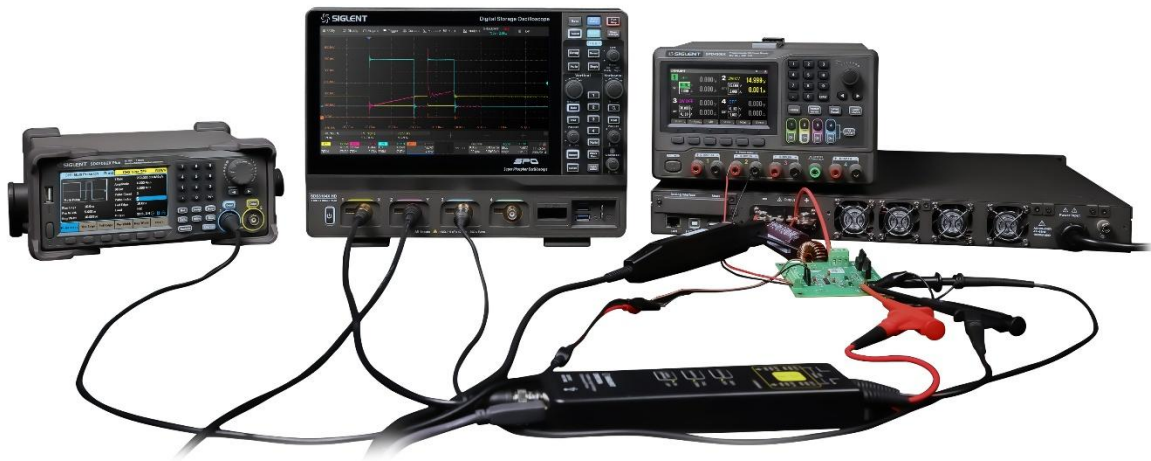


Power Measurements

Capabilities, Notes, and Limitations

Application Validation & Instrument Selection



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Overview

Power and power applications intersect with a number of measurement tools and instruments. Capabilities include the ability to deliver voltage, current, and power as well as the ability to draw or load voltage, current, and power. Power measurements are also made using meters and oscilloscopes with specialized probing.

DC Power supplies are separated into two categories based on their design approach. A linear DC power supply includes a transformer that is directly tapped to provide power. Linear benchtop supplies can have multiple channels and tend to have low ripple and noise as they provide clean power from the transformer. They also tend to be heavier and limited in voltage and power due to this design. **Switching DC power supplies** improve density and extend voltage and power envelopes to broaden capabilities beyond what linear supplies are usually capable of. The switching device impacts noise, ripple, and efficiency but adds capability. Both types of DC power supplies may have an option for sense lines or 4 wire measurements. This allows the voltage drop at the device to be measured directly removing loss in the cables from impacting the measurement. With high currents, this voltage drop becomes more significant.

Many power supplies are built with strict current and voltage limits as opposed to power limits. This can simplify design, but limits usability. The

operating envelope of a channel or supply is an important consideration beyond the banner specifications.

High resolution oscilloscopes provide higher speed and advanced measurements that aren't possible within the power supply or load. Measurement techniques for efficiency, harmonics, operating area, and more are often powered by high speed data capture of the current and voltage with an oscilloscope or similar device. This often requires advanced probing techniques including:

- Differential voltage probing
- Current probing
- Power rail probing
- Optically isolated probing
- Techniques that limit inductance and capacitance

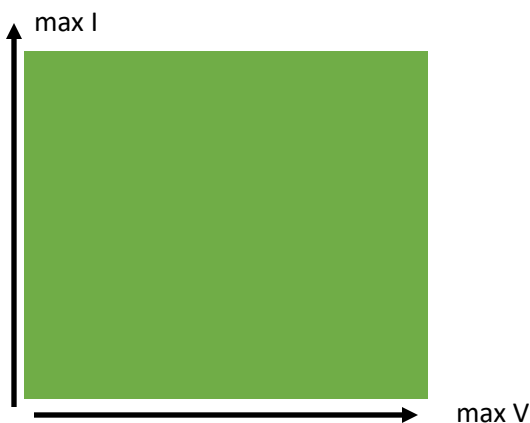
SIGLENT oscilloscopes, generators, and probes provide analysis related to power electronics measurements in a number of measurement toolkits including power analysis and bode plot. Applications like double pulse testing and loop stability utilize a waveform generator to generate input signals for the power system.

For some applications, **multimeters** can also be used in parallel to more accurately measure DC or AC voltages and currents. This can provide additional efficiency measurements over a longer time period.

Electronic Loads are also used in these measurements to test power supplies under varying load conditions. Electronic loads can vary test conditions by voltage, current, resistance, power, and time.

Power Supply Configurations

Flexibility and configurability are important in many power applications. With a wide range in designs and setups, let's take a look at how power supplies can be used in different applications to take advantage of their extensive power envelopes. SIGLENT linear power supplies can operate at both max voltage and max current at the same time. This means the supply is never limited by power and is always either in constant voltage (CV) mode or constant current (CC) mode.



Linear supply channels are also often isolated from ground. This includes the SPD3303X and SPD4000X series. Linear supply channels can also often be used in series or parallel. Putting channels in series increases the voltage while adding channels in parallel increases the current. These power supplies have internal connections that enable those configurations

without complicating external wiring. These power supplies also have some 4 wire sense capability as described above. This table explains the configuration of the channels and connections on linear supplies:

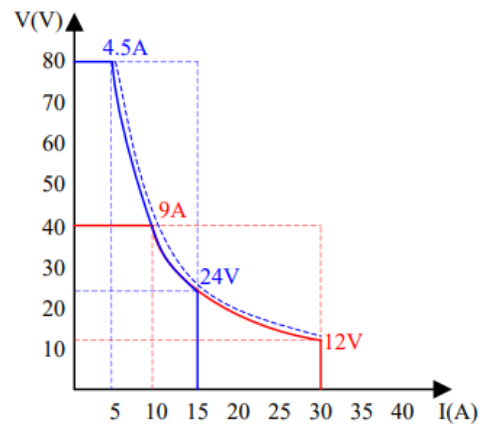
Channels	CH Config	SPD1168X			SPD1305X			SPD3303X/E			SPD4323X			SPD4121X			SPD4306X		
		V	A	W	V	A	W	V	A	W	V	A	W	V	A	W	V	A	W
CH1	Independent	16	8	128	30	5	150	32	3.2	102	6	3.2	18	15	1.5	22.5	15	1.5	22.5
CH2	Independent							32	3.2	102	32	3.2	102	12	10	120	30	6	180
CH3	Independent							5	3.2	16	32	3.2	102	12	10	120	30	6	180
CH4	Independent										6	3.2	18	15	1.5	22.5	15	1	15
CH1 & CH2	Series							60	3.2	192									
CH2 & CH3	Series										60	3.2	192	24	10	240	60	6	360
CH1 & CH2	Parallel							32	6.4	204									
CH2 & CH3	Parallel										32	6.4	204	12	20	240	30	12	360
Total Instrument Power (W)		128			150			220			240			285			400		
4 Wire Sense		on front panel			on front panel			No			CH2&3: rear panel			CH2&3: rear panel			CH2&3: rear panel		

SIGLENT switching power supplies are configured to allow more flexible use of the output power. These channels operating envelopes follow a curve that is related to the total power and the efficiency of the supply. For instance, the SPS5081X can provide 4.5 Amps at 80 Volts or 15 Amps at 24 Volts. Those points are connected by a curve that touches on 9 Amps at 40 Volts. Here is the curve for the 40 Volt and 80 Volt SPS5000X series models:

SPS5081X

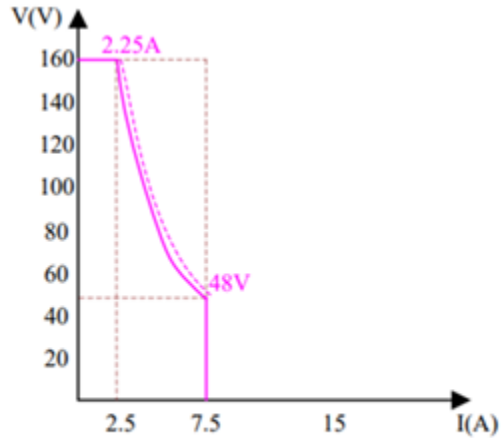
SPS5041X

- SPS5042X = SPS5041X current values X 2
- SPS5043X = SPS5041X current values X 3
- SPS5044X = 2 channels of SPS5041X
- SPS5045X = 3 channels of SPS5041X
- SPS5082X = SPS5081X current values X 2
- SPS5083X = SPS5081X current values X 3
- SPS5084X = 2 channels of SPS5081X
- SPS5085X = 3 channels of SPS5081X



80V 15A/ 40V 30A Output Operating Area

The 160 Volt models follow this curve:



160V 7.5A Output Operating Area

SPS5161X

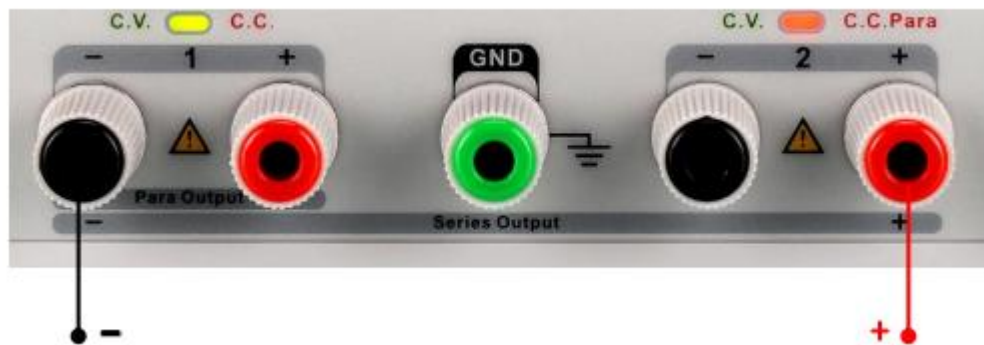
- SPS5162X = SPS5161X current values X 2
- SPS5163X = SPS5161X current values X 3
- SPS5164X = 2 channels of SPS5161X
- SPS5165X = 3 channels of SPS5161X

Most of these models have their connection points on the rear of the instrument. There are also limits to the number of channels that can be used in series or parallel. Use this table as a reference for switching power supplies:

Model	Total Channels	Channel Voltage	Channel Current	Total Power	SERIES: multiple channels or Instruments				PARALLEL: multiple channels or Instruments				Connections	4W Sense
					# CHs	V	A	W	# CHs	V	A	W		
SPS5041X	1	40 V	30 A	360 W	2	80	30	720	3	40	90	1080	FRONT/REAR	REAR
SPS5042X	1	40 V	60 A	720 W	2	80	60	1440	3	40	180	2160	REAR	REAR
SPS5043X	1	40 V	90 A	1080 W	2	80	90	2160	3	40	270	3240	REAR	REAR
SPS5044X	2	40 V	30 A	720 W									REAR	REAR
SPS5045X	3	40 V	30 A	1080 W									REAR	REAR
SPS5051X	1	50 V	10 A	180 W	2	100	10	360	3	50	30	540	FRONT/REAR	REAR
SPS5081X	1	80 V	15 A	360 W	2	160	15	720	3	80	45	1080	FRONT/REAR	REAR
SPS5082X	1	80 V	30 A	720 W	2	160	30	1440	3	80	90	2160	REAR	REAR
SPS5083X	1	80 V	45 A	1080 W	2	160	45	2160	3	80	135	3240	REAR	REAR
SPS5084X	2	80 V	15 A	720 W									REAR	REAR
SPS5085X	3	80 V	15 A	1080 W									REAR	REAR
SPS5161X	1	160 V	7.5 A	360 W	2	320	7.5	720	3	160	22.5	1080	FRONT/REAR	REAR
SPS5162X	1	160 V	15 A	720 W	2	320	15	1440	3	160	45	2160	REAR	REAR
SPS5163X	1	160 V	22.5 A	1080 W	2	320	22.5	2160	3	160	67.5	3240	REAR	REAR
SPS5164X	2	160 V	7.5 A	720 W									REAR	REAR
SPS5165X	3	160 V	7.5 A	1080 W									REAR	REAR
SPS6225X	1	200 V	25 A	1500 W	2	400	25	3000	5	200	125	7500	REAR	REAR
SPS6150X	1	100 V	50 A	1500 W	4	400	50	3000	5	100	250	7500	REAR	REAR

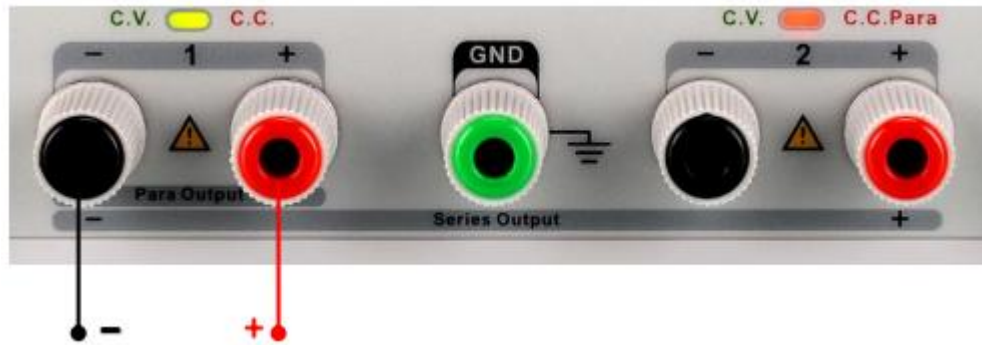
Series & parallel wiring

Depending on the model and the exact configuration, the wiring for series and parallel configurations may differ. Let's start with the linear power supplies and focus on the SPD3000X and SPD4000X series. For series connections, the SPD3000X models use channels 1 & 2 together as shown in the table above. To connect to the device under test with the supply channels in series, set the power supply mode from the front panel to "series" and then connect to the black terminal of channel 1 and the red terminal of channel 2 like so:



Output rating 0~60V/0~3.2A in series

Use the channel 1 settings to control this combined channel in series or parallel mode. In parallel mode, the SPD3000X should wire only to channel 1, but both channels appear here in parallel when the mode is set:



0~32V/0~6.4A in parallel

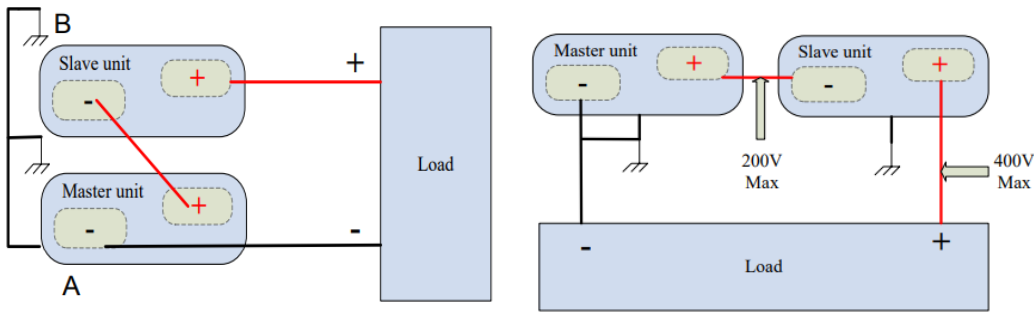
The SPD4000X models use channels 2 and 3 for series and parallel modes. To connect in series mode, set the mode from the front panel and then connect to the CH2 positive (red) terminal and the CH3 negative (black) terminal. Note that this is oriented differently than the SPD3000X:



On the SPD4000X, use the channel 2 settings to control this combined channel in series or parallel mode and make measurements.

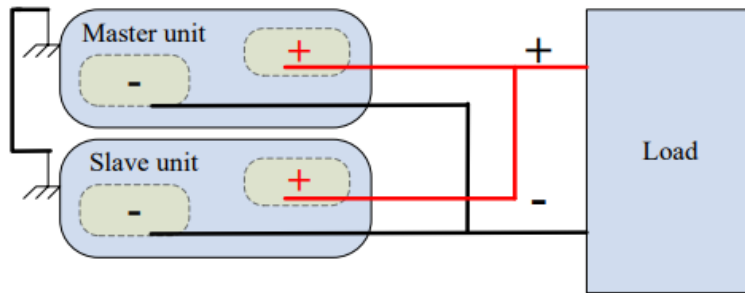
For parallel connections, the SPD4000X uses the channel 2 terminals as shown in the image above. The SPD3000X uses channel 1 terminals.

For the switching power supplies, we make the connections externally. These supplies require an analog cable connection to establish the series or parallel mode between instruments. Then, the connections are made like this in series and parallel mode:



SPS5000X models in series mode

SPS6000X models in series mode



SPS5000X and SPS6000X models in parallel mode

Split supply wiring

The SPD3000X and SPD4000X series power supplies can each produce both positive and negative potentials as power rails for a circuit or device if the supplies are operating in Independent Mode and are wired as a split supply.

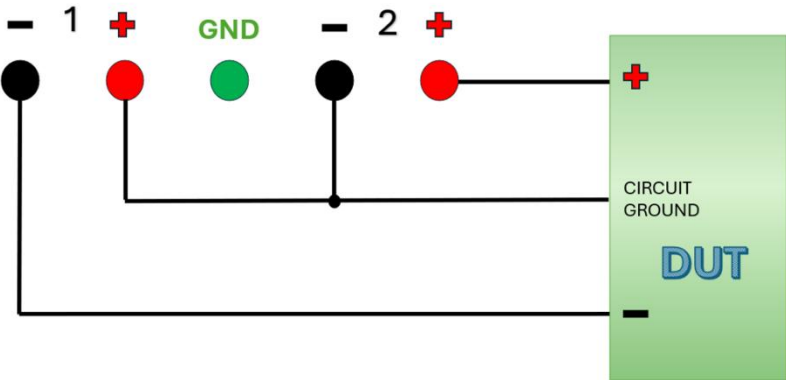
Independent Mode: The output channels on these supplies are in Independent Mode when both the Series and Parallel modes of the supply are turned OFF.

Wiring: On the SPD3000X for example, the Channel 1 and Channel 2 outputs can be wired together as a split supply by tying the positive output of one channel to the negative output of the other channel. The node which connects Channel 1 and Channel 2 provides the circuit common. The two remaining outputs supply the positive and negative rail voltages.

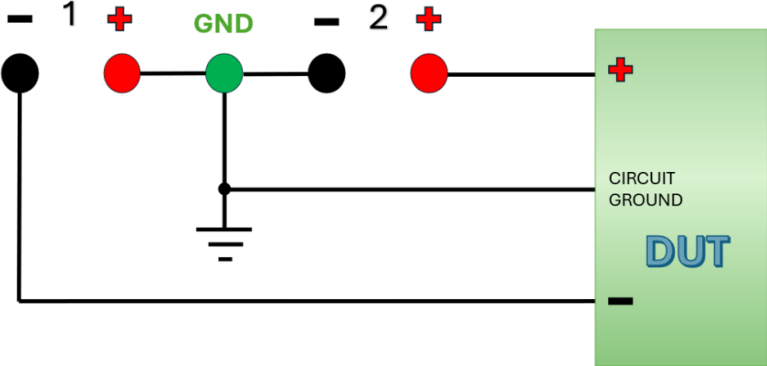
Note: The setpoints and readback measurements on these supplies can be only positive values. Therefore, the output channel that is used for negative polarity will show positive values on the screen. Measurement data that is read from the power supply to a remote device will also be represented by positive values.

Below are diagrams that show how the supply may be wired to provide positive and negative power rails to a circuit in floating and grounded configurations.

Floating Wiring Configuration:



Grounded Wiring Configuration:



4 Wire Compensation

Four wire compensation mode is designed to allow accurate measurement of voltage at the device under test by sensing around voltage loss in the lead cables. This is important as current levels increase since the current flow increases the voltage drop across a cable. For instance, if the lead resistance is 0.1 Ohms it may be fine for standard voltage measurements with a DMM, but if you are supplying 10 amps through that wire, there is a 1 volt voltage drop across that wire. Use the sense lines on the SPD1000X, SPD4000X, SPD5000X, or SPD6000X models. On the linear supplies (SPD1000X and SPD4000X) activate the sense mode from the front panel after connecting the sense wires as close to the DUT as possible. On the switching supplies (SPD5000X and SPD6000X) the sense connectors are by default in use, but are connected to the output stage on the rear of the instrument. Remove the bridge and connect the sense lines to where the power meets the device. Do not operate the instrument without the sense lines correctly connected to the supply or the circuit.

The SPD1000X can compensate for up to 1 volt of difference. The SPD4000 can compensate for up to 0.6 volts of difference. The SPD5000X and SPD6000X are both specified for remote compensation voltage of up to 0.6 volts on a single wire.

This capability is also standard on digital multimeters for voltage and resistance measurements.

Double Pulse Test Application Note

Why utilize the double pulse test?

Evaluating the switching characteristics of power semiconductors in extreme environmental conditions is a significant engineering challenge. Double pulse testing serves as a fundamental diagnostic technique in power electronics, enabling precise characterization of switching transients, dynamic behaviors, and efficiency parameters. By facilitating early-stage validation of semiconductor performance under realistic operating conditions, this method enhances design accuracy, mitigates potential reliability issues, and accelerates time-to-market for power electronic systems.

The Main Objective of the double pulse test setup is:

To evaluate the switching behavior (turn-on and turn-off losses) of a power semiconductor device under realistic operating conditions. It is used to characterize circuit capacitance and inductance and ultimately optimize the gate drive timing with respect to efficiency in operation.

Key Components and Their Roles in Double Pulse Test (DPT) Setup:

Power Semiconductor Device (DUT): MOSFET (or) IGBT (or) SiC/GaN transistor: This is the primary component being evaluated and It

undergoes switching transitions (turn-on, turn-off) to measure switching losses, dynamic characteristics, and voltage/current stress. In this application, we will use a ST Micro MOSFET.

Gate Driver Circuit: To control the gate of the DUT:

Provides the necessary gate drive signals (voltage and current) to turn the DUT on and off efficiently. This ensures fast and controlled switching to observe turn-on/turn-off behavior. It requires proper isolation, drive strength, and timing control to avoid false triggering and ensure accurate results. Here we will use a ST Micro gate drive IC.

