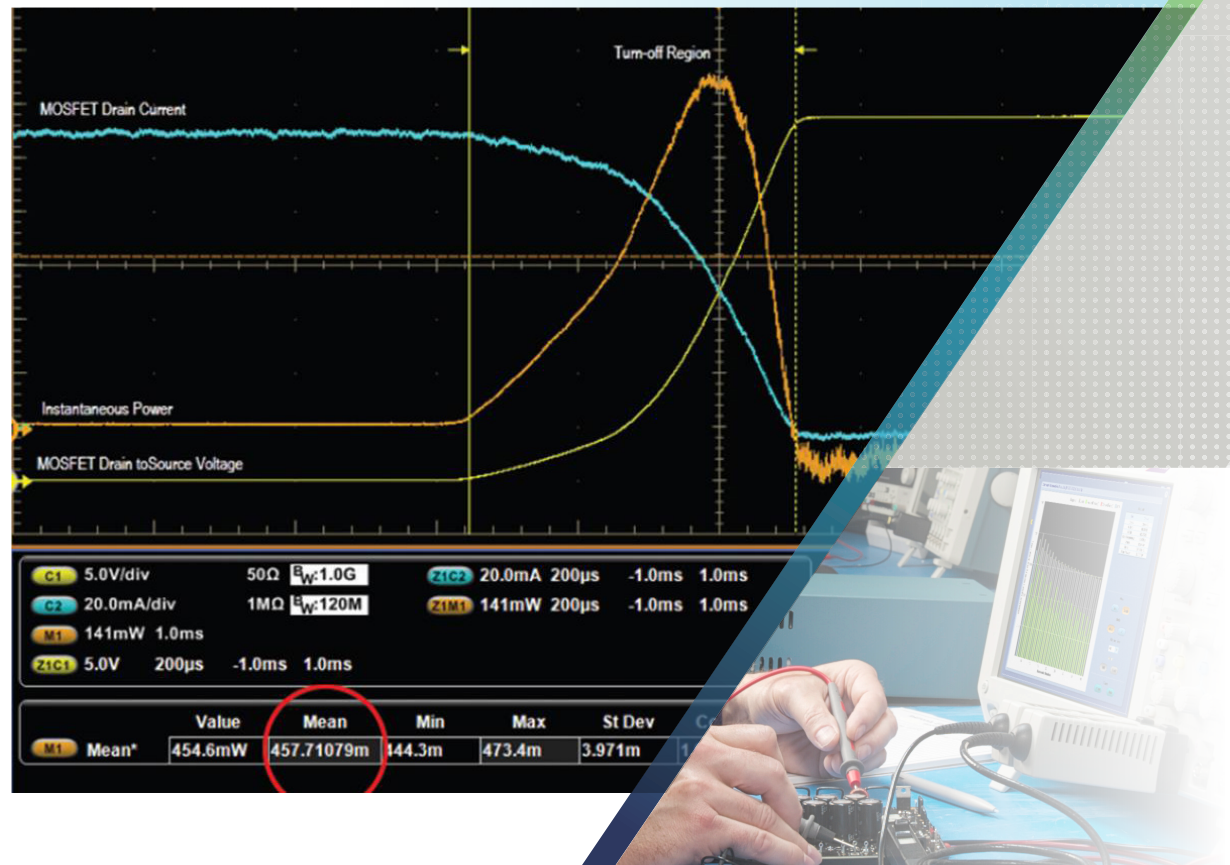# POWER SUPPLY MEASUREMENT TIPS

The 10 Stages of Design

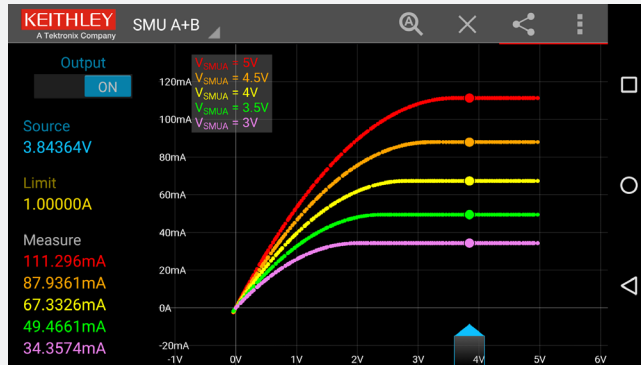# 10 Stages of Power Supply Design

Power supplies are the workhorses behind all electronics and electrical equipment. They come in numerous varieties to fit the gamut of systems they power. The race towards smaller, greener and cheaper power supply designs is more intense than ever. Higher efficiencies, higher power densities, time to market, standards requirements and cost reduction are impacting designs and designers alike.

