10 Practical Tips You Need to Know About Your Power Products

Application Note

Simple ways to improve your operation and measurement capabilities

KEYSIGHT
TECHNOLOGIES

Tip 1: Use remote sensing to compensate for load-lead effects

When your power supply leaves the factory, its regulation sense terminals are usually connected to the output terminals. This limits the supply's voltage regulation abilities, even with very short leads. The longer the leads and the higher the wire gauge, the worse the regulation gets (Figure 1). Compare the output impedance of a well-regulated 10 A supply, which might have an output impedance of 0.2 mΩ, with the resistance of copper wire:

AWG wire size	Resistance in mΩ/ft (at 20° C)
22	16.1
20	10.2
18	6.39
16	4.02
14	2.53
12	1.59
10	0.999

And regulation gets even worse if you use a relay to connect power to the load.

Remote sensing, in which you connect the sense terminals of the power supply's internal feedback amplifier directly to the load, lets the power supply regulate its output at the load terminals, rather than at its own output terminals (Figure 2). The supply voltage shifts as necessary to compensate for the resistance of the load leads, relays, or connectors, thereby keeping the voltage at the load constant.

To implement remote sensing, disconnect the local sense leads from the output terminals. Use twisted two-wire shielded cable to connect the power supply sensing terminals to the sense points on the load. (Don't use the shield as one of the sensing conductors.) Connect one end of the shield to ground and leave the other end unconnected.

Sensing currents are typically less than 10 mA, and as a general rule, you should keep the voltage drop in the sense leads to less than 20 times the power supply temperature coefficient (usually stated in mV/°C). This is easy to achieve with readily available shielded two-wire cable.
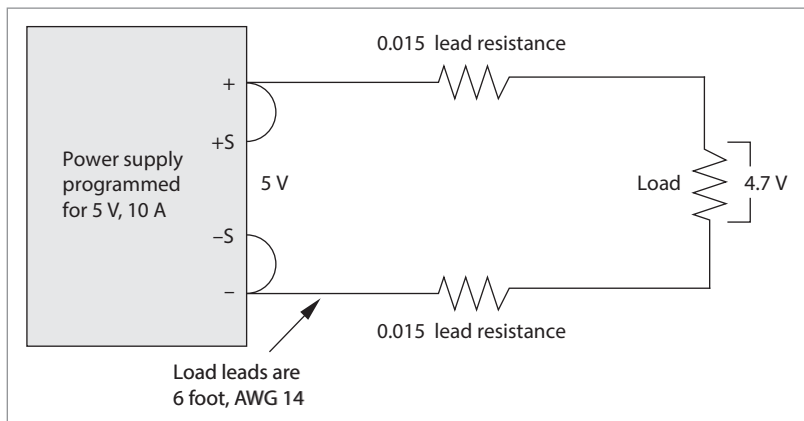

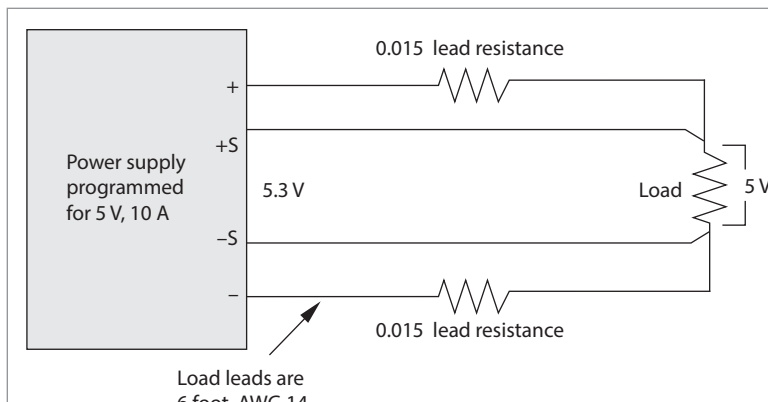Figure 1: The effects of six feet of AWG 14-gauge leads without remote sensing

Figure 2: Using remote sensing to correct the lead-load problem

Tip 2: Increase safety with remote disable feature

Remote disable offers a safe way to shut down a power supply to respond to some particular operating condition or to protect system operators (in response to a cabinet door being opened unexpectedly or someone pushing a panic button, for instance).

Remote inhibit (RI) is an input to the power supply that disables the output when the RI terminal is pulled low (Figure 1). Shorting the normally open switch turns off the supply's output. You could also use a logic chip with an open collector transistor output instead of the switch. Figure 1 also shows a discrete fault indicator (DFI) that you can use to signal an operator or other components in the system when the power supply detects a user-defined fault.
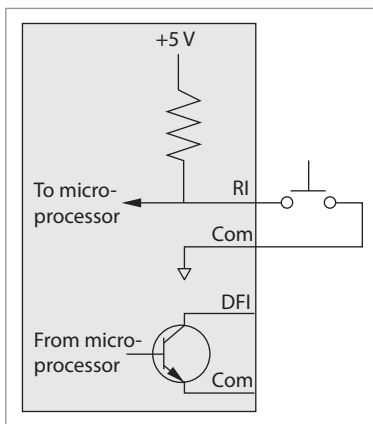
Almost any operating condition can create a DFI signal. For example, to generate a DFI signal when the load draws excessive current, enable the over-current protection (OCP) mode, program the unit to generate a DFI signal when it enters constant current mode, then program the maximum current the load normally draws. If the load current exceeds the maximum, the DFI output goes low, disables the power supply, and informs the operator of the over-current condition (or performs another user-defined function), without tying up the system bus or interrupting the system controller.