DC Power Supply: Provides voltage for the test circuit: Supplies the high voltage across the DUT for switching tests.

Arbitrary waveform Generator: Generates the double pulse waveform: the first pulse allows the inductor to charge with the current, and the second pulse triggers turn-off and subsequent turn-on transitions, revealing switching dynamics.

Current Probe: Measures drain/collector current: Measures drain/collector current flowing through the DUT during the switching process.

Voltage Probe: Measures drain-source voltage: Measures drain-source (V_{DS}). Captures voltage spikes, dv/dt transients, and switching waveforms to analyze switching behavior.

High-voltage differential probes are often used to safely measure high voltages.

Voltage Probe: Measures gate-source voltage: standard passive probe to monitor the gate drive waveform.

Load Inductor (L_{load}): Stores energy and simulates real inductive loads: Ensures current continuity during switching events.

Oscilloscope: To Capture and analyze waveforms: Provides insights into device performance, efficiency, and possible issues like ringing, overshoot, and undershoot.

Equipment to be used:

Siglent's 12-bit oscilloscope SDS3000XHD

Siglent's current probe: CP6030A

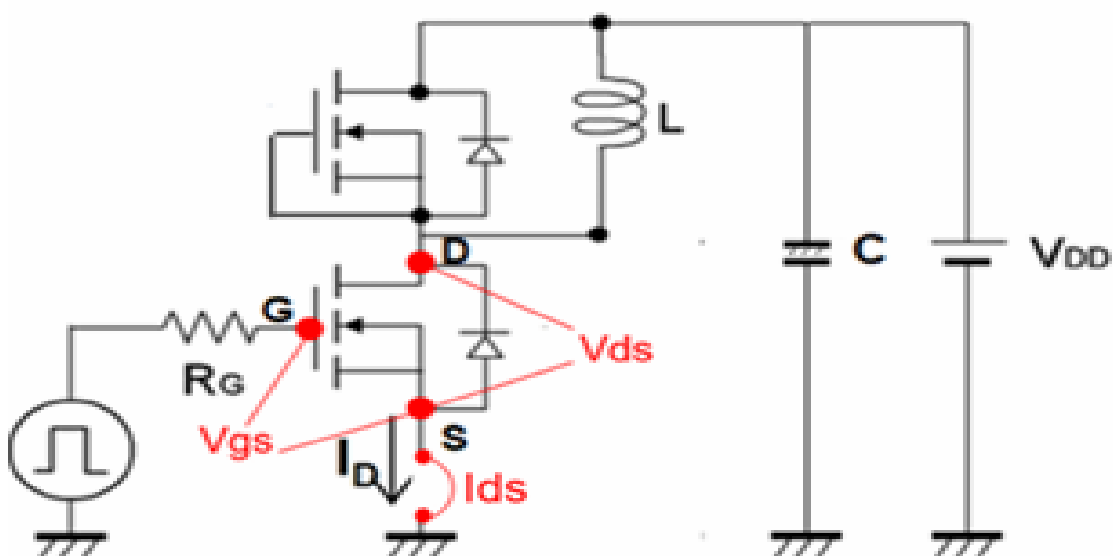
Siglent's high voltage differential probes: DPB5700A

Siglent's power supply SPD4000X and SPD6000X (1Channel with 15V to power the drive IC, Other channel driving the MOSFET voltage)

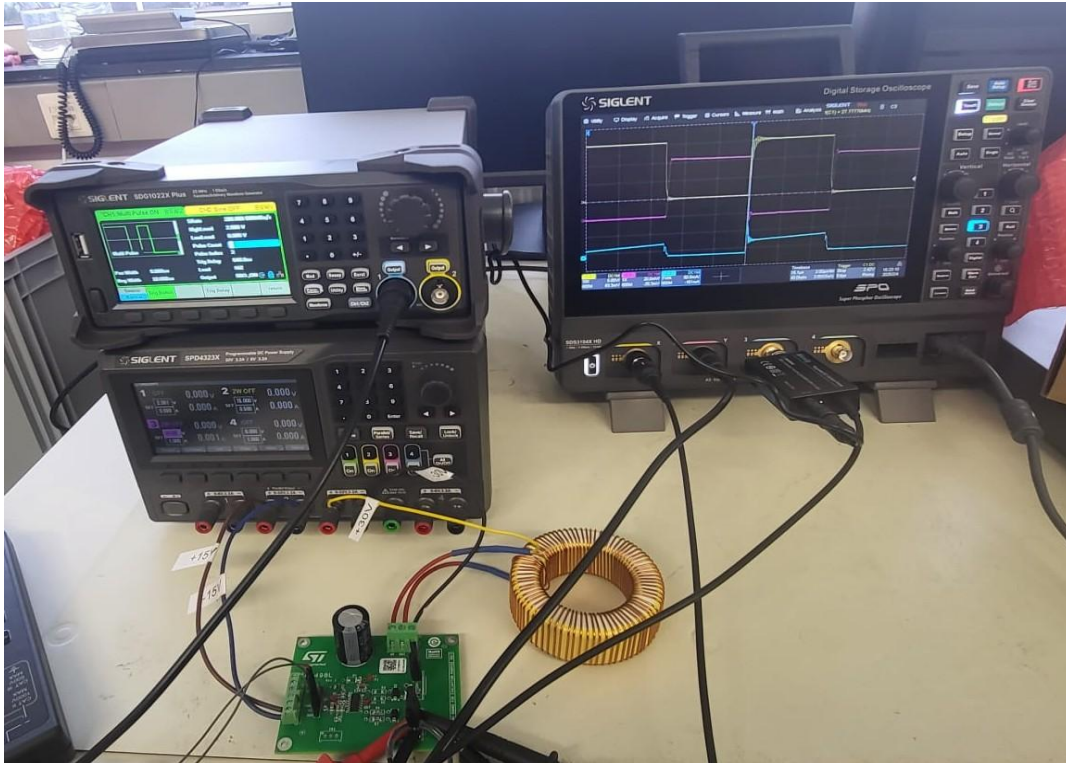
Inductor: ~1 mH

Connections are as follows:

- The MOSFETs are connected in the following configuration. We will measure on the low side:



- Gate and source on the high side will need to be shorted since that device will not be turned on.
- SDG1062X Plus is connected to the Q2 Gate drive circuit
- Siglent's SPS4000X power supply is connected to V_{cc} and GND inputs to provide power to the gate driver IC. (15Vdc)
- Siglent's SPD6000X is connected to HV and GND to provide power to the inductor. (30Vdc)



Test Execution:

Step 1: Apply Double Pulse Signal

Use a function generator SDG1000X Plus to generate two pulses: set amplitude as high level 2.5V, low level 0 V;

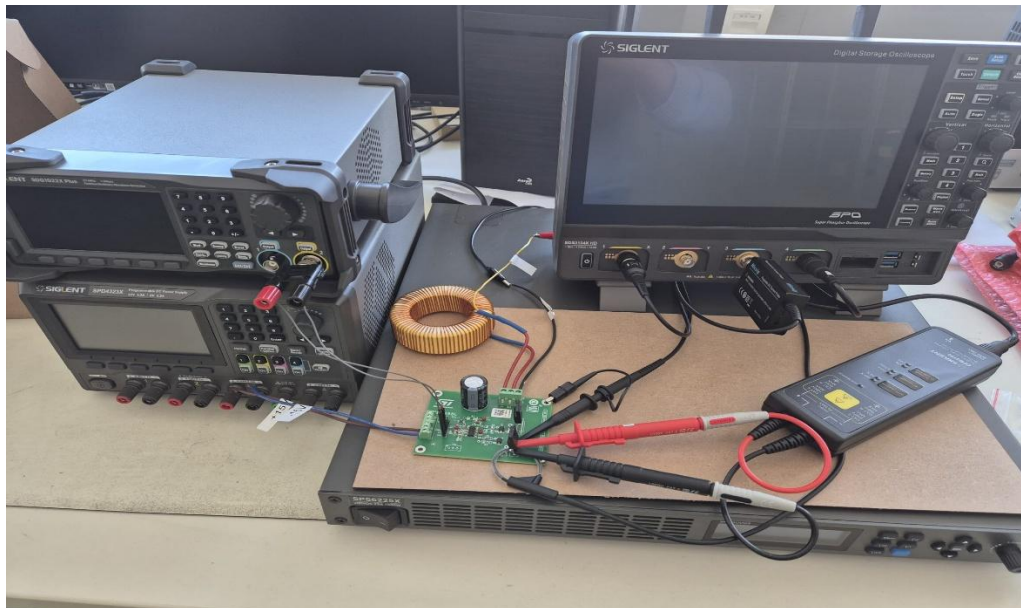
Multi-pulse parameter:

Pulse index 1- Pulse one positive width 10us, negative width 5us (this Determines the inductor current rise),

Pulse index 2- Pulse two positive width 5us, negative width 10us. (this Triggers turn-off transition after a delay.)

Adjust pulse widths and dead times carefully to prevent excessive currents.

Note: And open Burst, one cycle, Manual trigger. This is to avoid overheating the MOSFETs.



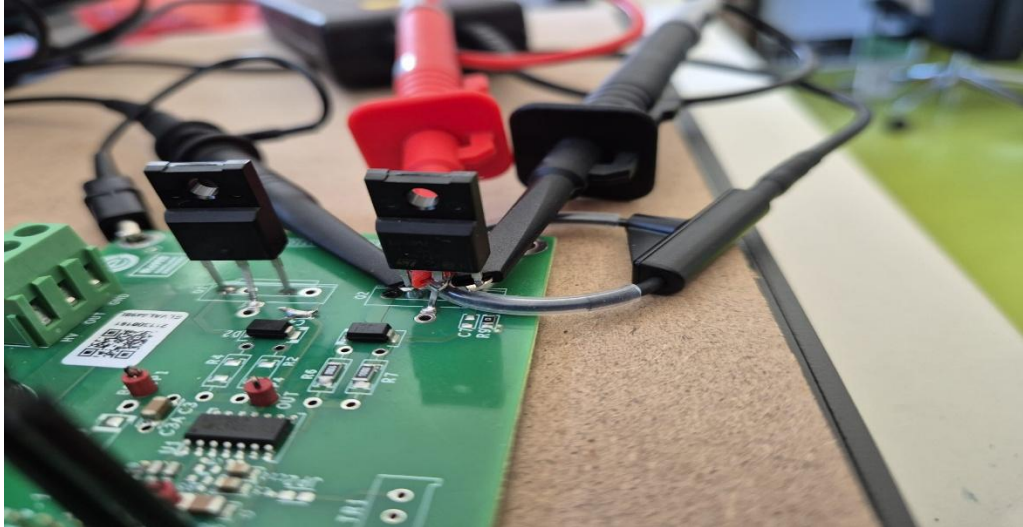
Step 2: Capture Waveforms

Use an oscilloscope to capture the following signals:

VDS (Drain-Source Voltage) – with DPB5150A

IGS (Drain Current) – with CP6030A

VGS (Gate-Source Voltage) – with SP3050A passive probe



Step 3: Analyze Switching Events

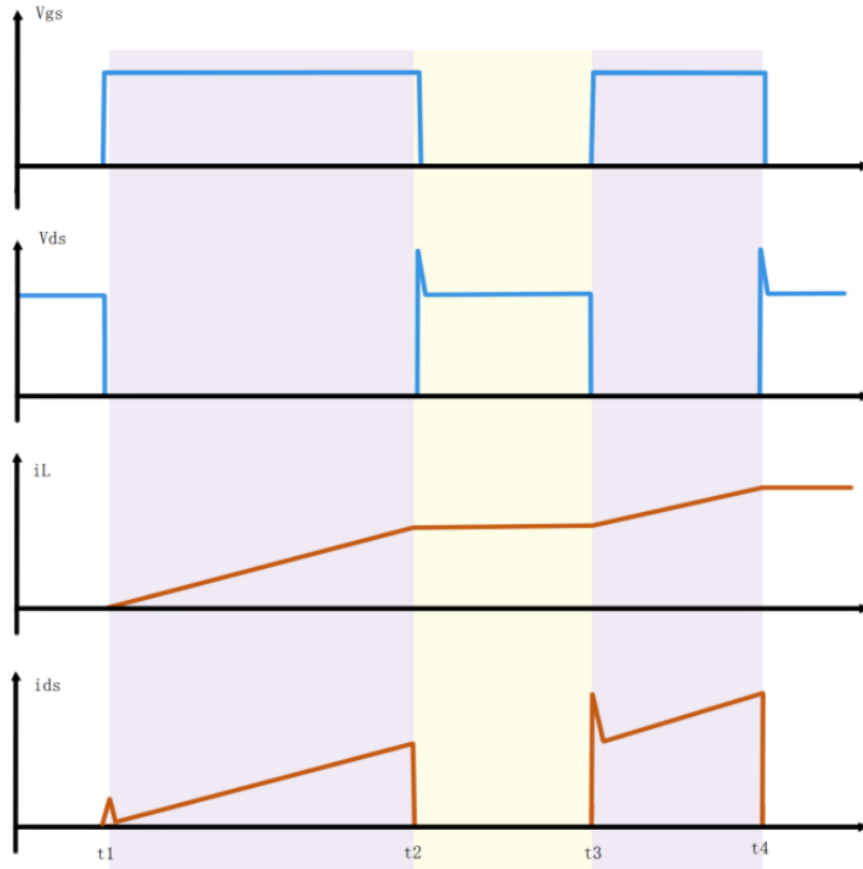
Turn-on loss measurement: Observe overshoot and current rise.

Turn-off loss measurement: Check voltage spike due to parasitic inductance.

Evaluate ringing, voltage spikes, and the impact of gate resistance.

When analyzing these switching events, there are several principles we reference from our demo kit guide.

Refer to the figure below and consider these effects over time. This analysis comes from the TF1000DN DPT demo kit UM 20250320 guide for one of our demonstration tools:



- t_1 to t_2 :
 - i_{ds} and i_L increase linearly through 1st pulse
 - Spike current caused by stray capacitance of inductor L
- t_2 to t_3 :
 - Inductor current loop slowly reduces current level, but stays active
 - The V_{ds} spike at the moment t_2 is the product of the dc bus stray inductance L_s and the di/dt of the i_d current
- t_3 to t_4
 - 2nd pulse event increases inductor and Q2 current levels
 - The spike current of i_d at moment t_3 is the reverse recovery current of Q1 diode
 - t_4 V_{ds} spike same as caused at t_2

Using the measurement system, we can clearly see these measurement artifacts:



Conclusions

There are several decisions and conclusions to draw from double pulse test evaluations. It enables an engineering team to evaluate switching efficiency by measuring the turn-on and turn-off losses under real world test conditions. Comparison of these results is an important tool in evaluating different technologies and materials for the switching device.

Once devices are selected, gate drive pulse timing is used to optimize performance and improve efficiency. Finally, double pulse testing assists in dead time optimization. This is done to minimize MOSFET body diode conduction.

Power Analysis Measurements Application Note

Power converter design has become an important part of electronic product development. Modern design needs have increased the importance of power supplies that have greater efficiency, more reliability, with lower electromagnetic emissions (EMI) than past designs. This is especially true for designs implementing Switch Mode Power Supplies (SMPS) that can be especially noisy. Highly specialized Power Design Engineers can measure many of the parameters of SMPS manually, but this is extremely time consuming and inconvenient. To help minimize time-to-market and maximize Engineering efficiency SIGLENT's oscilloscopes offer a Power Analysis option that includes the capability to automate and simplify many of the standard SMPS measurements that engineers rely on. These measurements include:

- Input Parameters
 - Power Quality
 - Power Factor, Real Power, Apparent Power, Reactive Power, Phase, I&V Crest
 - Current Harmonics based on IEC61000-3-2 A/B/C/D, up to 40th harmonics
 - Inrush Current
- Switching Parameters
 - Switching Loss
 - Power Loss, Energy Loss. Conduction: Waveform, Rds(on), Vce(sat)
 - Slew Rate
 - Top/Base of Voltage/Current
 - Modulation
 - Average, AC-RMS, Period, Width, Duty, Rise/Fall time
- Output Parameters

- Output Ripple and Turn On/ Turn Off
- Transient Response Efficiency
- Frequency Response Measurements
 - Power Supply Rejection Ratio (PSRR)
 - Power Efficiency
 - Safe Operating Area

Power analysis measurements require improved signal fidelity and accuracy. Improvements in characterization of these parameters have a big impact on the overall value of these measurements. Therefore, SIGLENT recommends using power analysis on our high resolution oscilloscopes. These following oscilloscopes, listed by bandwidth and channels, have 12 bit vertical resolution and low noise to get the most out of these power measurements:

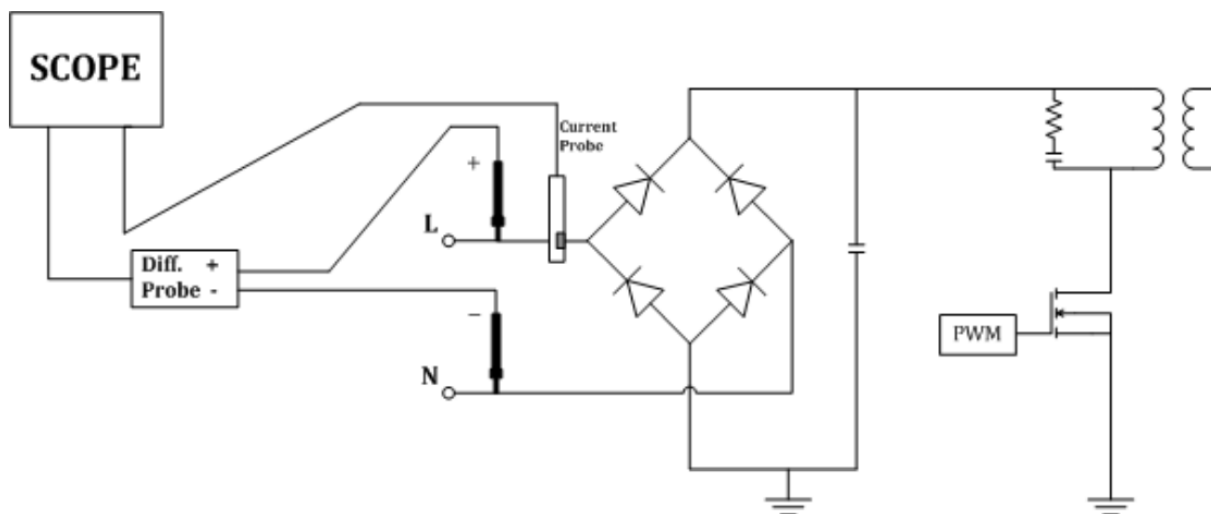
Series	Channels	Bandwidth	Power Analysis Option Model
SDS800X HD	2 or 4	70 – 200 MHz	SDS800XHD-PA
SDS1000X HD	2 or 4	100 – 200 MHz	SDS1000XHD-PA
SDS2000X HD	4	200 – 350 MHz	SDS2000HD-PA
SDS3000X HD	4	350 MHz – 1 GHz	SDS3000HD-PA
SDS7000A	4	3 – 8 GHz	SDS7000A-PA

*See appendix for Probe selection guide.

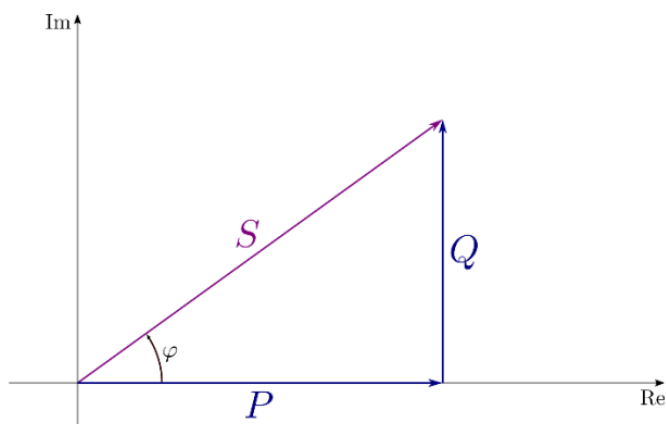
Power Quality

The specific measurement parameters of power quality analysis include active power, apparent power, reactive power, power factor, power phase angle, voltage effective value, current effective value, voltage crest factor, and current crest factor of power input of a switching power supply.

Connections with a differential voltage probe:



Measurement Definitions:



$$P: \text{Active Power} = (1/N) * \sum_{i=0}^{N-1} V_i * I_i$$

S: Apparent Power = $V_{rms} * I_{rms}$

Q: Reactive Power = $\sqrt{(\text{Apparent Power}^2 - \text{Active Power}^2)}$

ϕ : Power Phase Angle: Phase difference between voltage and current

$\cos \phi$: Power Factor, which is the ratio of active power and apparent power.

Voltage Crest -- Voltage parameters of the power input include voltage crest, voltage effective value, and voltage crest factor.

$$V_{rms} = \frac{1}{N} * \sqrt{\sum_{i=0}^{N-1} V_i^2}$$

$$V_{Crest} = V_{peak} / V_{rms}$$

Current Crest -- Current parameters of the power input include current crest, current effective value, and current crest factor.

$$I_{rms} = \frac{1}{N} * \sqrt{\sum_{i=0}^{N-1} I_i^2}$$

$$Crest = I_{peak} / I_{rms}$$

Measurement View:



Current Harmonics

IEC 61000-3-2 is an international standard that limits mains voltage distortion by prescribing the maximum value for harmonic currents from the second harmonic up to and including the 40th harmonic current. There are 4 different classes in the EN 61000-3-2 that have different limit values:

Class A: Balanced 3-phase equipment, household appliances excluding equipment identified as class D, tools, excluding portable tools, dimmers for incandescent lamps, audio equipment, and all other equipment, except that stated in one of the following classes.

