

DC-DC Converter Testing Fundamentals

Guide to Performing Accurate Testing of DC-DC
Converters

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Introduction

A DC-DC converter is an electronic device designed to transform one direct current (DC) voltage level into another. It plays a crucial role in power management across various applications, from consumer electronics to industrial systems, electric vehicles, and data centers.

Operating Principles

DC-DC converters work by using high-frequency switching components, such as MOSFETs, and energy storage components, such as inductors and capacitors, to efficiently convert from one voltage level to another. Each converter has a defined input voltage range that will produce a regulated output voltage, such as converting a 10 to 12 V input to a 6 V output.

Types of DC-DC Converters

There are three main types of DC-DC converters: buck, boost, and buck-boost converters. A buck (step-down) converter decreases voltage, a boost (step-up) converter increases voltage, and a buck-boost converter can increase or decrease voltage. Each type of converter uses the same fundamental components but with slight topology variations that change their behavior.

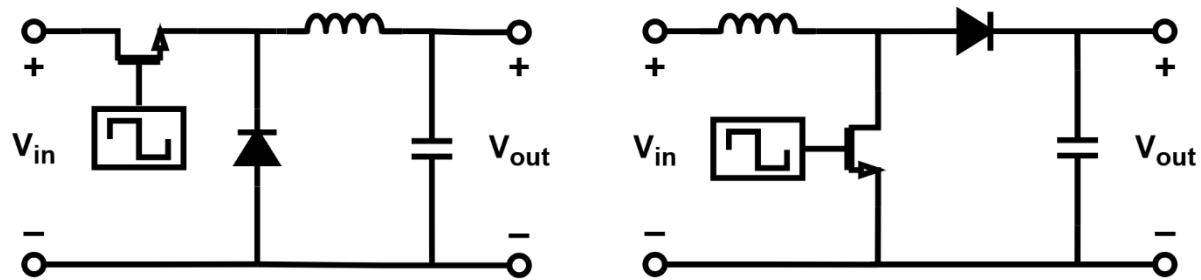


Figure 1. Generic buck (left) and boost (right) converter circuits

Benefits and Applications

DC-DC converters have many benefits that make them essential in electronic systems:

- Voltage conversion to match component voltage requirements.
- Efficiency to reduce heat and power loss.
- Stability and performance to maintain output voltage under varying conditions.
- Small footprint to enable light and compact designs.

These benefits make DC-DC converters widely used in the following areas:

- AI data centers for power delivery to GPUs, servers, and racks.
- EVs and HEVs for power transfer from battery to auxiliary systems.
- Renewable energy to optimize and regulate solar panel output.

- Space applications to manage power from spacecraft solar panels, batteries, and payload systems.
- Consumer electronics for managing power delivery to components.

Test Equipment Requirements

To ensure DC-DC converters meet application and performance requirements, designers, users, and manufacturers must conduct thorough electrical testing.

These tests rely on the following test equipment, along with advanced control and analysis software, to provide the functionality, accuracy, and precision required to simulate input / output conditions and capture relevant measurements and waveforms:

- DC power supplies and electronic loads provide input power and programmable load conditions; support static and dynamic testing with built-in measurement.
- Software controls test equipment, automates testing, and captures data for analysis.
- Oscilloscopes capture high-speed waveforms such as ripple, noise, and transients. They are required only for tests involving fast dynamic signals or high frequencies.
- Digital multimeters provide high-accuracy voltage and current measurements. They are useful when built-in measurements are not precise enough, especially for high-performance converters.

Test Setup and Configuration

Using these components, a DC-DC converter test setup can be built as shown in Figure 2.

