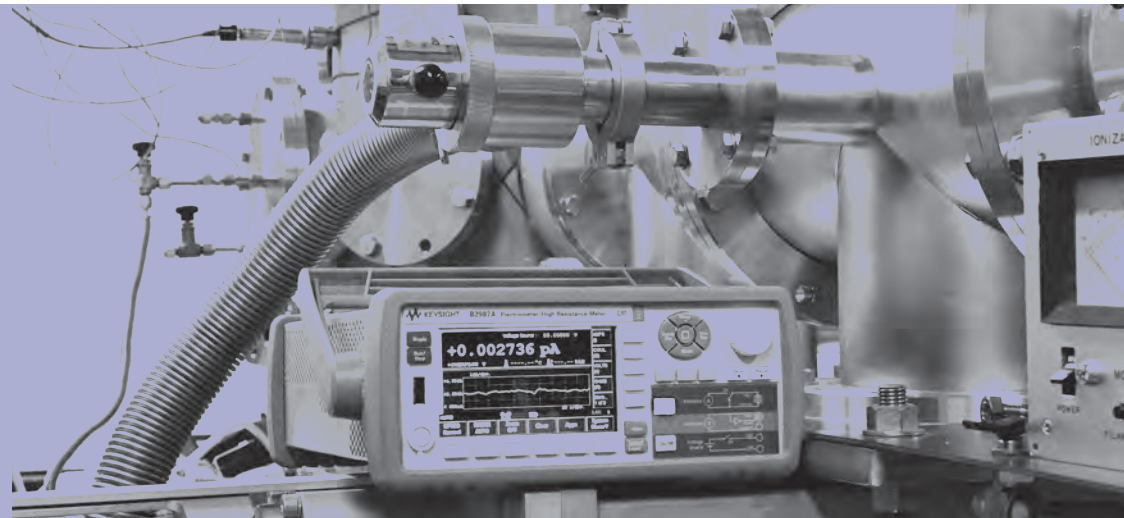


Keysight Basic Instruments

November 2017 - January 2018



The right techniques and tool
to measure PΩ resistances and
sub-femtoamp currents



SPOTLIGHT

Fundamentals of Low-Current and Ultra-High Resistance Measurements

Let's start at the beginning: What do we even mean by high resistance and low current?

We define high resistance as any measurement greater than 1 GΩ, the limit of most digital multimeters (DMMs). So we're talking about making measurements not just into the TΩ range, but all the way up into the PΩ range. And that creates challenges. Measuring PΩ resistances requires instruments capable of measuring femtoamp or even sub-femtoamp currents.

Important terms:	
▪ Peta (P) = 10 ¹⁵	▪ pico (p) = 10 ⁻¹²
▪ Tera (T) = 10 ¹²	▪ femto (f) = 10 ⁻¹⁵
▪ Giga (G) = 10 ⁹	▪ atto (a) = 10 ⁻¹⁸

Figure 1. Scale of measurements.

Even if you apply hundreds of volts to a large value resistor, you'll be measuring relatively small currents. For example, if we apply 1,000 V to a 1-TΩ resistor, the resultant current is only 1 nA. So high-resistance measurements require current measurement capabilities of less than 1 nA. In addition, you also need to account for tiny parasitic currents that can safely be ignored when making low-resistance measurements.

You may be familiar with making current and resistance measurements using a handheld DMM. However, for high-resistance measurements, we need either a picoammeter or an electrometer.

Picoammeter and electrometer

A picoammeter is an extremely precise current meter. A DMM can measure currents down to around 10 nA, but a picoammeter can measure down into the femtoamp or even attoamp range. (Fun fact: 0.01 fA (or 10 aA) is approximately equal to 62 to 63 electrons per second.)

An electrometer includes the capabilities of the picoammeter but adds (at a minimum) the ability to source very large voltages, so no additional equipment is needed to make a resistance measurement.

Fundamentals of resistance measurements

The first fundamental choice you must make is whether to perform the measurement in a floating or grounded configuration. As *Figure 2* shows, the configuration for the two cases is quite different, but you can make good high-resistance measurements with both.

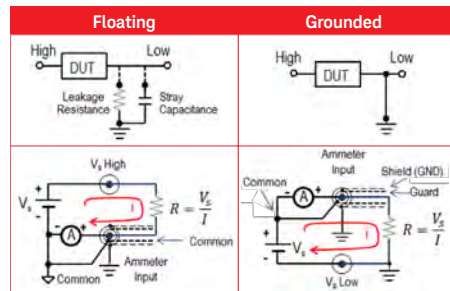


Figure 2. Floating and grounded resistance measurement configurations.