Class B: Portable tools, arc welding equipment which is not professional equipment

Class C: Lighting equipment

Class D: PC, PC monitors, radio, or TV receivers. Input power $P \leq 600 \text{ W}$

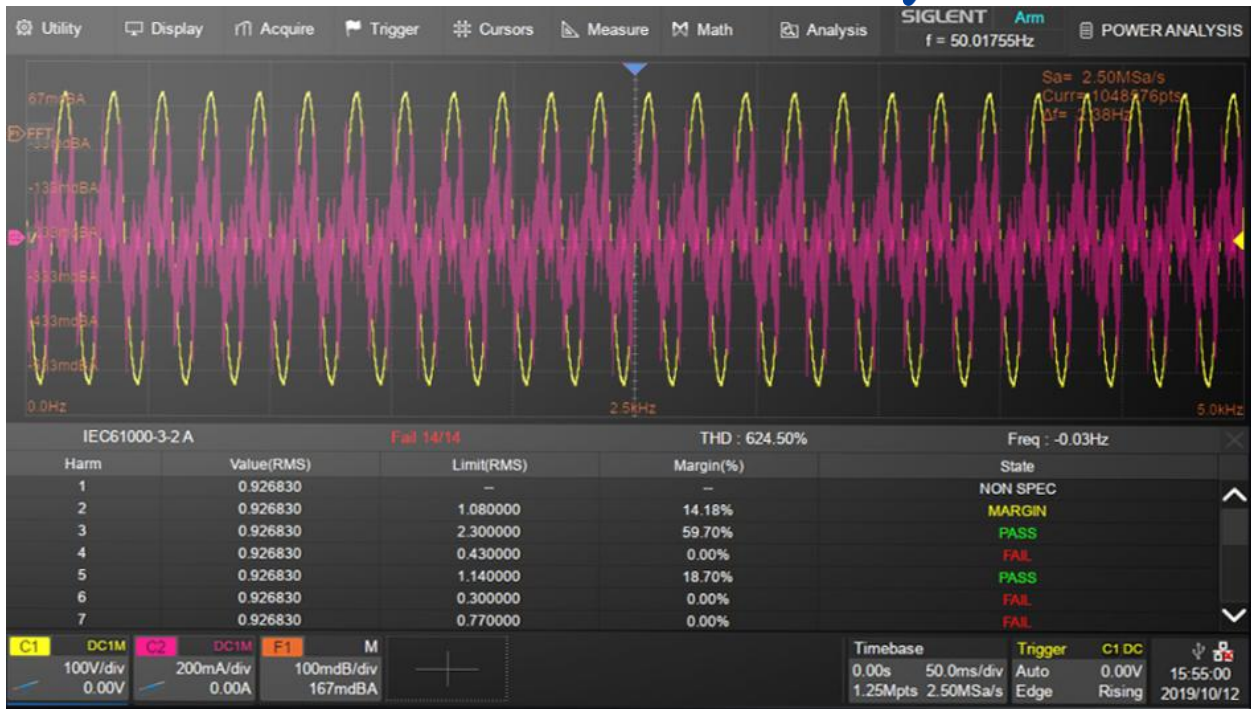
Measurements captured:

The current harmonics test displays measured and limit values in V_{rms} as well as Margin (%) and a pass/fail result for each of the first 40 harmonics.

Total Harmonic Distortion (**THD**) is also calculated as:

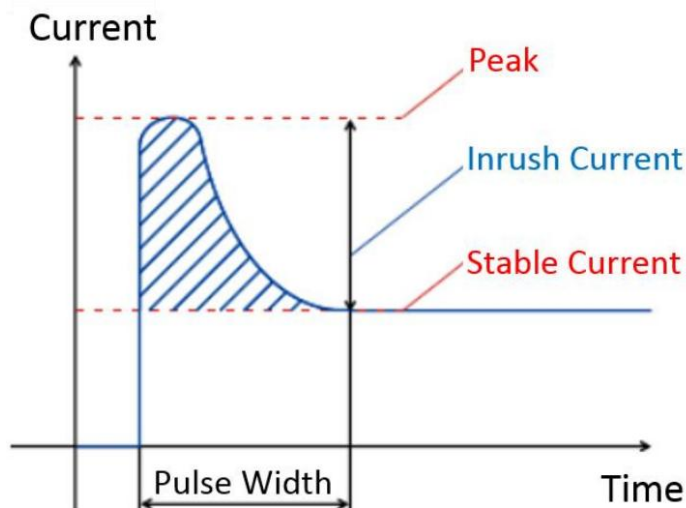
$$\text{THD} = 100\% * \frac{\sqrt{X_2^2 + X_3^2 + \dots + X_n^2}}{X_1} \quad , \text{ where } X_n \text{ is the } n^{\text{th}} \text{ harmonic and } X_1 \text{ is the primary signal.}$$

Measurement View:



Inrush Current

A large current far greater than the stable current may flow through at the moment of switching on a power supply. The large current is called the inrush current. The current waveform when switching on is shown in the figure below:



Switching Loss

Switching loss evaluates the amount of power lost during the switching action of the supply. One critical adjustment for switching loss measurement is deskew. Deskew adjusts the timing of the current measurement to match with the associated voltage change by compensating for the time delay in the current probe measurement. Typically, this can be done with a deskew board like the DF2001A:



Auto deskew adjustment:



Before deskew calibration



After deskew calibration

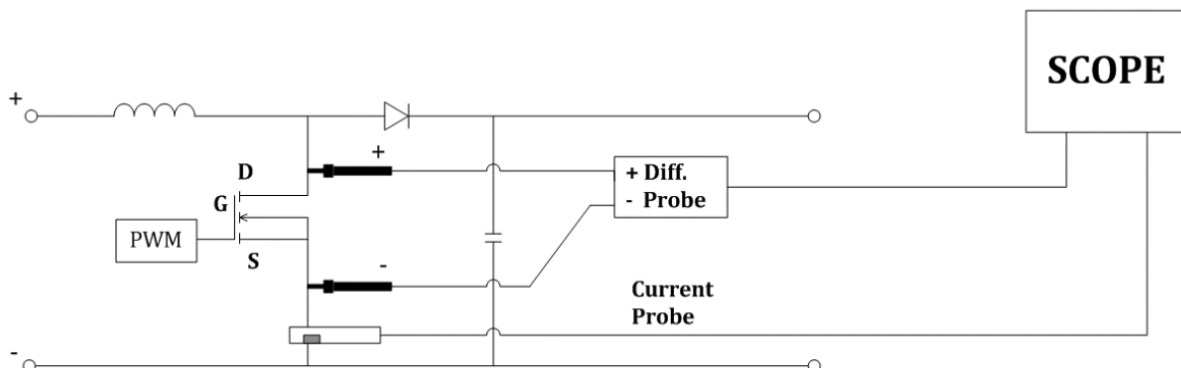
Measurement Definitions:

Waveform -- The power waveform uses the original data, and the calculation formula is $\text{Power} = V * I$, $\text{Energy} = P * T$

Rds (on) -- In the on area (where the voltage level is lower than the voltage reference (adjustable)), the power calculation formula is $P = I^2 * R_{ds}(\text{on})$. In the off area (where the current level is lower than the current reference (adjustable)), the power calculation formula is $P = 0$ watt.

Vce (sat) -- In the on area (where the voltage level is lower than the voltage reference (adjustable)), the power calculation formula is $P = V_{ce}(\text{sat}) * I$. In the off area (where the current level is lower than the current reference (adjustable)), the power calculation formula is $P = 0$ watt.

Connection Guide:



*All measurement connection guides can be displayed on the oscilloscope front panel

Slew Rate

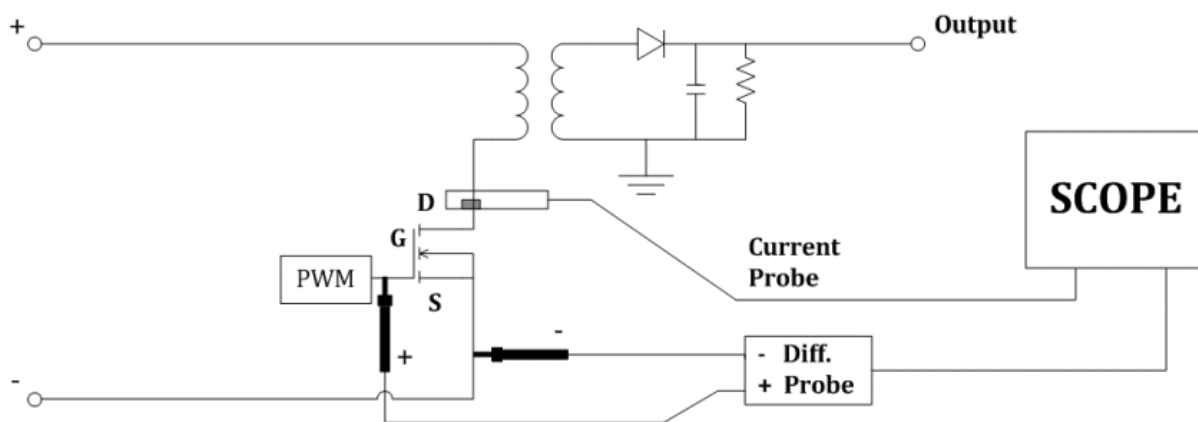
The slew rate measures the change rate of voltage or current during switching. This is essentially calculated as pulse height over rise time or fall time. Rates can be calculated for voltage or current during turn on or turn off.

The connection diagram is the same as switching loss.

Modulation

Modulation analysis measures the control pulse signal of the switching device (MOSFET) and observes the pulse width, duty, period, frequency, and other trends of the control pulse signal in response to different events.

Here we connect to the gate driving signal:



This characterization is related to the dual pulse test (DPT) where we analyze the efficiency of the system under high speed pulse conditions.

Ripple and Turn On / Turn Off

Power supply ripple is an important parameter to evaluate DC power supply, which represents the quality of output DC voltage. Ripple analysis can measure the current value, average value, minimum value, maximum value, and standard deviation of the power supply output ripple.

At the same time we can measure the on and off time of the supply using these measurement definitions:

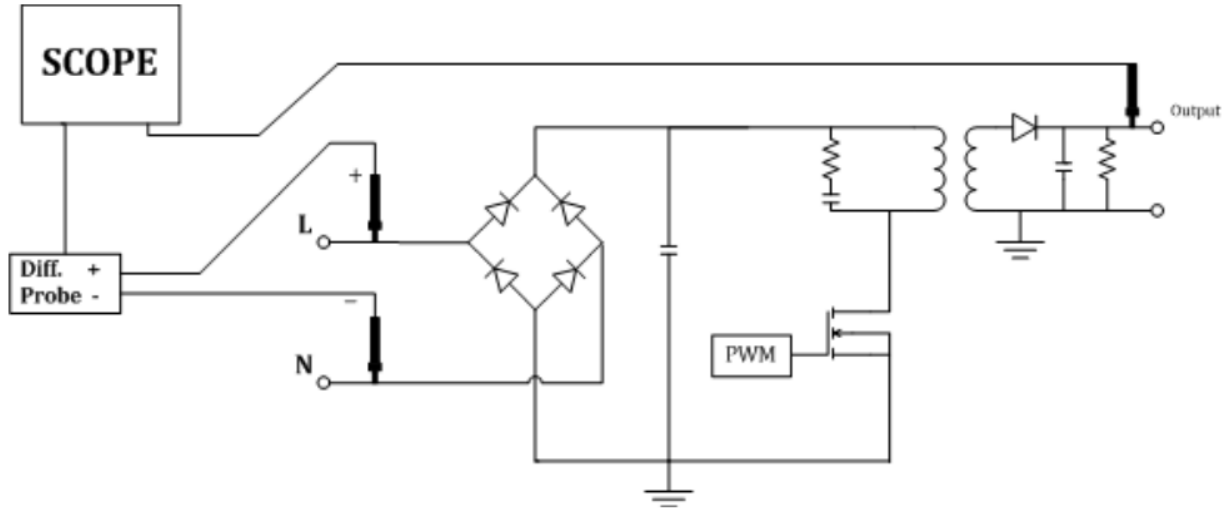
Turn On -- Determines the time taken for the power to reach a certain percentage of its steadystate output. The turning on time is between T2 and T1, where: T1 = When the input voltage first rises to a certain percentage (usually 10%) of its maximum amplitude T2 = When the output DC voltage rises to a certain percentage (usually 90%) of its maximum amplitude.

Turn Off -- Determines the time it has taken for the power supply to be turned off to fall to a certain percentage of its maximum output voltage. The turning off time is between T2 and T1, where:

- T1 = When the input voltage finally falls to a certain percentage (usually 10%) of its maximum amplitude
- T2 = When the output DC voltage finally falls to a certain percentage (usually 10%) of its maximum amplitude

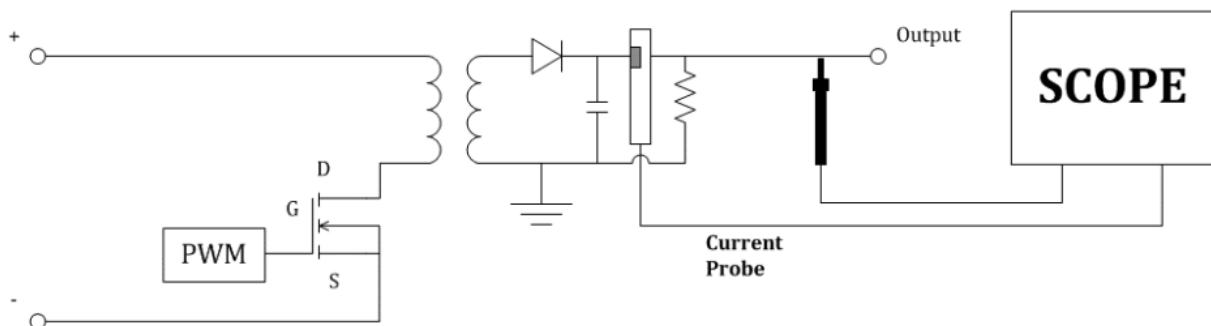
Connections:

We can connect for both of these measurements like so:



Transient Response

Transient response measures the supply's ability to respond to dynamic load changes. This time starts from the first time that the output voltage exits the stable band and ends at the last time that the output voltage enters the stable band. Test inputs include the overshoot %, the stable voltage level, and the high and low current values. This measurement uses a voltage and current probe on the output as shown:



Power supply rejection ratio (PSRR)

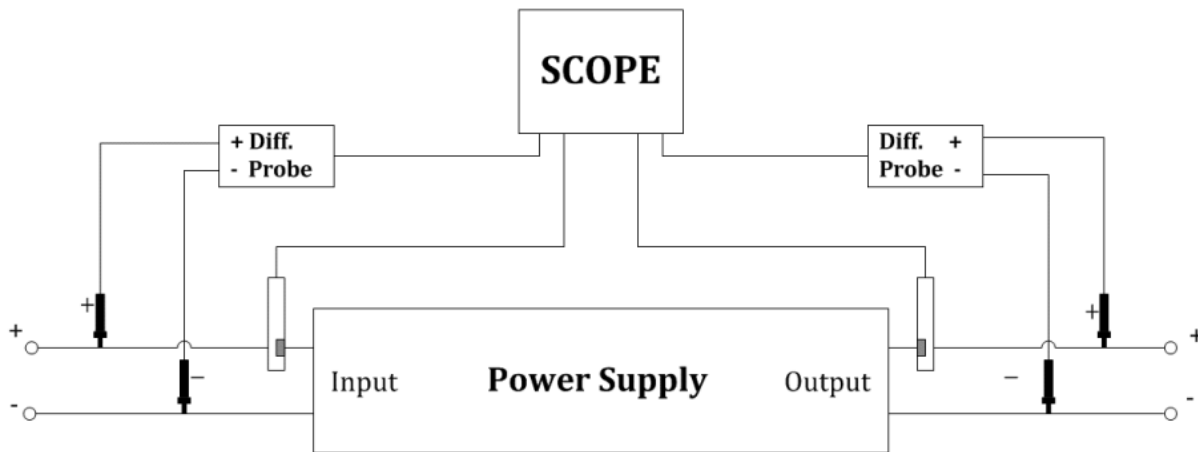
The power supply rejection ratio (PSRR) test is used to determine how the regulator suppresses ripple noise in different frequency ranges. The oscilloscope controls the arbitrary waveform/function generator to output a sweep signal, which is used to introduce ripple into the DC voltage transmitted to the voltage regulator. Measure the AC RMS ratio of input to output, and plot the relationship between the ratio and frequency. The background noise of the oscilloscope is higher than that of the network analyzer, and the sensitivity is lower than that of the network analyzer, so the PSRR measured by the oscilloscope is difficult to exceed -60 dB. The PSRR test is generally acceptable for sampling the overall PSRR behavior of the power supply under test. SIGLENT uses the Bode Plot capability to measure this rejection ratio.

This ratio is measured in degrees of phase and gain in dB between the generator on the input and the resulting ripple on the output.

Power Efficiency

Power efficiency analysis can test the overall efficiency of the power supply by measuring the output power and input power. This analysis is only supported on 4-channel models because all of the input voltage, input current, output voltage, and output current are necessary for the measurement.

Connections are made with 2 differential probes and 2 current probes:

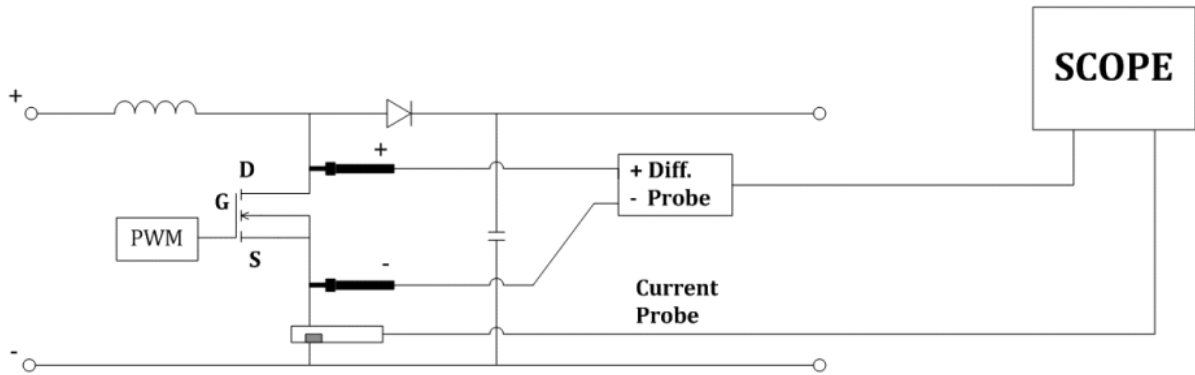


Efficiency is measured as a percentage. Min, max, peak-peak, and standard deviation statistics are all available.

Safe Operating Areas

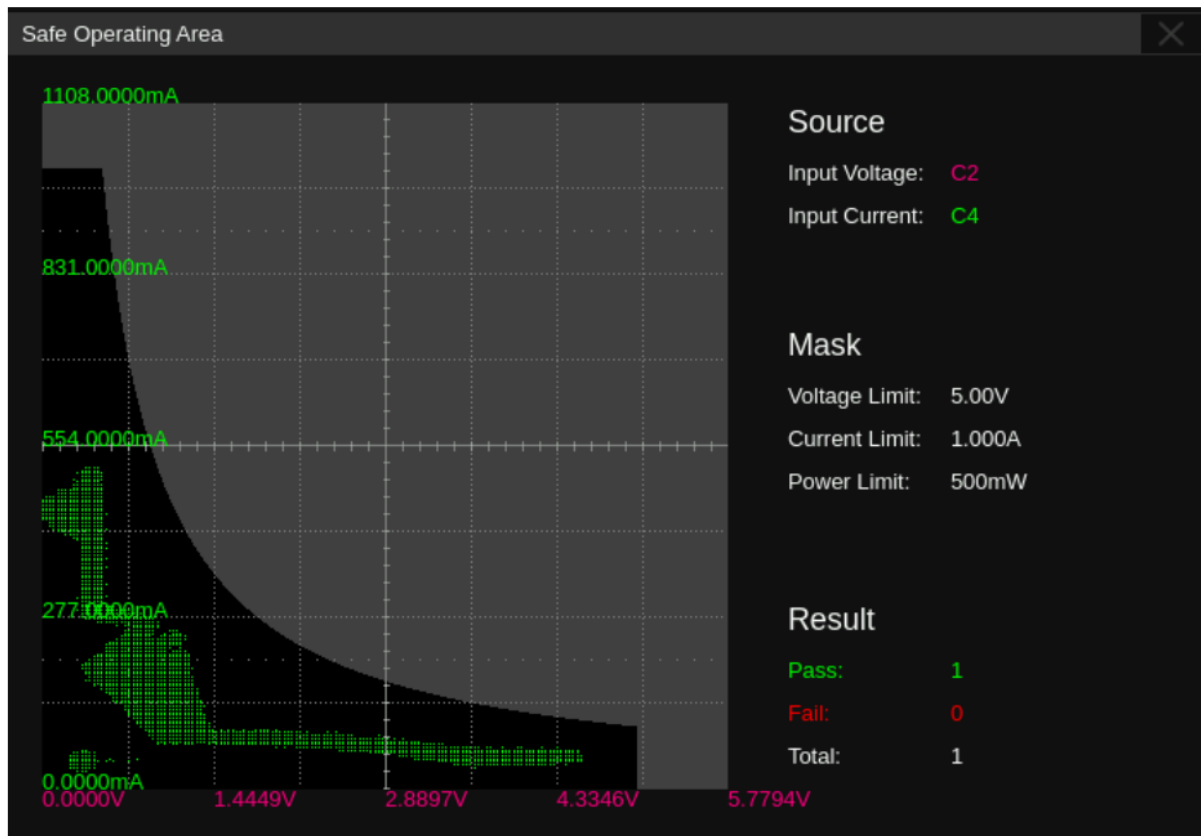
The safe operating area (SOA) of MOSFETs defines the voltage, current, and power consumption conditions over which the device can be expected to operate without damage. The oscilloscope can automatically generate the SOA according to the Voltage Limit, Current Limit, and Power Limit parameters set in the Config menu. The test system judges the stress on the MOSFET to characterize the edges of the SOA. This helps the designers to quickly find a problem and analyze risk in the circuit.

Connect across the VDS with a differential voltage probe and measure the current from the source like this:



Perform a deskew operation to correctly measure the safe operating area.

The measurement results are shown in a voltage and current map:



SOA, in which the mask is created according to the voltage limit, current limit, and power limit. The result shows “Pass” because all the stresses are within the mask.

Summary

The power analysis option for advanced, high resolution oscilloscopes provides an array of characterization functions for design and debug of switching mode power systems. Combine with the correct probe solutions for full performance analysis.

