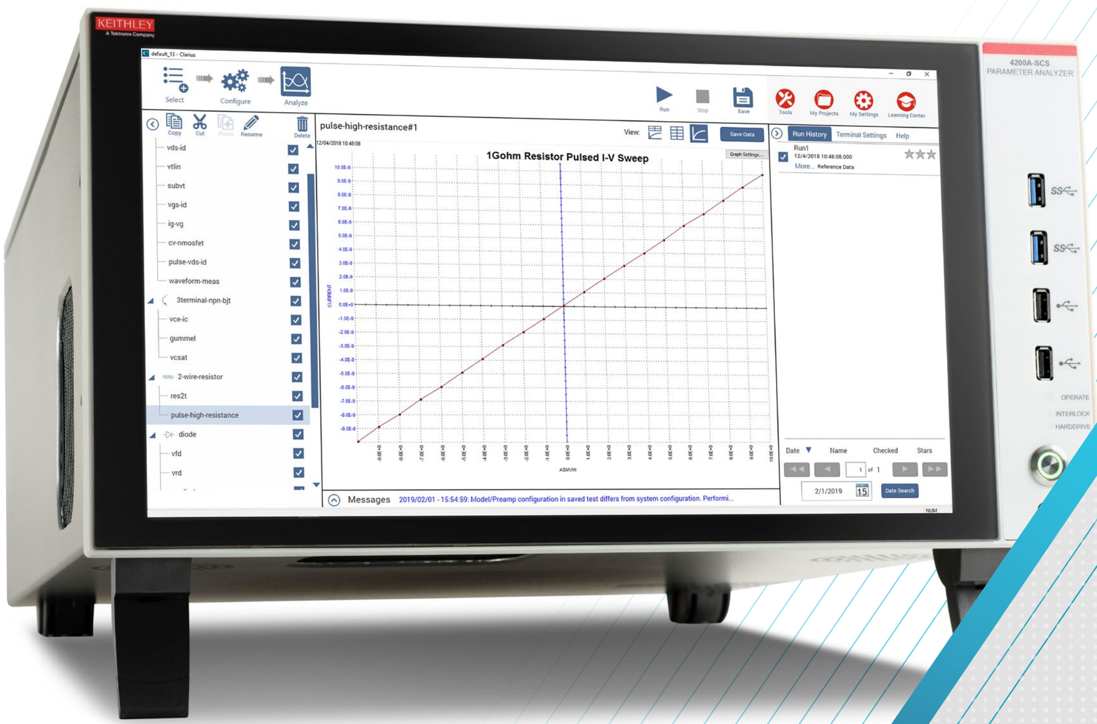
Making Low Current Pulse I-V Measurements with the 4225-PMU Pulse Measure Unit and 4225-RPM Remote/Preamplifier Switch Modules

APPLICATION NOTE



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Introduction

The ability to source high-speed voltage pulses and simultaneously measure low current simultaneously is important to many semiconductor device applications. Using pulsed I-V rather than DC signals to characterize devices allows eliminating or studying the effects of self-heating or to minimize current drifting in measurements due to trapped charge. Transient I-V measurements allow an engineer or scientist to capture a current or voltage waveform in the time domain or study a dynamic test circuit.

The 4200A-SCS Parameter Analyzer with the 4225-PMU Pulse Measure Unit option supports making ultra-fast I-V measurements. Adding 4225-RPM Remote Preamplifier/ Switch Modules (**Figure 1**) expands the current ranges of the PMU down to 100 nA full scale to make sensitive pulsed low current measurements.

Figure 1. 4225-RPM Remote Preamplifier/Switch Modules.

The graph in F**igure 2** illustrates the low current capability of the PMU with RPMs. In this graph the open circuit offset current is measured as a function of time at 0 V. The measurements were made on the 100 nA range with a pulse width of 800 µs and averaging 10 pulses.