Designing a power supply is a complex process with numerous steps. With this guide, we will follow a simple work flow and provide testing tips at each of 10 design stages. Hopefully you will find a few that will make your testing more effective and your life a little easier.
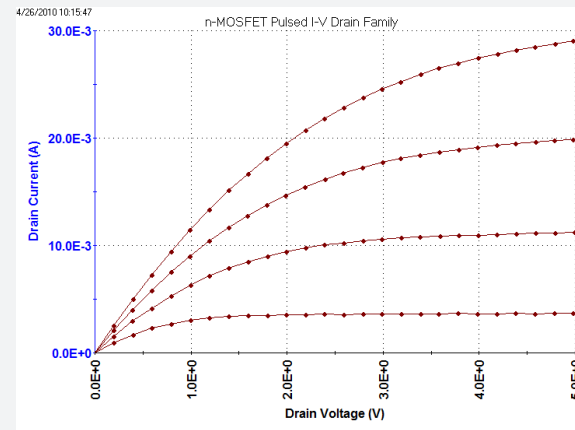
Index

1

A two-channel Source Measure Unit with PC software is a cost-effective solution for building characteristic curves

Pulsed I-V testing prevents device self-heating and closely approximates actual device operation.

Component Selection and Characterization

Traditionally, component manufacturers' detailed datasheets have given designers all the necessary operating characteristics for a good power supply design. But increasingly stringent requirements on new designs may require the designer to characterize components beyond the standard datasheet parameters.

- Critical power components such as MOSFETs, IGBTs and diodes should be selected for an optimized key parameter such as an on-state, off-state or AC characteristic.

- Components should be tested across temperature ranges beyond the ideal conditions defined by the data sheet.

- Passive components should also be tested for real world conditions along with active components.

LEARN MORE

How to Validate Power Semiconductor Device Designs Webinar:
**www.tek.com/webinar/learn-how-validate-power-semiconductor-device-designs-simply-and-accurately**

MEASUREMENT TIPS:

- To measure small differences in on-state characteristics such as gate threshold voltage (V_{TH}), gain (g_M) and on resistance (R_{DSON}), use an instrument capable of driving tens of amps to produce measurable voltage. Likewise, for low-current, off-state measurements such as leakage (I_{DSS}), use an instrument capable of sourcing high voltage to produce measurable current.

- For breakdown voltage (B_{VDSS}), you'll need to be able to source several times the working voltage of your device.

- Measure device capacitance versus voltage (C_{ISS}, C_{OSS}, C_{RSS}) on simple 2 terminal devices or complex 3 to 4 terminal transistors using a capacitance measurement system capable of testing over the full range of the device's DC operating voltage. Traditional LCR meters can tell you the capacitance, but not across the full operating voltage.

**INSTRUMENT FACTS:**

- **Keithley SourceMeters act as 4 instruments in one:**
- **voltage/current source**
- **voltage/current meter**
- **sweep and function generator programmable load.**
- **Keithley SourceMeters can measure IV characteristics on components from µV to 3 kV and fA to 100 A.**
- **IVy touchscreen software for Android platform makes it easy to check IV characteristics on components.**

2
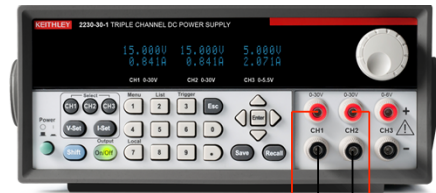
A triple isolated output DC power supply can power sub-circuits independently

Power Circuit 1
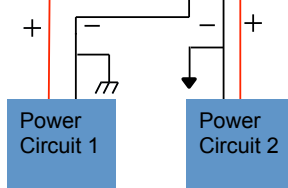
Power Circuit 2

2280S Series Power Supplies deliver low output noise with 6 1/2-digit current resolution.

Low-Voltage DC Circuit Power-On

The next stage in the design cycle is prototyping. First prototypes are prone to numerous failure modes. A lot can go wrong with board routing, solder joints, component placement and parasitics, so proceed cautiously.

- Always use a digital multimeter to check for shorts across all the input and output stages before power on.

- Isolate the low-voltage analog and digital circuit into as many sub-circuits as possible and power on the prototype board one sub-circuit at a time.

- Isolate the on-board power supply and test the output with and without load. Check if output voltage and ripple are as expected.

- Use a precision DC power supply to power on individual low-voltage sub circuits instead of relying on the on-board power supply. (If the on-board power supply has multiple outputs, use a DC power source with multiple isolated channels.)

