

Understanding Essential Tools and Techniques for Power Conversion Efficiency Testing

PWM

Understanding Essential Tools and Techniques for Power Conversion Efficiency Testing



Introduction

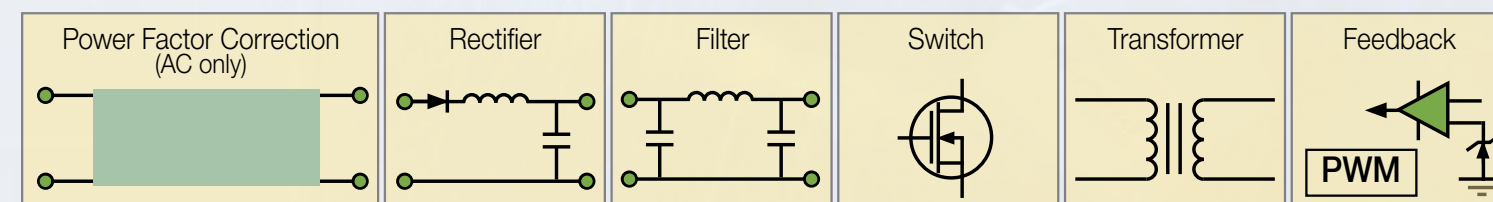
Wherever electrical power is generated, transmitted, or consumed, it has to go through at least one power conversion process. Whether the application involves stepping voltages up or down, converting from AC to DC or DC to AC, or converting power in some other way, ensuring the efficiency of these processes is essential. This guide outlines the latest tools and techniques for testing the power conversion efficiency of a wide variety of components, subassemblies, and systems.

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Speaking the Language of Power Conversion

Power conversion products are typically made up of the same six building blocks: power factor correction circuits, rectifiers, filters, switching transistors, transformers, and feedback loops. The power factor correction circuit shapes the input current to maximize the real power available from the AC line by aligning the voltage and current phase to make power delivery more efficient and minimize loss on the grid. The rectifier converts a sine wave to a pulsating wave. A filter smooths the wave to DC, at which point it passes through a switching transistor that creates a square or pulse wave. The pulse wave is often passed through a transformer, which provides filtering and isolation and can shift voltage level. At that point, the signal is filtered again to achieve a flat DC signal. Finally, a feedback loop adjusts the output voltage to align with a reference voltage.



Other important power converters include:

- An inverter converts DC power to AC power so it can be used by an electrical/electronic circuit or fed into the power grid.
- A DC-DC converter converts DC power to a different DC voltage/current level.
- A cycloconverter/frequency converter converts AC electricity to a different frequency (often lower) AC wave. It's also used to convert from three-phase to single-phase power, and vice versa.

Selecting the Right Power Conversion Device

The first step in power conversion design is selecting the right components for the application. Although component specification sheets typically specify performance at a few distinct current and voltage levels, they often don't match the conditions of the design under consideration. You may need to choose from multiple vendors or assess normal component-to-component variations from a single vendor. Many designs have variations in the power levels provided to individual components, which demand stress testing of the component under consideration to assess the impact of these variations. Keeping components within temperature limits for each design requires applying known power levels to the component while evaluating its safe operating area parameters.

You can't resolve these questions by reading a specification sheet; you need precision DC tools capable of characterizing a potential component's operation at the actual design power levels and in the environment in which they'll be used. Source measure unit (SMU) instruments have proven their usefulness for characterizing and selecting components because they integrate all the source and measure functions necessary to validate that components under consideration perform as specified and to characterize their operation under final design conditions:

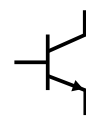
- Current-voltage (I-V) curves
- Device characteristics (device gain, leakage, on resistance, off resistance, forward voltage, reverse voltage, etc.)
- Input power/output power (module)
- Line and load regulation
- Stress test for reliability and failure analysis (thermal profiling, safe operating area, breakdown voltage)

Diodes & Rectifiers



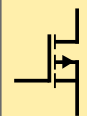
Forward Voltage (V_f)
Reverse Voltage (V_r)
Reverse Leakage (I_r)

Bipolar Transistor & IGBTs

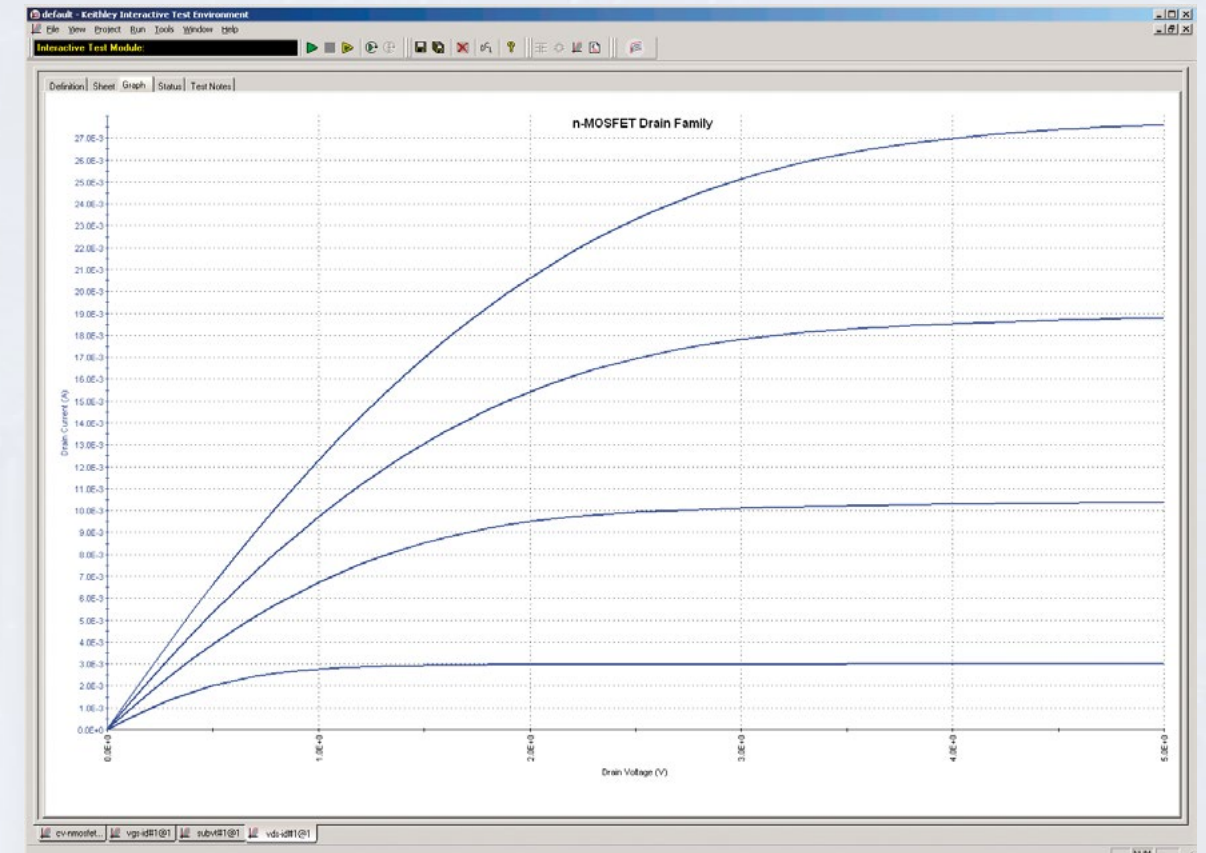


Saturation Voltage (V_{cesat})
Family of Curves (V_{ce-ic})
Breakdown Voltages (V_{ceo} ,
 V_{ebo} , V_{cbo})
Leakage Currents (I_{ces} , I_{ebo})
DC Current Gain (h_{fe})