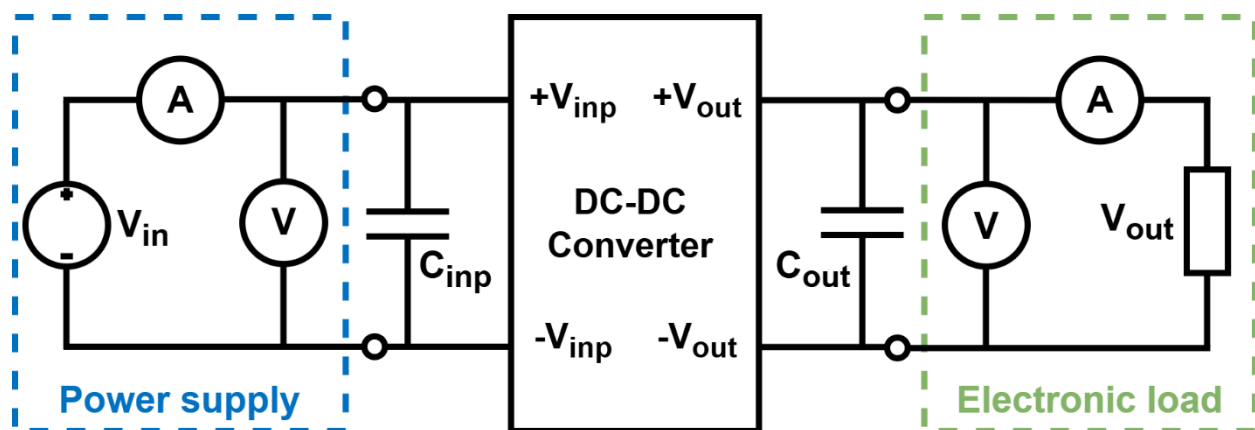


Figure 2. DC-DC converter test setup

The programmable DC power supply acts as the input source, and the electronic load acts as the output load. Engineers can program both test components to have constant or dynamic profiles and can use built-in measurement systems to capture relevant data. By using this setup, the input and output conditions can be adjusted and measured to conduct the various DC-DC converter tests.

Specifications and Testing Methodologies

There are electrical specifications and characteristics that describe the operation and performance of DC-DC converters. Here are the key specifications and how they are evaluated.

Input Voltage Range

This refers to the range of DC voltages the converter can tolerate for proper output voltage regulation. To test this specification, the input voltage is swept, and the output voltage is measured to verify the range in which the DC-DC converter can reliably regulate the desired output voltage.

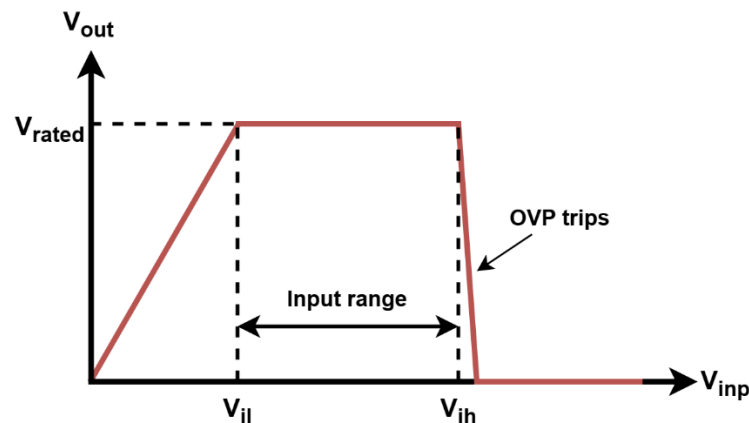


Figure 3. Input range test example

Output Voltage Accuracy

This describes how closely the converter's output voltage aligns with its nominal value. This is tested by applying an input voltage and load condition within the operating range, measuring the resulting output voltage, and computing how much it deviates from the nominal output voltage.

Load Regulation

This is the DC-DC converter's ability to regulate the output voltage as the load current changes. It is measured by how much the output voltage deviates as either a percentage or as a voltage difference. This is tested by applying a constant input voltage, stepping the electronic load between two valid load currents, and measuring the output voltage before and after the load transition to determine the deviation.

Line Regulation

This refers to the DC-DC converter's ability to regulate the output voltage as the input voltage changes. Like load regulation, it is measured by how much the output voltage deviates. This is tested by applying a constant load, stepping a power supply between two valid input voltages, and measuring the output voltage before and after the input voltage transition to determine the deviation.