You can daisy chain DFI and RI as shown in Figure 2. If one supply detects a fault, all supplies in the system are disabled. Using this approach, you can chain together an unlimited number of supplies.
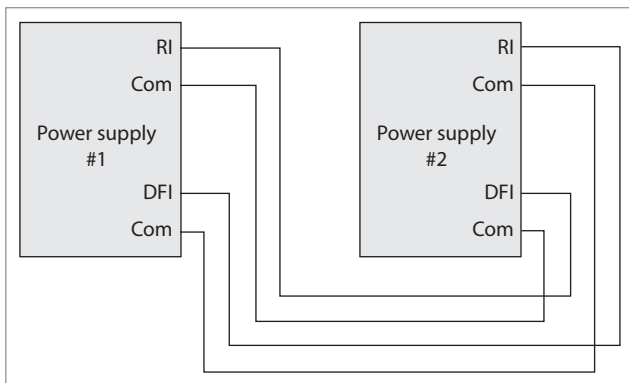

Figure 1. Remote inhibit and discrete fault indicator schematic

Figure 2. Daisy-chained DFI and RI

Tip 3: Eliminate noise from low-level measurements

Noise in low-level measurements can come from a number of different sources, and it's easier to eliminate noise than to filter it. Check these noise sources:

1. Power supply

Starting with a low-noise supply is naturally a great way to keep noise out of your measurements. Linear power supplies have lower common-mode noise currents and generally operate at low frequency. However, you can use switch-mode supplies successfully if their specifications include a low common-mode current. As a rule of thumb, common-mode current over 20-30 mA is likely to cause trouble. Keep reading for hints on how to minimize the problem.

2. DUT to power supply connections

Minimize conducted noise by eliminating ground loops. Ideally, there should be only one connection to ground. In rack systems, where multiple ground points are inevitable, separate the dc distribution path from other conductive paths that carry ground currents. If necessary, float the power supply (don't connect either terminal directly to ground).

Minimize radiated pick-up (both electric and magnetic) by using twisted shielded conductors for the output and remote sense leads. To make sure the shield doesn't carry current, connect the shield to ground at one end only, preferably the single-point ground on the supply (Figure 1).

Minimize the power supply's common-mode noise current by equalizing the impedance to ground from the plus and minus output terminals. Also equalize the DUT's impedance to ground from the plus and minus input terminals. Magnetic coupling or capacitive leakage provide a return path for noisy ground loop current at higher frequencies. To balance the DUT's impedance to ground for your test frequencies, use a common-mode choke in series with the output leads and a shunt capacitor from each lead to ground.

3. Current variations to the DUT

Rapid changes in the DUT's current demand cause voltage spikes. To prevent this, add a bypass capacitor close to the load. The capacitor should have a low impedance at the highest testing frequencies. Avoid imbalances in load lead inductance; direct connections to the DUT, such as twisted shielded pair, are your best bet.
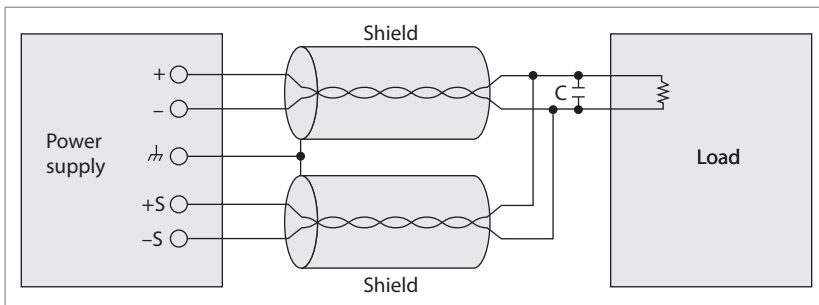

Figure 1: Minimizing radiated pick-up with twisted shield leads for both output and remote sense leads

Tip 4: Use down programming to increase test speed

Under light or no load conditions, a power supply's output capacitor discharges slowly. If you're using the supply as a static voltage source, this is not problematic, but when you're making tests at varying voltage levels, slow discharge means slow tests.

Down programming circuits in power supplies rapidly decrease the output voltage, reducing discharge times by hundreds of milliseconds. Keysight Technologies, Inc. power supplies use two types of down programming circuits:

– In Figure 1, an FET is placed across the output terminals. Whenever the output voltage is higher than the programmed value, the FET activates and discharges the output capacitor. The FET can sink currents ranging from 10 percent to 20 percent of the supply's output current rating. The maximum load at low voltages is limited to the On resistance of the FET plus the series monitoring resistor, resulting in a slight degradation of the down programming current near zero volts.

– In Figure 2, the down programmer lies between the power supply's positive terminal and a negative source. This configuration pulls the output completely down with no degradation near zero.