MOSFETS & JFETS



Family of Curves (V_{ds-I_d})
Transfer characteristics
(V_{gs-I_d})
On-resistance (R_{dson})
Breakdown voltages
(BV_{dss} , BV_{dg}) Leakage
Currents (I_{dss} , I_{gss})



Device Selection

Design
Characterization

Final Design
Testing &
Compliance

Get advice on optimizing your power conversion test applications.

Send us your question or join the discussion on our [application forum](#).

High Resolution, High Accuracy DC Measurements for Component Selection and Characterization



The **Model 2450 Advanced Touchscreen SourceMeter® SMU Instrument** is the latest addition to Keithley's rapidly expanding SMU instrument line. An intuitive Touch, Test, Invent® design means you can learn faster, work smarter, and invent easier. Its combination of a five-inch, full-color, high resolution touchscreen and simple icon-based menu structure speeds measurement configuration.

- Combines the capabilities of analyzers, curve tracers, and I-V systems at a fraction of their cost
- Five-inch color touchscreen display
- Source and measure up to 2000V/1A
- 0.012% basic measure accuracy with 6½-digit resolution
- Enhanced sensitivity with 10nV and 10fA resolution
- Four "Quickset" modes for fast setup and measurements

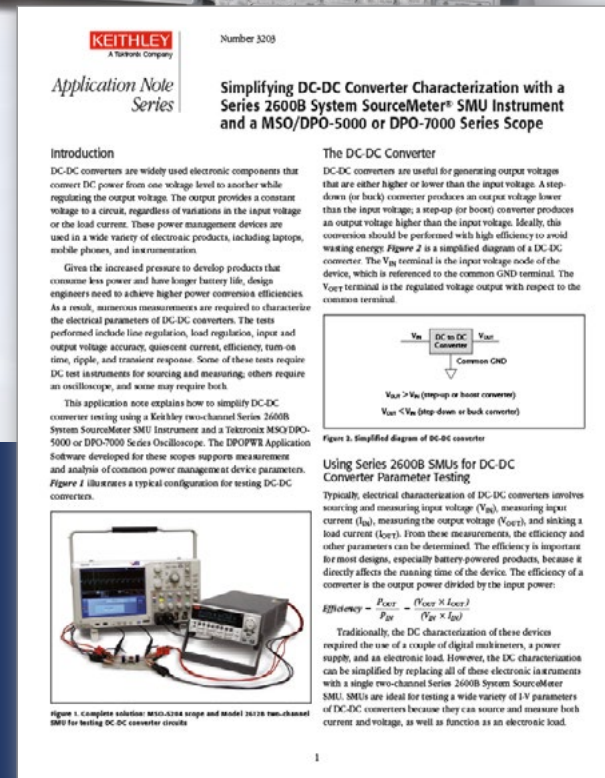


Keithley's **Series 2600B System SourceMeter® SMU Instruments** offer single- and dual-channel models that combine the capabilities of a precision power supply, true current source, 6½-digit digital multimeter (DMM,) arbitrary waveform generator, pulse generator, and electronic load – all into one tightly integrated instrument. Because these instruments have fully isolated channels that do not require a mainframe, they can be easily reconfigured and re-deployed as new test applications evolve.

- Family of models offers industry's widest dynamic range: 10A pulse to 0.1fA and 200V to 100nV
- Built-in, Java-based test software enables true plug & play I-V characterization and test through any browser
- Test script processor (TSP®) technology embeds complete test programs inside the instrument for best-in-class system-level throughput
- TSP-Link® expansion technology for multi-channel parallel test without a mainframe
- USB 2.0, LXI-C, GPIB, RS-232, and digital I/O interfaces
- Optional ACS-Basic semiconductor component characterization software

Get advice on optimizing your power conversion test applications.

Send us your question or join the discussion on our [application forum](#).



High Resolution, High Accuracy DC Measurements for Component Selection and Characterization

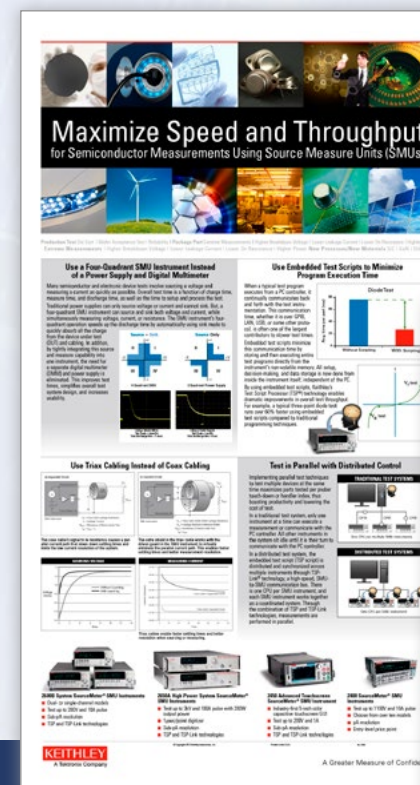


Model 2651A High Power/High Current System SourceMeter® Instrument simplifies characterizing high current components with unprecedented power, precision, speed, flexibility, and ease of use. Its unique ability to generate sub-100µs pulses at 2000W enables precise characterization of power semiconductors without the typical self-heating issues that can distort results or destroy devices.

- Source or sink 2,000W of pulsed power ($\pm 40V$, $\pm 50A$), 200W of DC power ($\pm 10V @ \pm 20A$, $\pm 20V @ \pm 10A$, $\pm 40V @ \pm 5A$)
- Easily connect two units (in series or parallel) to create solutions up to $\pm 100A$ or $\pm 80V$
- 1pA resolution enables precise measurement of very low leakage currents
- 1µs per point (1MHz), 18-bit digitizing A-to-D converter accurately characterizes transient behavior
- Combine with Model 2657A High Power/High Voltage System SourceMeter Instrument, Model 8010 Test Fixture, and ACS Basic Software for a complete characterization system

Model 2657A High Power/High Voltage System SourceMeter® Instrument adds high voltage to Keithley's SMU instrument solutions. The Model 2657A has the unique ability to source, sink, and measure up to 3kV/1fA for precise characterization of a wide variety of power semiconductors.