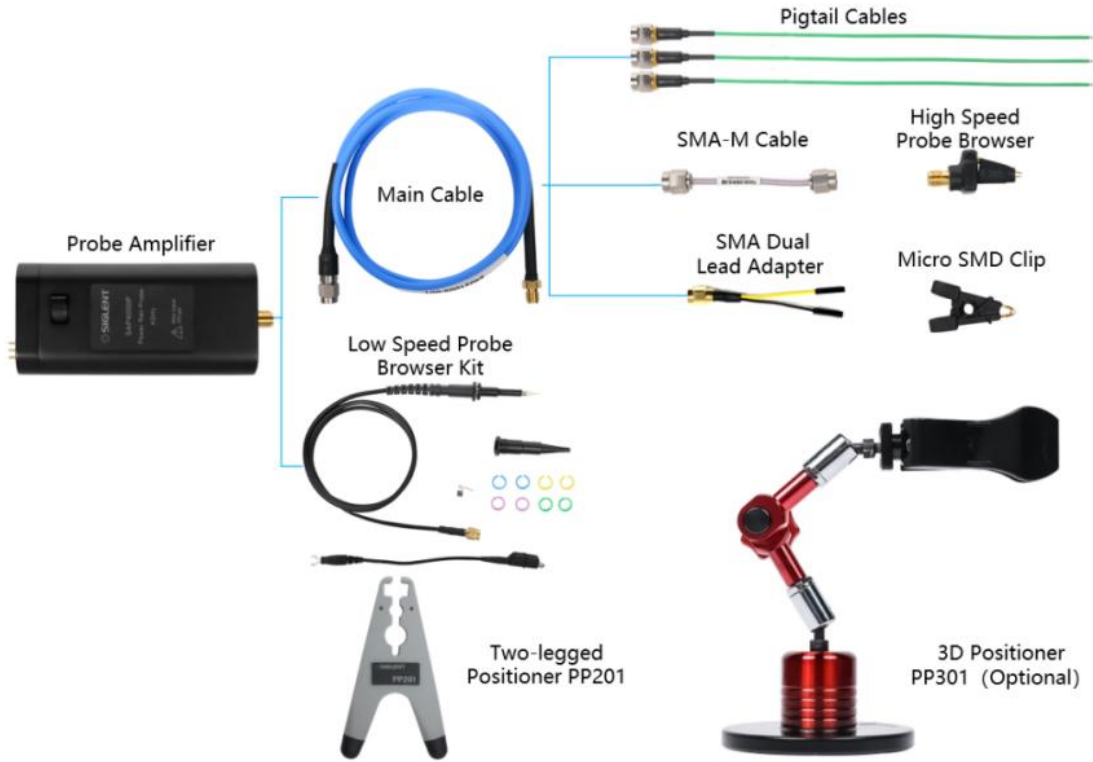


Appendix: Power Analysis Probe Selection Guide

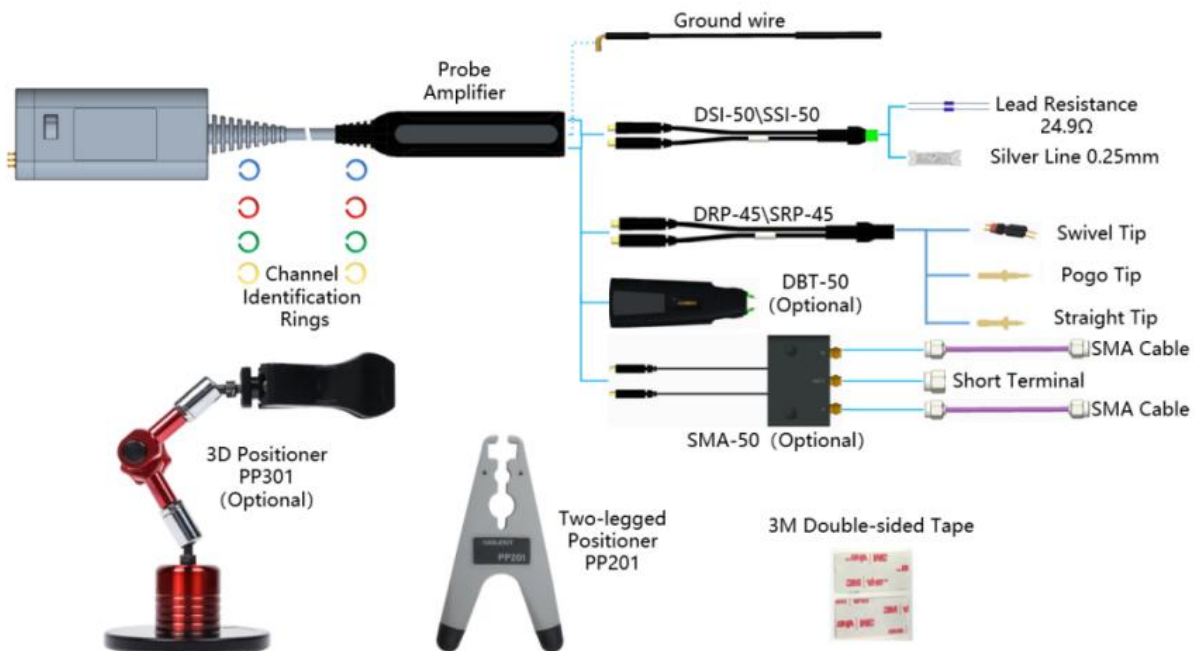
Model	Family	Type	Impedance	Max. Amplitude (Pk-Pk / RMS)	Bandwidth	Rise Time	Attenuation	Description
SAP4000P	3XHD, 5X, 6A, 7A	Power Rail	20 kΩ LF / 50Ω HF	+/- 600 mV with +/- 24 V offset	4 GHz		1.1 x	4 GHz Power Rail Probe
CP4020	All	Current	High Z	60 A / 20 Arms	200 kHz	1.75 μs	50mV/A ; 5 mV/A	60 A, 200 kHz Current Probe
CP4050	All	Current	High Z	140 A / 50 Arms	1 MHz	0.35 μs	500mV/A ; 5 mV/A	140 A, 1 MHz Current Probe
CP4070	All	Current	High Z	200 A / 70 Arms	300 kHz	1.2 μs	500mV/A ; 50mV/A	200 A, 300 kHz Current Probe
CP4070A	All	Current	High Z	200 A / 70 Arms	300 kHz	1.2 μs	100mV/A ; 10mV/A	200 A, 300 kHz Current Probe
CP6030	All	Current	High Z	50 A / 30 Arms	50 MHz	7 ns	1V/A ; 0.1V/A	50 A, 50 MHz Current Probe
CP6030A	All	Current	High Z	50 A / 30 Arms	100 MHz	3.5 ns	1V/A ; 0.1V/A	50 A, 100 MHz Current Probe
CP6150	All	Current	High Z	300 A / 150 Arms	12 MHz	29 ns	0.1V/A ; 0.01V/A	300 A, 12 MHz Current Probe
CP6500	All	Current	High Z	750 A / 500 Arms	5 MHz	70 ns	0.1V/A ; 0.01V/A	750 A, 5 MHz Current Probe
CPL5100	All	Current	High Z	100 A	600 kHz	583 ns	0.1V/A ; 0.01V/A	100 A, 600 kHz Current Probe
SCP5030	3XHD, 5X, 6A, 7A	Current	High Z	50 A / 30 Arms	50 MHz	7 ns	1V/A ; 0.1V/A	50 A, 50 MHz Current Probe
SCP5030A	3XHD, 5X, 6A, 7A	Current	High Z	50 A / 30 Arms	100 MHz	3.5 ns	1V/A ; 0.1V/A	50 A, 100 MHz Current Probe
SCP5150	3XHD, 5X, 6A, 7A	Current	High Z	300 A / 150 Arms	12 MHz	29 ns	0.1V/A ; 0.01V/A	300 A, 12 MHz Current Probe
SCP5500	3XHD, 5X, 6A, 7A	Current	High Z	750 A / 500 Arms	2 MHz	175 ns	0.1V/A ; 0.01V/A	750 A, 2 MHz Current Probe
SAP1000	5X, 6A/L, 7A	Active	1 MΩ 1.2pF	8 V	1 GHz		10 x	Active Probe, 1 GHz
SAP2500	5X, 6A/L, 7A	Active	1 MΩ 1.1pF	8 V	2.5 GHz		10 x	Active Probe, 2.5 GHz
SAP2500D	5X, 6A/L, 7A	Active Differential	200kΩ 1pF	8 V	2.5 GHz		10 x	Differential Active Probe, 2.5 GHz
SAP5000D	5X, 6A/L, 7A	Active Differential	20kΩ 400fF	+/-2.5V	5 GHz		10 x	Differential Active Probe, 5 GHz
DPB1300	All	Differential High V	5 / 10 MΩ	130 V / 1300 V	50 MHz	7 ns	50 X / 500 X	50 MHz, 1300 V Differential Voltage Probe
DPB5150	All	Differential High V	5 / 10 MΩ	150 V / 1500 V	70 MHz	5 ns	50 X / 500 X	70 MHz, 1500 V Differential Voltage Probe
DPB5150A	All	Differential High V	5 / 10 MΩ	150 V / 1500 V	100 MHz	3.5 ns	50 X / 500 X	100 MHz, 1500 V Differential Voltage Probe
DPB5700	All	Differential High V	10 / 20 MΩ	700 V / 7000 V	70 MHz	5 ns	100 X / 1000 X	70 MHz, 7kV Differential Voltage Probe
DPB5700A	All	Differential High V	10 / 20 MΩ	700 V / 7000 V	100 MHz	3.5 ns	100 X / 1000 X	100 MHz, 7kV Differential Voltage Probe
HPB4010	All	Passive High V	100MΩ	30 kV pulse / 10 kVrms	40 MHz	8 ns	1000 X	40 MHz, 10 kVrms High Voltage Probe

Power Measurements Capabilities

Power Rail Probe kit - SAP4000P



Active Probe Kit - SAP5000D with optional accessories



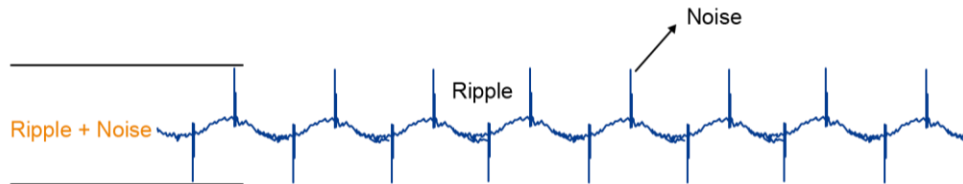
Power Integrity Measurements Application Note

Introduction

The power supply is the core of electronic product, delivering continuous energy to the system. Ripple and noise are critical parameters for evaluating the quality of a power supply, as they reflect the instability and interference in the power supply's output. Excessive ripple or noise can lead to inefficient operation, system instability, and accelerated equipment aging. Therefore, when designing power modules, it is crucial to accurately measure and assess ripple and noise levels.

The ripple in a power supply refers to the periodic changes or slight fluctuations in the output that align with the switching frequency. These fluctuations are superimposed on the stable DC signal as an AC component, creating interference. The amplitude of this ripple is typically measured in millivolts (mV). Power supply's ripple can be caused by various factors, including circuit design details, filter configuration, load variations, and external environmental interference.

Power supply noise differs from ripple, it is another high-frequency component that appears between the output terminals. Noise refers to aperiodic random interference in the power supply output, manifesting as discontinuous and irregular voltage or current spikes. These spikes are often caused by internal and external interference within the system, such as improper circuit design, inadequate wiring, or poor contact.



Measurement Challenges

In recent years, as power supply voltages continue to decrease, circuit switching speeds increase, chip packages become smaller, and power supply networks grow more complex, the demand for power integrity has risen significantly. Consequently, measuring power supply ripple and noise has become increasingly challenging. We typically use an oscilloscope probe to measure these parameters, as it offers high input impedance, minimizing its impact on the circuit under test, making it an ideal tool for such measurements.

However, because the power supply's noise is typically very low, both the oscilloscope and probe can introduce additional noise during testing. When using a common oscilloscope with a probe, the power supply's ripple and noise may be obscured by excessive noise floor, or the oscilloscope's limited offset range may hinder accurate viewing of the test results. To achieve more precise measurements, it is essential to use an oscilloscope with high resolution and an ultra-low noise floor, along with a power rail probe that offers low noise and a high bias range. This

Power Measurements Capabilities

combination ensures that the ripple and noise of the power supply are accurately captured.

In addition, the actual testing process involves many operations, and improper handling can introduce interference noise or external electromagnetic interference, thereby reducing measurement accuracy. Therefore, mastering the correct method for measuring ripple and noise is crucial to obtaining reliable results.

Reference Solutions

Use a 12-bit high resolution oscilloscope.

There are three types of oscilloscopes on the market: 8-bit, 10-bit, and 12-bit. Of these, the 12-bit oscilloscope offers the highest quantization level (4096) and the smallest quantization error, resulting in more accurate waveform restoration and measurement results. Additionally, a true 12-bit oscilloscope features a front-end amplifier and analog-to-digital converter (ADC) specifically designed for high-resolution applications, providing lower noise, better effective number of bits (ENOB), and improved DC gain accuracy. SIGLENT's oscilloscopes have enhanced resolution mode, which can achieve 16-bit high resolution, making it particularly beneficial for measuring power supply's ripple and noise.

The basic switching frequency of power conversion devices may be slow, but the edge speed and rise time are fast, which can easily generate high-

Power Measurements Capabilities

frequency noise and harmonics. Therefore, users must select an oscilloscope with high bandwidth to effectively diagnose issues related to high-frequency interference. Currently, the bandwidth of SIGLENT's high-resolution series oscilloscopes ranges from 70 MHz to 4 GHz, offering users a variety of options.



Use a Power Rail Probe with high bandwidth, low noise, high input impedance and large DC offset.

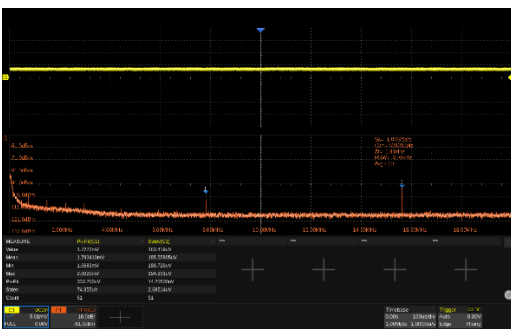
In the past, when engineers measured the ripple and noise of power supply, they often used passive probes to directly detect the power and ground network near the chip under test. However, when conventional passive probes are set to a 1x attenuation, the bandwidth is limited significantly, which is insufficient for accurate measurements. On the other hand, increasing the attenuation to 10x improves bandwidth but significantly increases the oscilloscope's noise floor, compromising the accuracy of the measurement results. Additionally, to measure ripple or noise on the DC component, engineers traditionally set the oscilloscope to

Power Measurements Capabilities

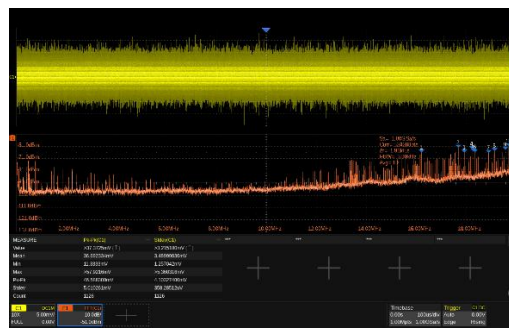
AC coupling mode. However, AC coupling filters out not only the DC component but also low-frequency noise and drift, necessitating the use of a probe with a large vertical offset range for accurate testing.

SIGLENT recommends the SAP4000P power rail probe, specifically designed for testing power supply's ripple and noise. Its millivolt-level sensitivity enables users to accurately detect noise, ripple, and transient changes in DC power supplies. Additionally, it offers a low-noise solution with a large DC offset, making it ideal for measuring power rail signals.

When no DUT is connected and all test conditions are consistent, a noise comparison between the power rail probe and a 10:1 passive probe reveals that the passive probe generates significantly more noise than the power rail probe:



Measure with power rail probe



Measure with 10:1 passive probe

Power Measurements Capabilities

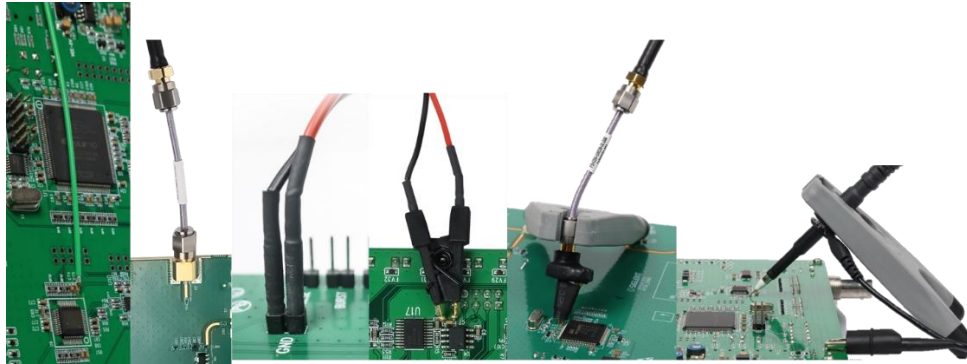
The SAP4000P's 4 GHz bandwidth and low noise level are instrumental in distinguishing the noise generated by the oscilloscope and probe from the noise and ripple of the DC power supply under test. With a bias setting range of $\pm 24\text{V}$, the dynamic signal with a DC component can be easily centered on the oscilloscope screen, and the input dynamic range of $\pm 600\text{mV}$ allows for accurate measurement of significant voltage fluctuations. Additionally, the probe's high impedance of $50\text{k}\Omega$ at low frequencies helps eliminate the load effect and minimizes interference from the power supply being tested, while its low impedance of 50Ω at high frequencies ensures proper coaxial cable matching and enhances test bandwidth.



The SAP4000P Power Rail Probe also provides various accessories, such as a double male SMA cable, high-frequency spot probe, and miniature SMD clip. Users can flexibly choose from various test connection methods, including direct cable connection, soldering at the measurement point,

Power Measurements Capabilities

and using a passive probe tip point for measurement. These accessories can meet the needs of different application scenarios.



Key Considerations:

The bandwidth of the oscilloscope

The ripple in a power supply is a low-frequency noise, typically ranging from tens to hundreds kHz, which corresponds to the switching frequency. To accurately measure ripple without the interference of high-frequency noise, the oscilloscope's bandwidth can be limited to 20 MHz. In contrast, power supply's noise is high-frequency interference, often referring to the AC component superimposed on the output voltage across the oscilloscope's full bandwidth. Therefore, it's necessary to utilize the full bandwidth of the oscilloscope for accurate noise measurement.

Power Measurements Capabilities

The vertical scale of oscilloscope

The lower the vertical scale setting on the oscilloscope, the smaller system's noise floor. This allows for more precise measurements. To optimize signal observation, adjust the oscilloscope's vertical scale setting so that the signal waveform occupies 80%-90% of the screen. This setup enhances the oscilloscope's resolution, making it easier to observe subtle changes in the signal.

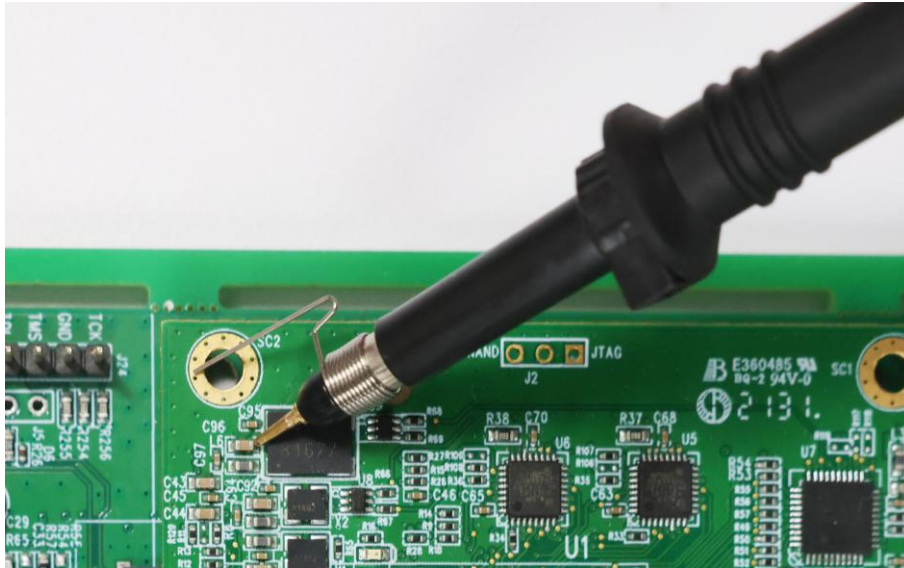
The sampling rate of oscilloscope

To accurately capture waveform details, an oscilloscope should sample 3-5 points, ideally more than 5 points, on the rising edge of the signal of interest. A high sampling rate is crucial, as it minimizes distortion in the test waveform.

Advanced probe grounding

When testing with common passive probes, minimizing noise interference is crucial. To achieve this, the probe's ground terminal (GND) should be placed as close to the test point as possible, reducing the risk of unnecessary electromagnetic interference (EMI) from a large signal loop. Correct use of the probe's tip point to touch the test point, combined with grounding using a short spring ground pin, effectively minimizes EMI coupling. Additionally, using auxiliary tools like double-lead adapters or miniature SMD clips enhances testing flexibility and further improves accuracy and convenience.