Some power supplies, such as the Keysight 663xA series, can sink currents equal to their full output current rating. This sink current is programmable, so you can use the supply both as a programmable source and load.
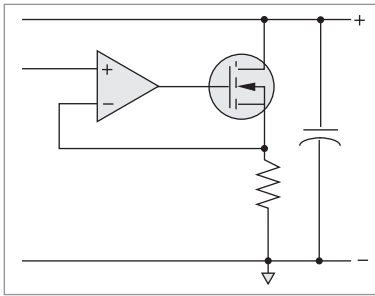

Figure 1: A down programming circuit with an FET across the output terminals
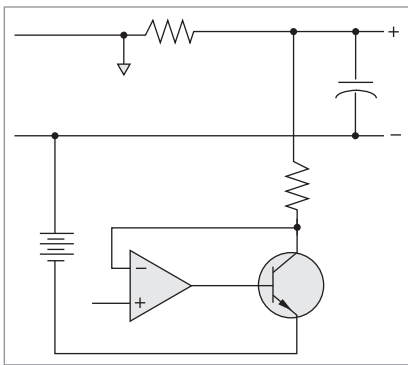
Figure 2: A down programmer situated between power supply's positive output and a negative source

Tip 5: Simplify setup with autoranging power supplies

With bench and rack space at a premium, having the ability to produce a wide range of voltage and currents with one power supply is beneficial. Applications that require many voltage and current combinations require many power supplies or a very large power supply to span the largest voltage and current combination. For example, a dc/dc converter is tested under several voltage and current combinations at about the same power level.

A very basic dc power supply has a rectangular output (Figure 1). It has a maximum voltage setting (Vmax) and a maximum current setting (Imax) with a single maximum power point (Pmax) which equals Vmax * Imax. This creates a rectangular output characteristic.

More advanced power supplies have multi-range outputs. For example, a dual-range power supply (Figure 2) has two rectangular output characteristics, each having a different Vmax and Imax. However, both output characteristics have the same Pmax but at two different points. The power supply can switch between the different ranges to satisfy both rectangular output characteristics.

Autoranging outputs (Figure 3) satisfy many different voltage and current combinations that are limited by Pmax. The output characteristic follows a constant Pmax curve allowing for several different power curves rated at the same power level, Pmax.

Using autoranging outputs simplifies the test setup by eliminating the need for many power supplies. Supplies such as the Keysight N675xA and N676xA have autoranging outputs that help do this and drive the cost of test down.
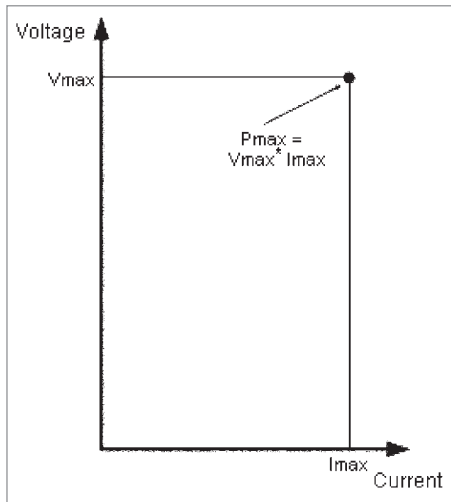

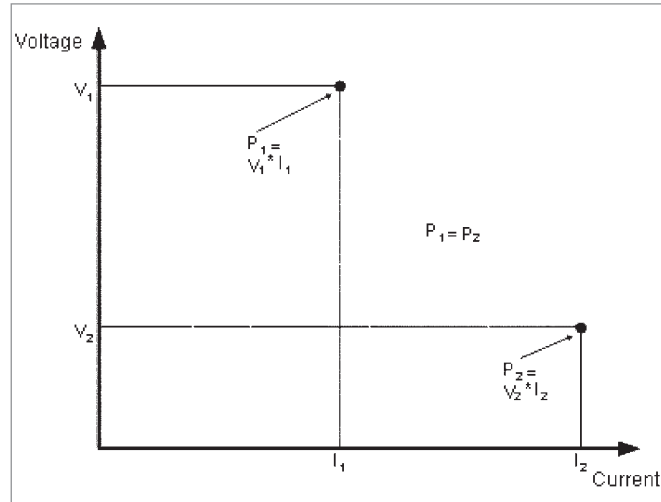Figure 1: Rectangular output characteristic
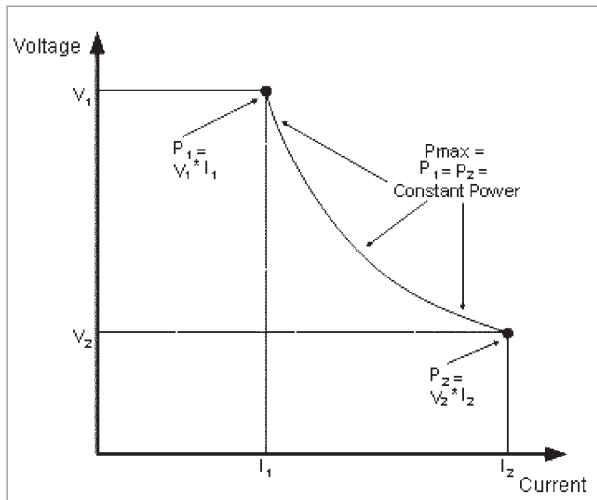

Figure 2: Dual-range output characteristic

Figure 3. Autoranging output characteristic

Tip 6: Connect power supplies in series or parallel for higher output

Connecting two or more power supplies in series (Figure 1) provides higher voltages, but observe these precautions:
– Never exceed the floating voltage rating of any of the supplies.
– Never subject any of the power supplies to negative voltages.

Program each power supply independently. If two supplies are used, program each one for 50% of the total output voltage. If three supplies are used, program each supply for about 33% of the total output voltage. Set the current limit of each supply to the maximum that the load can safely handle.

Connecting two or more power supplies in parallel (Figure 2) provides higher currents, but again, observe these precautions:

– One unit must operate in constant voltage (CV) mode and the other(s) in constant current (CC) mode.
– The output load must draw enough current to keep the CC unit(s) in CC mode.