- Source or sink up to 3000V @ 20mA or 1500V @ 120mA to capture important parametric data that other equipment can't
- 1fA measurement resolution for characterizing the low leakages of next-generation devices
- 1µs per point (1MHz), 18-bit digitizing A-to-D converter accurately characterizes transient behavior
- Combine with Model 2651A High Power/High Current System SourceMeter Instrument, Model 8010 Test Fixture, and ACS Basic Software for a complete characterization system



To learn more about what Keithley SMU instruments can offer your component characterization and selection process, download:

- **Maximize Speed and Throughput for Semiconductor Measurements** application note
- **Optimizing Reliability Testing of Power Semiconductor Devices and Modules** application note
- **Choosing the Optimal Source Measurement Unit Instrument** white paper

Get advice on optimizing your power conversion test applications.

Send us your question or join the discussion on our [application forum](#).

SourceMeter® SMU Instruments Selector Guide



Feature	2651A / 2657A High Current / High Voltage	2634B / 2635B / 2636B Low Current	2602B / 2612B Dual Channel	2601B / 2611B Single Channel	2604B / 2614B Dual Channel Benchtop
# of Channels	1 (optional expansion to 32 via TSP-Link®)	1 – 2 (optional expansion to 64 via TSP Link for 2635B/2636B)	2 (optional expansion to 64 via TSP-Link)	1 (optional expansion to 32 via TSP-Link)	2
Current Max / Min	2651A: 50A pulse/100fA 2657A: 120mA/1fA	2634B: 10A pulse/1fA 2636B, 2635B: 10A pulse/0.1fA	10A pulse/100fA	10A pulse/100fA	10A pulse/100 fA
Voltage Max / Min	2651A: 40V/100nV 2657A: 3,000V/100nV	200V/100nV	40V/100nV for 2602B 200V/100nV for 2612B	40V/100nV for 2601B 200V/100nV for 2611B	40V/100nV for 2604B 200V/100nV for 2614B
System-Level Automation	Digital I/O, TSP-Link, Contact Check	Digital I/O, TSP-Link, Contact Check (not available on 2634B)	Digital I/O, TSP-Link, Contact Check	Digital I/O, TSP-Link, Contact Check	N/A
Max readings / sec	38,500 1µSec/pt., 18-bit digitizer	20,000	20,000	20,000	20,000
Computer Interface	GPIB, LAN (LXI), RS-232	GPIB, LAN (LXI), RS-232, USB 2.0	GPIB, LAN (LXI), RS-232, USB 2.0	GPIB, LAN (LXI), RS-232, USB 2.0	GPIB, LAN (LXI), RS-232, USB 2.0
Connectors/Cabling	2651A: Screw terminal, adaptors for banana 2657A: HV triax, SHV	Triax	Screw terminal, adaptors for banana or triax	Screw terminal, adaptors for banana or triax	Screw terminal, adaptors for banana or triax



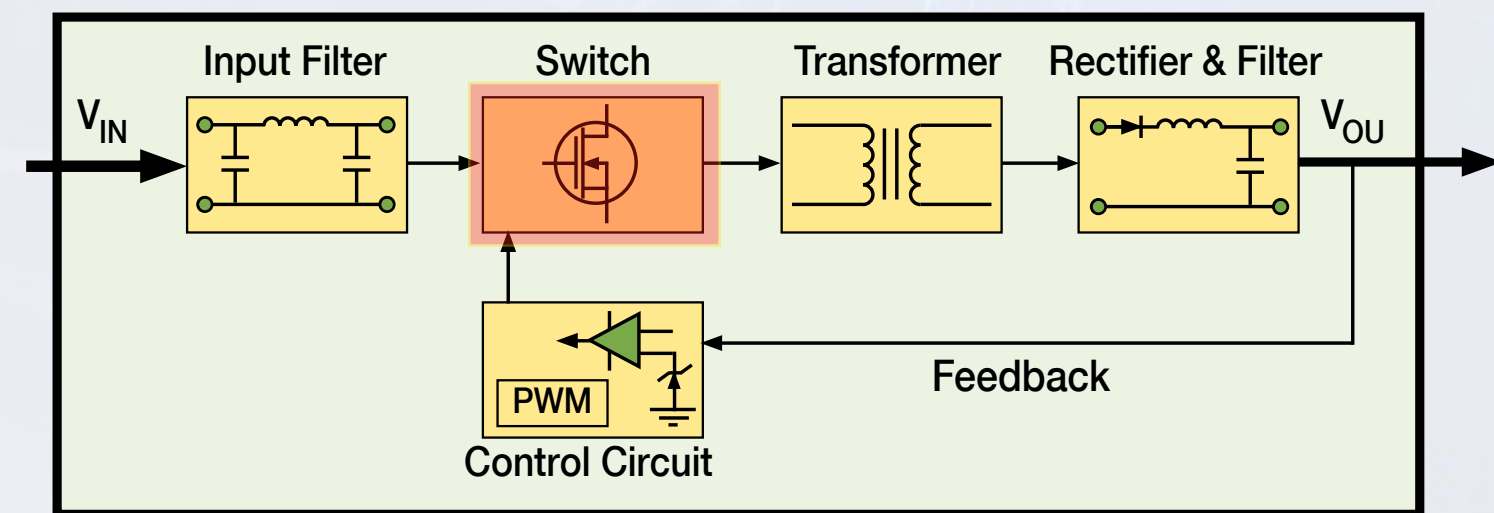
Feature	6430 Low I SourceMeter	2430 High Power SourceMeter Instrument	2410 High V SourceMeter Instrument	2420 / 2425 / 2440 High I SourceMeter Instruments	2400 / 2401 Low Power SourceMeter Instruments	2450 Advanced Touchscreen SourceMeter Instruments
Current Max / Min	105mA / 10aA	10.5A pulse / 100pA	1.05A / 10pA	5.25A/ 100pA	1.05A / 10pA	1.05A/10fA
Voltage Max / Min	200V / 1uV	200V / 1uV	1100V / 1uV	100V / 1uV	200V / 1uV	200V/10nV
Power	2W	1100W	22W	110W	22W	20W
Max readings / sec	256	2,000	2,000	2,000	2,000	3,100
Interface	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, RS-232, Digital I/O, Trigger Link Trigger Bus	GPIB, USB 2.0, LAN/LXI, Digital I/O, TSP-Link
Connectors	Triax	Banana (front / rear)	Banana (front / rear)	Banana (front / rear)	Banana (front / rear)	Banana (front) Triax (rear)

High Accuracy AC Measurements for Power Conversion Design Characterization

Design Characterization: Switching Measurements

Once you've completed the component selection process, you'll need higher-frequency tools to characterize these power semiconductor devices further and optimize your overall power conversion designs. Oscilloscopes, high performance probes, and power analysis software are the AC tools of choice for characterizing components at high frequencies, analyzing the performance of a power conversion design, and understanding the source of problems.