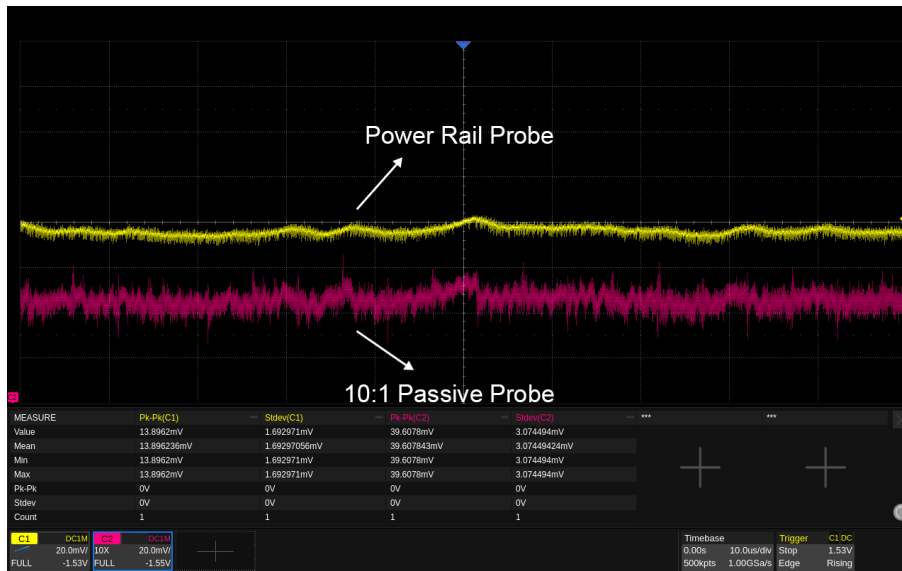
Power Measurements Capabilities



Measurement Results

When testing the same measurement point on a DUT, such as the filter capacitor on the power pin of DDR3, both a power rail probe and a passive probe can be used. In this scenario, the oscilloscope's horizontal time scale, vertical scale, and impedance are set identically (with different vertical offsets applied to clearly distinguish the two waveforms, without adjusting the vertical scale until the waveform fills the screen). By selecting standard deviation and peak-to-peak value as measurement parameters, it becomes evident that the signal measured with a common passive probe is overwhelmed by noise. In contrast, the power rail probe can still accurately capture the test results.

Power Measurements Capabilities

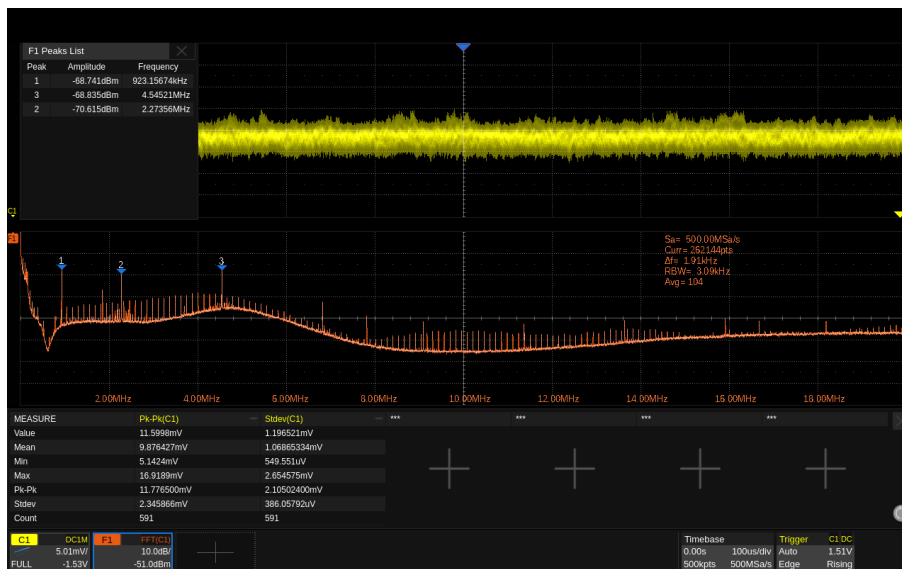


Measurement Analysis

When analyzing a power supply’s noise, an oscilloscope can be used to directly observe and measure ripple and noise, allowing for the identification of interference sources. However, as the voltage of digital devices continues to decrease, the complexity of power supply design increases. In some cases, the time-domain waveform alone may not reveal the underlying issues. At this point, converting the time-domain waveform into the frequency domain using FFT (Fast Fourier Transform) can be beneficial. The FFT below shows the main frequency components of the noise, which can help speed up circuit debugging by providing insights from both time-domain and frequency-domain perspectives.

Power Measurements Capabilities

It's important to note that the effectiveness of the FFT varies with the number of test points; more test points result in higher frequency resolution and a clearer FFT result. The SDS7000A series oscilloscopes from SIGLENT support up to 32Mpts in an FFT calculation, offering a peak list display that quickly reveals the amplitude and frequency of key components.



Power Measurements Capabilities

Conclusion

Power supply measurements of ripple and noise, while increasingly complex, are more important than ever, as they impact system aging, reliability, and efficiency. The availability of high bandwidth high resolution oscilloscopes, advanced power rail, and integrated FFT analysis improves accuracy and simplifies debugging of modern power signals. SIGLENT's SDS3000X HD and SDS7000A series Oscilloscopes match high bandwidth with high resolution while SIGLENT's new SAP4000P power rail probe combines wide DC offset with low noise and high accuracy. Improve power supply efficiency and reliability working with SIGLENT's newest power measurement capabilities.

Power Supply Control Loop Response

Measurements using Bode plots

Introduction

Stability is one of the most important characteristics in power supply design. Traditionally, stability measurements require expensive frequency response analyzers (FRA) which are not always available in a laboratory. SIGLENT has released Bode Plot II features to the SIGLENT SDS1104X-E, SDS1204X-E, SDS2000X-E, SDS2000X Plus, SDS5000X, and SDS6000A series of oscilloscopes. When combined with a Siglent arbitrary waveform generator (SDG or SAG) and an injection transformer, quick frequency response curves can be created.

In this application note, we will show you the basic principles for making this stability measurement and how to use these instruments to make the measurement.



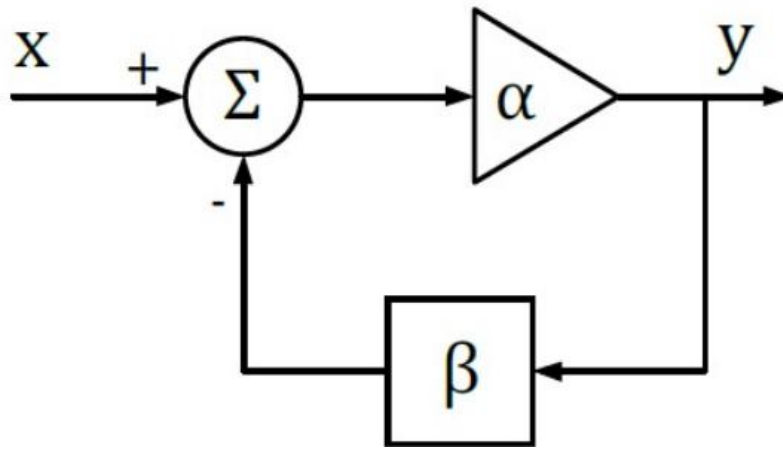
Measurement system setup

Stability of The Feedback System

A regulated power supply is actually a feedback amplifier with a large amount of current sourcing capability. Any theory that applies to a basic feedback amplifier also applies to a regulated power supply.

In feedback theory, the stability of a feedback system can be determined by evaluating the loop transfer function. A more practical way is to measure the bode plot of the loop gain. This figure shows a typical feedback system. The closed loop transfer A is the mathematical relationship between input x and output y . The loop gain T , by its name, is defined as the gain of a signal traveling around the loop.

Power Measurements Capabilities



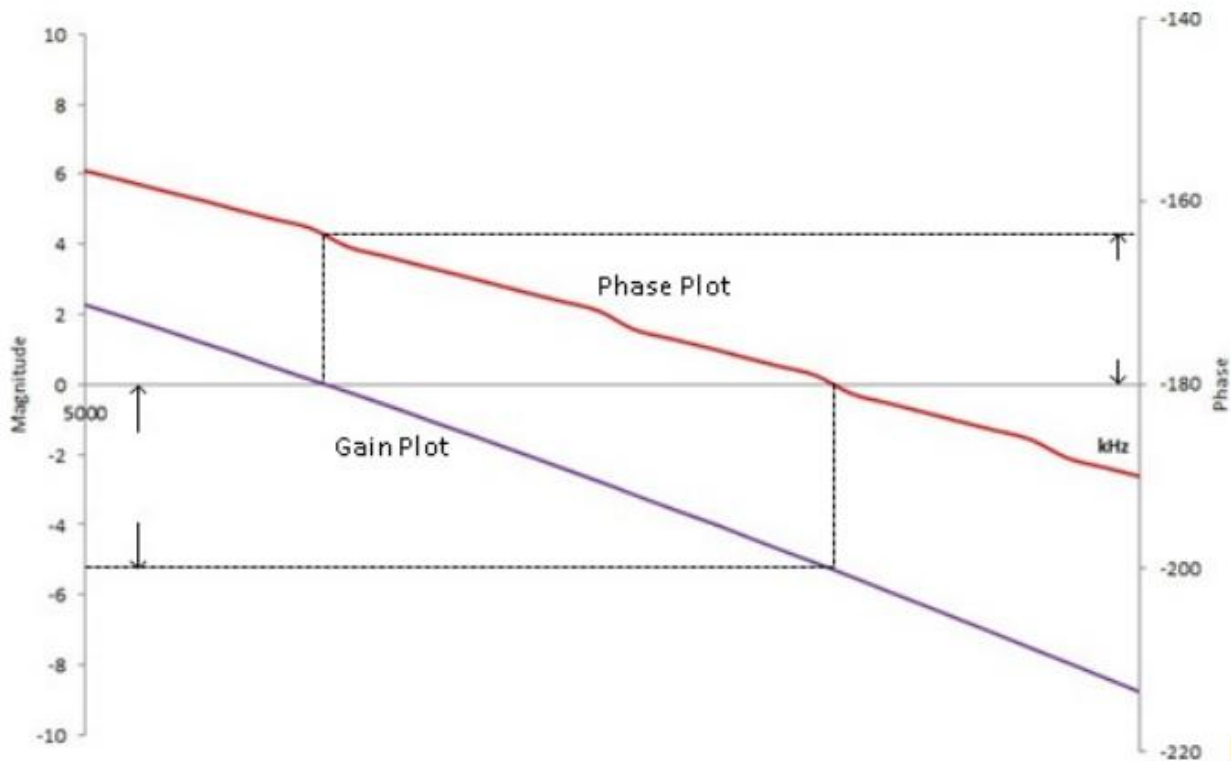
$$A = \frac{y}{x} = \frac{\alpha}{1 + \alpha\beta}$$

$$T = \alpha\beta$$

Typical feedback loop

Since α and β are complex variables, they have not only magnitude but also phase angle, as also does the loop gain T . If the phase angle of T reaches -180° while the magnitude is 1, the closed-loop transfer function A becomes infinity. In this situation, the system will maintain an output signal while there is no input. Thus, the system acts as an oscillator rather than as an amplifier, which means that the system is not stable.

If we plot the loop gain in a bode plot, we can evaluate the stability by finding the phase margin and gain margin. A phase margin is defined as how many degrees the phase can be decreased before reaching -180° while the magnitude is 1 (or 0 dB). The gain margin is defined as how many dB in magnitude can be added before reaching 1 (or 0 dB) while the phase is -180° .

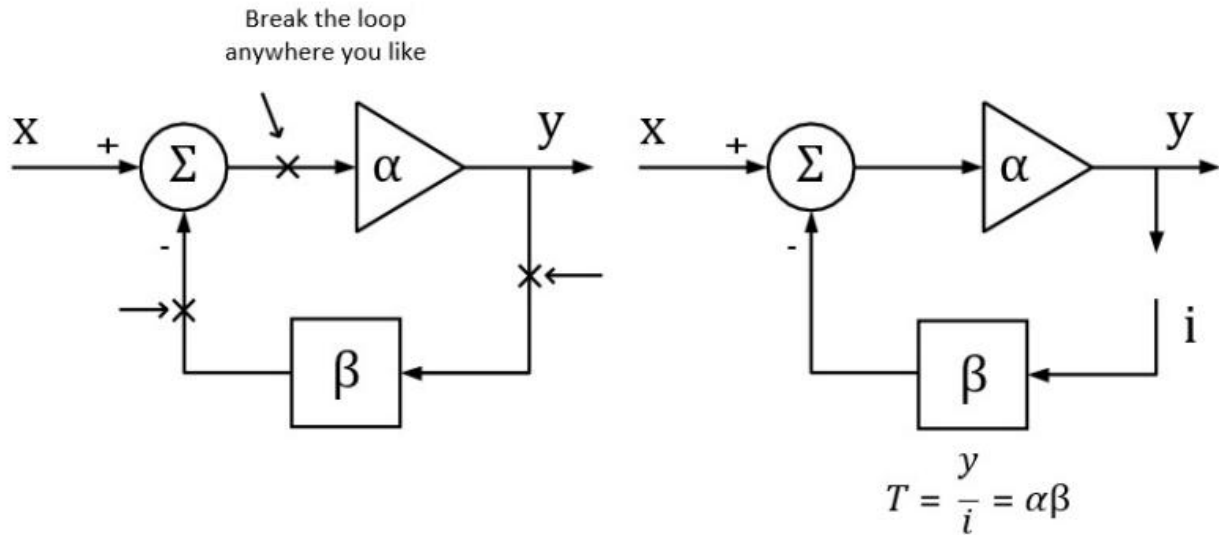


Bode plot phase and gain margin

Break the Loop

To get the desired loop gain, we simply break the loop. The following figure shows how to break the loop in a typical feedback system. Technically you can break the loop any place you like. We commonly choose to break the loop at the point between the amplifier output and the feedback network. Then we insert a test signal i to travel around the loop. The loop gain is the mathematical relationship between the output y and the test signal i .

Power Measurements Capabilities



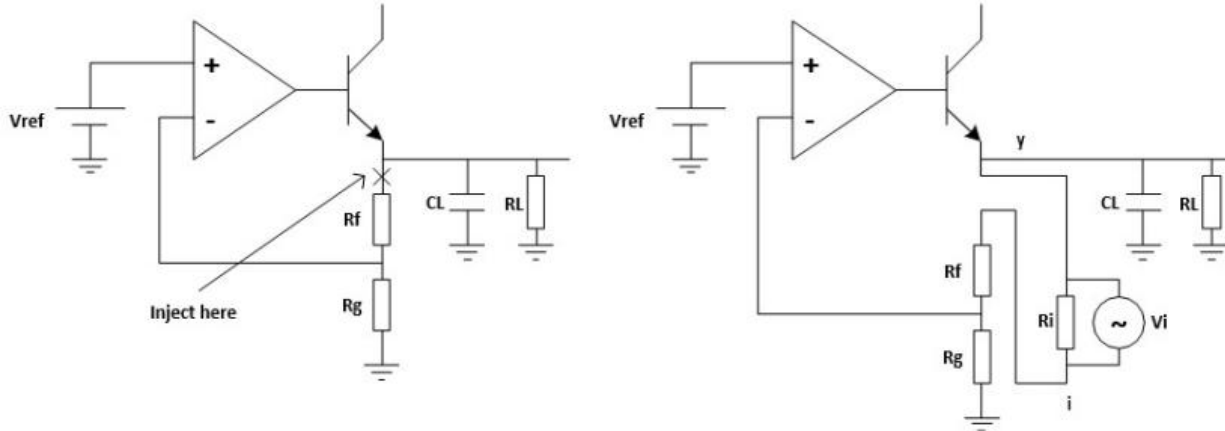
Breaking the loop in a typical feedback system

Loop Injection

In reality, we can never really break the loop because the feedback loop serves to maintain the DC quiescent operation point of the circuits. Without the feedback loop, the device under test will become saturated because of the small input offset voltage, and then no useful result can be measured.

To overcome this, we should measure the open-loop response inside a closed loop. Therefore, we just inject a signal into the loop rather than breaking the loop. The figure below shows a typical method of loop injection. The injection point is chosen so that the impedance looking in the direction of the loop is much higher than that looking backward. One possible point is between the output and the resistor divider feedback network. Other points that meet this requirement may be chosen.

Power Measurements Capabilities

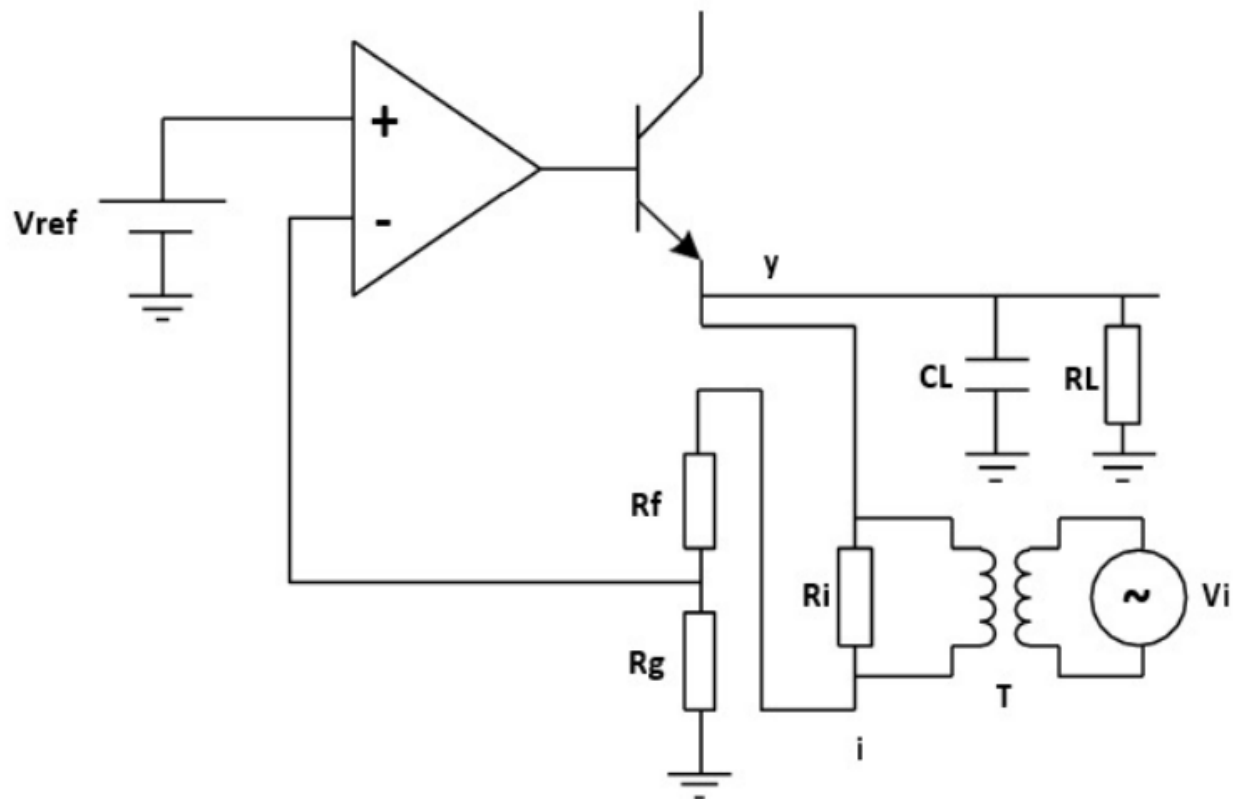


Loop injection

To maintain the closed loop, a small injection resistor R_i is inserted at the injection point. The resistor should be small enough so that it will have little effect on the circuit and also the lower the resistor value the lower the frequency the transformer will operate. Picotest recommends a resistor value of 4.99Ω for the J2100A, and a larger value may be chosen depending on the circuits. The injection signal is then applied across the injection resistor.

The signal injected should have no effect on the DC operating point of the circuit. A method to solve the common ground connection problem is to use an injection transformer as shown in the next figure.

Power Measurements Capabilities



Injection Transformer

The injection signal starts at one end of the injection resistor, travels through the resistor divider feedback network, the error amplifier and the pass element transistor, and finally to the output, which is the other end of the injection resistor. The relationship between the injection signal i and the output signal y is the loop gain that we wish to measure.

Be aware that we are measuring an open-loop parameter inside a closed loop, the phase starts at 180° and decreases to 0° , rather than starting at 0° and decreasing to -180° . So, the phase margin should be measured relative to 0° .

Measurement Setup and Result

Equipment:

Power Measurements Capabilities

Oscilloscope: Siglent SDS1204X-E with firmware version > 6.1.27R1

Signal Source: Siglent SDG2042X

Power Supply: Siglent SPD3303X

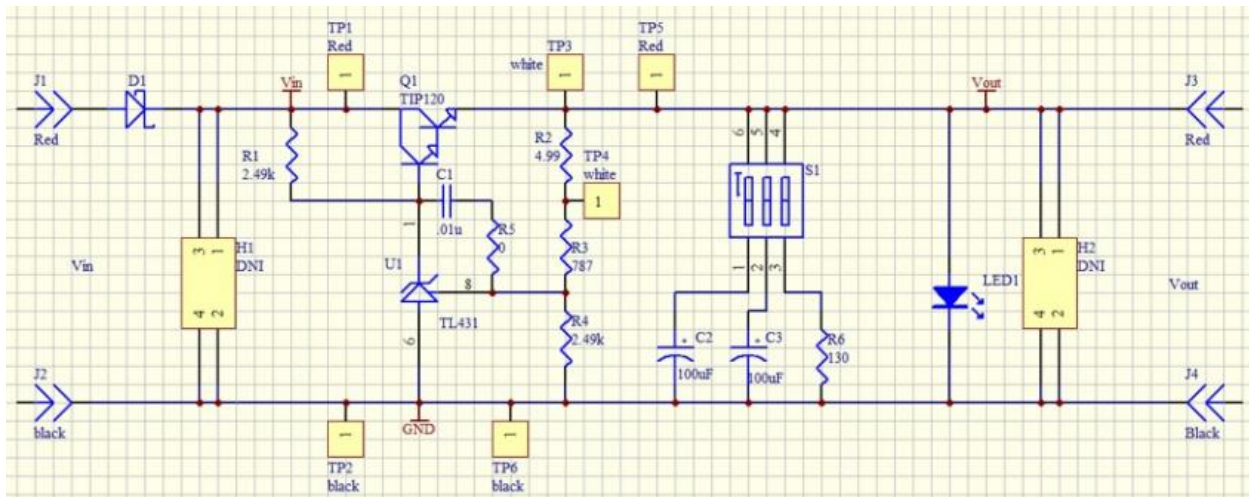
Probe: Siglent PP215 passive probe switched to 1X

Injection Transformer: Picotest J2100A

Device-Under-Test: Picotest VRTS v1.51

Circuit Connection

The Picotest VRTS v1.51 is a demonstration board for voltage regulator testing. Technically it is a linear regulator built from the famous TL431 and a discrete transistor. The schematic is shown in Figure 7. Different output capacitors can be selected to see the impact on the control loop stability.