Program the current limit of each unit to its maximum value and program the output voltage of the CV unit to a value slightly lower than the CC unit(s). The CC units supply the maximum output current that they have been set to and drop their output voltage until it matches the voltage of the CV unit, which supplies only enough current to fulfill the total load demand.

The Keysight N6700 supplies have a grouping function that virtually parallels outputs. Output channels can be configured or "grouped" to create a single output with higher current and power capability.
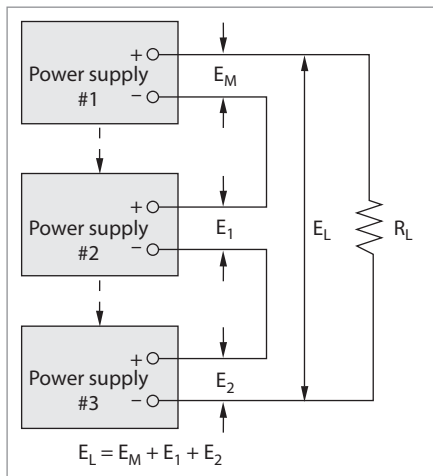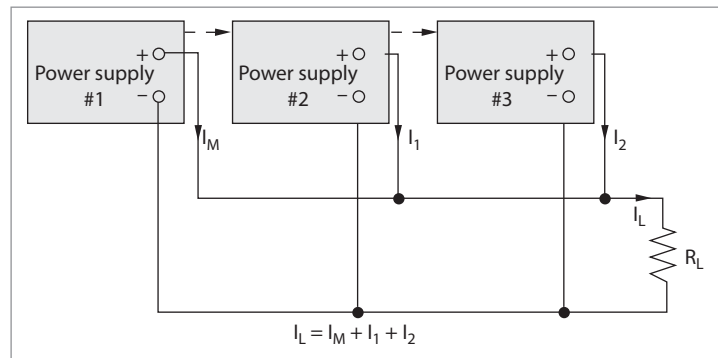

Figure 1: Connecting units in series

Figure 2: Connecting units in parallel

Tip 7: Simplify battery drain analysis with analysis tools

To adequately specify the power source for products that exhibit pulsed and dynamic current loading (such as digital cellular phone and hard drives), you need to evaluate both the peak and dc averages current draws.

You could use an oscilloscope to monitor a shunt or a current probe, but this approach raises issues with voltage drops, ground loops, common mode noise, space, and calibration.

As a simpler and cheaper alternative, use a power supply with built-in measurement capabilities. The Keysight 66300 mobile communications dc sources store up to 4,096 data points at sample intervals from 15 µs to 31,200 s. Like an oscilloscope, they acquire pre- and post-trigger buffer data by crossing a user-set threshold.

The Keysight 14565B device characterization software is an automation tool compatible with the 66319/21B or D. These four sources have battery emulation capabilities and work with the software to accurately test today's communication devices as well as your next generation designs for cell phones, PDAs, *Bluetooth™* enabled devices, and wireless LAN access devices. The software features dynamic current characterization (Figure 1), data logging (Figure 2), and CCDF measurements (Figure 3).
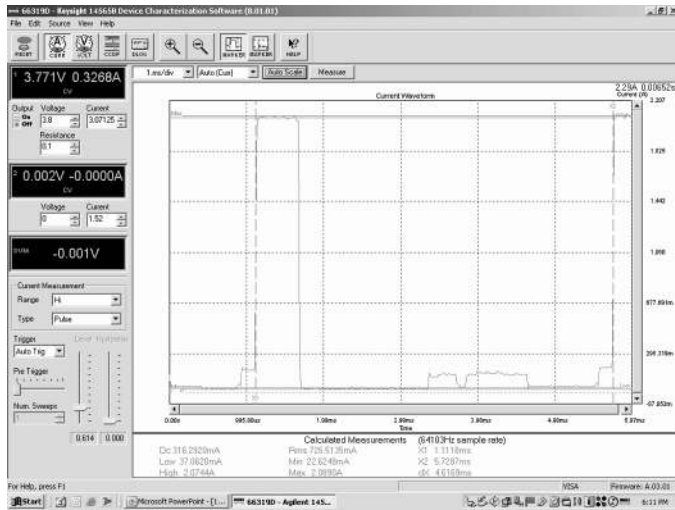

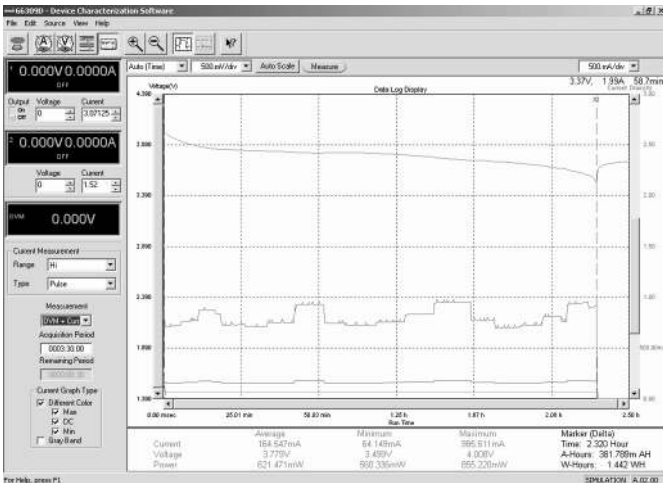Figure 1. Waveform capture and analysis using the Keysight 14565B software.