At left, the device under test (DUT) is floating with respect to earth ground. The resistance between the high terminal and the low terminal is measured. The bottom left shows the corresponding circuit diagram, with the test device connected between the V_S high output and the ammeter input.

At right, the DUT is grounded. The applied test voltage and current measurement must both occur at the DUT's high-side terminal. The bottom right shows the corresponding circuit diagram, with the ammeter connected to the V_S positive output.

Transient behavior and noise

Two basic issues impact measurement of low-level signals: transient behavior and statistical analysis.

Almost all measurements give a different value depending upon how recently you applied a stimulus. Ideally, you use a graph of measurement data versus time to select when to capture your measurement. Therefore having graphical display capability is highly desirable in a picoammeter or electrometer.

Although all measurements have some uncertainty associated with them, this is especially true for low-level measurements. The ideal solution is to view statistical data (i.e., mean and standard deviation) in real time, so you can adjust measurement parameters to optimize results.

The biggest single source of noise when making measurements is the AC power line. This will show up as 50 or 60 Hz variations in your measurement data. You can compensate by making multiple measurements across power-line cycles, but this will greatly increase time. The best solution is to run the measurement equipment off a DC battery supply—and you can also make measurements in locations that don't have easy access to AC power.

Electrometer capabilities

Figure 3 shows the key features of an electrometer, including sourcing and measurement input terminals. The instrument here is the Keysight B2985A electrometer, a member of the B2900 precision instrument family.

Learn more about making these challenging measurements at:

www.keysight.com/find/SensitiveMeasurement

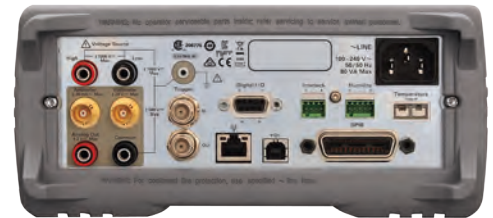


Figure 3. The Keysight B2980 Series lets you perform ultra-low-current and high-resistance measurements without the need for any external equipment.

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Keysight and our network of Keysight Authorized Distributors have teamed up to provide fast, easy access to the world's largest selection of off-the-shelf T&M instruments. It's the best of both worlds: Keysight's measurement expertise and product breadth combined with speed, convenience and same-day shipping from our distribution partners. It's never been easier to get the right instrument in the right hands, right away.



B2900 precision benchtop instrument family

These powerful precision sourcing and measurement solutions have broad applications from R&D and education to industrial development, production test, and automated manufacturing. The B2900 units work equally well as standalone or system components.



B2961/62A low-noise power source

- Ultra-low noise source (10 μ Vrms, 1 nVrms/ $\sqrt{\text{Hz}}$ @10kHz)
- Unmatched source resolution (6.5 digit, 100 nV/10 fA)
- Precision ARB capability (1 mHz ~ 10 kHz)
- Time-domain waveform viewer

BenchVue software enabled

[B2961/62A Data Sheet](#)

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B2900A precision source/measure unit

- Wide application coverage (from 100 nV/10 fA to 210 V/ 3 A DC & 10.5 A pulsed)
- Best-in-class source and measure resolution (6.5 digit, 100 nV/10 fA)
- Fast current-voltage (I-V) sweep measurement capability
- Graphical I-V curves view

BenchVue software enabled

[B2900A Data Sheet](#)

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B2980A femto/picoammeter and electrometers

- Best-in-class current measurement performance
- (2 pA range and 0.01 fA resolution)
- Integrated 1,000-V source supports resistance measurements up to 10 Ω
- Battery operation models for line-free noise measurements
- Graphical time domain and histogram views

[B2980A Data Sheet](#)

[Learn more about the B2980A](#)

Digital Multimeters | www.keysight.com/find/dmm

Truevolt digital multimeters (DMMs)

BenchVue software enabled

[34460A, 34461A, 34465A, 34470A Data Sheet](#)

[Learn more about Truevolt](#)

- 6½ and 7½ digit performance
- Graphical capabilities such as trend and histogram charts
- Measure very low current, 1 μ A range with pA resolution, allowing measurements on very low power devices
- Auto calibration to compensate for temperature drift
- Basic measurements: DCV, ACV, DCI, ACI, 2- and 4-wire resistance, frequency, period, continuity, diode, temperature, capacitance