Efficiency

This is the ratio of output power to input power, which indicates the converter's conversion efficiency. To determine the efficiency for a given condition, a constant input voltage and a constant load are applied to the converter. The input and output voltages and currents are then measured to determine the input and output power. The efficiency of the converter under that specific condition can then be determined using this equation.

$$\eta = \frac{V_{out} * I_{out}}{V_{in} * I_{in}} = \frac{P_{out}}{P_{in}}$$

Additionally, the efficiency of the converter over all conditions can be determined by sweeping the source or load through all input voltages and load currents in the operating range and calculating the efficiency at each of those conditions.

Transient Response

This refers to the DC-DC converter's output behavior when a change in load occurs. There are two characteristics of the output when analyzing the transient response of the converter: transient recovery time and transient response deviation.

- Transient recovery time is the time it takes for the output voltage to recover to a specified voltage band after loading or unloading.
- Transient response deviation is the magnitude of the voltage spike that occurs during loading and unloading.

Both characteristics can be tested by using a constant input voltage within the converter's operating range and an electronic load stepping between two load current values. After capturing the output voltage waveform during the load step, the transient recovery time is determined by measuring the time it takes for the output voltage to recover to a specified voltage band, and the transient response deviation is determined by measuring the magnitude of the voltage spike when the load is stepped.

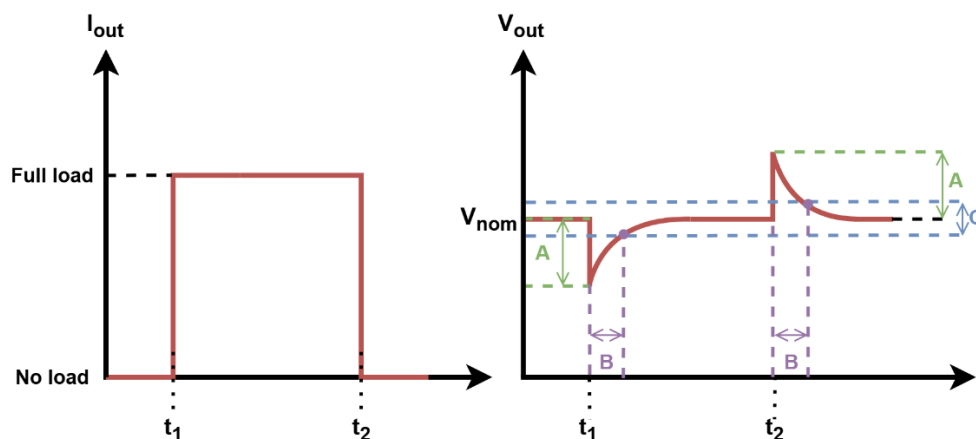


Figure 4. Transient response

Turn-on / Turn-off Time

This is the amount of time it takes for the DC-DC converter output to respond and reach its rated output voltage after a change in input voltage going above (turn-on) or below (turn-off) the converter's minimum input voltage. It is tested by using a voltage step at the input and measuring the delay between the input step and the output reaching its rated voltage or zero.

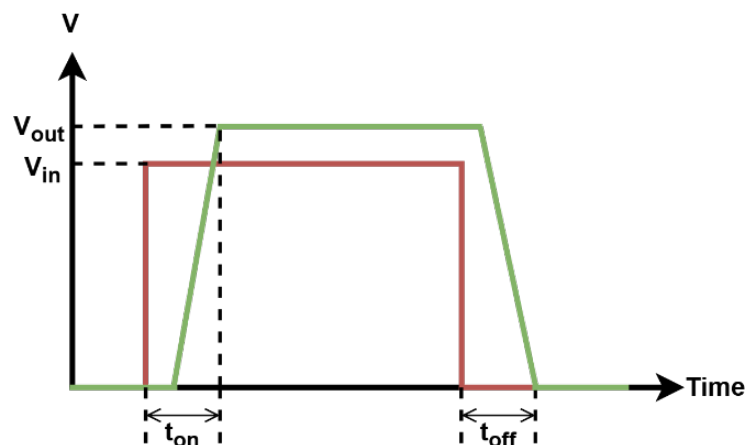


Figure 5. Turn-on and turn-off time

Ripple and Noise

This specifies the V_{pk-pk} and/or V_{rms} of the AC fluctuations that are present on the DC output. It is tested by applying a constant input voltage and constant load condition to the converter, then measuring the output voltage using an oscilloscope set to AC coupling with a bandwidth limit of 20 MHz. The captured waveform can then be used to determine the V_{pk-pk} and/or V_{rms} of the AC components.