MEASUREMENT TIPS:
- Use a DC power supply that shows both the programmed settings and the actual measured outputs simultaneously to quickly indicate if the DC stages are drawing too much current. Otherwise connect a DMM between the power supply and the device under test to closely monitor current draw.
- When you need to provide a precise voltage to your system under test, use a 4-wire, remote sensing bench power supply to eliminate the impact of any voltage drop in wiring between the bench power supply and your system under test.
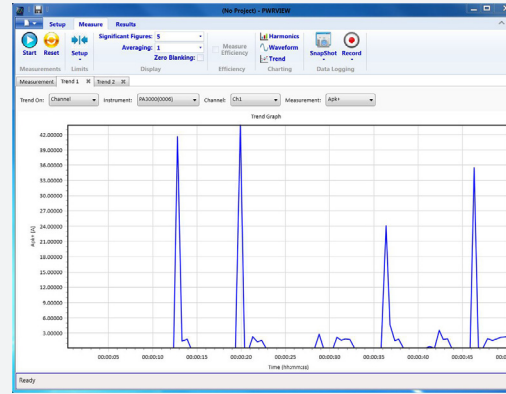
INSTRUMENT FACTS:
- Keithley's 2280S Precision Measurement Power Supply can measure low sleep mode state currents with 10 nA resolution and 0.05% accuracy.
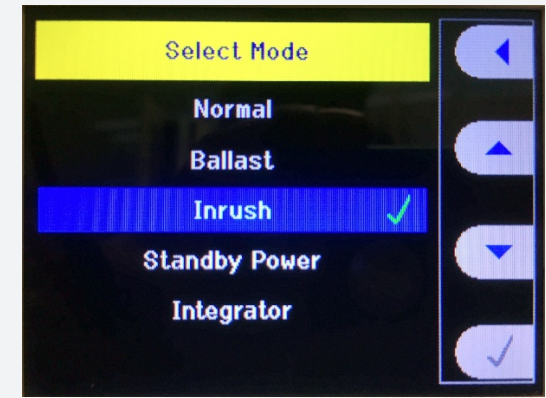
3

AC power analysis using DPOPWR on an MSO5000B oscilloscope

PWRVIEW - Trend chart for monitoring power-on events.

PA1000 – Inrush current mode

High-Voltage AC Circuit Power-On

Now that all your low-voltage circuits are checked out, it's time to power-on the high-voltage circuits. This is the stage where your prototype will see high voltage for the first time.

- It is always a good idea to isolate high-voltage stages from all low-voltage stages during the first power-on.

- Consider using an AC power source with current limiting. Always start from the lowest AC voltage for your design. This will help reduce major blowouts due to bad soldering, poor assembly or PCB design mistakes.

- Using appropriately-rated differential and current probes, measure the AC input voltage and current.

- Use a scope or a power analyzer on the AC input with logging enabled before powering on the device under test for the first time. Capture the inrush currents and transients.

- Once the high-voltage power stage checks out, enable the low-voltage control circuit for a complete picture.

MEASUREMENT TIPS:
- To use a clamp-on current probe to measure the low AC input current draw of your unloaded system you can boost the current seen by the probe. Simply loop the line conductor through the jaw more than once. Just remember to divide your current reading by the number of turns!
- Use a Power Analyzer with a continuous logging function to log start-up current. In the event of a catastrophic failure during turn-on, you will at least have some data to investigate possible causes.

INSTRUMENT FACTS:
- **PA1000 Power Analyzer offers inrush current mode to test peak during current inrush.**
- **DPOPWR scope software offers an extensive power analysis suite that can help you measure and debug input AC power parameters during power-on.**

LEARN MORE
*Inrush Current Measurement with PA3000 Video:*
www.tek.com/how/measuring-inrush-current-electric-chainsaw

4

Digital and Analog Control Circuit Debug

This is the stage where you check the control logic. This is probably the most important and complex part of the design where you have to test for proper compensation, voltage, timing and frequency responses.

- Measure the modulation signal at the switching device driver during power-on to verify proper switching frequency, pulse width and duty cycle at different loads.

- Check the loop frequency response by injecting a frequency sweep signal through a wideband injection transformer in the control loop.