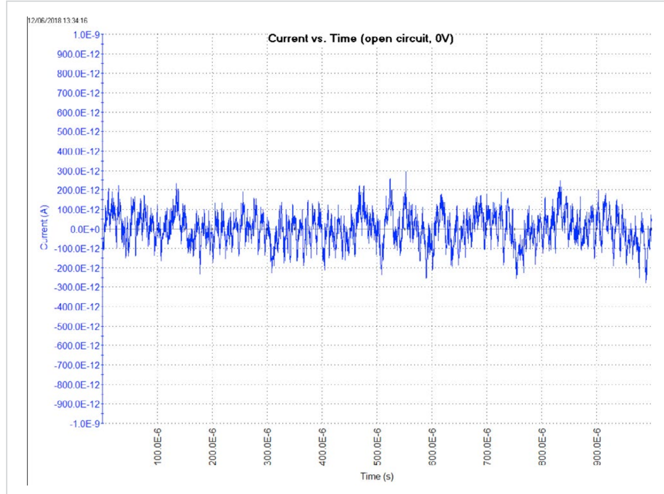

Figure 2. Offset current for the 100 nA range at 0 V (average 10 discreet pulses)

Given that semiconductor device measurements often require measuring low currents, using the PMU with two RPMs can provide these capabilities:

- Two independent or synchronized channels of pulsed I-V source and measure
- A wide current measurement range, from ± 800 mA down to ± 100 nA full scale
- Autoranging over all current ranges – ideal for I-V tests on devices with a wide range of current response, such as diodes
- The ability to switch between DC I-V, C-V, and pulsed I-V
- Built-in interactive software for easy test configuration and execution

This application note defines ultra-fast I-V, explains the fundamental limits of current measurements as a function of time and measure window, and describes the techniques for making ultra-fast I-V low current measurements.

What is Ultra-Fast I-V?

The 4225-PMU can perform three types of ultra-fast I-V tests: pulsed I-V, transient I-V, and pulsed sourcing. These three modes are illustrated in **Figure 3**.

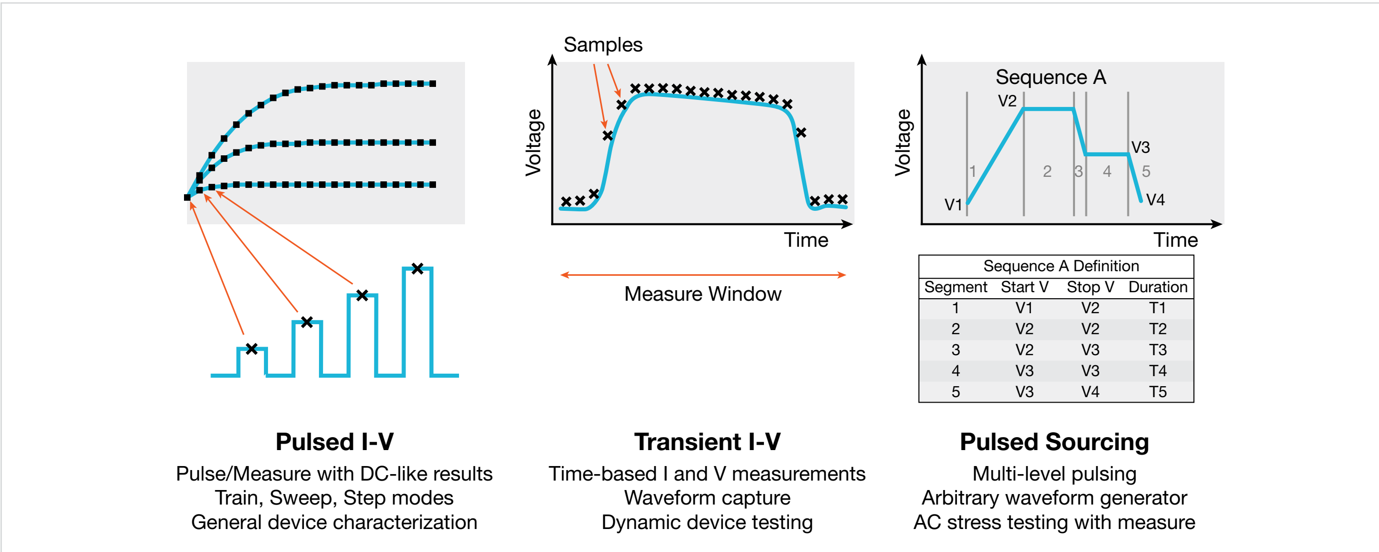

Figure 3. The 4225-PMU Ultra-Fast I-V Module's three modes of operation.