Model	Description	Digits of resolution	Max reading rate at 4½ digits (rdgs/s)	Built-in PC interfaces
34460A	New industry standard. Display DMM results in ways you never have before and measure with unquestioned Truevolt confidence.	6½	300	USB; optional GPIB, LAN
34461A			1,000	USB, LAN; optional GPIB
34465A	More measurements, higher speed, better accuracy, and more memory than the 34461A.	6½	5,000; optional 50,000	USB, LAN; optional GPIB
34470A		7½		

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NEW E36300 Series triple output DC power supplies



- 4.3" color display that shows voltage and current on all three channels simultaneously
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- Output ripple and noise: < 2 mVpp/350 uVrms
- Data logging plus output sequencing and coupling
- Front and rear output terminals
- Color-coded channels and individual knobs for voltage and current
- Modern I/O (USB, LAN and GPIB)

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 [E36300 Series Data Sheet](#)

 [Learn more about the E36300 Series](#)

Model	E36311A			E36312A			E36313A		
Performance specifications	80 W			80 W			160 W		
Channels	1	2	3	1	2	3	1	2	3
DC output	0 to 6 V	0 to +25 V	0 to -25 V	0 to 6 V	0 to 25 V	0 to 25 V	0 to 6 V	0 to 25 V	0 to 25 V
Rating (0 to 40 °C)	0 to 5 A	0 to 1 A	0 to 1 A	0 to 5 A	0 to 1 A	0 to 1 A	0 to 10 A	0 to 2 A	0 to 2 A


BenchVue Software | www.keysight.com/find/benchvue

BenchVue control, automation and analysis software

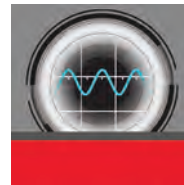
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- MegaZoom IV responsive, uncompromised smart memory
- Multiple instrument functionality
- Upgradable: bandwidth, MSO, serial analysis, built-in WaveGen function generator, or digital voltmeter and counter

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[Oscilloscope how-to video series. The basics for beginners and some helpful tips for more advanced users.](#)

Model	Description	Bandwidth	Channels	Sample rate	Memory depth	Standard warranty	Calibration period	Special triggers	Built-in instruments*
1000 X-Series 1000X Data Sheet Videos	Basic R&D bench - 50,000 wfms/s update rate - 7-inch display - Serial bus options	50 MHz to 100 MHz	2	Up to 2 GSa/s	Up to 1 Mpts	3 years	5 years	Serial protocol	Frequency response analyzer, 20 MHz FG, 5-digit counter
2000 X-Series 2000X Data Sheet Videos	Basic R&D bench - 50,000 wfms/s update rate - 8.5-inch display - Serial bus options	70 MHz to 200 MHz	2, 2+8, 4, 4+8	Up to 2 GSa/s	Up to 1 Mpts	5 years	2 years	Serial protocol	20 MHz FG, 5-digit counter
3000T X-Series 3000TX Data Sheet Videos	Everything the 2000X has plus - 1,000,000 wfms/s update rate - Advanced math and power analysis - Capacitive touch screen	100 MHz to 1 GHz	2, 2+16, 4, 4+16	Up to 5 GSa/s	4 Mpts and segmented memory standard	3 years	3 years	Near Field Communication (NFC) Trigger, Serial protocol, Zone touch	20 MHz AWG, 8-digit counter, totalizer and frequency response
4000 X-Series 4000X Data Sheet Videos	Everything the 3000T has plus - 12.1-inch capacitive touch screen - FFT, USB 2.0 pre-compliance - Up to four active probes	200 MHz to 1.5 GHz							Dual 20 MHz AWG, 5-digit counter and frequency response analyzer
6000 X-Series 6000X Data Sheet Videos	Everything the 4000X has plus - 450,000 wfms/s update rate - Multi-touch display - Voice control - Jitter and real-time eye diagram analysis	1 GHz to 6 GHz		Up to 20 GSa/s		2 years	Serial protocol, Zone touch	Dual 20 MHz AWG, 10-digit counter, totalizer and frequency response analyzer	

*All models have built-in protocol analyzer and 3-digit DVM.