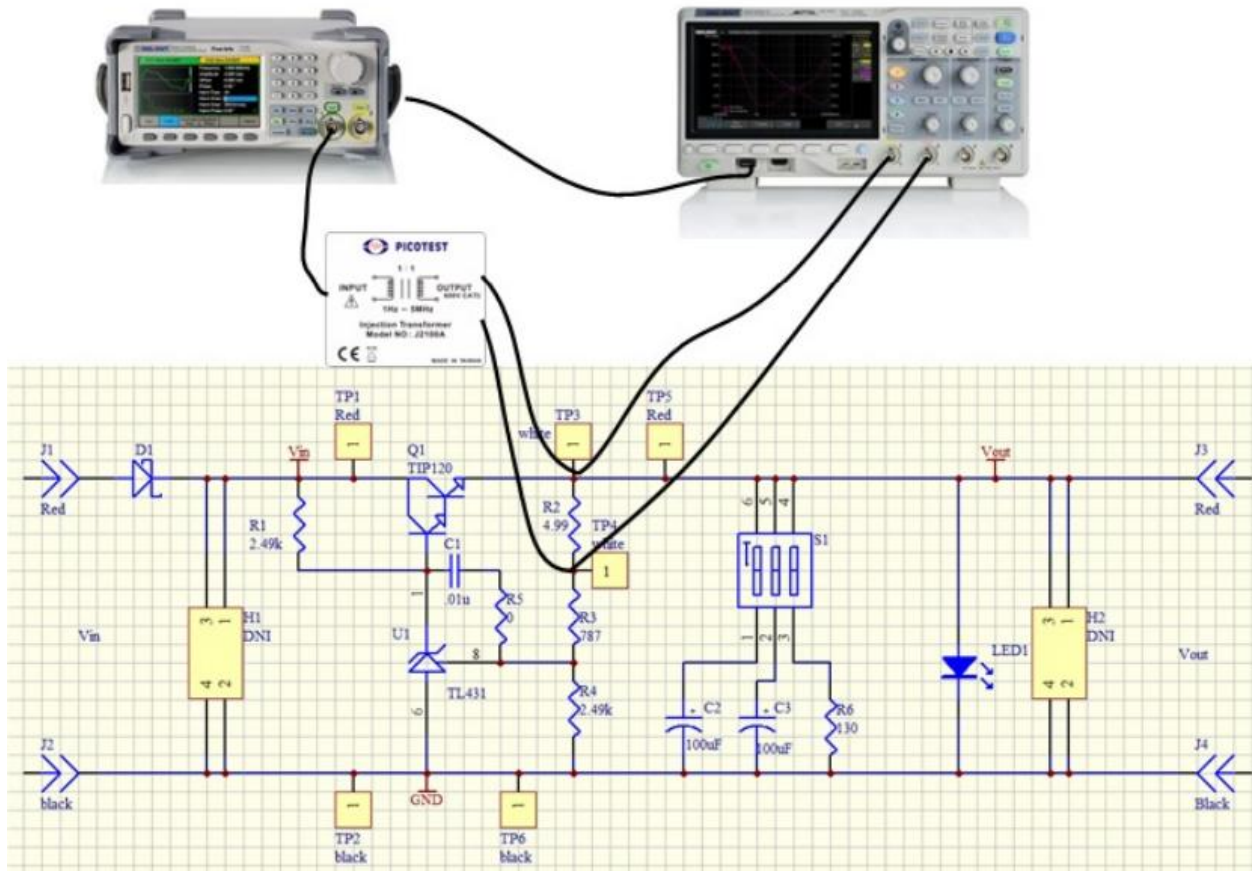


VRTS v1.51 schematic

For the propose of our power supply control loop response measurement, the injection point is TP3 and TP4. The circuit connection is shown below. The generator is connected to the oscilloscope through USB (connection through Ethernet is also supported). The injection transformer is connected in parallel with the injection resistor so that the signal is

Power Measurements Capabilities

injected to the loop while preventing the circuit DC operation point from being affected by the generator. The TP3 and TP4 points are also connected to the oscilloscope, and the TP4 is defined as the DUT Input while the TP3 is the DUT Output in the Bode Plot.



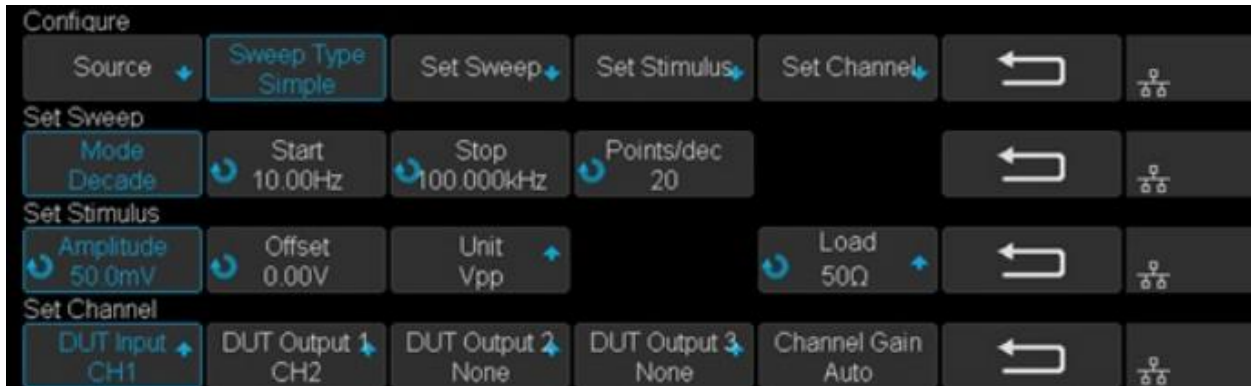


Circuit Connections

Instrument Configuration

In this section, we will show how the key configuration should be made in order to make the measurement correctly. For complete instructions to the Bode Plot II, please refer to the user manual and the quick start guide. Before entering the Bode Plot, it is recommended that you enable the oscilloscope's 20 MHz bandwidth limit setting. At this time, we want to measure the bode plot from 10 Hz all the way to 100 kHz. This frequency range should be enough for a circuit with an expected crossover frequency at about 10 kHz. Enter the Config menu and set the Sweep Type to Simple, then enter Set Sweep to set the sweeping frequency. Set the Mode to Decade and Start to 10 Hz, Stop to 100 kHz. Set Points/dec to 20, enough for a typical sweep. Enter the Set Stimulus menu to set Amplitude to 50 mV. Enter the Set Channel menu to set DUT Input to CH1 and DUT Output to CH2.

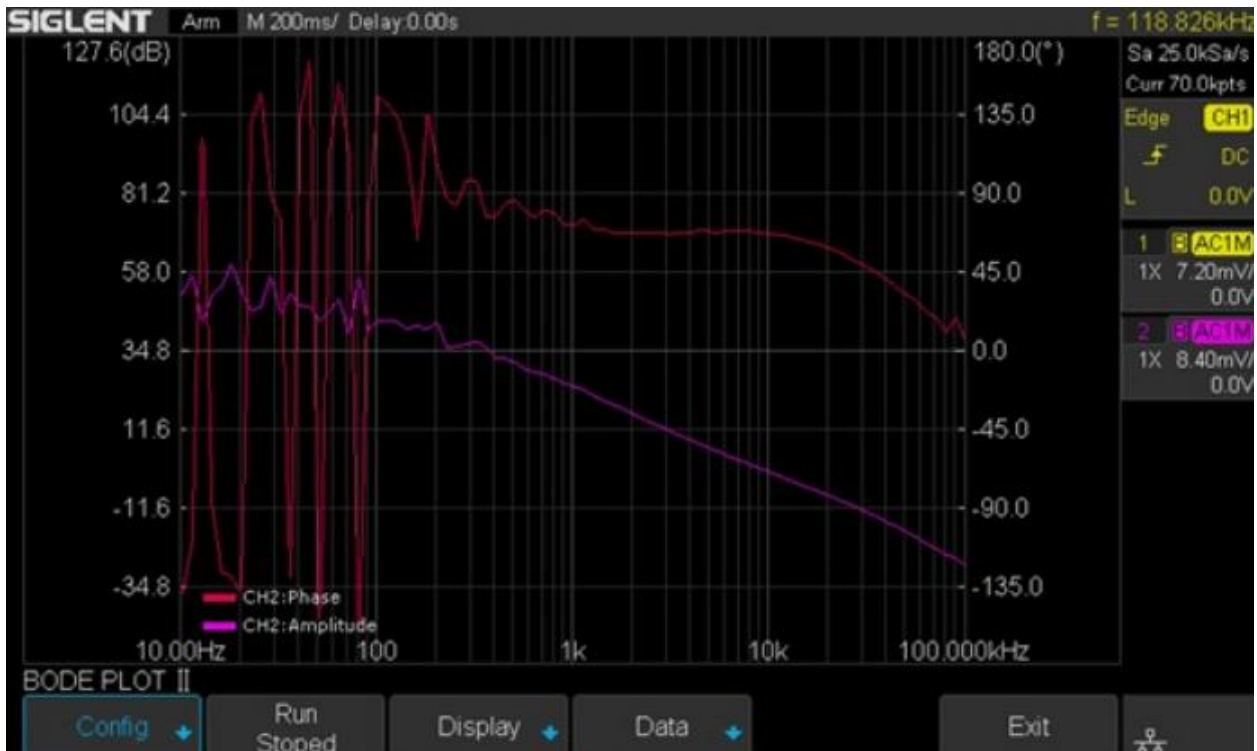
Power Measurements Capabilities



Oscilloscope configuration

Results and Data analysis

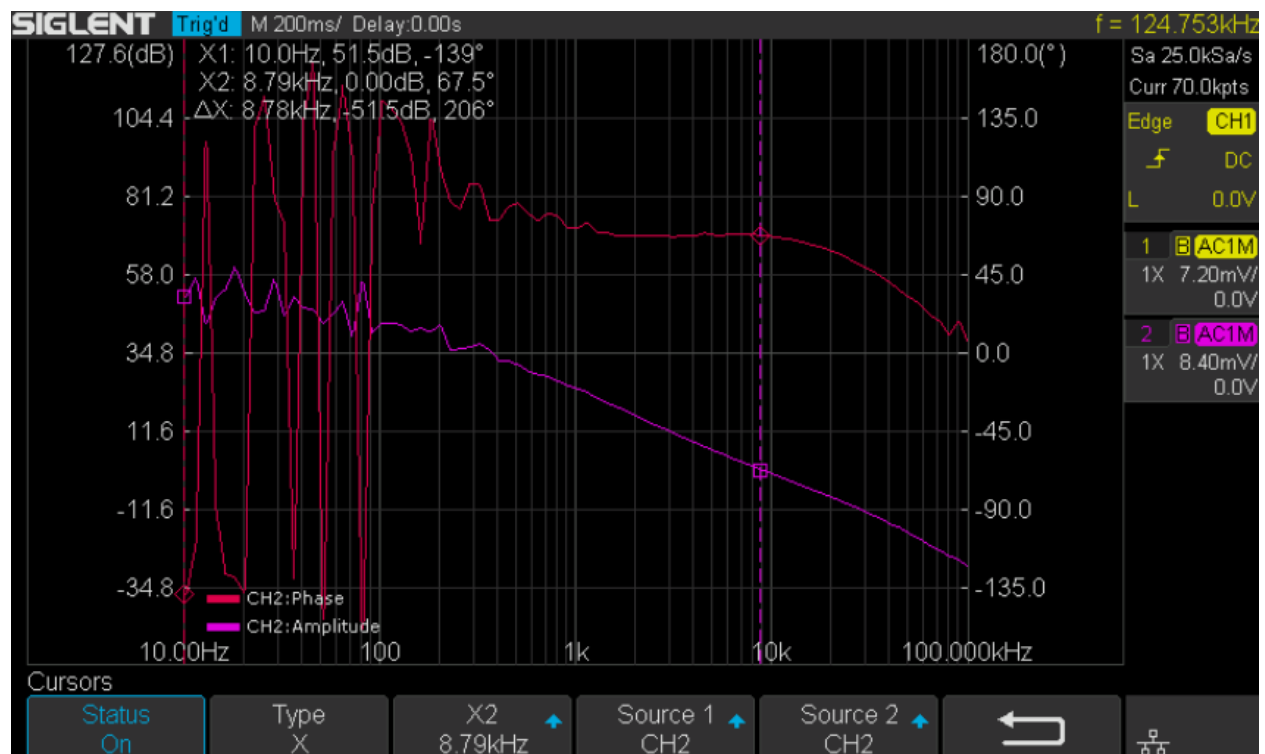
After the configuration is done, return to the main menu and press Run to start the sweep. Wait to see the results as shown below. The result is somewhat confusing and suspect because of the trace at low frequency, especially the phase trace, alternating up and down. We will introduce a method called Vari-level to resolve this problem in the next section.



After the sweep has completed, press Run again to stop the sweep. Enter the Display menu and then enter the Cursors menu to turn on the cursors.

Power Measurements Capabilities

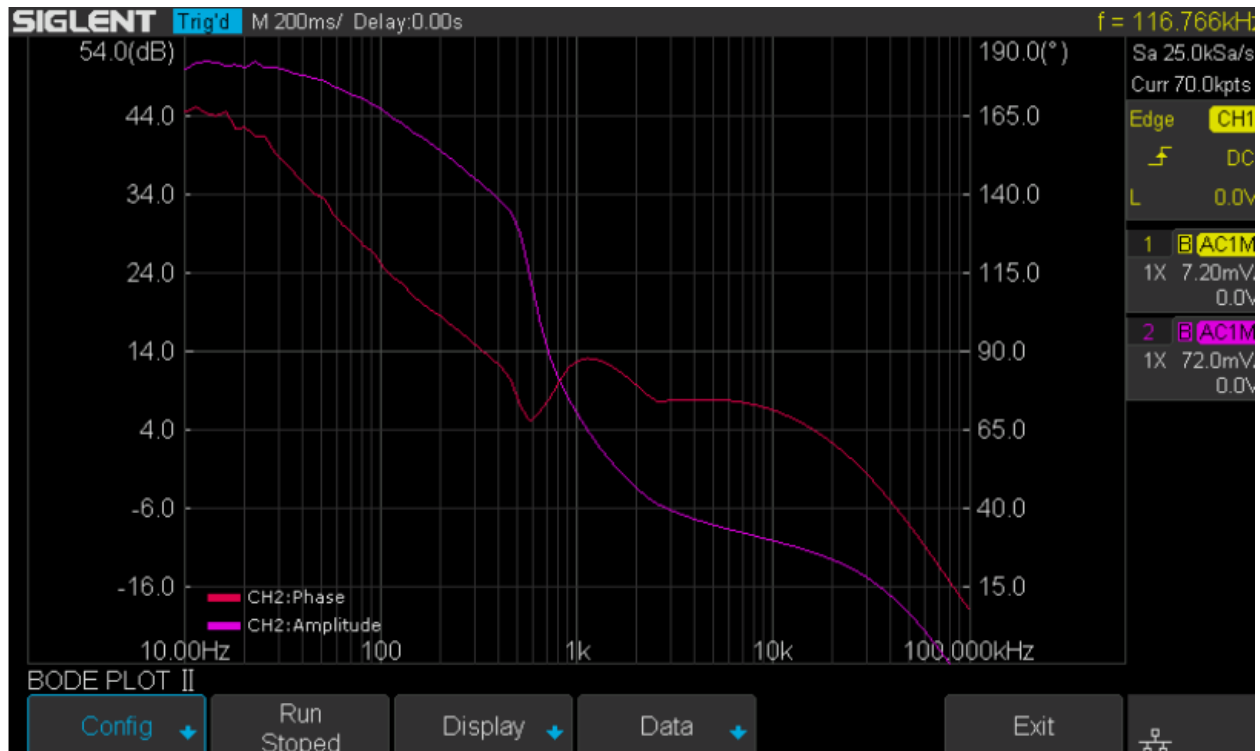
Use the Adjust knob to move the cursors and set the phase margin as shown here:



Bode plot cursor measurement

We can see that the results are not ideal, for the bouncing trace at low frequency. This is because at low frequency the amplitude difference between the input and output channel is relatively large, and since we are using a relatively small stimulus signal (this time 50 mVpp), the signal presented at the DUT Input channel is extremely small so that a commercial general purpose oscilloscope cannot measure it accurately. But we cannot simply increase the stimulus's signal amplitude. The result will be similar to this:

Power Measurements Capabilities



Increased stimulus and distortion

The large signal near the crossover frequency region causes serious distortion in the loop. The distorted signal in the time domain is shown here:



Power Measurements Capabilities

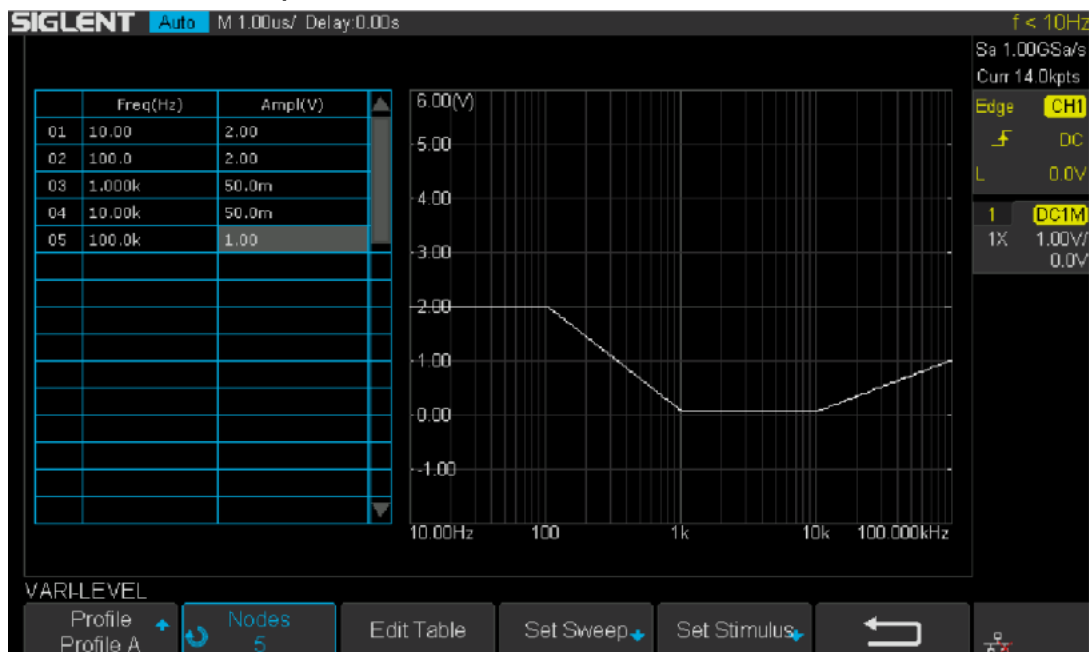
Remember that a bode plot only makes sense in a linear system, and has no meaning in a heavily nonlinear system. The result is useless.

One possible solution to the problem is Vari-level (other manufactures may call it “Shaped Level” or “Level Profile”). The Vari-level concept is simple: The stimulus signal amplitude is variable over the frequency. If we use a large signal at low frequencies and decrease the amplitude to a fairly small level near the crossover region so that it causes little distortion to the loop, in theory, we can get an ideal result.

Under the Configure menu, set Sweep Type from Simple to Vari-level, and push Set Vari-level to enter the Vari-level profile editor:



Here is the Vari-level profile editor:



The Profile option allows the user to select and save up to 4 profiles. The Nodes sets the number of nodes in the profile trace, the minimum allowed number of nodes is 2 because at least 2 points can determine a line, and

Power Measurements Capabilities

always the first and the last node set the start and stop of the trace. Press Edit Table will enter the profile editor mode. The parameter under editing is highlighted by cursors, and next push Edit Table again to cycle the cursors between “Freq”, “Amp” and the entire row, which allows the user to navigate through the entire table. Users can use the Adjust knob to set the highlighted parameter, and pushing the knob will call out a visual keypad that allows direct input to the parameter. The Set Sweep and Set Stimulus option is somewhat similar to that in the Simple type of sweep, but they are not correlated. This time we set the sweep Mode to Decade and a 40-point-per-decade is sufficient. The profile shown above is used in this measurement. It is not the optimum profile for this circuit but should be a good place to start.

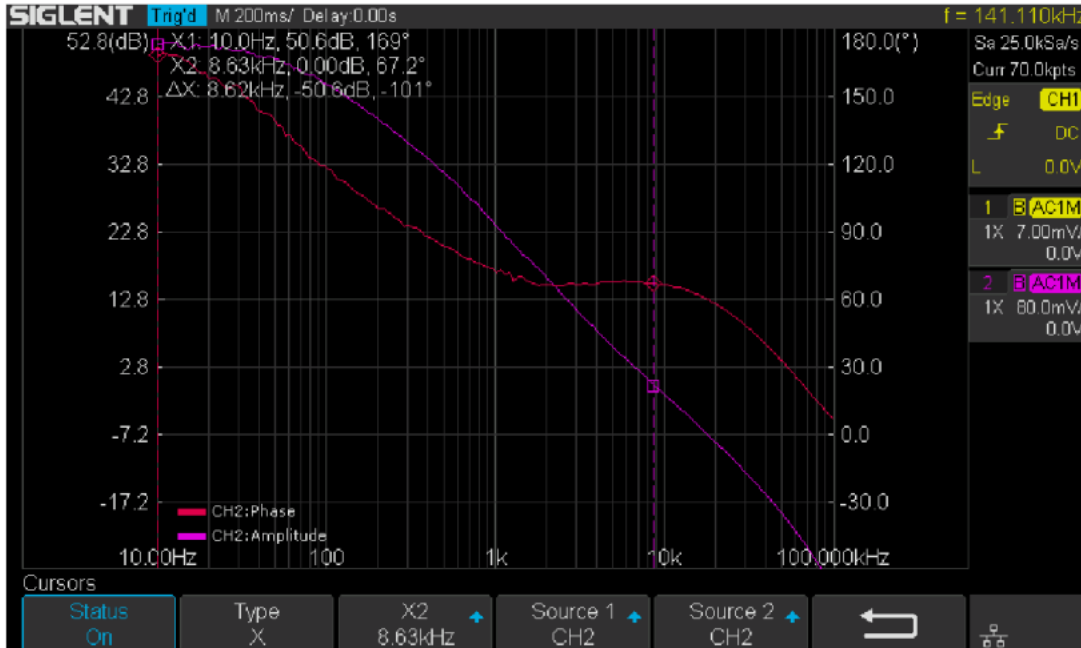
In practice, one should always experiment with those parameters to find an optimum solution for a particular circuit. One practical way to do this is to monitor the signal in the time domain, decrease the amplitude of the stimulus signal until no visible distortion can be observed, then decrease the amplitude by another 6 dB. Next, record the amplitude and frequency, jump to another frequency and repeat the process.