Inrush Current

This refers to the current drawn at the converter's input when it is first powered on, caused by capacitors in the converter's circuitry. The magnitude of this current is determined by this equation:

$$i = C \frac{dV_c}{dt}$$

This equation shows how capacitance and slew rate affect inrush current. By stepping the input voltage with varying slew rates or capacitance while under any load condition, designers can evaluate what the inrush current of a converter is under different conditions.

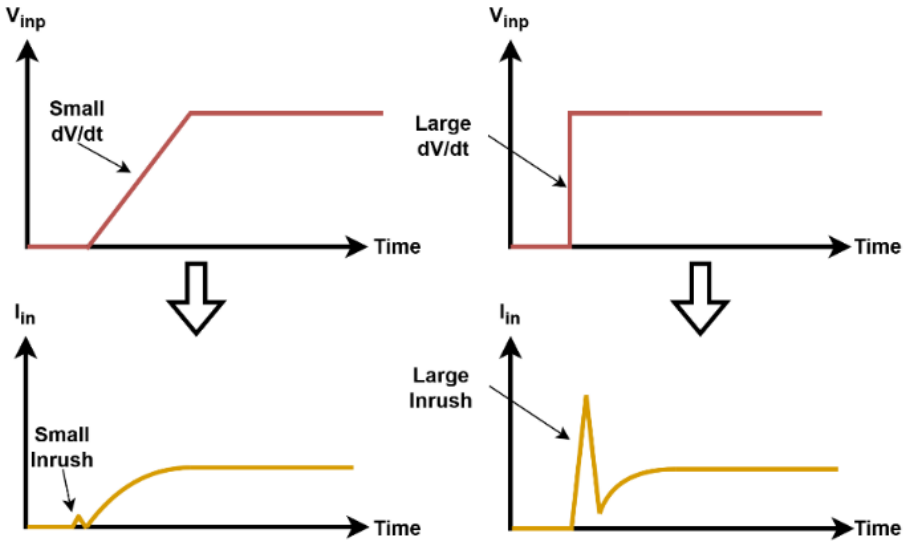


Figure 6. Inrush current with varying slew rates

Test setup considerations

While the described test configuration provides a general setup for performing DC-DC converter tests, several factors must be considered to ensure the measurements reflect the true behavior of the converter.

Simultaneous Voltage and Current Measurements

Accurate power and efficiency measurements under dynamic conditions require synchronized voltage and current readings from both the power supply and electronic load. This typically requires dual Analog-to-Digital Converters (ADCs) to capture voltage and current simultaneously. For static conditions, a single ADC may be sufficient.

Remote Sensing

Wiring resistance can cause voltage drops between the power supply / load and the DC-DC converter, resulting in the converter receiving a lower voltage than intended and inaccurate measurements. To correct this, the supply and load can be configured in a four-wire setup. This measures voltage directly at the converter's terminals, allowing the power supply to compensate for any voltage drop and deliver the programmed voltage to the converter's terminals. Additionally, the voltages measured by the supply and load will accurately reflect the voltage at the converter's input and output terminals.