Figure 2. Data logging and analysis using the Keysight 14565B software.
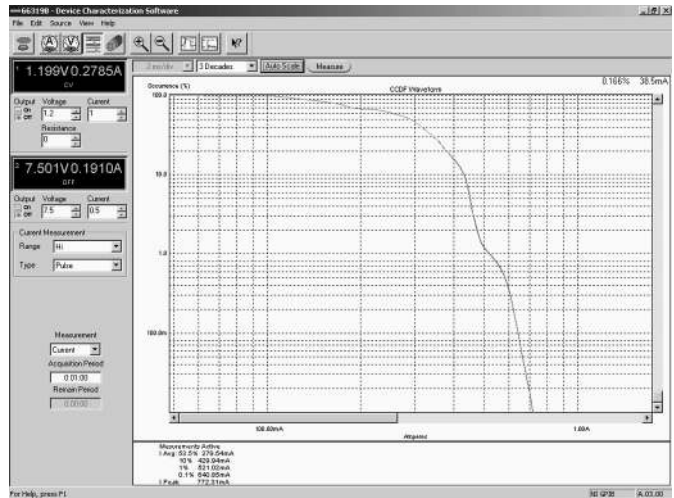

Figure 3. Complementary cumulative distribution function (CCDF) capture and analysis using the Keysight 14565B software.

Tip 8: Characterize inrush current with an ac power source/analyzer

The inrush current characteristics of ac-dc switch mode power supplies vary with the turn-on phase of the voltage cycle. Usually, these power supplies have input capacitors that draw high peaks of inrush current as they charge from the rectified ac line at turn-on. Characterizing inrush current versus turn-on phase can provide some important design insights:
- Uncover component stresses
- Check to see if a product produces ac mains disturbances that interact with other products connected to the same branch circuit
- Select proper fuses and circuit breakers

However, this can be a challenging measurement because you have to synchronize the current digitization and peak current measurement with the startup phase of the voltage. Worst case inrush currents occur near the voltage cycle's peak and when the ac input capacitor of the DUT is fully discharged at startup.

Therefore, you must perform tests at incremental voltage startup phases from about 40° to 90° (Figure 1) and let the DUT's ac input capacitor discharge between tests.

A traditional test setup includes an ac source with programmable phase capability and an output trigger port, a digital oscilloscope, and a current probe. However, using an advanced ac power source/analyzer such as the Keysight 6800 series ac power source/analyzers is easier because they have built-in generation, current waveform digitization, peak current measurement, and synchronization capabilities that let you perform inrush current characterization without cabling and synchronizing separate instruments.

On the dc side, the Keysight N6705A dc power analyzer helps characterize the power of a device much like the ac power source/analyzer, except for dc power.
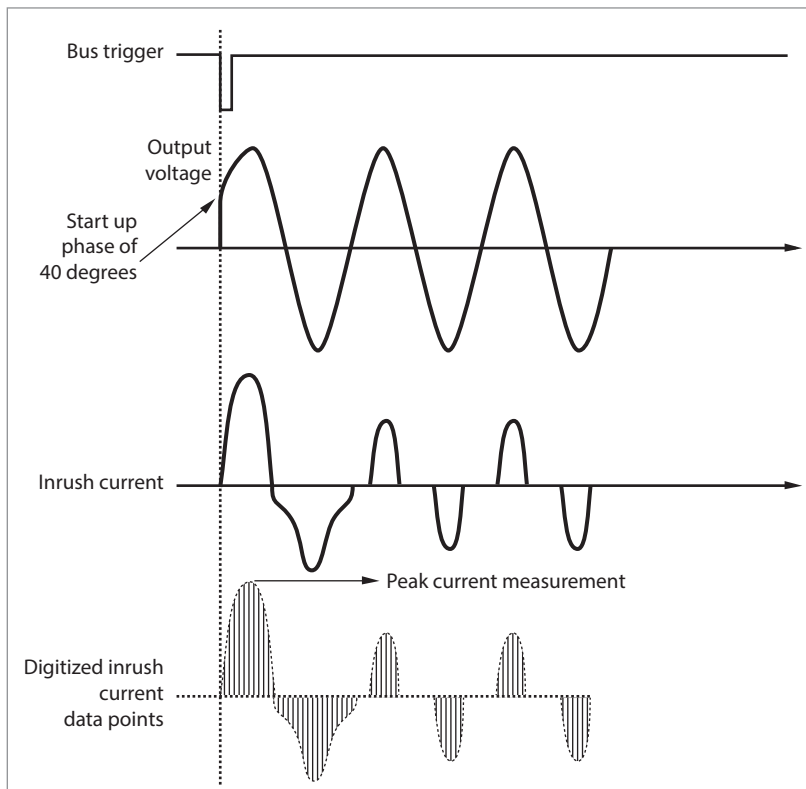

Figure 1: An inrush current measurement at 40° using Keysight 6800 series ac power source/analyzers

Tip 9: Use a power supply to measure DUT supply current

Accurately measuring DUT supply currents above 10 A is beyond the range of the typical DMM in ammeter mode. You could use an external shunt and the DMM's voltage mode, but using the power supply itself is a better solution. Many supplies include an accurate measurement system, including a shunt. Current (with the internal shunt) or voltage measure-ments at the DUT can be as simple as sending a MEAS command to the power supply.