- Use a frequency response analyzer to measure the gain and phase of the circuit.
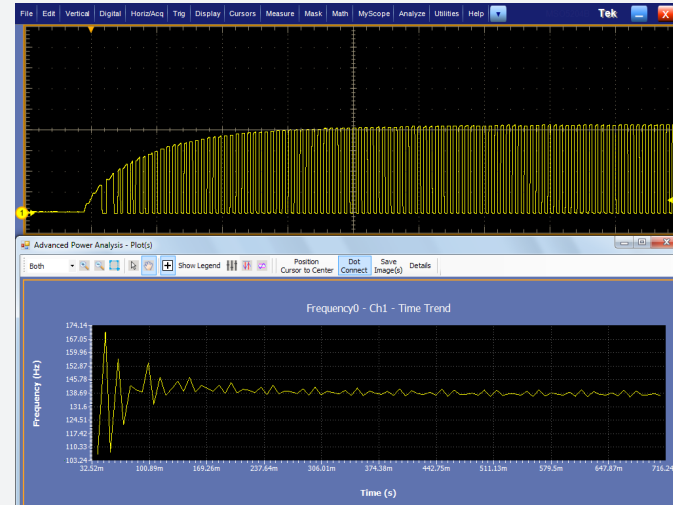
DPOPWR- Modulation Analysis on an MSO5000B oscilloscope

MEASUREMENT TIPS:
- Monitor input and output voltages, as well as feedback or control signals to verify that the loop response (e.g. critical damping) is as expected during changes of input voltage and output load.
- Monitor the input and output voltages and currents along with the control signals to verify operation of circuits such as soft start, short-circuit protection, shutdown and current fold-back.
- For digitally-controlled supplies, capture and display time-correlated views of the analog, digital, and serial bus control signals to visualize the system operation and verify that the control system is working as designed.
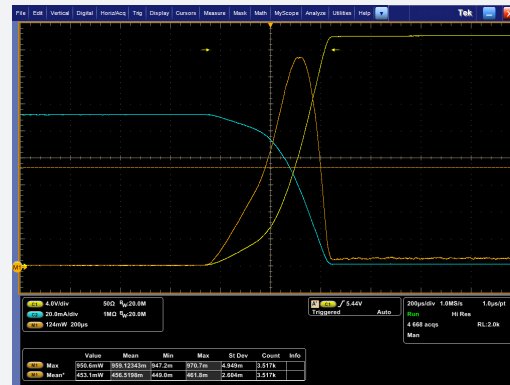
INSTRUMENT FACTS:
- **DPOPWR software can help you with modulation analysis on difficult to measure PWM signals.**
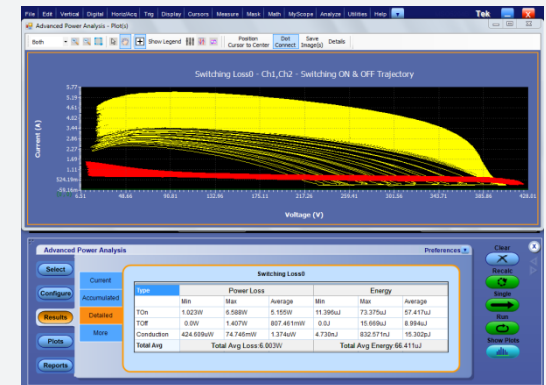
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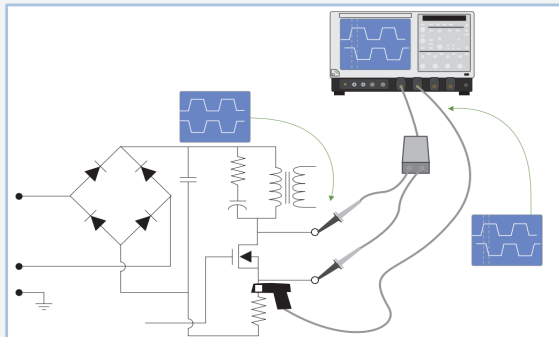
Switching Measurements

Switch timing analysis

Switch On-Off trajectory

Power Stage Switching Characteristics

After the high-voltage circuits, low-voltage circuits and control logic have been verified, it's time to check the switching characteristics of the power stage.

- Test switching characteristics at no-load, nominal-load and full-load conditions.

- Make sure the turn-on, turn-off, duty-cycle and dead-times of all switches (MOSFETs, IGBTs, etc.) are as expected based on design calculations.

- Check all the V_{GS} signals for noise and bumps as any unintended glitches on this terminal can lead to unwanted turn-on and shoot-through.

- Depending on the topology, check the dead-time for sync rectifiers or H-bridges, to make sure there is no possibility of shoot-through.

- Verify timing relationships among gate drivers and related signals to make sure they are as expected.