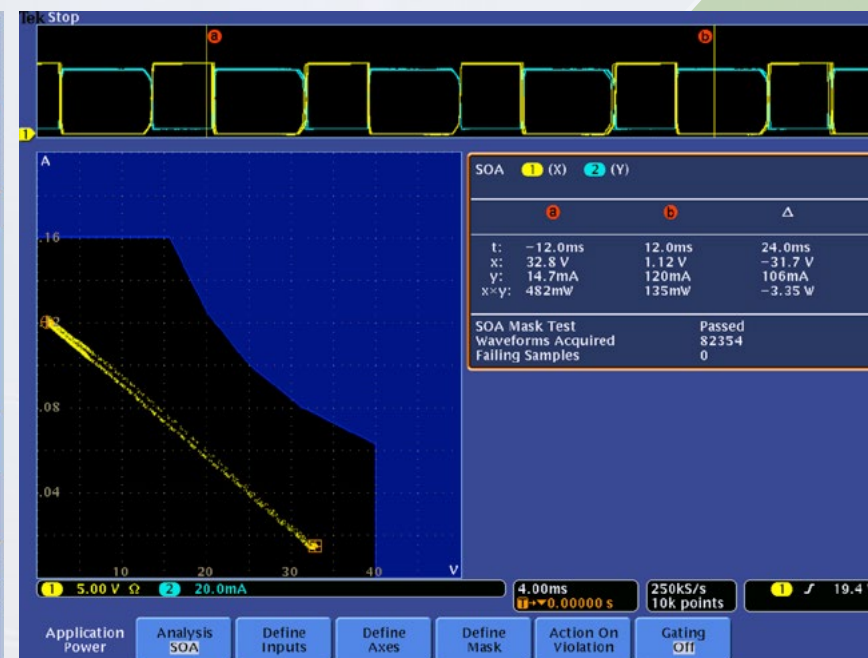
With the right probe and an oscilloscope equipped with power analysis software, you can easily measure parameters like switching losses (turn-on, turn-off, and conduction) and characterize the device's operating region (safe operating area). Precise timing between voltage and current waveforms is crucial to maintain measurement accuracy, so the power analysis software should provide automated de-skew.



Device Selection

Design Characterization

Final Design Testing & Compliance

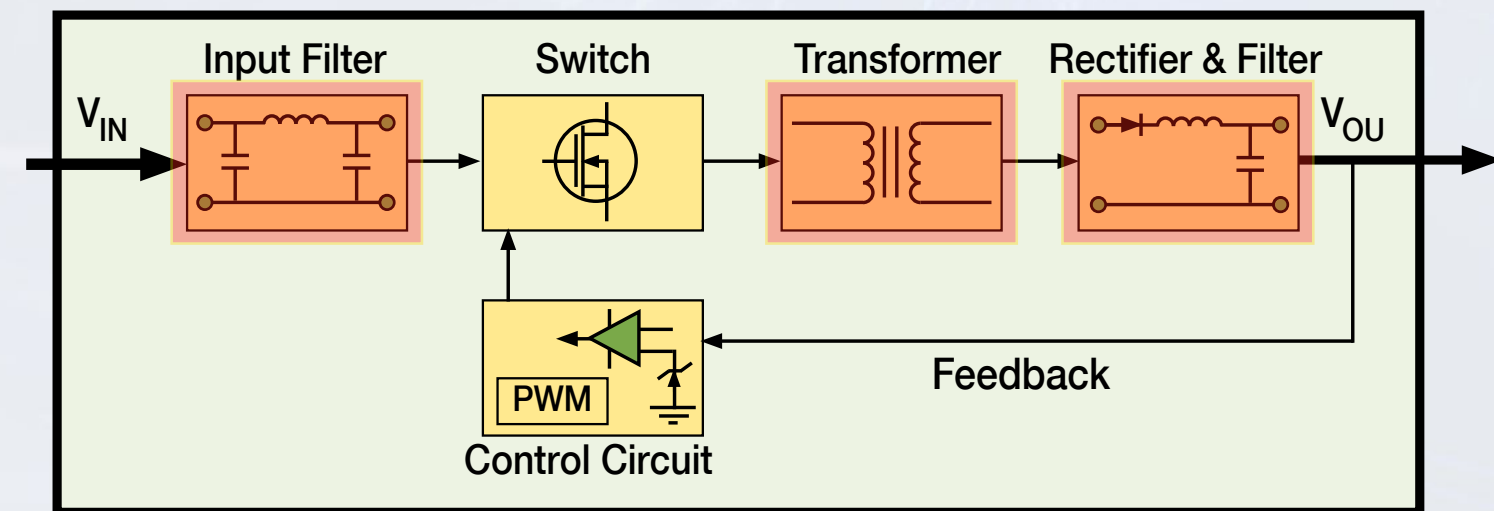


See pages 10-12 for recommended Tektronix design characterization solutions.