The following table shows the level of measurement accuracy you can expect with a good-quality supply:

Output level	Typical accuracy
Full	0.1% to 0.5%
10% of full output	0.5% to 1%
10% of full output	near 10%

While the advantages of using the power source to measure high currents is clear, using it to measure low currents may not be as obvious. A system DMM has 0.01 percent to 0.1 percent accuracy, although this doesn't include other possible errors that can affect the measurement, such as cabling. In contrast, the power supply accuracy figures in the table include all applicable factors.

A good system DMM can measure current down to the picoamp level, but you rarely need to measure DUT supply currents this low. In most cases, the toughest measurement will involve current draw by a battery-powered device in sleep mode (such as a cellular phone), where measuring 1-10 mA with reasonable accuracy is usually all you need.

Most power supplies' current readback performs well between full scale and 10% of full scale. You can also choose a power supply with multiple range readback. For example, power sources, such as the Keysight N676xA precision modules, offer full scale accuracy of 0.04% + 15 µA at low range (100 mA) or 0.04% + 160 µA at high range (3 A).

Tip 10: Create dc power waveforms with list mode

Instead of using a DAC or arbitrary waveform generator to drive a power supply to create dc power waveforms, consider using a single power product with list mode. List mode lets you generate complex sequences of output changes with rapid, precise timing which may be synchronized with internal or external signals. They contain up to 512 individually programmed steps and can be programmed to repeat themselves.

Using list mode helps you create dc power waveforms such as:
  – Pulse trains
  – Ramps
  – Staircases
  – Low frequency sinewaves with dc offset
  – Arbitrary voltage and current waveforms

You can create a sequence of up to 512 command steps to define voltage or current steps and set dwell times for each step. These waveforms can also trigger on internal or external events and be repeated (Figure 1). Once the list of commands is stored in the power supply, the entire list is executed by a single command. This reduces command processing time and simplifies code. Example applications include powering power supply rejection ratio test, simulating automotive crank profiles, and generating pulse dropouts.

Power products such as the Keysight N675xA and N676x modules in the Keysight N6700 Modular Power System have list mode. The maximum frequency of the waveform is limited by the power module and voltage setting of the test.

In addition, the Keysight N6705A dc Power Analyzer is a unique bench product with list mode. You can program arbitrary waveforms directly from the front panel without writing a single line of code.
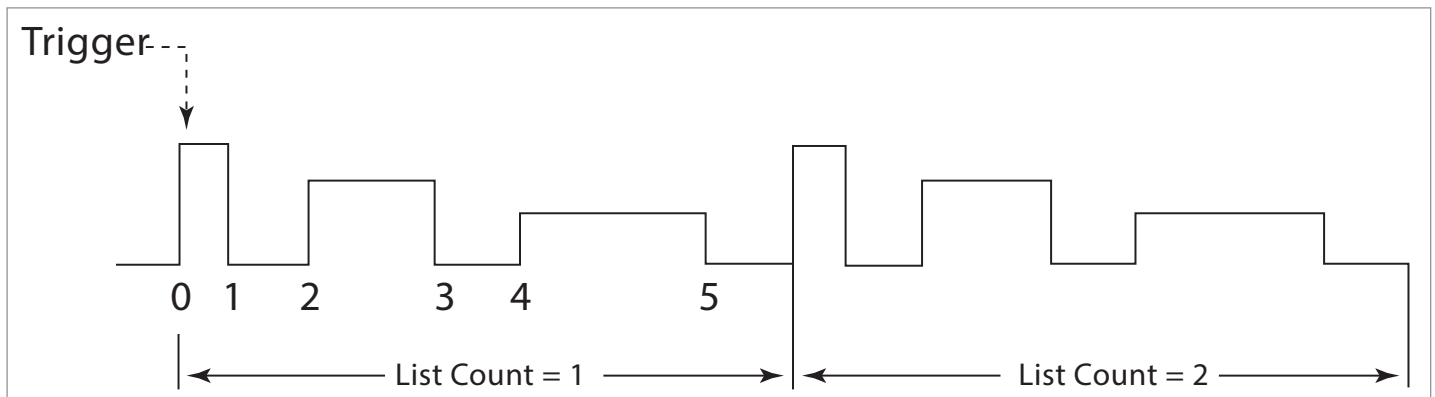

Figure 1: An arbitrary voltage waveform example with a repeat count of 2.

Power products that do more and demand less

Keysight Technologies' "one-box" philosophy means we pack more and more capability into the power products themselves, in some cases giving you a rack's worth of capability in a single box.

By offering more, these products demand less from you—fewer instruments, less rack space, simpler test setups, and lower cost of ownership.

Modular Power Systems (MPS)

With rack space at a premium, the Keysight 66000 and N6700 modular power systems' growing popularity is no surprise. Mix and match modules to fit the needs of many applications. These systems are small, flexible, and fast.

The Keysight N6705A is the bench version of the N6700. It uses the same modules as the N6700 and combines the functionality of many instruments for dc power characterization.