LEARN MORE
Probing Techniques to Accurate Voltage Measurements on Power Converters with Oscilloscopes Application Note:

www.tek.com/document/application-note/probing-techniques-accurate-voltage-measurements-power-converters-oscillos

MEASUREMENT TIPS:
- Use differential probes with an appropriate voltage rating to safely measure non-ground-referenced signals. Do not float the scope – it is dangerous.
- If it is difficult to measure floating gate signals, probe the input of the gate driver to verify dead-times between the top and bottom FETs.
- Measure currents at points of minimum voltage slew rate to minimize crosstalk.
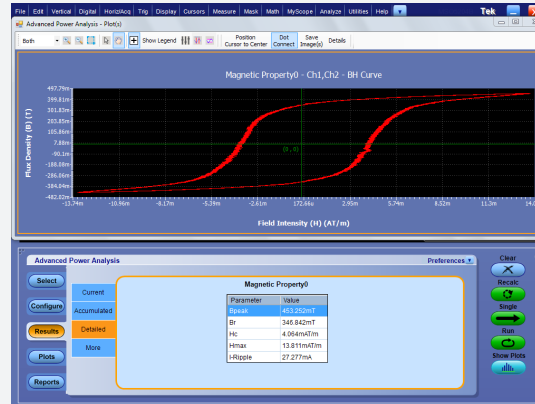
INSTRUMENT FACTS:
- **Tektronix scopes provides a high resolution mode to minimize noise and make sure turn-on and turn-off can be calculated with the highest accuracy possible.**
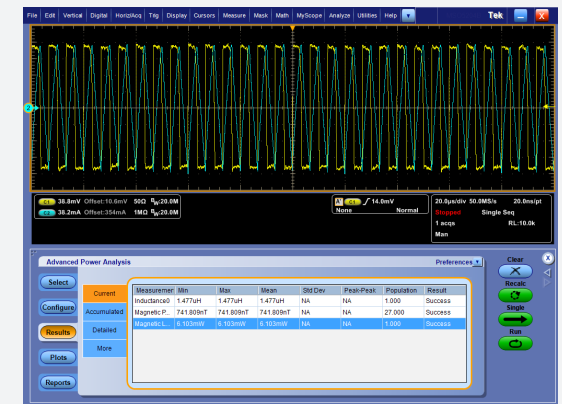
6

Switching and Conduction Losses on an MSO5000B oscilloscope

Magnetic Characterization on an MSO5000B

Magnetic Losses on an MSO5000B

Switching and Conduction Loss Testing

Switching and conduction losses through power switches and magnetics are major contributors to the overall loss of a system. It's important to minimize these losses especially for modern high-efficiency designs.

- Calculating switching and conduction losses based on a datasheet can be misleading, as it does not provide a comprehensive loss profile accounting for operating conditions and circuit parasitics.

- It's important to check the rectifier, switches (MOSFETs, IGBTs, etc.), and magnetics for losses when the circuit is active and loaded. More often than not, magnetics are custom-designed. Like switching devices, it's important to test magnetics in operation to properly characterize them.

LEARN MORE
Measuring Power Supply Switching Loss with Oscilloscopes Application Note:
www.tek.com/document/application-note/measuring-power-supply-switching-loss-oscilloscope
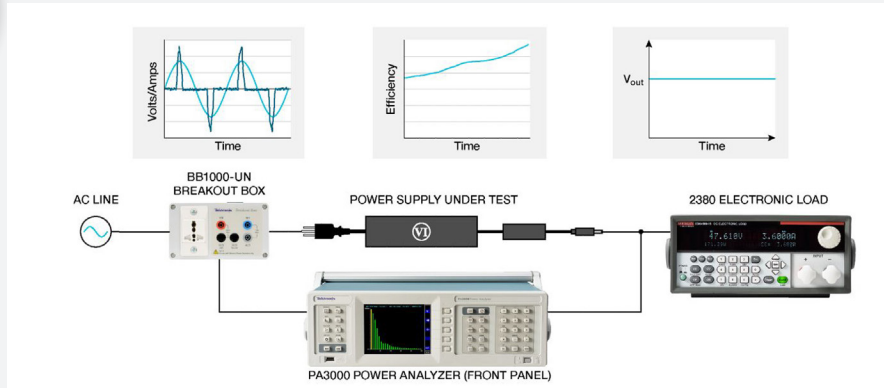
MEASUREMENT TIPS:
- For measuring switch losses, use a high-resolution scope and remember to deskew voltage and current probes. Use filtering and averaging functions to get accurate results over a set period.
- To measure switching loss on an oscilloscope, you can multiply voltage by current, and take the mean of the resulting power waveform during turn-on or turn-off. If you have power analysis make this process easier and more repeatable.