Pulsed I-V refers to any test with a pulsed source and a corresponding high speed, time-based measurement that provides DC-like results. The current and/or voltage measurement is an average of readings taken in a measurement window. This average of readings is called the "spot mean."

Transient I-V, or waveform capture, is a time-based current and/or voltage measurement that is typically the capture of a pulsed waveform. A transient test is typically a single pulse waveform that is used to study time-varying parameters.

Pulsed Sourcing involves outputting user-defined two-level or multi-level pulses using the built-in Segment ARB® function or outputting an arbitrarily defined waveform.

Fundamental Limits of High-Speed Low Current Measurements

The fundamental limit to a current measurement is Johnson-Nyquist noise in the source resistance. In any resistance, thermal energy produces motion of charged particles. This charge movement results in noise which is also called thermal noise. The power (P) available from this motion is given by:

$$P = 4kTB$$

where: k = Boltzmann's constant (1.38 x 10^{-23} J/K)
T = absolute temperature (K)
B = noise bandwidth (Hz)

Johnson current noise (I) developed by a resistor (R) is:

$$I = \frac{\sqrt{4kTRB}}{R} \text{ amperes, rms}$$

All real current sources have internal resistance, therefore, they exhibit Johnson noise. **Figure 4** shows the current noise generated by various resistances vs. measurement window in time at room temperature (T = 290K). The measurement window, in seconds (s), is defined in terms of the bandwidth (B) by:

$$B = \frac{1}{(2 \times Measure\ Window)}$$

If an application requires a current measurement that is below the line representing the DUT resistance, it will not be possible to make the measurement due to Johnson noise in the resistor. Reducing the temperature of the source resistance will help to reduce the noise levels.

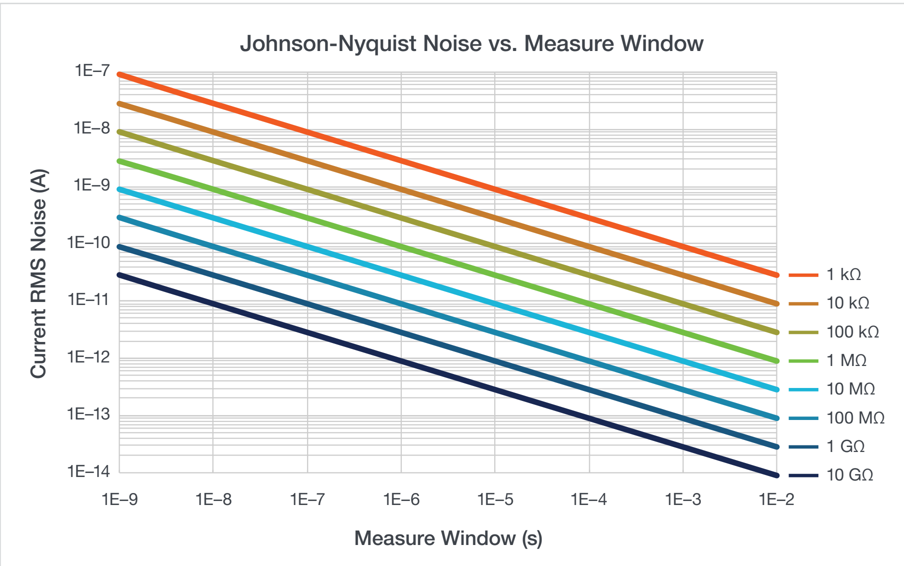

Figure 4. Current noise vs. measure window at various source resistances.

High Impedance Measurement Techniques

To make optimal low current and high impedance pulsed I-V measurements you must use the appropriate measurement techniques which are outlined in the following sections.

Correct for Current Offsets Using Connection Compensation

You can easily correct for offset current errors caused by connections and cable length between the PMU and the device under test by using the built-in connection compensation feature. When connection compensation is enabled, the measured offset current values are factored into each current measurement. The PMU offset current correction is a two-part process:

1. Acquire the current offset on each current range with an open circuit. Probes must be up or the device removed from the test fixture during the compensation. In Clarius, go to the Tools menu at the top of the screen and select PMU Connection Compensation. Select Measure Offset and the error current on all ranges on both channels will be measured and stored.

2. Once the offset correction data is acquired, enable the connection compensation within a test. From the Configure view within the test, go to the Terminal Settings tab and select Advanced. In the upper-right corner, select Offset Current Correction. Stored compensation measurements will be automatically subtracted from subsequent readings.