66000 MPS

- High power density – up to eight supplies in seven inches of rack space
- Low noise, stable power
- High accuracy programming and readback

N6700 MPS

- Up to four supplies in 1.25 inches of rack space
- Flexible – three performances: basic, hi-perf, and precision modules
- Easy connectivity – LXI Class C with GPIB, LAN, and USB

- Feature rich – up to 4 supplies, oscilloscope-like display, arb capabilities
- Output synchronization controls, inrush current testing, data logging
- External BNC and digital port for easy triggering

| Modular power systems						
Model	66101A	66102A	66103A	66104A	66105A	66106A
Output ratings at 40° C						
Output voltage	0 to 8 V	0 to 20 V	0 to 35 V	0 to 60 V	0 to 120 V	0 to 200 V
Output current	0 to 16 A	0 to 7.5 A	0 to 4.5 A	0 to 2.5 A	0 to 1.25 A	0 to 0.75 A
Maximum power	128 W	150 W	157.5 W	150 W	150 W	150 W
Basic Models	**N6731A/41A**	**N6732A/42A**	**N6733A/43A/73A**	**N6734A/44A/74A**	**N6735A/45A/75A**	**N6736A/46A/76A**
Output ratings at 40° C						
Output voltage	5 V	8 V	20 V	35 V	60 V	100 V
Output current	10 A/20 A	6.25 A/12.5 A	2.5 A/5 A/15 A	1.5 A/3 A/8.5 A	0.8 A/1.6 A/5 A	0.5 A/1 A/ 3 A
Maximum power	50 W/100 W	50 W/100 W	50 W/100 W/300 W		52.5 W/105 W/300 W	50 W/100 W/300 W
Hi-Perf, Precision Models	**N6751A/52A**	**N6753A****	**N6754A**	**N6761A/62A***		
Output ratings at 40° C						
Output voltage	50 V	20 V	60 V	50 V		
Output current	5 A/10 A	50 A	20 A	1.5 A/3 A		
Maximum power	50 W/100 W	300 W	300 W	50 W/100 W		

*   Precision power supplies
** Module not compatible with the N6705A.

Power you can count on year after year

We've been a leader in the power products business for more than half a century because engineers like you know they can count on Keysight performance, reliability and value. Even our least-expensive dc supplies offer low ripple and noise with tight load and line regulation. Our high precision products give you the exact power levels you need, with accurate readback measurements to match. Plus, every product you see here is covered by a one-year warranty.

To learn more about these power solutions, visit our Web site at www.keysight.com/find/power.
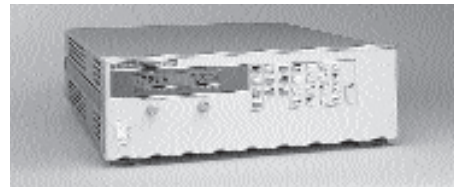
Single-output dc supplies

These supplies will clean up your ATE power without cleaning out your budget. Not only do you buy more performance with the Keysight 6600 or N5700 series, their one-box integration means you'll buy less equipment overall, too.

– Clean, reliable dc power from 40 W to 6.6 W
– Designed for fast, easy system integration
– Built-in V & I readback for one-box convenience
– LXI Class C N5700 supplies with GPIB, LAN, and USB

Single-output dc supplies

40 W and 100 W	6612C	6632C	6633C	6634B		
Voltage	0 to 20 V	0 to 20 V	0 to 50 V	0 to 100 V		
Current	0 to 2 A	0 to 5 A	0 to 2 A	0 to 1 A		
200 W	**6541A***	**6542A***	**6543A***	**6544A***	**6545A***	
	6641A	**6642A**	**6643A**	**6644A**	**6645A**	
Output voltage	0 to 8 V	0 to 20 V	0 to 35 V	0 to 60 V	0 to 120 V	
Output current (40° C)	0 to 50 A	0 to 10 A	0 to 6 A	0 to 3.5 A	0 to 1.5 A	
500 W	**6551A***	**6552A***	**6553A***	**6554A***	**6555A***	
	6651A	**6652A**	**6653A**	**6654A**	**6655A**	
Output voltage	0 to 8 V	0 to 20 V	0 to 35 V	0 to 60 V	0 to 120 V	
Output current (40° C)	0 to 50 A	0 to 25 A	0 to 15 A	0 to 9 A	0 to 4 A	
750 W	**5741A****	**5742A****	**5743A**	**5744A****	**5745A**	**5746A****
1.5 kW	**5761A****	**5762A****	**5763A**	**5764A****	**5765A**	**5766A****
Output voltage	0 to 6 V	0 to 8 V	0 to 12.5 V	0 to 20 V	0 to 30 V	0 to 40 V
Output current (40° C)	100 A / 180 A	90 A / 165 A	60 A / 120 A	38 A / 76 A	25 A / 50 A	19 A / 38 A
750 W (continued)	**N5747A**	**N5748A****	**N5749A**	**N5750A**	**N5751A**	**N5752A****
1.5 kW (continued)	**N5767A**	**N5768A****	**N5769A**	**N5770A**	**N5771A**	**N5772A****
Output voltage	0 to 60 V	0 to 80 V	0 to 100 V	0 to 150 V	0 to 300 V	0 to 600 V
Output current (40° C)	12.5 A / 25 A	9.5 A / 19 A	7.5 A / 15 A	5 A / 10 A	2.5 A / 5 A	1.3 A / 2.6 A
2 kW	**6571A***	**6572A***	**6573A***	**6574A***	**6575A***	
	6671A	**6672A**	**6673A**	**6674A**	**6675A**	
Output voltage	0 to 8 V	0 to 20 V	0 to 35 V	0 to 60 V	0 to 120 V	
Output current	0 to 220 A	0 to 100 A	0 to 60 A	0 to 35 A	0 to 18 A	
5 kW	**6680A**	**6681A**	**6682A**	**6683A**	**6684A**	
Voltage	0 to 5 V	0 to 8 V	0 to 21 V	0 to 32 V	0 to 40 V	
Current	0 to 875 A	0 to 580 A	0 to 240 A	0 to 160 A	0 to 128 A	
(40° C, then derated linearly 1%/° C to 55° C						
6.6 kW	**6690A**	**6691A**	**6692A**			
Voltage	0 to 15 V	0 to 30 V	0 to 60 V			
Current	0 to 440 A	0 to 220 A	0 to 110 A			
(40° C, then derated linearly 1%/° C to 55° C						

* Precision power supplies ** Module not compatible with the N6705A.