There is a better way to find the optimum profile if you already have a known good profile. Reduce the signal amplitude by 6 dB and run a sweep to see if the plot changes. If it does change, reduce the amplitude by another 6 dB and sweep again. Until the result doesn't change, then you can increase the amplitude by 6 dB and that's an optimum profile. This is time-consuming but necessary to get a meaningful result.

Once profile editing is completed, return to the main menu and push Run to start the sweep. Figure 18 shows the final result of the measurement

Power Measurements Capabilities

with Vari-level. Changing the capacitor selection switch S1 on the VRTS v1.51 demo board will alter the loop response due to the impact of different capacitors.



Results using vari-level

The Siglent oscilloscope using Bode Plot together with a Siglent signal generator and a Picotest injection transformer offer a very flexible and easy-to-use power supply control loop measurement system.

Power Supply Design: Load Step Response with a SIGLENT DC Electronic Load

Building a power supply that can handle various loads without oscillating can be a challenge. Computational models and computer simulations can help get your design headed in the right direction, but physical testing is essential to proving the performance of your design. One method of quickly determining stability is to use a load step response.

In this test, a DC electronic load is used to provide a current load that steps from a low current draw to a higher value in a short period of time. By directly measuring the voltage and current output of the supply with the stepped load, we can visually observe the recovery of the power supply feedback loop and make changes to the design to optimize the response.

For this note, we are going to perform identical tests on two supplies and compare the output voltage and current waveforms: One has been tuned so that the output quickly recovers with minimal overshoot and ringing. The other supply is not tuned and subsequently oscillates. We will also discuss some measurement techniques to help get the right data as quickly as possible.

We also have a video to accompany this note:

[Power Supply Design: Load Step Response with a SIGLENT DC Electronic Load](#)

Equipment

- DC Electronic Load: The SIGLENT SDL1020X-E is a 200 W load with dynamic testing capabilities to perform the load step. It also features remote sense capabilities to compensate for the voltage drop across the load leads. High currents can provide a substantial voltage drop across the leads and will add unwanted error.
- Oscilloscope: The SIGLENT SDS2354X Plus scope has a large display, easy-to-use interface, and features that make capturing these waveforms very easy.

Power Measurements Capabilities

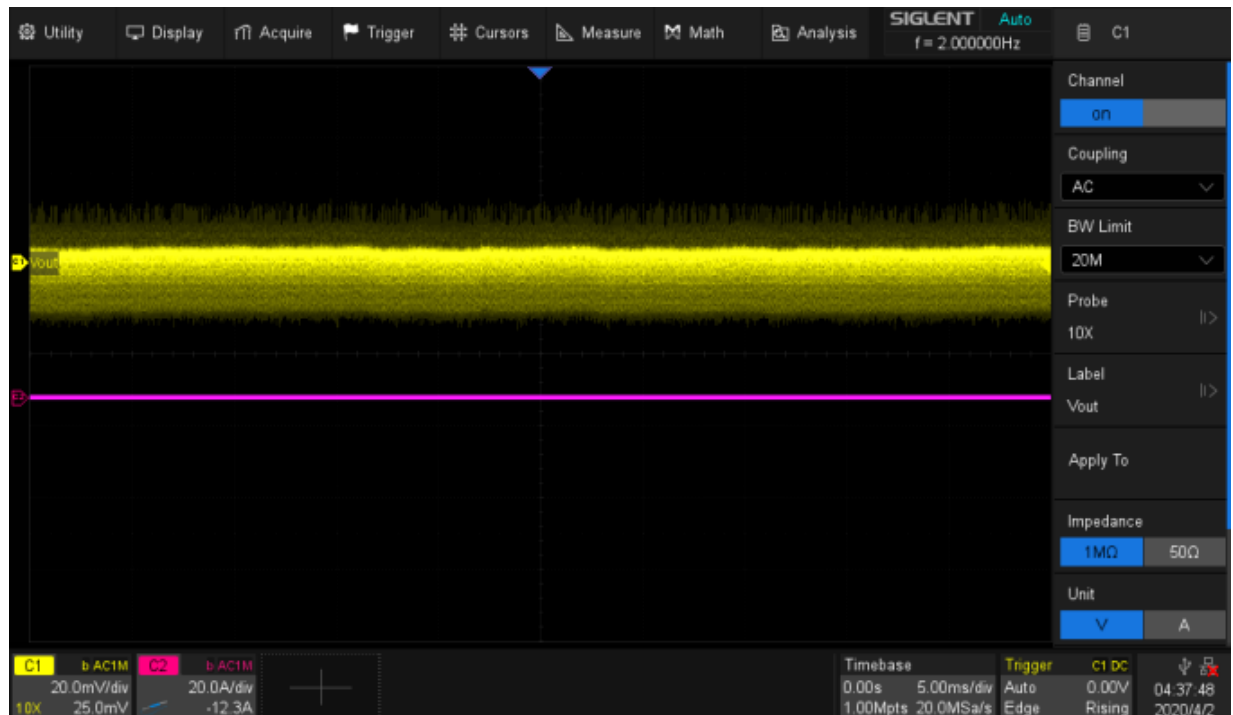
- Power supply: The SIGLENT SPD1168X single output supply delivers power to our power supply board.
- Current probe: The SIGLENT CP4070 features a 150 kHz bandwidth that will minimize most switching noise from the measurement
- Power supplies to test: Analog Devices LTM4646 series of uModule Regulators. This module features two 10A DC-DC converters. One has been “detuned” to show some common problems associated with power supply design. The other supply has been left in it’s tuned state as a comparison to the detuned supply.

Test setup

- Connect the SPD bench power supply to the power supply to test and configure the output values to match your supply needs. Here, we set the supply for 12 V @ 3 A.
- Connect the SDL electronic DC load to the output of the power supply to test. Configure the load for Constant Current (CC), set the voltage and current ranges to the lowest ranges that still accommodate the requirements of the test, set the current load to a value near the maximum for your design. You may also wish to wire up and enable the SDL remote sense which enables remote voltage measurement to minimize the voltage drop caused by the high current flow through the electronic load leads. Here, we set the current to 5 A.
- Connect a passive probe to the oscilloscope CH1. This probe should be connected to the power supply feedback loop to monitor the voltage as the supply adjusts to the load.
- On the oscilloscope, configure CH1 for AC coupling to provide the most resolution to view the feedback voltage which can have high DC offsets. Enabling the Bandwidth Limit (BW limit) can also decrease noise. Here, the SDS2X Plus also has on-screen labels for traces, which can be a convenient way of keeping information organized. Here, I labeled CH1 Vout.
- Connect the current probe to the oscilloscope CH2.
- On the oscilloscope, set the trigger for Rising Edge, CH2 and AUTO. This will allow you to adjust the current probe zero position without dealing with the trigger setting.

Power Measurements Capabilities

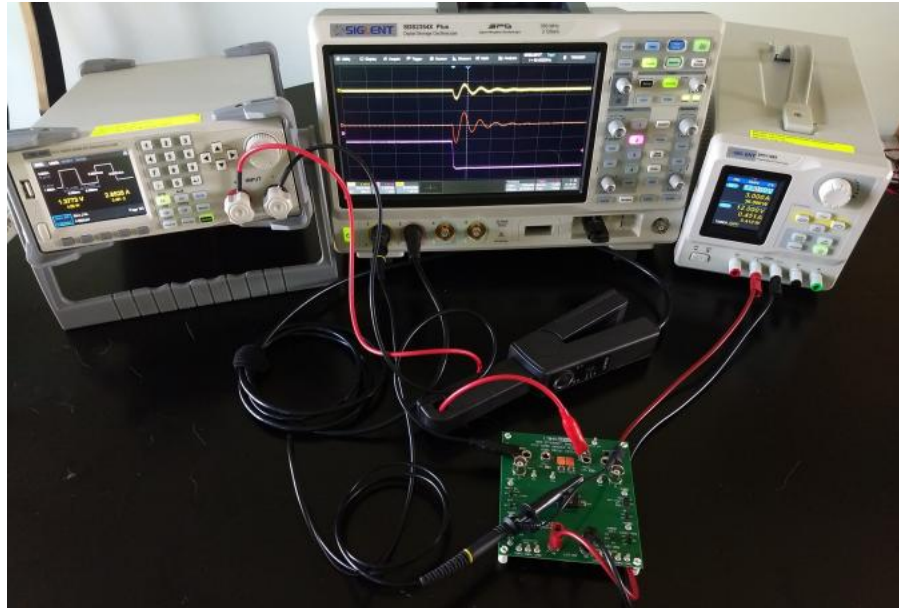
- Configure CH2 as a current probe (Units = A), set the Probe attenuation to the proper value (50 mV/A in this case). DC coupling here because we want to see the total signal amplitude. I also applied a label to the output current (Iout).



- Zero the current probe. The CPs have a knob that you can use to move the DC offset. Set the scope to a low current range and adjust the probe to get 0 A on the display.
- Clip the current probe around the positive current lead going from the power supply under test to the DC load. Make sure to have the clamp connected such that positive current flow (into the load) produces a positive signal on the scope.

Now, everything is connected and ready to test:

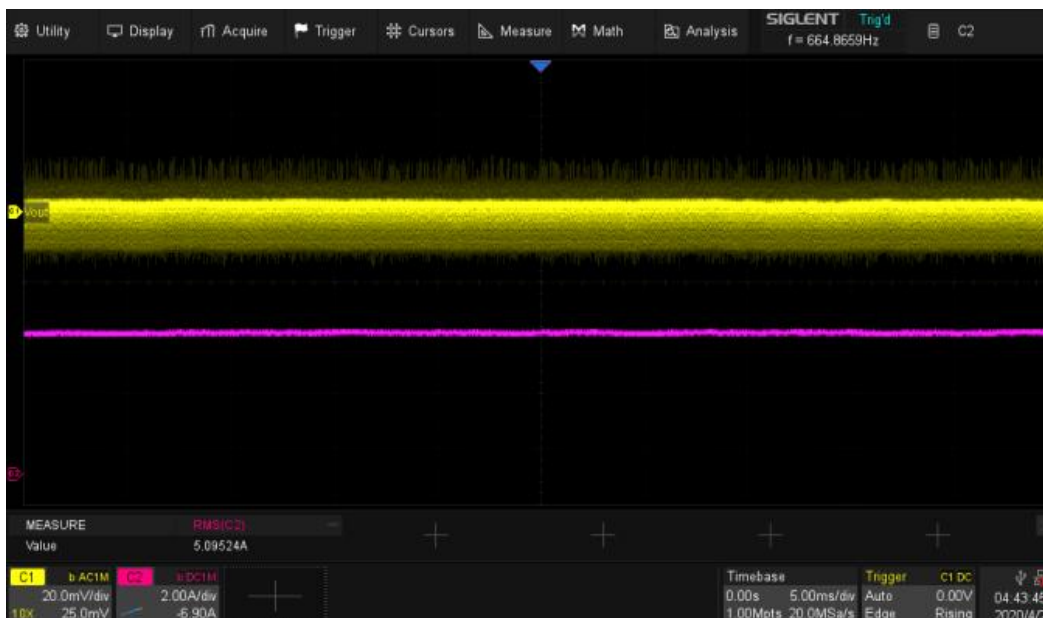
Power Measurements Capabilities



Test Setup

DC Load Verification

Now, you can power on the SPD power supply and SDL load. Make sure that the scope is set to AUTO trigger for now. You can also add an RMS measurement on CH2 so that you can verify the current draw matches the setting on the DC Load. Here, we have a setting of 5 A on the DC load.. and we show 5 A RMS on the scope:



Power Measurements Capabilities

DC Load Step Response

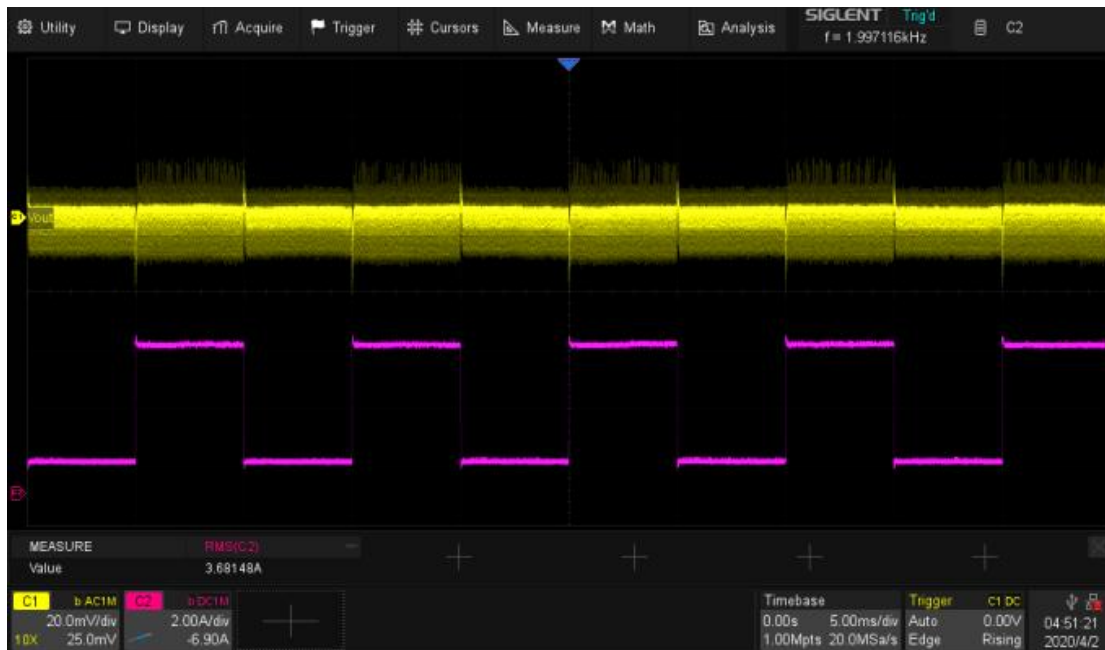
Now, set the DC load to Dynamic Current mode by pressing Utility > CC.. and configure the appropriate ranges, low and high current values and duration, and slew rate for your application.

Here are the settings used for this test:



This will continuously cycle from 1 A for 5 ms to 5 A for 5 ms with 500 mA/us slew rate.

Now, switch the scope trigger mode to Normal and adjust the vertical, horizontal scales and positions.. as well as the trigger level to get a stable trigger and a few periods of transition on the display:



Power Measurements Capabilities

Verify that the supply high and low current values match the setpoints. For this example, we have 1 A for 5 ms and 5 A for 5 ms.. which is what we observe.

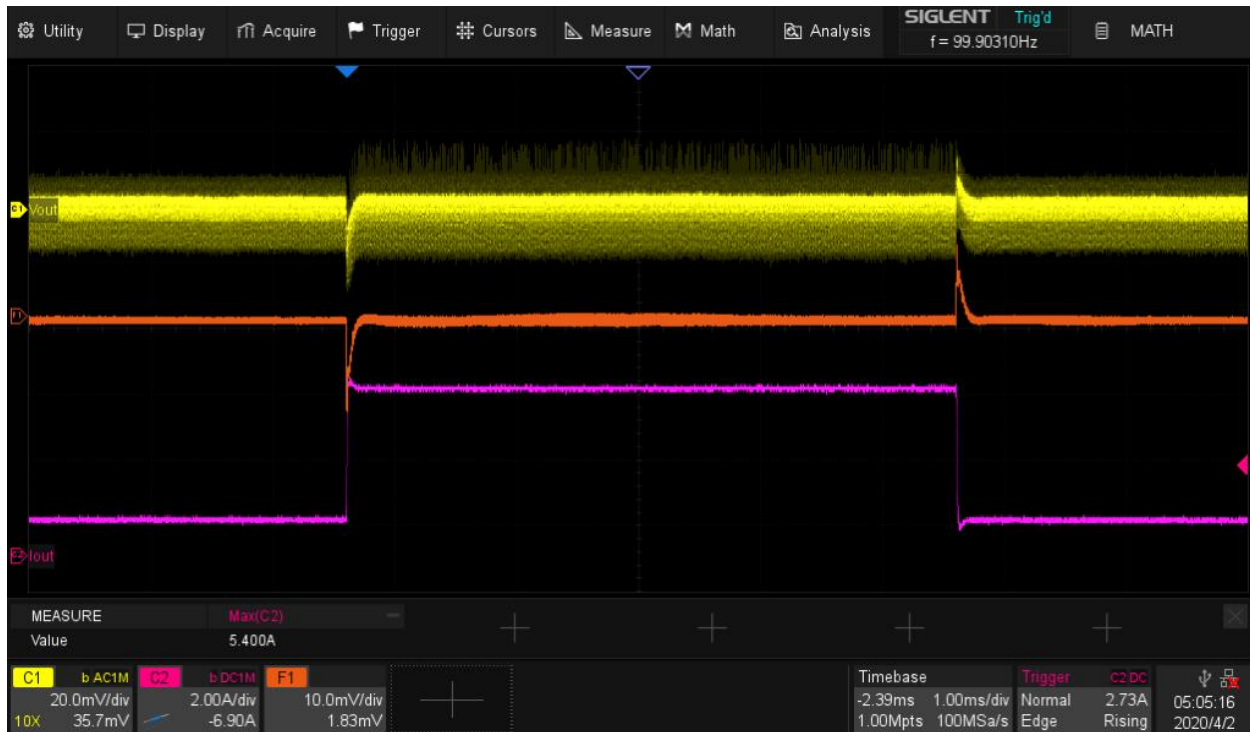
Observe and Optimize

Now, let's compare a tuned setup to one that is not tuned for our load as well as some techniques to gather more information about the response. First, you likely see quite a bit of noise on your signal. The majority of this is due to switching noise in the supply being tested. Here is a zoomed image of the feedback voltage where you can see the switching noise quite clearly:



Enabling waveform averaging can help. Now, we see the output voltage from CH1 (yellow), output current from CH2 (pink/purple), and the average voltage math function (orange):

Power Measurements Capabilities



This is the tuned setup.

Now, let's look at a detuned supply:

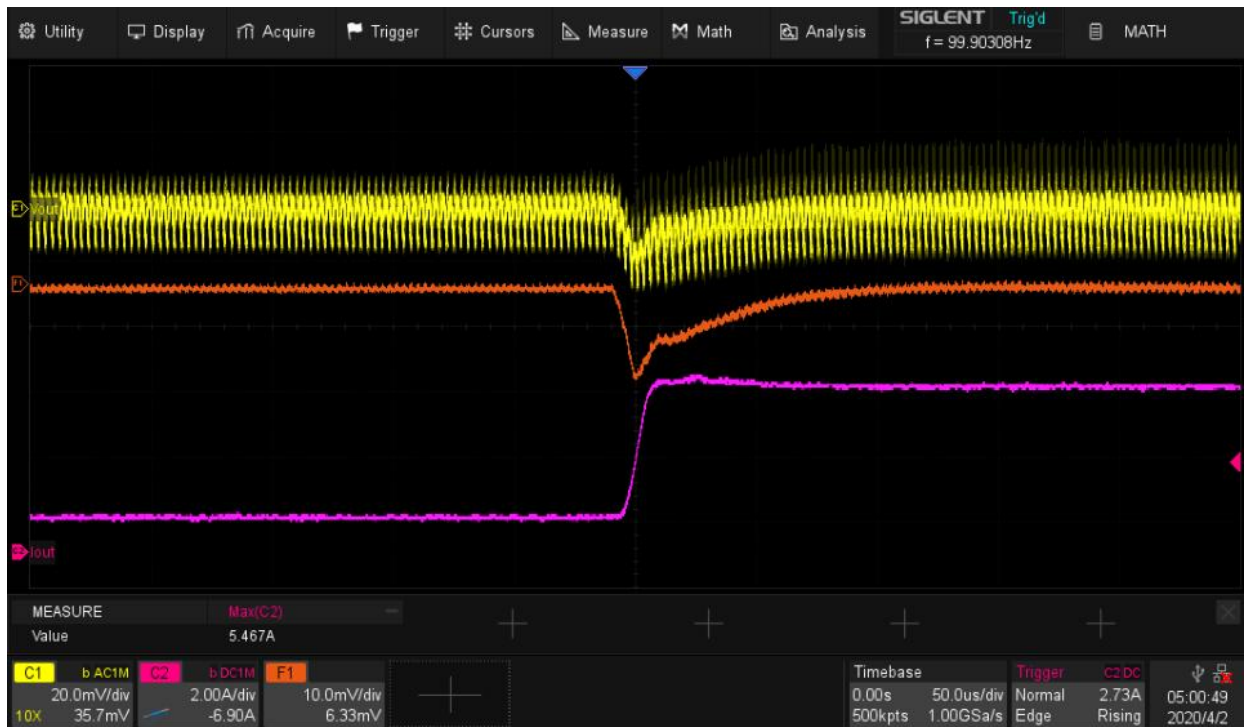


Power Measurements Capabilities

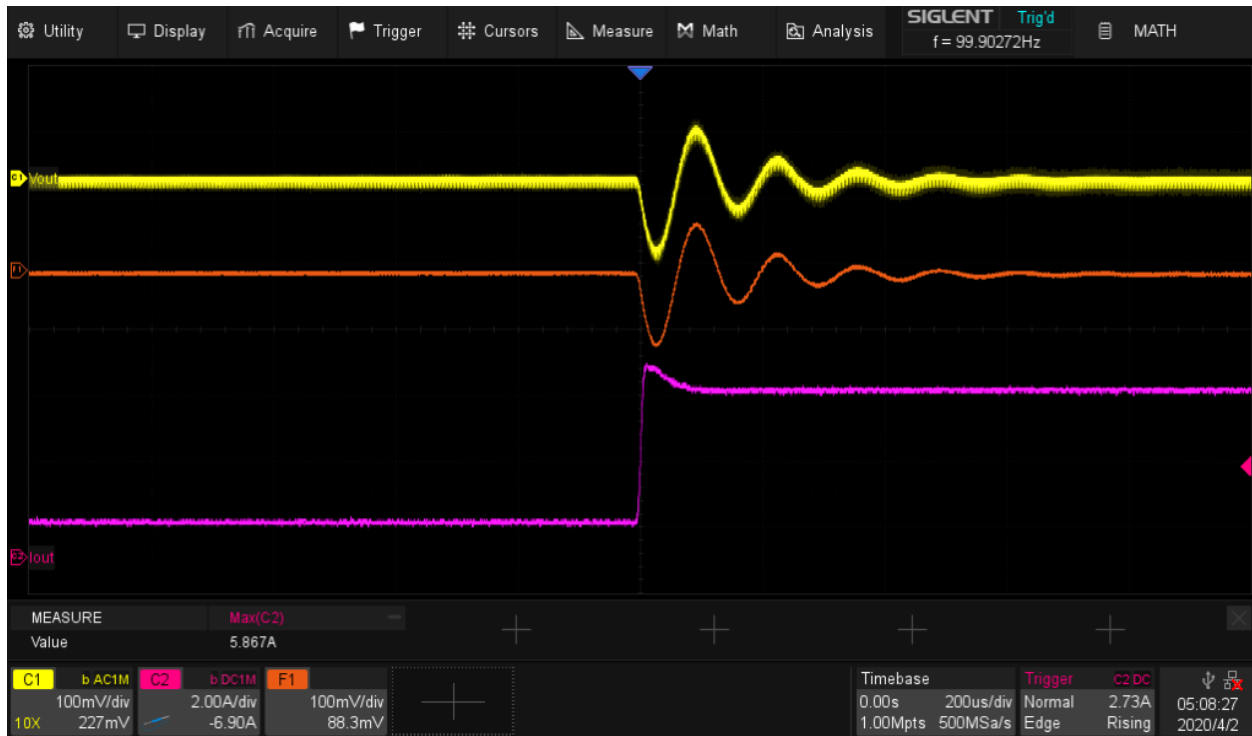
The scaling on these two images is exactly the same. You can see a large amount of ringing associated with the detuned supply. This design is very close to becoming an oscillator with this load. If our step duration was any shorter, the supply voltage wouldn't be settled and our output would be very poorly regulated.