High Accuracy AC Measurements for Power Conversion Design Characterization

Design Characterization: Magnetics Measurements

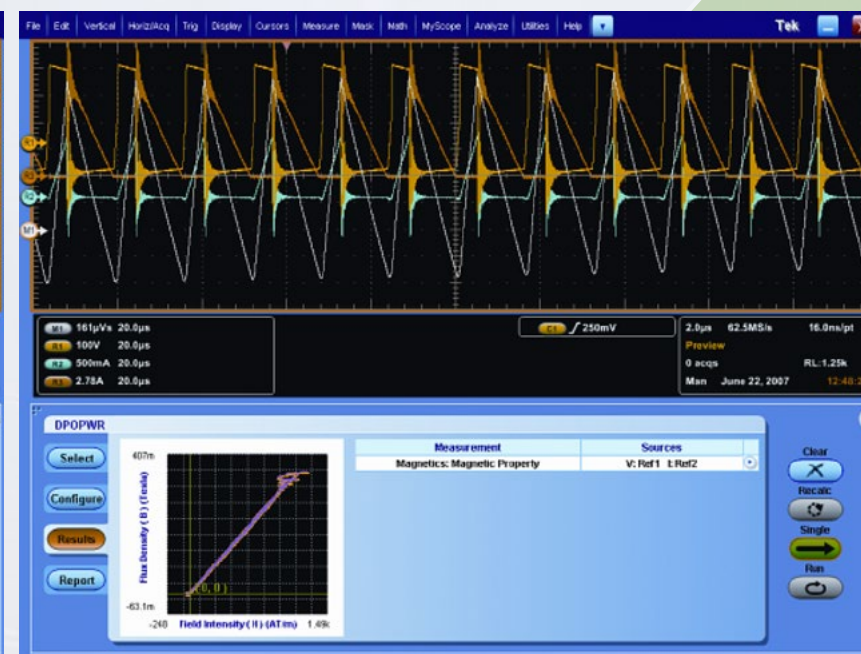
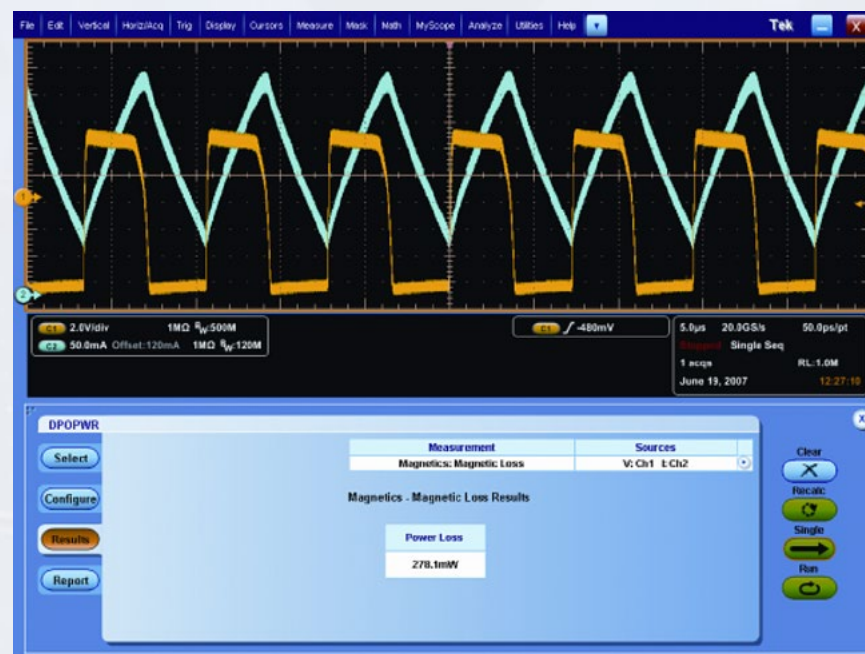
Magnetic components are an important part of any power supply system. Both switch-mode and linear power supplies employ inductors and transformers as energy storage devices and filters. Given their important role in the system, it's essential to characterize these magnetic components to determine the stability and overall efficiency of the power supply. Required test capabilities include voltage and magnetizing current and magnetic power loss. These applications also require the ability to calculate complex magnetic properties such as input number of turns, magnetic length, and cross-sectional area, as well as maximum magnetic flux density, remanence flux density, permeability, coercive force, and B-H plots.