InfiniiVision software applications

Serial protocols and triggering

I²C, SPI, RS232, UART, USB 2.0, CAN, CXPI, LIN, FlexRay, Audio, MIL-STD 1553, ARINC 429, and more

Features



Dual-channel WaveGen, jitter, real-time eye diagram, integrated voltmeter, 10-digit counter, mask limits, USB signal quality, video/TV, FPGA dynamic probe, power analysis, frequency response analysis via Bode plot, near field communication testing, and more.

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33500B and 33600A Series waveform generators

- Generate Trueform arbitrary waveforms with less jitter, more fidelity and greater resolution
- Modulation, sweep, burst, dual-channel coupling
-  BenchVue software enabled
-  [Learn more about benchtop waveform generators](#)





Model	Description	Channels	Frequency range	Pulse	Arbitrary waveforms					
					Std/Opt arb	# bits	Sample rate	Memory/Channel		
33509B 33510B	Exclusive Trueform waveform technology with <40 ps jitter and <0.04% THD.	1	20 MHz	20 MHz	Opt	16	160 MSa/s	1 M Standard, 16 M Optional		
33511B 33512B		2			Std					
33519B 33520B		1	30 MHz	30 MHz	Opt					
33521B 33522B		2			Std					
33611A		1	80 MHz	80 MHz	Std		14		660 MSa/s	4 M Standard, 64 M Optional
33612A		2								
33621A	1	120 MHz	100 MHz							
33622A	2			1 GSa/s						

Data Acquisition Units and Modules | www.keysight.com/find/34972A

34970A/34972A data acquisition switch units



- Low-cost, 3-slot unit with 6½ digit DMM and built-in signal conditioning
- Choose from 8 plug-in modules, up to 120 1-wire (60 2-wire) channels or 96 cross points
- 34972A has built-in Web interface
-  BenchVue software enabled
-  [34970A/34972A Data Sheet](#)

34970A/72A modules

Model	Key specifications
34901A/02A/08A multiplexers	Up to 300 V, 16, 20, or 40 channels
34903A general-purpose switch	300 V, 20 actuator channels
34904A matrix	4x8 matrix
34905A/06A RF switches	2 GHz dual, 50 and 75 Ω
34907A multi-function	DIO, DAC, totalizer

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E5063A ENA Series network analyzer

- Various frequency options to suit your test needs and budget, upgradable at any time
- PCB manufacturing test capability with Option 011
- Support for six languages via softkey and the embedded help manual in English/Simplified Chinese
- Supports all Keysight calibration kits including the N755xA economy ECal module

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 [Learn more about the E5063A ENA Series network analyzer](#)

 [Learn more about Keysight calibration kits](#)




E5063A highlights	
Frequency ¹	100 kHz to 500 M, 1.5, 3, 4.5, 6.5, 8.5, 14 or 18 GHz
Test port	2-port 50 Ω S-parameter test set
Dynamic range	117 dB (spec.), 122 dB (typ.)
Trace noise	0.005 dBrms (spec.), 0.002 dBrms (typ.)
Cycle time	19 msec (typ. 201 points, full 2-port cal)
Stability	0.01 dB/°C
Source power	-20 to 0 dBm
Key software capability	Fixture simulator, Time domain analysis/Test Wizard option ² , Wireless power transfer analysis ³ , and Materials measurement ⁴
Interface	LAN, USB (front 2, rear 4), USBTMC, GPIB ⁴ , Handler I/O ⁴

1. The E5063A starting frequency can be set down to 50 kHz.
2. Optional capability. Consists of conventional time domain analysis capabilities and GUI for PCB test.
3. Optional capability.
4. External software (Keysight N1500A Material Measurement Suite) required.

FieldFox Handheld Analyzers | www.keysight.com/find/fieldfox



- Maximum frequency from 4 to 50 GHz across family of 22 models
- Measurement results agree with those obtained with benchtop analyzers
- Compact form factor measures 29 x 19 x 7 cm (11.5 x 7.4 x 2.8 in)
- Light weight (3.2 kg /7.1 lbs), dust-free, and weather-resistant
- MIL-PRF-28800F Class 2 compliant
- MIL-STD-810G, Method 511.5 Procedure I requirements for operation in explosive environments (type tested)