INSTRUMENT FACTS:
- **DPOPWR software offers an excellent solution for dynamically testing magnetic power loss and magnetic properties like inductance and B-H curve.**
- **DPOPWR provides automatic calculation techniques for measuring repeatable switching and conduction losses on high-power switches while active in the circuit.**

7

AC-DC Power supply, efficiency measurement setup

	GROUP A Ch1		GROUP B Ch2		GROUP C Ch3		GROUP D Ch4		Result 1332
Vrms	109.85	V	Vrms 12.077	V	Vrms 109.88	V	Vrms 11.965	V	
Arms	330.82	mA	Arms 1.3762	A	Arms 136.85	mA	Arms 527.76	mA	
Watt	20.628	W	Watt 16.620	W	Watt 7.3105	W	Watt 6.3129	W	
VA	36.339	VA	Vdc 12.077	V	VA 15.037	VA	Vdc 11.965	V	
Freq	60.000	Hz	Adc 1.3762	A	Freq 60.000	Hz	Adc 527.63	mA	
PF	0.5677				PF 0.4862		VII -----		
Apk+	1.0227	A			Apk+ 494.55	mA			
Apk-	-1.0184	A			Apk- -485.91	mA			
Vdc	10.299	mV			Vdc 37.148	mV			
EFFCIENCY1	80.569	%			EFFCIENCY2	86.329	%		
	-----				-----				
	-----				-----				02:02P 11/20

Power analyzer showing efficiencies of two AC-DC power supplies

Efficiency and Specifications Testing

The next step is to see whether the design meets efficiency standards and other required specifications such as line and load regulation, ripple, noise, short-circuit protection and transient response.

- Measure efficiency using a high accuracy multi-channel Power analyzer while sweeping the the power from no load to full load using an electronic load.

- For load regulation, use a high-precision DMM directly on the input and the output terminals of the power supply and sweep the load from minimum to maximum. It is important that the input voltage be kept constant during the test. Log any changes in output voltage versus load to determine load regulation.

- Line regulation can be tested with a similar setup where output voltage is measured across a constant load, while input AC voltage sweeps from minimum to maximum. This test is especially critical for universal input power supplies.

- Check for noise and ripple at full load using a scope optimized for high-resolution measurements or a high-precision graphical sampling multimeter. The scope will typically provide higher bandwidth, but the multimeter will give better accuracy.
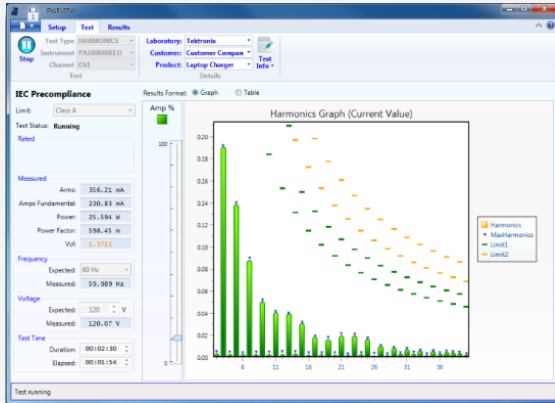
MEASUREMENT TIPS:

- To measure low-level voltages such as ripple, minimize probe attenuation (1X or 2X, if possible) to get the best signal-to-noise ratio in your oscilloscope measurements.

- Do not rely on the AC source or electronic load readouts for line or load regulation tests. Use precision instruments directly at the terminals of the power supply for better measurement accuracy and to minimize drop across input and output cables.

- Use a low-inductance ground-spring probe adapter or similar accessory when measuring high-frequency noise and ripple with an oscilloscope. Standard probe ground wires act as antennas and pick up ambient noise, generating significant errors in readings.
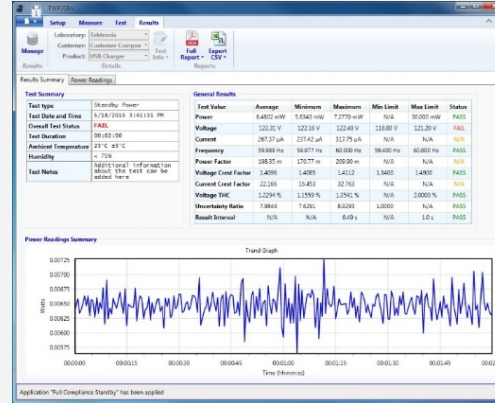
DID YOU KNOW?