Device Selection

Design Characterization

Final Design Testing & Compliance

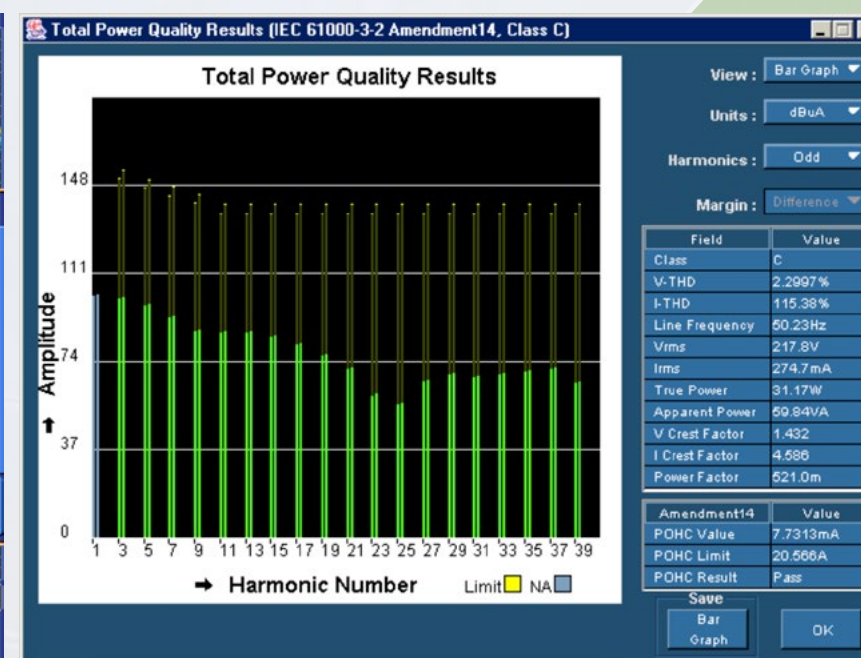
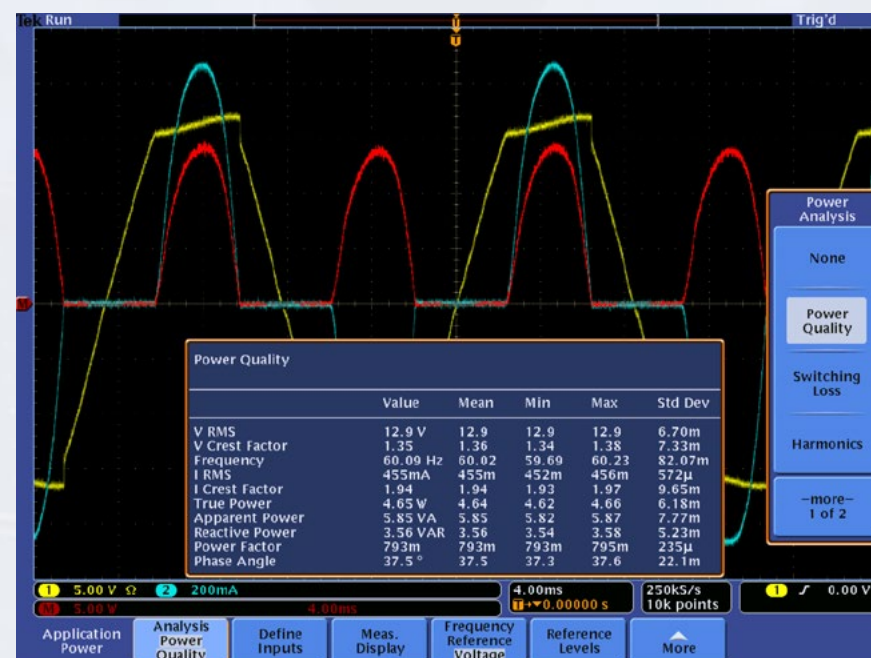
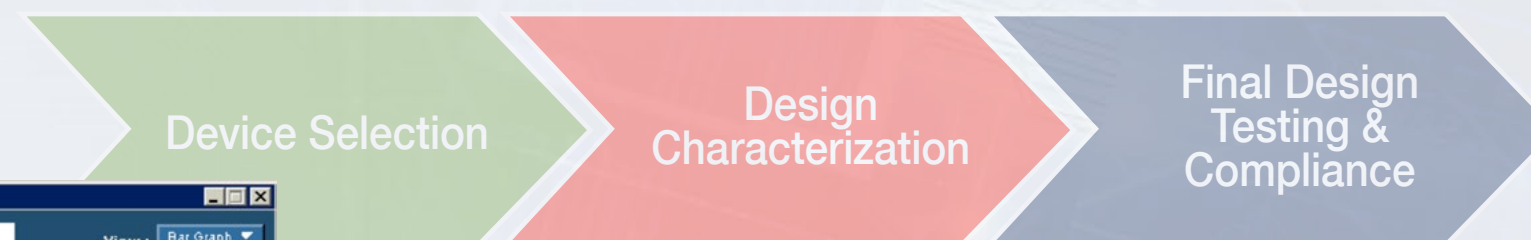
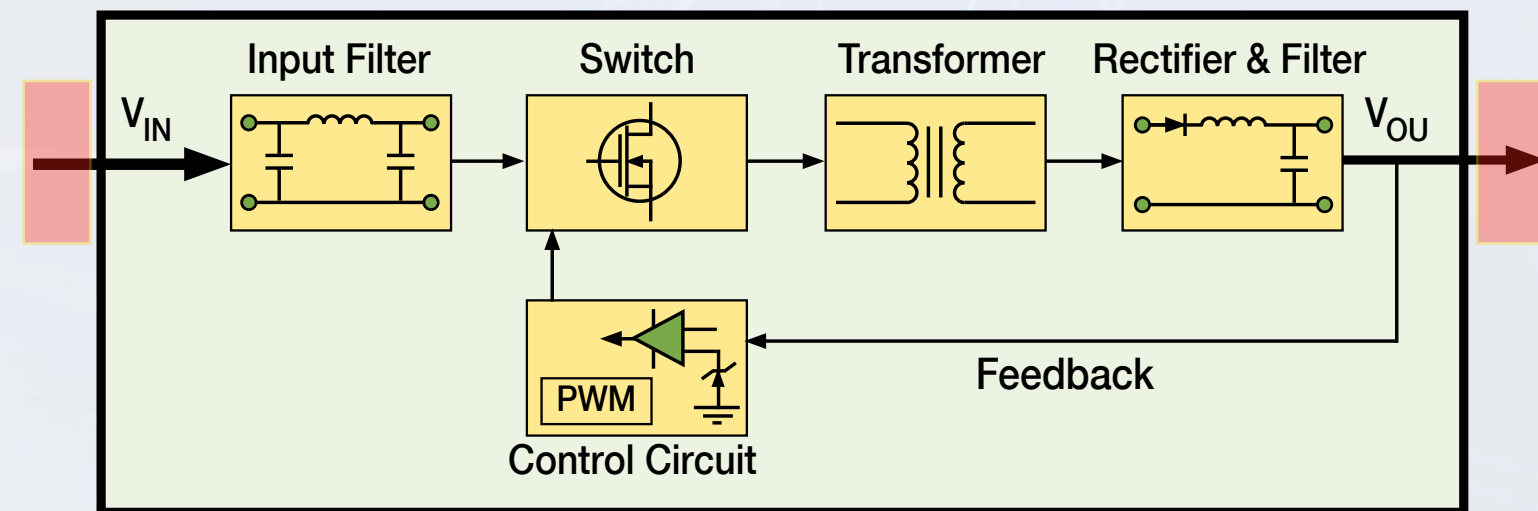


See pages 10-12 for recommended Tektronix design characterization solutions.

High Accuracy AC Measurements for Power Conversion Design Characterization

Design Characterization: Power Line Measurements

Accurate power line measurements are essential to characterize the interaction of the supply and its service environment. These applications require the ability to measure and/or calculate both power quality (true power, reactive power, apparent power, power factor, crest factor, THD) and current harmonics (for comparing harmonics and THD to industry standards like EN61000-3-2).



See pages 10-12 for recommended Tektronix design characterization solutions.