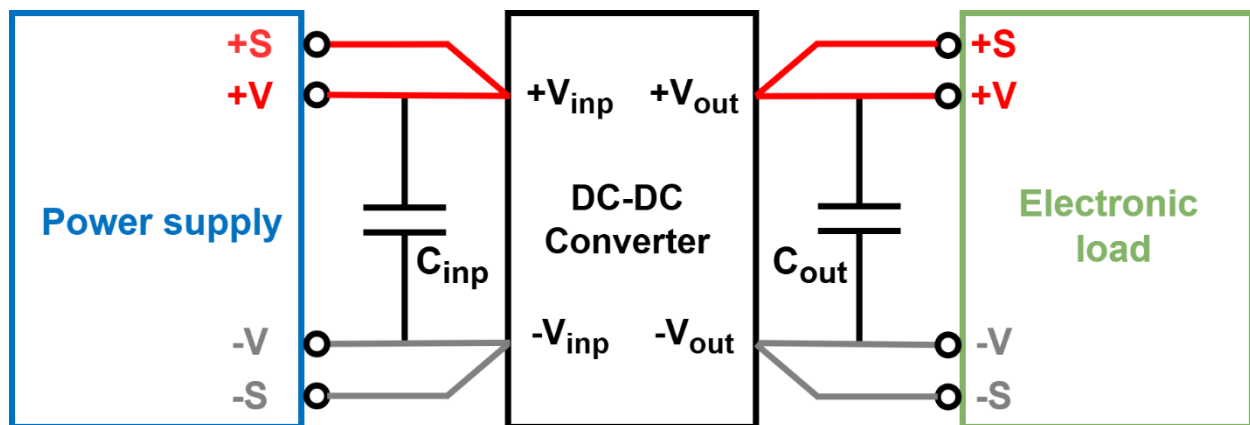


Figure 7. Remote sense test configuration

Resolution and Accuracy

Test equipment must match the precision required by the converter under test. Low resolution and accuracy can lead to incorrect settings and unreliable results.

High-resolution power supplies and electronic loads allow for fine control of voltage and current. High accuracy ensures that the programmed and measured values closely match actual conditions. These are especially critical when testing converters with tight margins.

For some converters, the measurement resolution and accuracy required may be higher than those of the power supplies and load. In these cases, a digital multimeter should be used for voltage and current measurements, especially for load regulation and line regulation measurements.

Dynamic signal capture and generation

Accurate testing of DC-DC converters often requires capturing and generating fast-changing signals. This is critical for evaluating transient response, ripple, noise, and inrush current.

Measurement bandwidth and sampling rate

To capture dynamic behavior, consider the following requirements:

- Measurement bandwidth should be sufficient to capture the desired signal without attenuation.
- Sampling rate should be fast enough to measure without aliasing or distortion.

Power supplies and electronic loads typically lack the performance to capture transient responses in high-performance converters and high-frequency ripple and noise in all converters. For these tests, an oscilloscope with an appropriate bandwidth and sampling rate will maximize accuracy. For other dynamic tests and lower performance converters, the built-in measurement capabilities of the supply and load are usually sufficient.

Arbitrary waveform generation and slew rate

When generating input or load transients, the power supply or electronic load must have an adequate output bandwidth and slew rate. Additionally, adjustable slew rates are especially useful for evaluating startup behavior and inrush current under different conditions.

Using Keysight Power Products for DC-DC Converter Tests

Keysight offers several power products that can be used for DC-DC converter testing, each with varying specifications, features, characteristics, and performance to match different testing needs. These range from low power to high power and from low performance to high performance. This flexibility allows engineers to choose the right tools based on their converter's testing needs. Figure 8 shows how various Keysight power products fit into a DC-DC converter test setup.