Figure 5 illustrates an example of pulsed I-V curves taken with and without offset correction applied.

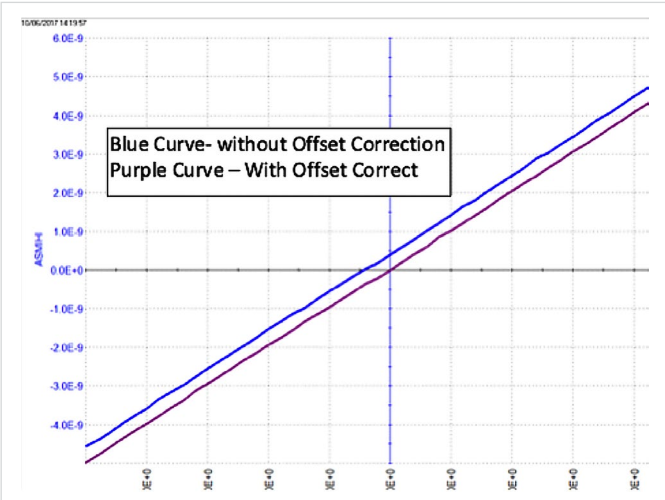

Figure 5. Pulsed I-V sweeps of 1 GΩ resistor generated with and without offset correction.

For optimum performance, repeat the connection compensation whenever the connection setup is changed or disturbed, including changes in temperature and humidity.

Use the "Low Side" Measurement Technique

The "low side" measurement technique is used to make ultra-fast high impedance measurements. With this method, illustrated in **Figure 6**, CH1 is used to source voltage only and CH2 is used to measure current only.

When CH1 sources the voltage, some of the current flows to the device (I_{DUT}) and some of the current flows through the leakage resistance and capacitance of the cable (I_{LEAK}). The measurement includes both the current of the device and the leakage current of the cable ($I_{MEAS} = I_{DUT} + I_{LEAK}$).

CH2 is set to output 0 V so that both the center conductor and outside shield of the cable are at the same potential, 0 V. As a result, no leakage flows through the cable. The measured current is the device current ($I_{MEAS} = I_{DUT}$). Multiply the current of CH2 by (-1) using the Formulator because the current will be the opposite polarity. The current measured by CH2, not CH1, is used in the high impedance measurement.

This method allows for faster measurements (because there's need to wait for CH1 to settle) and avoids errors due to leakage of the cable and long settling times.

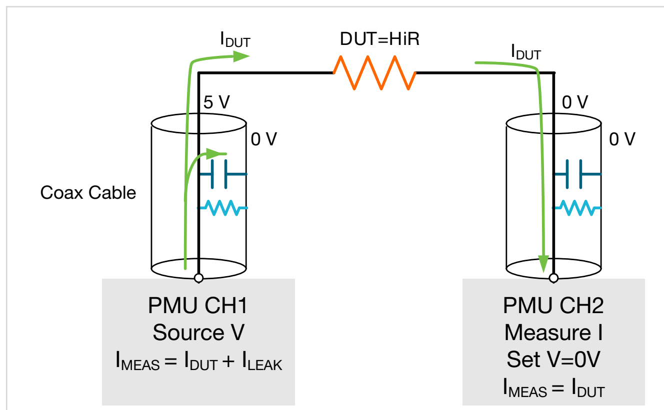

Figure 6. "Low side" high resistance ultra-fast measurement technique.

Figure 7 shows an example of a pulsed I-V sweep on a 1 GΩ resistor. The graph was generated using the "low side" measurement technique. The test used to generate this curve is called *pulse-high-resistance* and can be found in the Clarius Test Library.