Tektronix Oscilloscopes for Challenging Converter Designs

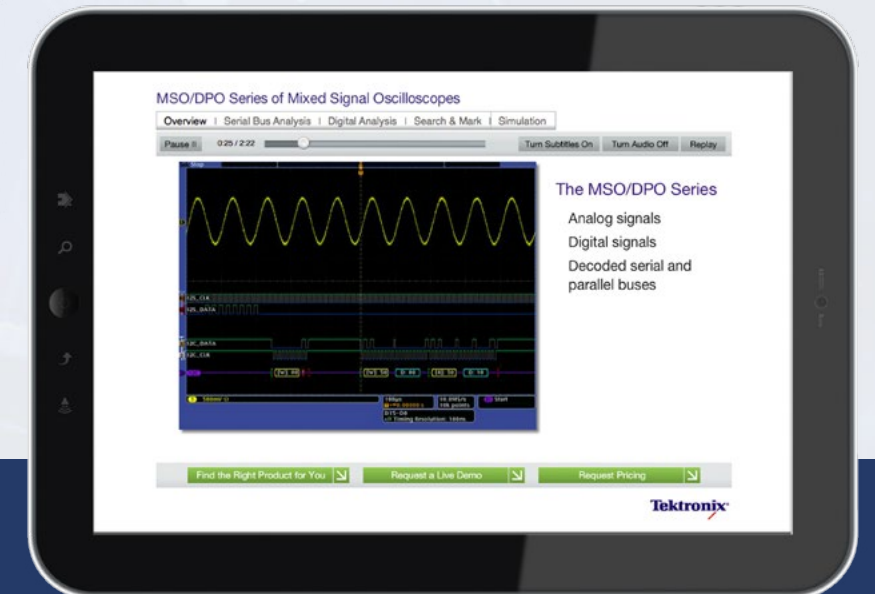
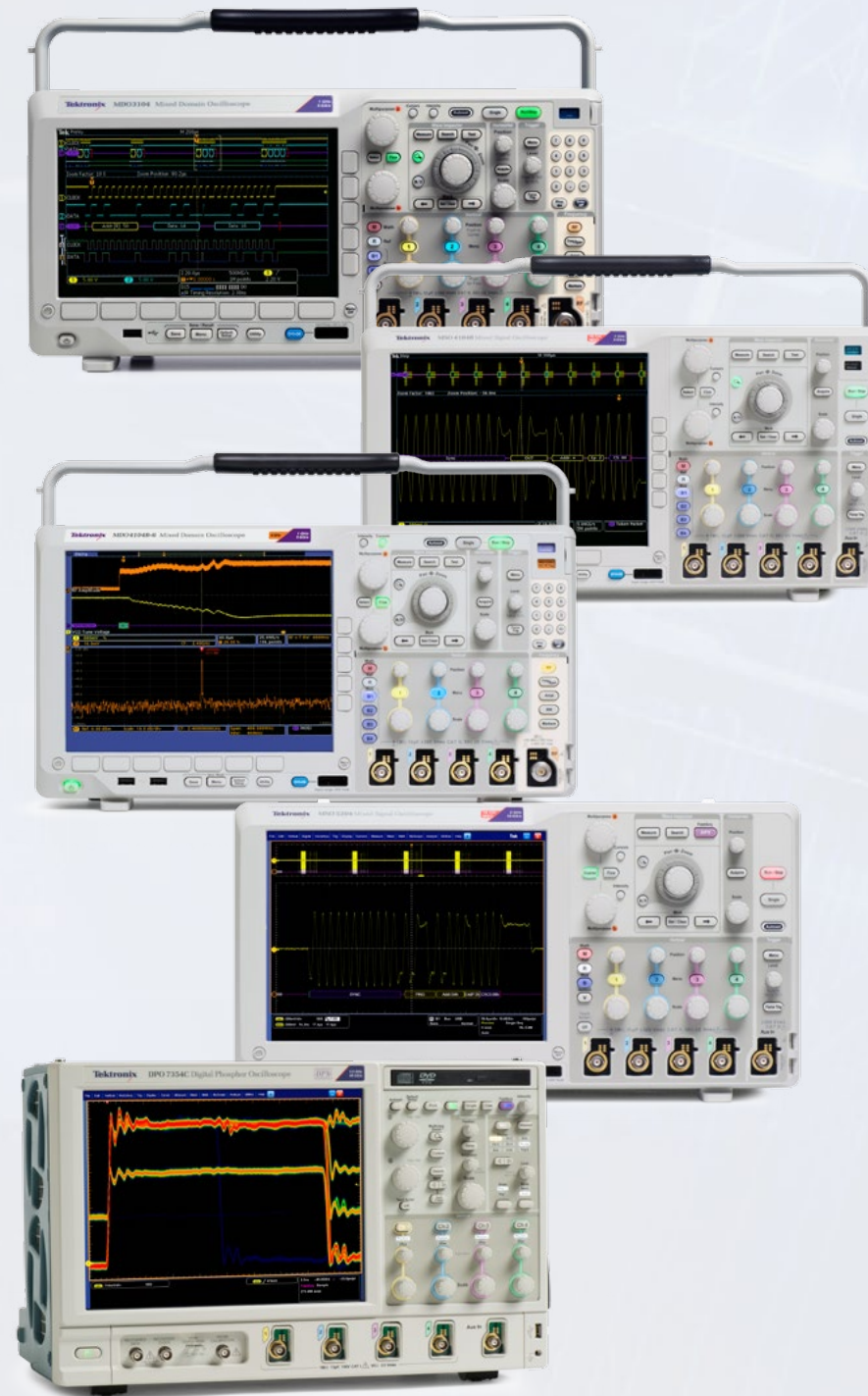
Today's integrated designs need an oscilloscope that is just as integrated - such as the **MDO3000 Mixed Domain Oscilloscope Series**. It's the ultimate 6-in-1 oscilloscope that includes an integrated spectrum analyzer, arbitrary function generator, logic analyzer, protocol analyzer, and digital voltmeter/counter. The built-in spectrum analyzer helps pinpoint radiated noise sources, and the MSO3PWR application module provides power and switching measurements.

With the **MSO/DPO4000B Mixed Signal Oscilloscope Series**, you can analyze up to 20 analog and digital signals with a single instrument to find and diagnose problems quickly. Sample rates up to 5GS/s and record length of 20MS provide high detail on power waveforms. DPO4 PWR automated power analysis software provides power and switching measurements.

The **MDO4000B Mixed Domain Oscilloscope Series** has the same features as the MSO/DPO4000B Series but also integrates a built-in spectrum analyzer. It lets you see frequency domain spectra and time domain waveforms, synchronized by triggers in either domain. This ability makes the MDO4000B the tool of choice for correlating signal problems with noise sources.

Offering up to 2GHz bandwidth, 10GS/s sample rate, and up to 250MS record length, the **MSO/DPO5000B Mixed Signal Oscilloscope Series** features affordable, yet powerful Windows®-based models. With more than 25 different application software packages available, you can test many different applications with a single instrument. The PWR option provides power measurements and switching measurements. It also includes magnetics measurements. Exclusive Tektronix features such as FastAcq with DPX® technology and a superior suite of triggers let you find intermittent events quickly that other oscilloscopes miss.

With the **DPO7000C Digital Phosphor Oscilloscope Series**, you can analyze analog and serial bus signals with a single instrument to find and diagnose problems in complex designs quickly. Bandwidths up to 3.5GHz and sample rates up to 40GS/s ensure the performance you need to see fast-changing signal details.



Want the rest of the story on Tektronix oscilloscopes?

Watch our product demos:

- **MDO3000 Mixed Domain Oscilloscope**
- **MSO/DPO4000B Mixed Signal Oscilloscope**
- **MDO4000B Mixed Domain Oscilloscope**
- **MSO/DPO5000B Mixed Signal Oscilloscope**
- **DPO7000C Digital Phosphor Oscilloscope**

Get advice on optimizing your power conversion test applications.

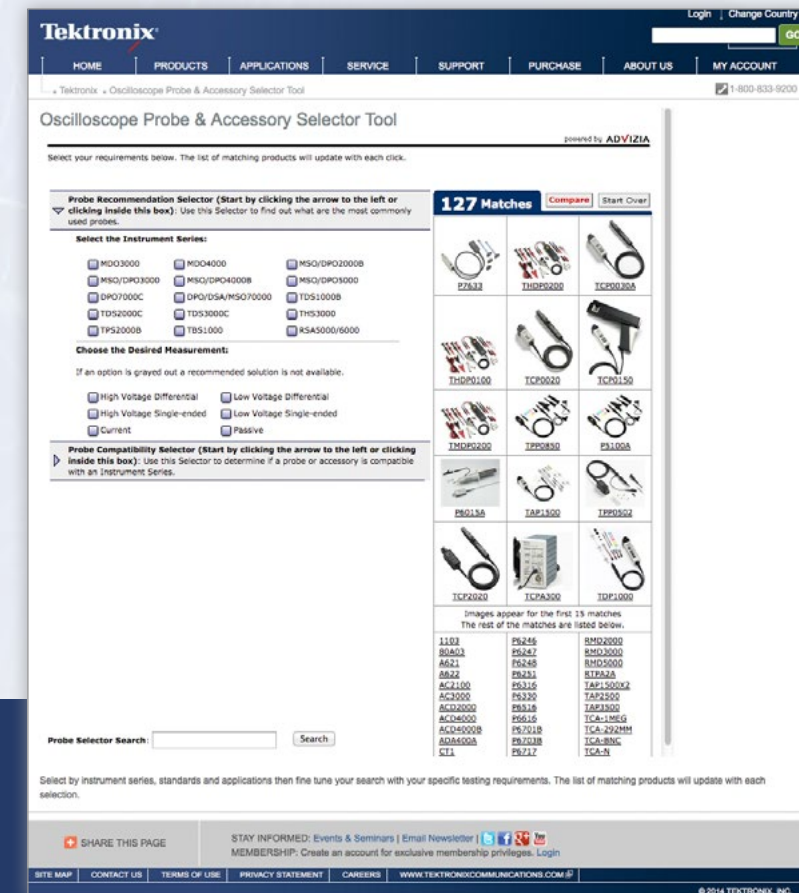
Send us your question or join the discussion on our [application forum](#).