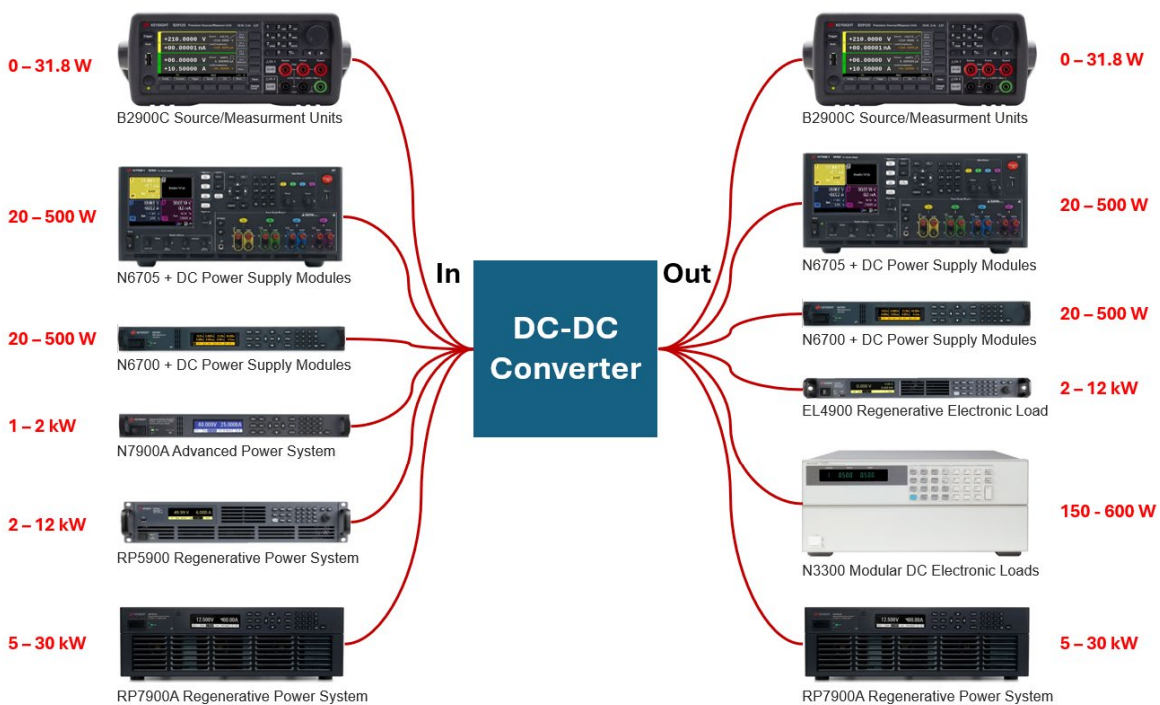


Figure 8. DC-DC converter test setup using Keysight power products

When paired with the Keysight PathWave Advanced Power Application Suite, control and measurement of the instruments can be leveraged through software, enabling precise control, data visualization, logging, and analysis.



Figure 9. Keysight PathWave Advanced Power Control and Analysis software

Example: DC-DC Converter Efficiency Test

In this example, a Keysight RP5900 Regenerative DC Power Supply and an EL4900 Regenerative Electronic Load are used to source and load a DC-DC converter to determine its efficiency under a constant voltage with a varying load current.



Figure 10. DC-DC converter efficiency test setup with Keysight RP5900 and EL4900

Using PathWave Advanced Power Control and Analysis software, the instruments can be connected and configured to conduct the test. The arbitrary waveform generator of the RP5900 is set to output a fixed DC voltage, while the EL4900 is programmed to ramp from 10% to 100% of the converter's maximum rated current. The data logger is also configured to record voltage, current, and power from both instruments. Once configured, the arb and data logger are started to run the test.

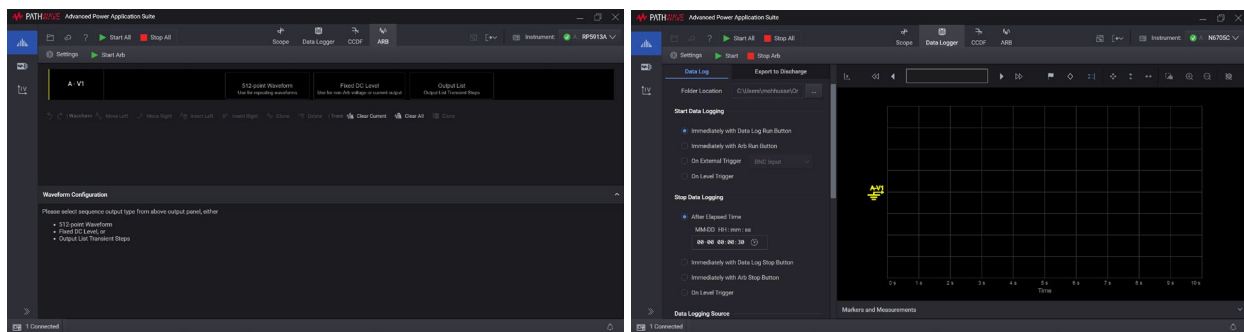


Figure 11. Keysight PW9252A arbitrary waveform setup window (left) and PW9252A data logging configuration setup window (right)

Using the data logger and a formula trace, the converter's efficiency curve can be calculated and displayed, showing its efficiency under a constant input voltage and varying load current.