- **Tektronix PA3000 with 0.04% accuracy and 10mW standby power capability, allows accurate efficiency and power measurement from no load to full load.**

- **Keithley 2380 DC Electronic Loads can sink a wide range of currents and voltages, in 200 W, 250 W, and 750 W versions.**

- **Keithley's DMM7510 Graphical Sampling Multimeter has an 18-bit, 1 MS/s digitizer to accurately capture fast transients and small ripple.**

LEARN MORE

Efficiency Measurement (LEVEL VI) with PA3000 Power Analyzer video:

www.tek.com/how/efficiency-measurement-level-vi-power-supply

8

IEC 61000-3-2 current harmonics testing

IEC 62301 Ed 2. standby power testing

Power Line Compliance Testing

Congratulations! Your first prototype is up and running. It's time to check if the design will comply with local power line standards.

- Most AC-DC power supplies are designed to operate from an AC wall socket and are subject to stringent power consumption and power quality standards such as IEC 62301 standby power and IEC 61000-3-2 current harmonics standards. Compliance to these standards should be tested early in the design cycle to avoid future headaches.

- Make sure that the power analyzer you use for testing current harmonics complies with the IEC 61000-4-7 standard for measurement techniques.

LEARN MORE

Standby Power (IEC62301) Measurement with PA3000 Power Analyzer Video:
**www.tek.com/how/performing-standby-power-measurements-based-iec-62301-standard**

IEC 61000-3-2 Current Harmonics Measurement with PA1000 Video:
www.tek.com/webinar/iec61000-3-2-current-harmonics-testing

INSTRUMENT FACTS:
- **Tektronix provides pre-compliance solutions for IEC61000-3-2 current harmonics, compliance solutions for IEC62301 standby power and ENERGY STAR , as well as user-defined limits, all at an affordable price.**
- **PA1000 Power Analyzer has 20 µA current measuring capability that allows standby power measurement as low as 5 mW.**
- **The Tektronix Breakout Box provides two separate terminals for load and source side measurements, making it easy and safe for accurate low-power readings for standby power testing.**

MEASUREMENT TIPS:
- Skip the wait and use affordable pre-compliance solutions to test for compliance with CE mark, ENERGY STAR®, IEC standby & harmonics standards. This will save a lot of time and trouble later in the design cycle. Test pre-compliance early and often.
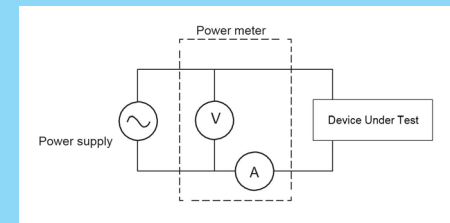

- Double check your connections when measuring low and distorted standby power. Incorrect wiring can lead to significant errors. Make sure you always connect the voltmeter channel on the source side of the current shunt so you don't measure the current through the voltmeter impedance.

9
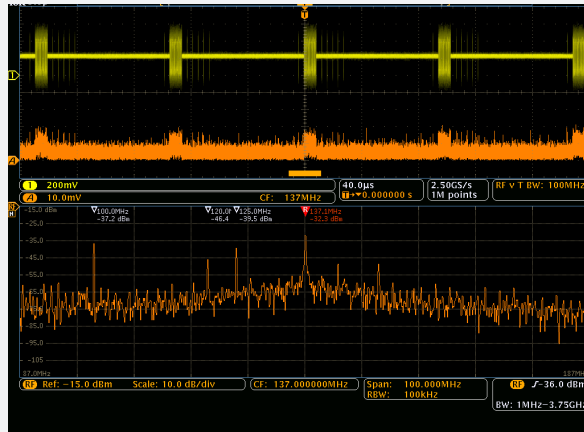
EMI troubleshooting with synchronized time and spectrum traces on an MDO4000 oscilloscope
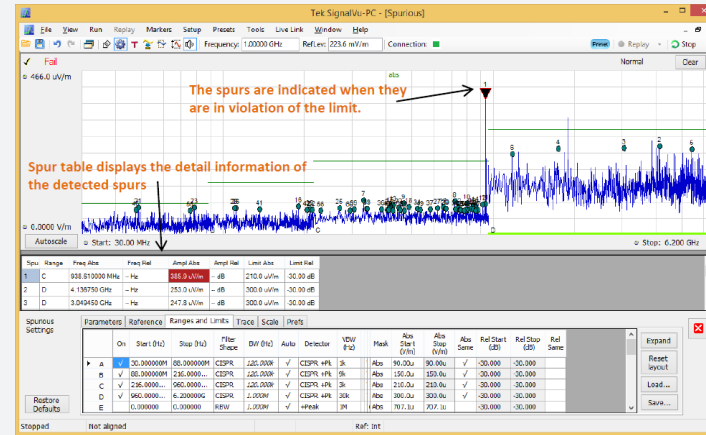
Pre-compliance EMI scan with an RSA306 real-time spectrum analyzer

EMI Troubleshooting and Pre-compliance

EMI and RFI testing are often ignored in early design stages due to the difficulty and expense of testing. This can result in unpleasant surprises and project delays as deadlines loom.