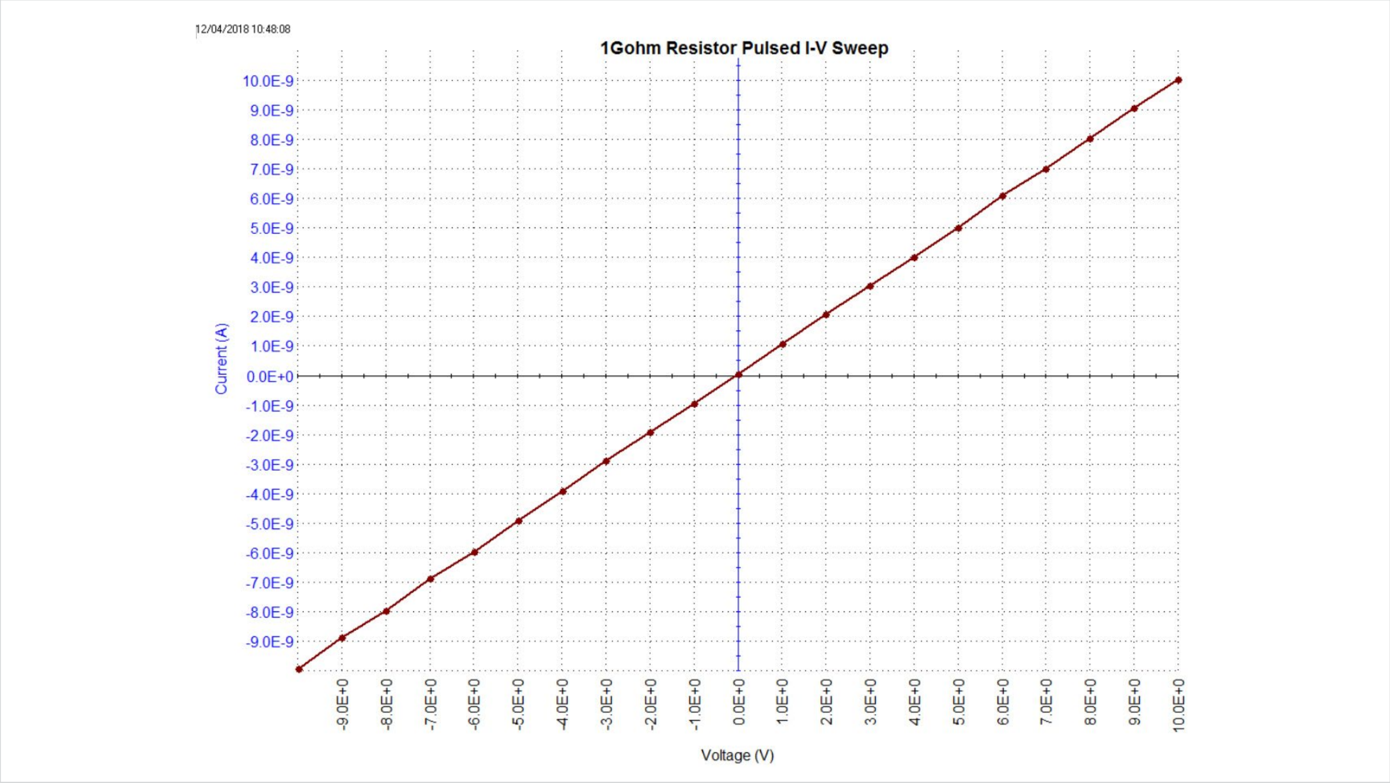

Figure 7. Pulsed I-V sweep on a 1 GΩ resistor measured with "low side" measurement technique.

Shield the DUT, Connections, and Test Fixturing

Just as when making sensitive DC current measurements, use shielding to prevent unwanted pick-up, which causes noisy readings. Ultra-fast I-V measurements will be susceptible to 50/60 Hz noise because there is no line cycle integration as there is with SMUs.

An example of shielding is shown in **Figure 8**. In this case, the resistor DUT is placed in a shielded test fixture. The shield is connected to the LO terminal of the PMU, which is the outside shield of the triax connector of the RPM. The tap on the triax connectors located on the output of the RPMs can also be used.