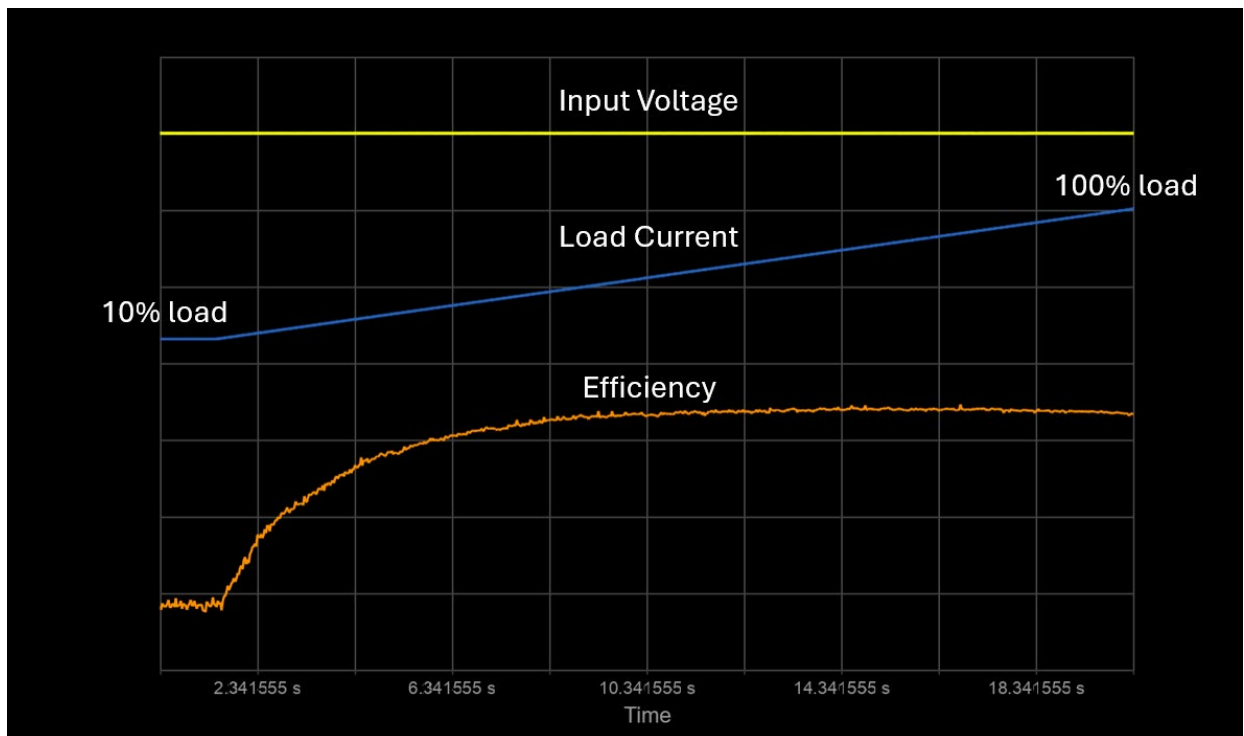


Figure 12. DC-DC converter efficiency test example with swept load using PW9252A

Keysight Power Supplies and Electronic Loads

Keysight's power portfolio offers a range of products that fulfill DC-DC converter testing requirements. From low-power benchtop to regenerative high-power automated test equipment, Keysight provides a flexible and scalable selection of power supplies and electronic loads.