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	Combination analyzers			Vector network analyzers		Spectrum analyzers	
Model number	N9912A	N9913/4/5/6/7/8A	N9950/1/2A	N9923A	N9925/6/7/8A	N9935/6/7/8A	N9960/1/2A
Maximum frequency range	4, 6 GHz	4, 6.5, 9, 14, 18, 26.5 GHz	32, 44, 50 GHz	4, 6 GHz	9, 14, 18, 26.5 GHz	9, 14, 18, 26.5 GHz	32, 44, 50 GHz
Cable and antenna analyzer	Standard			Optional		Optional (VSWR & RL)	
Vector network analyzer	Optional (1 port)	Optional		Standard		—	
QuickCal	Optional		—	Optional		—	
Full 2-port S-parameters	—	Optional		Optional		—	
VNA time domain	Optional			Optional		—	
Spectrum analyzer	Optional			—		Standard	
Real-time spectrum analyzer	—	Optional		—		Optional	
Interference analyzer	Optional			—		Optional	
Tracking generator	Optional			—		Optional	
Vector voltmeter	Optional			Optional		—	
Built-in power meter	Optional			—	Optional	Optional	

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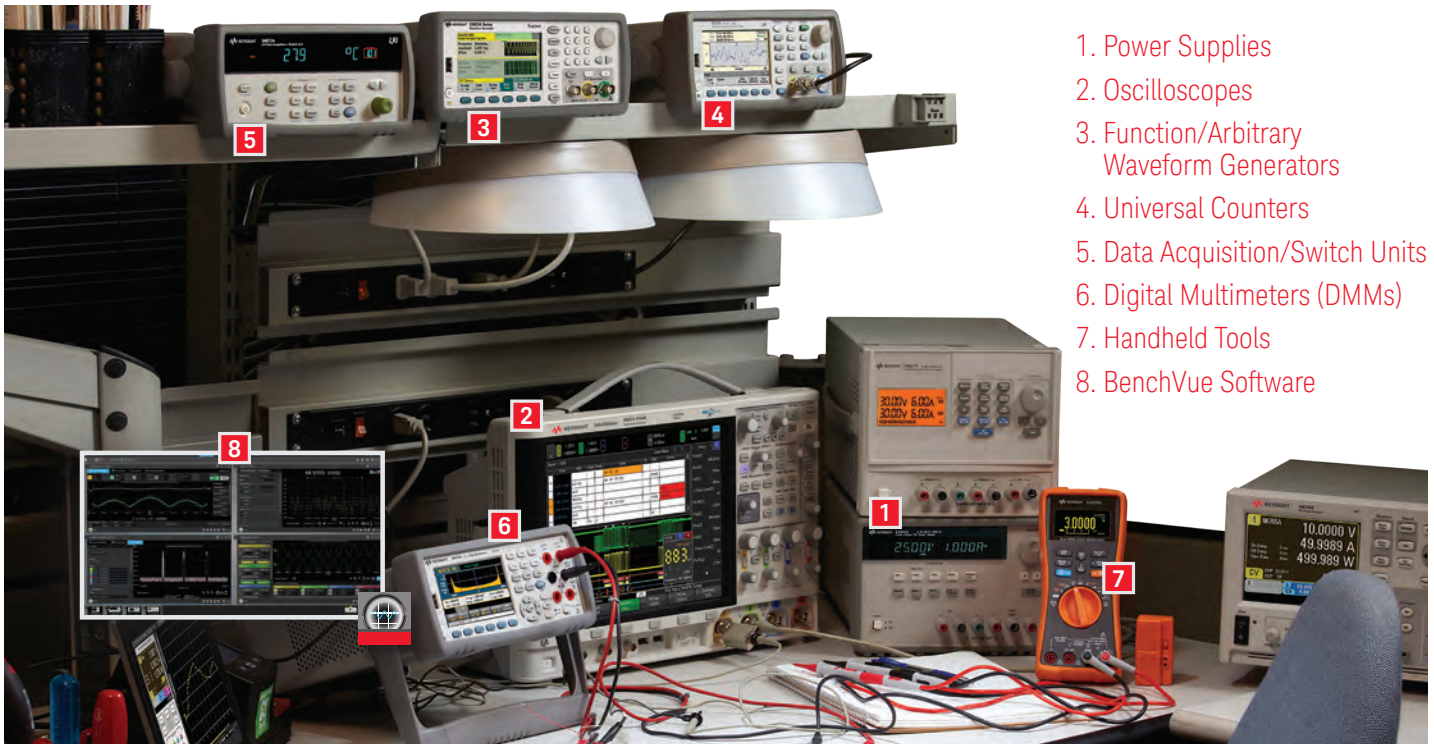
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