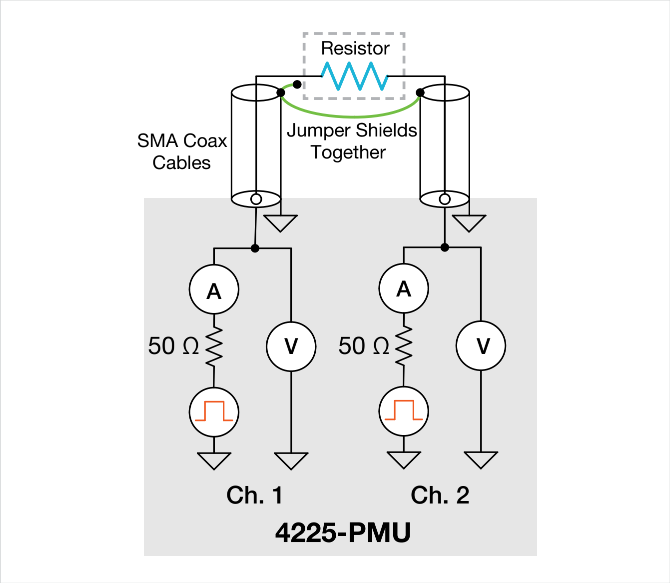

Figure 8. Shielding a device.

Average Readings to Reduce Noise

Although averaging readings can reduce the noise, averaging will also increase the total test time and will apply more pulses to the DUT. Averaging is good for users who need to keep their pulse widths to a minimum but want low noise. Select the Number of Pulses to Average after changing the Measure Mode from Discrete Pulses to Average Pulses in the Test Settings window of the Configure view. The Pulse Settings are shown in **Figure 9**.

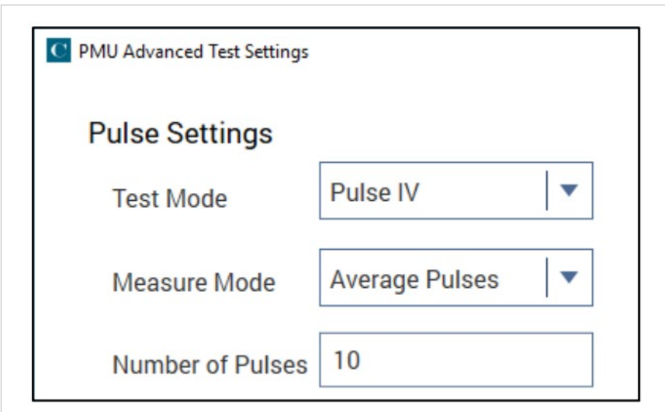

Figure 9. Average Pulse settings in the PMU Advanced Test Settings window

When you choose Average Pulses in the pulse I-V mode, each returned reading is a mean-of-the-means. This mode averages the mean readings for all the pulses in the burst. The higher the number of readings averaged, the lower the noise will be.

Warm Up the Test System

For best practices, always warm-up the 4200A-SCS system for at least one hour or longer so that the system temperature reaches equilibrium.

Conclusion

The 4225-PMU with the 4225-RPMs can be used to make low current pulsed I-V measurements on devices. Understanding the fundamental limits of low current measurements and using the proper techniques can allow making high-speed low current measurements.

Contact Information

Australia* 1 800 709 465
Austria 00800 2255 4835
Balkans, Israel, South Africa and other ISE Countries +41 52 675 3777
Belgium* 00800 2255 4835
Brazil +55 (11) 3759 7627
Canada 1 800 833 9200
Central East Europe / Baltics +41 52 675 3777
Central Europe / Greece +41 52 675 3777
Denmark +45 80 88 1401
Finland +41 52 675 3777
France* 00800 2255 4835
Germany* 00800 2255 4835
Hong Kong 400 820 5835
India 000 800 650 1835
Indonesia 007 803 601 5249
Italy 00800 2255 4835
Japan 81 (3) 6714 3086
Luxembourg +41 52 675 3777
Malaysia 1 800 22 55835
Mexico, Central/South America and Caribbean 52 (55) 56 04 50 90
Middle East, Asia, and North Africa +41 52 675 3777
The Netherlands* 00800 2255 4835
New Zealand 0800 800 238
Norway 800 16098
People's Republic of China 400 820 5835
Philippines 1 800 1601 0077
Poland +41 52 675 3777
Portugal 80 08 12370
Republic of Korea +82 2 565 1455
Russia / CIS +7 (495) 6647564
Singapore 800 6011 473
South Africa +41 52 675 3777
Spain* 00800 2255 4835
Sweden* 00800 2255 4835
Switzerland* 00800 2255 4835
Taiwan 886 (2) 2656 6688
Thailand 1 800 011 931
United Kingdom / Ireland* 00800 2255 4835
USA 1 800 833 9200
Vietnam 12060128

* European toll-free number.
If not accessible, call: +41 52 675 3777

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