DC Power Supplies

Parameters	B2900C	N6700C	N7900	RP7900	RP5900
Power	31.8 W	20 W – 500 W	1 kW / 2 kW	5 kW – 30 kW	2 kW – 12 kW
Voltage	± 210 V	0 – 150 V	0 – 160 V	0 – 2,000 V	0 – 800 V
Current	0 – 10.5 A	0 – 50 A	0 – 200 A	0 – 800 A	0 – 240 A
Outputs	1 – 2	4	1	1	1
Size	2U	1U / 4U	1U / 2U	3U / 5U	1U / 2U
Volt. prog. resolution	100 nV – 1mV	6 μ V – 43 mV	0.21 mV – 1.68 mV	191 μ V – 21 mV	1 mV – 10 mV
Curr. prog. resolution	10 fA – 100 μ A	0.1 μ A – 16 mA	0.24 mA – 1.9 mA	190 μ A – 15.5 mA	1 mA – 10 mA
Volt. meas. resolution	100 nV – 100 μ V	1 μ V – 77 mV	18 b	191 μ V – 20 mV	1 mV – 10 mV
Curr. meas. resolution	10 fA – 10 μ A	0.1 nA – 10 mA	18 b	190 μ A – 15.5 mA	1 mA – 10 mA
Voltage rise / fall time	50 μ s	12 μ s – 20 ms	0.5 ms / 0.35 ms	75 μ s – 33 ms	15 ms – 60 ms
Transient recovery time	Not specified	<35 μ s – <250 μ s	100 μ s	300 μ s / 500 μ s	1 ms
Minimum sampling interval	10 μ s – 200 μ s	5 μ s / 10 μ s	5 μ s	5 μ s	100 μ s
Measurement bandwidth	Not specified	2 kHz – 30 kHz	25 kHz	Not specified	Not specified
CD arb points	10k / 100k points	Up to 65,535	Up to 65,535	Up to 65,535	Up to 65,535
CD arb dwell time	10 μ s / 200 μ s to 100,000 s	10.24 μ s	10.24 μ s	10.24 μ s to 0.30 seconds	1 ms to 3,600 seconds
Data-logging integration period	100 μ s	100 μ s	100 μ s	100 μ s	100 μ s
PathWave support	Yes	Yes	Yes	Yes	Yes
Sink current	Yes	Yes (N87X1)	Yes	Yes	Yes
Datasheets	B2900C	N6700C	N7900	RP7900	RP5900



Electronic Loads

Family	N6791A/N6792A	EL4900	N3300
Power	100 W / 200 W	2 kW – 12 kW	150 W – 600 W
Voltage	0 – 60 V	0 – 800 V	0 – 240 V
Current	0 – 40 A	0 – 240 A	0 – 120 A
Number of outputs	2 – 4 (in mainframe)	1	1 – 6
Size	1U / 4U	1U / 2U	4U
Volt. prog. resolution	1.5 mV	1 mV – 10 mV	0.1 mV – 4 mV
Curr. prog. resolution	25 μ A – 500 μ A	1 mA – 10 mA	0.02 mA – 2 mA
Volt. meas. resolution	1 mV	1 mV – 10 mV	0.1 mV – 4 mV
Curr. meas. resolution	0.12 mA – 0.8 mA	1 mA – 10 mA	0.02 mA – 2 mA
Current max slew rate	5 MA/s	60 kA/s	10 MA/s
Minimum sampling interval	10 μ s	100 μ s	10 μ s
Measurement bandwidth	20 kHz	Not specified	10 kHz
Minimum sinking resistance	40 m Ω / 80 Ω	3.3 m Ω – 500 m Ω	12 m Ω – 100 m Ω (typical)
Arb points	Up to 65,535 (CD arb)	Up to 65,535 (CD Arb)	Up to 50 (List)
Dwell time	10.24 μ s (CD arb)	1 ms – 3,600 s (CD Arb)	0 – 10 s (List)
Data-logging integration period	100 μ s	100 μ s	N / A
PathWave support	Yes	Yes	No
Datasheets	N6781A / N6792A	EL4900	N3300



Summary

DC-DC converters play a crucial role in modern electronics, enabling efficient and reliable operation in a wide range of applications. Accurate testing of their specifications is essential to ensure reliable behavior and performance. These tests require power supplies and electronic loads, while additional instruments and software can enhance automation, analysis, and measurement precision. By leveraging these tools and testing methodologies, engineers can determine converter behavior under various conditions and ensure that the device meets their application and performance requirements.