Oscilloscope Selector Guide



MDO3000 with MDO3PWR Module **MSO/DPO/MDO4000B** with DPO4PWR Module **MSO/DPO5000B** with PWR Option **DPO7000C** with PWR Option

	MDO3000 with MDO3PWR Module	MSO/DPO/MDO4000B with DPO4PWR Module	MSO/DPO5000B with PWR Option	DPO7000C with PWR Option
Specifications	Bandwidth 100 MHz to 1 GHz	350 MHz to 1 GHz	350 MHz to 2 GHz	500 MHz to 3.5 GHz
Record Length	Up to 10 M	Up to 20 M	Up to 250 M	Up to 500 M
Sample Rate	Up to 5 GS/s	Up to 5 GS/s	Up to 10 GS/s	Up to 40 GS/s
Maximum Input Voltage	300 VRMS CAT II	300 VRMS CAT II	300 VRMS CAT II	150 V
Special Features	Integrated Spectrum Analyzer	•	•	
TekVPI™ Probe Interface	•	•	•	•
Automated De skew	•	•	•	•
Windows OS and Desktop			•	•
Automated Report Generator			•	•
Line Power	VRMS, IRMS	•	•	•
True, Reactive, Apparent Power	•	•	•	•
Power, Crest Factor, Phase	•	•	•	•
Harmonics, THD	•	•	•	•
EN61000-3-2 Pre-Compliance	•	•	•	•
MIL-STD-1399 Pre-Compliance	•	•	•	•
Output Analysis	Line Ripple	•	•	•
Switching Noise	•	•	•	•
Active Component Measurements	Switching Loss Measurements	•	•	•
Safe Operating Area	•	•	•	•
RDSon, dv/dt, di/dt	•	•	•	•
Modulation Analysis	•	•	•	•
Magnetic Component Measurements	Magnetic Power Loss		•	•
Flu* Density			•	•
B-H Plots			•	•



Want to learn more?

Tektronix probes and accessories are perfectly matched to our oscilloscopes. TekVPI probes communicate with the oscilloscopes listed in the selector guide to simplify scaling, degaussing, and de-skewing for fast, accurate power measurements. With more than 100 choices available, finding the one that best fits your needs is simple:

- High voltage probes to 40kV
- Current probes to 2000A
- High voltage differential probes to 6kV

Verifying Overall Power Conversion Performance

During product design, it's important to confirm that overall energy-efficiency goals are being met. Once individual switching component level performance has been optimized, a precision power analyzer is used to confirm the overall power performance of products with a high degree of certainty. This helps the designer save time by focusing on elements of the design that are necessary to achieve goals for power loss, efficiency, standby power, harmonics, and power factor.

- High-accuracy power measurements: V, I, VA, VAR, watts, PF, phase angle, Harmonics, W-Hr, etc.
- Three-phase or single-phase product testing
- Overall power conversion losses and efficiency

Ensure Superior Power Measurement Accuracy with Tektronix Power Analyzers

Tektronix power analyzers provide accurate measurements on the complex real-world waveforms of power supplies and inverters, as well as on the home, office, and industrial electrical products that contain them. They're invaluable in evaluating the performance of a power conversion design and validating that it will meet industry standards. The PA series of power analyzer/wattmeter instruments provides precise measurements of power (watts), power factor, harmonics, and efficiency via PWRVIEW PC software, as well as on their color graphics displays.



PA1000 Power Analyzer Series

- Single-phase power measurements
- Dual Spiral Shunt™ system for 0.05% basic accuracy
- Color graphics display including waveforms and harmonics
- USB, Ethernet LAN, GPIB interfaces
- Application-based measurement modes and PC software

PA4000 Power Analyzer Series



- One to four input modules allow several configurations to match your application
- High measurement accuracy of 0.01% (basic voltage & current accuracy) for demanding test requirements
- Dual internal current shunts for each module maximize accuracy for high- and low-current measurements
- Unique Spiral Shunt™ design maintains stability over variations in current, temperature, etc.
- Proprietary frequency detection algorithms ensure rock-solid frequency tracking, even on noisy waveforms
- Application-specific test modes simplify instrument setup

Want to learn more?

Watch our **“Fundamentals of Testing Power Conversion Efficiency”** webinar to discover techniques for measuring conversion efficiency and other performance parameters accurately using a precision power analyzer.



Power Analyzer Selector Guide

	Product Series	Channels	Basic Accuracy (V & I) Range	Max Voltage Input Range	Max Current Input Range	Measurements
	PA1000	1	0.05% reading + 0.05% range	600 VRMS	20 ARMS	Vrms, Irms, watts, VA, VAR, freq, power factor, crest factor, harmonics, THD, phase angle, Vpeak, Ipeak, W-Hr, VA-Hr, A-Hr
	PA4000	Choose 1, 2, 3, or 4	0.01% reading + 0.04% range	1000 VRMS	30 ARMS	Vrms, Irms, watts, VA, VAR, power factor, crest factor, harmonics, THD, TIF, phase angle, Vpeak, Ipeak, W-Hr, VA-Hr, A-Hr



Want to learn more?

Download our [Fundamentals of AC Power Measurements](#) or [Fundamentals of Three-Phase Power Measurements](#) application notes or take the virtual tours of the [PA1000](#) and [PA4000](#) Power Analyzer Series.

Get advice on optimizing your power conversion test applications.

[Send us your question](#) or join the discussion on our [application forum](#).

Want to learn more?

Contact us by phone, fax, mail, or email:



Keithley Instruments hosts an online applications forum to encourage idea exchange, discussions among users. [Join the discussion today.](#)

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www.keithley.com

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