- Test for EMC issues early in the design cycle to avoid unnecessary board turns and missed timelines. With a spectrum analyzer and pre-defined EMI compliance masks, you can perform pre-compliance tests and catch EMI problems before you go to the test house.

- Use a Mixed Domain Oscilloscope (MDO) with a built-in spectrum analyzer and near-field probes to quickly localize sources of EMI. You can measure the spectral peaks and deduce root causes, armed with the oscilloscope and a schematic.

LEARN MORE
Practical EMI Troubleshooting Application Note:
**www.tek.com/document/application-note/practical-emi-troubleshooting**

MEASUREMENT TIPS:
- Use affordable EMI pre-compliance solutions to test for EMC and RFI compliance earlier in the prototype phase to save time and money in the long run.
- Use near-field probes with mixed domain scopes or spectrum analyzers to find and localize RF sources.

INSTRUMENT FACTS:
- **MDO4000 Series oscilloscopes can help you view the entire system and measure the relationships between analog, digital, serial bus events, and spectral emissions.**
- **The Tektronix RSA306 provides real-time spectrum analysis and enables you spot short-duration EMI bursts. Long recording time helps you capture infrequent bursts.**
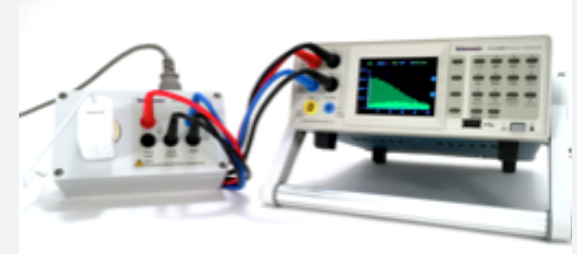
10
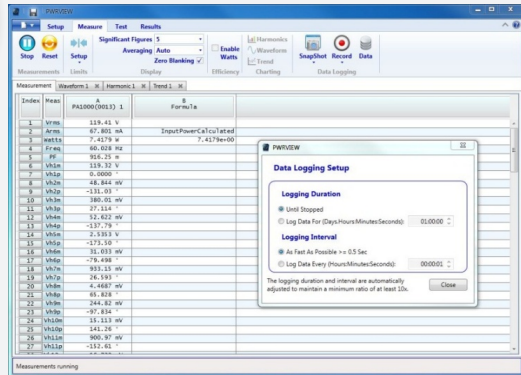
Custom logging and user limits for automation
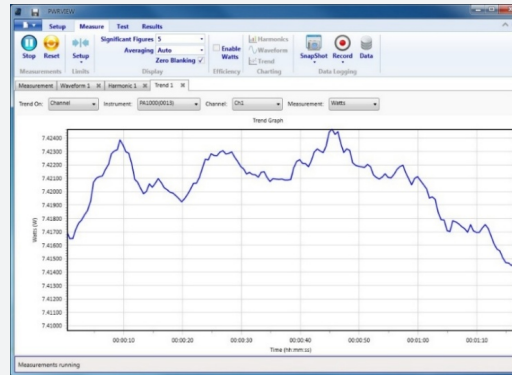
Trend chart for validation testing

PA1000 Power Analyzer and Break-out Box setup

Design Validation

Now that you've thoroughly tested your first prototype, it's time to shift into overdrive and go for the next revision.

- Repeat all the testing steps discussed earlier as a sanity check.

- When everything checks out, it's time to put some more miles on your design and check reliability.

- Test the power supply for all input configurations. This is especially important for universal-input power supplies.

- Sweep the load from no load to full load to test your power supply for all possible operating conditions.

- Run a lifetime test using environmental chambers to check the real-life performance of your design.

MEASUREMENT TIPS:
- Use an AC source with universal in put ratings and one that is certified for IEC testing. This will help make sure that your product will pass compliance tests.
- Use a Power Analyzer on the input and output of the power supply to measure all AC input parameters like power factor, crest factor, harmonics and peak current along with system efficiency.

INSTRUMENT FACTS:
- **PWRVIEW software with Tektronix Power Analyzers provide efficiency, standby power, harmonics and energy consumption (WHr) testing with a slew of graphing and logging features for long term design validation.**

VISIT:

www.tek.com/application/power-supply-measurement-and-analysis
to get a complete list of power supply literature, a product demonstration or quote.

46A-60180-2