Power products that do more and demand less

Dynamic measurement dc supplies

The Keysight 66300 series are the first power supplies with instantaneous peak measurement capability, so you no longer need a scope or high-speed digital voltmeter to test devices that draw pulsed current.

– Ideal for testing wireless and battery powered products
– Superior output transient performance*
– Programmable output resistance*
– 14565B device characterization software for battery drain analysis*

Solar array simulator (SAS)

The Keysight E4350-series SAS simulates the output characteristics of a satellite's solar panels. It's also a great example of our ability to create unique power solutions to meet unique application challenges.

– Simulate I-V curves of a solar array under various conditions
– Operate the system in three different modes for maximum flexibility
– Have fast recovery time
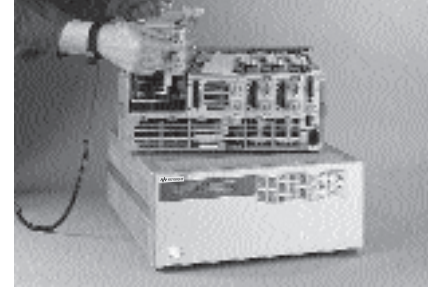
Electronic Loads

Keysight's integrated electronic loads help you save time, money, and rack space while delivering precise control and all the capabilities you need for analyzing dc power sources and devices. Use the programmable pulse waveform generator or use analog programming to simulate real-life load conditions.

– Ideal for evaluating dc power sources and power components
– Lower costs while improving ease of use and test quality
– Single-input and modular units with proven record of reliability

Dynamic measurement dc supplies					Solar array simulator	
Model	66332A	66319B/D	66321B/D		E4350B	E4351B
Voltage	0 to 20 V	0 to 15 V	0 to 15 V		0 to 65 V	0 to 130 V
Current	0 to 5 A	0 to 3 A	0 to 3 A		0 to 8 A	0 to 4 A
Maximum power	100 W	45 W	45 W		480 W	480 W
Electronic Loads						
Model	6060B, N3304A	6063B, N3303A	N3302A	N3306A	N3305A	N3307A
Input voltage	0 to 60 V	0 to 240 V	0 to 60 V	0 to 60 V	0 to 150 V	0 to 150 V
Input current Max. current derated linearly below 2 V	0 to 60 A	0 to 10 A	0 to 30 A	0 to 120 A	0 to 60 A	0 to 30 A
Maximum power	300 W	250 W	150 W	600 W	500 W	250 W

ac power source/analyzers

From avionics to uninterruptible power supplies, customers are demanding products that can use power efficiently while handling all kinds of ac line disturbances. To make sure your products meet these growing expectations, test them with the Keysight 6800-series ac power source/analyzers.
  – The fast, easy way to generate both clean and distorted ac power for product testing
  – A complete solution in a single, compact, tightly integrated box with graphical user interface
  – Built-in 16-bit power analyzer precisely measures all important parameters
  – dc output voltage capability of ±425 V (derated power)

ac Power Source/analyzers			
Model	6811B	6812B	6813B
Max power	375 VA	750 VA	1750 VA
# of phases	1	1	1
Rms output voltage	0 to 300 V	0 to 300 V	0 to 300 V
Rms output current	0 to 3.25 A	0 to 6.5 A	0 to 13 A

For more information, visit our Web site at
www.keysight.com/find/power.

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A personalized view into the information most relevant to you.

www.axiestandard.org

AdvancedTCA® Extensions for Instrumentation and Test (AXIe) is an open standard that extends the AdvancedTCA for general purpose and semiconductor test. Keysight is a founding member of the AXIe consortium. ATCA®, AdvancedTCA®, and the ATCA logo are registered US trademarks of the PCI Industrial Computer Manufacturers Group.

www.lxistandard.org

LAN eXtensions for Instruments puts the power of Ethernet and the Web inside your test systems. Keysight is a founding member of the LXI consortium.

www.pxisa.org

PCI eXtensions for Instrumentation (PXI) modular instrumentation delivers a rugged, PC-based high-performance measurement and automation system.

Three-Year Warranty

www.keysight.com/find/ThreeYearWarranty
Keysight's commitment to superior product quality and lower total cost of ownership. The only test and measurement company with three-year warranty standard on all instruments, worldwide.

Keysight Assurance Plans

www.keysight.com/find/AssurancePlans
Up to five years of protection and no budgetary surprises to ensure your instruments are operating to specification so you can rely on accurate measurements.

www.keysight.com/go/quality

Keysight Technologies, Inc.
DEKRA Certified ISO 9001:2008
Quality Management System

Keysight Channel Partners

www.keysight.com/find/channelpartners
Get the best of both worlds: Keysight's measurement expertise and product breadth, combined with channel partner convenience.

You're trying to get the most from your power products and get the best power products for your money—and this booklet is a great place to start. You'll find 10 easy and practical ways to improve power generation and measure-ment, along with a brief look at our most popular power instruments and systems.

www.keysight.com/find/power

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