Here are some closer images of the rising and falling edges on shorter time scales:

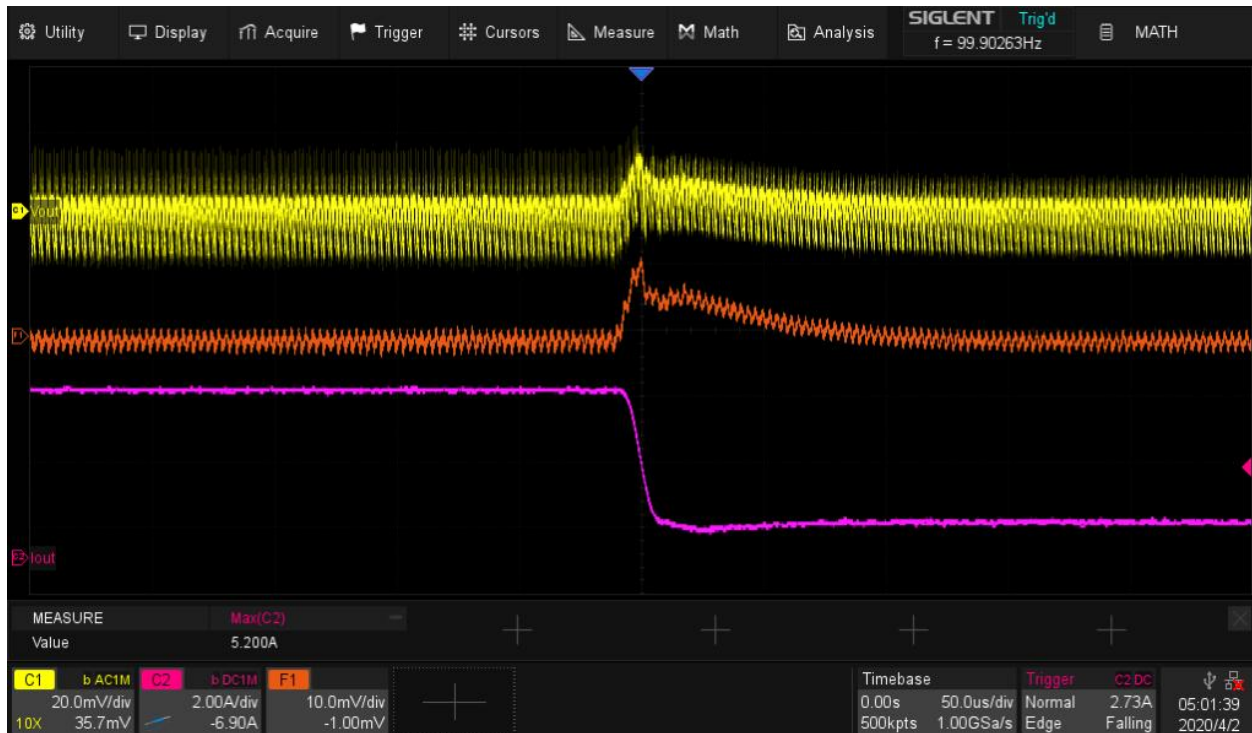
Rising edge (tuned and detuned):



Power Measurements Capabilities



Falling edge (tuned and detuned):



Power Measurements Capabilities



Conclusions

A DC load step test can quickly show you the performance and stability of a power supply design. Using a few common pieces of test gear, you can ensure that your design is ready to undertake the most challenging application requirements.

DC power supply efficiency measurements app note

Introduction

Many electronic designs require a power supply that delivers a known voltage over a specific range of current loads and conditions. In many instances, the efficiency of the supply is an essential characteristic of the design. More efficient designs convert the input power into a higher percentage of output power than less efficient designs. Since the majority of power supply losses are generated as heat within the supply, more efficient designs tend to run cooler, offer higher stability, and longer operating lifetime. More efficiency often just makes more sense. This is especially important for applications that require battery power like remote IOT sensing or communications modules that need to be operational for an extended length of time.

In order to make more efficient designs, we need to know how to measure power supply efficiency. In this note, we will introduce the basic theory for DC power supply efficiency calculations, present a physical setup for accurately measuring the important parameters, and provide an example program that coordinates measurements and automatically calculates power supply efficiency quickly.

Theory

The efficiency of a power supply is simply the ratio of the power out vs the power in. From power electronics theory:

$$\eta = P_{out} / P_{in}$$

Where η = Power Efficiency, P_{out} = Output power (Watts), and P_{in} = Input power (Watts)

Power Measurements Capabilities

For DC power,

$$P = V * I$$

Where P = Power (Watts = Joules/s), V = Volts (Joules/Coulomb), and I = Current (Amps = Coulombs/s)

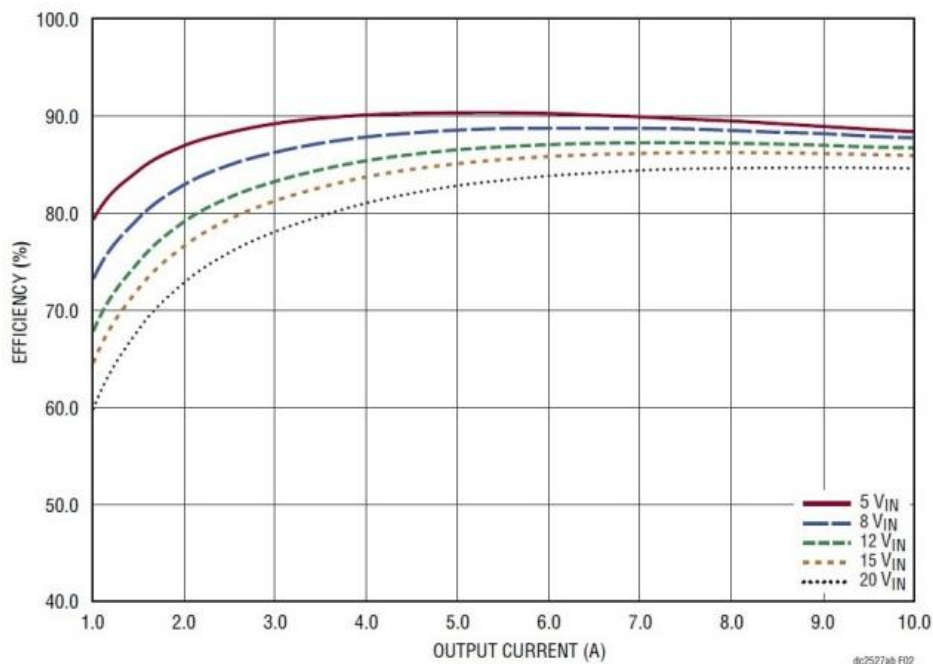
So, if we measure the input voltage and current draw, we can calculate the input power:

$$P_{in} = V_{in} * I_{in}$$

If we measure the output voltage and current draw, we can calculate the output power:

$$P_{out} = V_{out} * I_{out}$$

Now, some simple division provides Power Efficiency as a ratio which can be easily shown as a percentage at that specific load value. A curve of the efficiency vs. load values can be calculated by stepping the load value and calculating the efficiency at each load value and plotting it as shown below:



Sample Power Supply Efficiency Curve, from Linear Tech Datasheet for an LTM4646

Power Measurements Capabilities

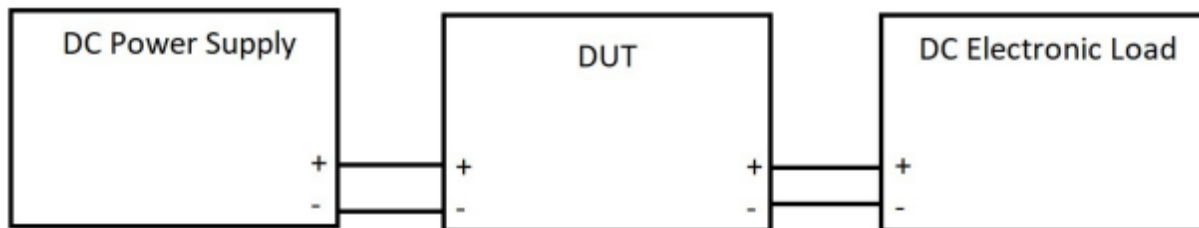
Setup

The most basic setup for this test uses:

Qty 1 Power Supply

Qty 1 DC electronic load

Typically wired as shown:



The process:

- Supply power to the DUT
- Set the load for a given current draw
- Measure the V_{in} , I_{in} , V_{out} , and I_{out} at the load current set point

This is about as simple as it gets with an electronics test.. but there are two important considerations with this setup:

1. How many load steps are required to accurately build an efficiency curve for your DUT?
2. What level of resolution and accuracy do you need for the calculation?

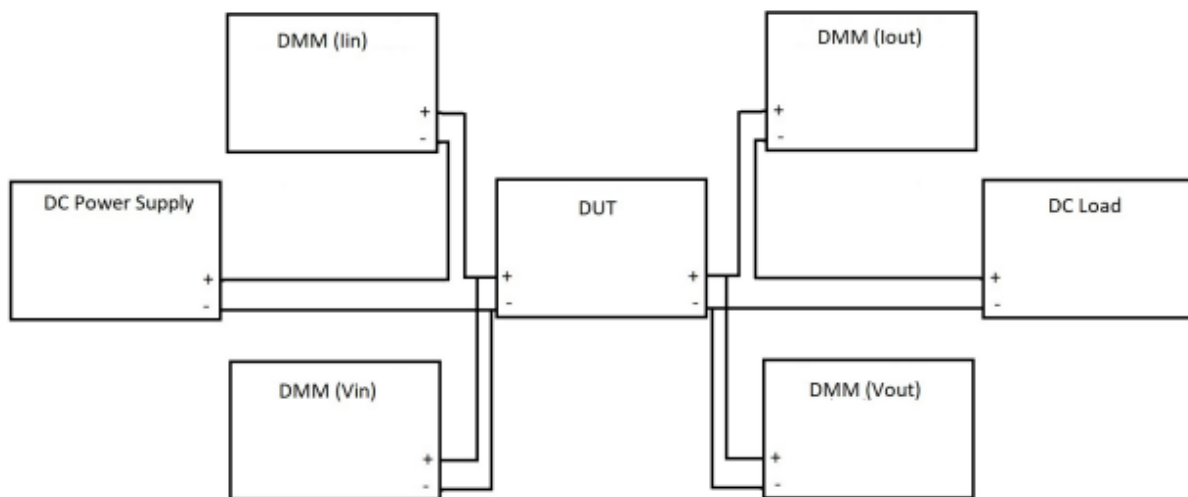
Typical power efficiency curves require 10 or more load current steps to get an accurate representation of efficiency. Manually performing this test can be a bit tedious and prone to error. To save time, you may want to consider automating the setup with a computer. See the next section for an example in python.

Power Measurements Capabilities

For the resolution question, consider that most commercial power supplies and DC loads have 3.5 digit measurement resolution and accuracy values that may not be high enough to characterize the DUT confidently.

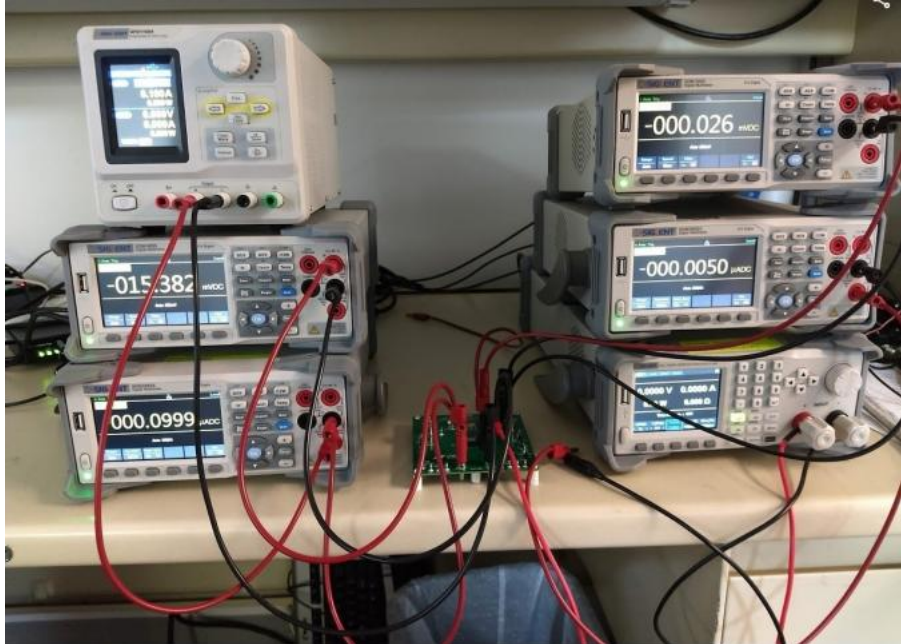
To address these two considerations, we added four multimeters: One to measure V_{in} , I_{in} , V_{out} , and I_{out} and created a computer program to automate the instrument configurations, step load current values, and data collection.

Here is a wiring diagram of the setup:



Power Measurements Capabilities

Here is a picture of the experimental setup which uses a SIGLENT SPD1168X, SDM3055s for I_{in} and I_{out} , SDM3045Xs for V_{in} and V_{out} , and an SDL1020X-E DC load:



Here the DUT is the Linear Technologies LTM4646 power module.

NOTE: Keep the leads to the load as short as possible to minimize $I \cdot R$ voltage drop and select DMMs with a low voltage burden on the current measurement ranges you expect to use. Long leads and a high voltage burden can cause the DUT to reach its output voltage limit before reaching the maximum expected current draw.

Summary

Power supply efficiency is an important aspect of any power supply design. Using a few standard pieces of test gear, one can quickly build a modular system with enough resolution to measure the most demanding applications.

Programming Example: Python Power Supply

Efficiency Example

Power supply efficiency is an important aspect of any power supply design. Using a few standard pieces of test gear, one can quickly build a modular system with enough resolution to measure the most demanding applications. This note describes a Python example that we created as a companion to the efficiency application note above.

Typical power efficiency curves require 10 or more load current steps to get an accurate representation of efficiency. Manually performing this test can be a bit tedious and prone to error.

For the resolution question, consider that most commercial power supplies and DC loads have 3.5 digit measurement resolution and accuracy values that may not be high enough to characterize the DUT confidently. To address these two considerations, we added four multimeters: one to measure V_{in} , I_{in} , V_{out} , and I_{out} and created a computer program to automate the instrument configurations, step load current values, and data collection.

Software

Automating this type of test is a great way to minimize errors as well as speed up the test process.

We put together an example program using Python that performs the following:

- Prompts the user for start, stop, and number of current load steps
- Power Supply settings to deliver proper power to the DUT
- Filename to save the CSV data file

Power Measurements Capabilities

Requirements:

- Qty 1 SIGLENT SPD series power supply
- Qty 1 SIGLENT SDL1000X series DC electronic load
- Qty 4 SIGLENT SDM3000 series digital multimeter
- Qty 1 6 port or more USB hub, USB cables
- Cabling* to connect all instruments and DUT
- Python 3.0 or greater
- tkinter
- PyVISA

*Use the proper gauge wiring and connectors that are rated above the maximum current draw expected to minimize the risk of fire or

overheating. **To run the program:**

- Download Python 3.6, PyVISA, and tkinter (a module that eases Graphical User Interface creation)
- Download the program [SIGLENT PS Efficiency.ZIP](#)
- Connect instruments and DUT. It may be helpful to put a small label on each DMM to make it easier to visually identify their roles.
- Open the program using a Python editor like IDLE
- Edit the USB addresses for each instrument.

Power Measurements Capabilities

Here is a screenshot of the code showing the addresses:

```

PS Efficiency GUI.py - C:\Users\jayre\Documents\Application Notes\Power Supply Efficiency\GUI Version\GUI Version\PS Eff...
File Edit Format Run Options Window Help
UserOutput3_Label.pack()
UserOutput4_Label.pack()

return StepOutput

def StartButtonAction(inboxes, outlabels):

    ConfigDel = 1 #Configuration delay in seconds
    SetupDel = 0.2 #Setup delay in seconds
    MeasDel = 0.01 #Configure mesure delay in seconds

    rm = visa.ResourceManager()
    SPDadd = 'USB0::0xF4EC::0x1410::SPD1XDAD1R0011::INSTR'
    SDLadd = 'USB0::0xF4EC::0x1621::SDL13FBQ3R0152::INSTR'

    SDMVinadd = 'USB0::0xF4EC::0xEE38::SDM35FAC3R0135::INSTR'
    SDMIinadd = 'USB0::0xF4EC::0xEE38::SDM36FAX1R0084::INSTR'

    SDMVoutadd = 'USB0::0xF4EC::0xEE38::SDM35FAC3R0135::INSTR'
    SDMIoutadd = 'USB0::0xF4EC::0xEE38::SDM36FAX1R0083::INSTR'

    SPD = rm.open_resource(SPDadd)
    SDL = rm.open_resource(SDLadd)

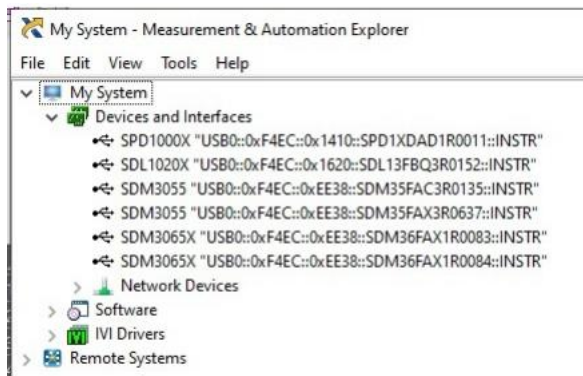
    SDMVin = rm.open_resource(SDMVinadd)
    SDMIin = rm.open_resource(SDMIinadd)

    SDMVout = rm.open_resource(SDMVoutadd)
    SDMIout = rm.open_resource(SDMIoutadd)
    
```

Where:

- SPDadd is the power supply address
- SDLadd is the electronic load address
- SDMVinadd is the address of the DMM measuring the input voltage
- SDMIinadd is the address of the DMM measuring the input current
- SDMVoutadd is the address of the DMM measuring the output voltage
- SDMIoutadd is the address of the DMM measuring the output current

One easy way to establish the USB addresses is to use the National Instruments MAX application. With Max, you can connect the instruments via USB and check all of the addresses:

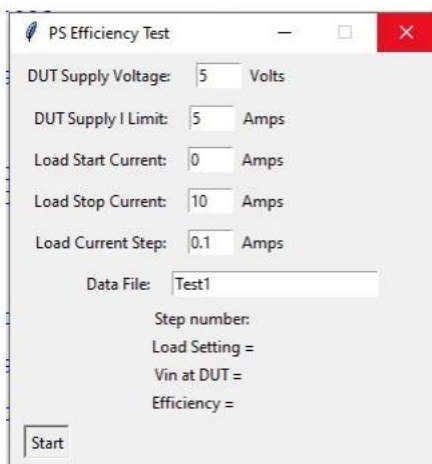


Power Measurements Capabilities

NOTE: The USB resource ID contains the instrument serial number, which can be used to help identify which instrument you are communicating with. As noted above, it may be helpful to put a small label on each instrument including the serial number to make it easier to visually identify each instrument and ensure they are wired correctly for their role in the test.

After wiring everything up, you can run the module.

The first thing you should see is the User Interface (UI) as shown below:



- Enter the proper values for each entry and press Start
- As the process begins, you should see the output indicator on the power supply turn on, the DC Load input light should turn on, and the displayed values for current and voltage should meet your programmed values
- The program prints each step value measurement on the display as shown here:

Power Measurements Capabilities

```

Python 3.6.5 Shell
File Edit Shell Debug Options Window Help
Load: Siglent Technologies,SDL1020X,SDL13FBQ3R0152,1.1.1.19R1
DMM V In: Siglent Technologies,SDM3055,SDM35FAX3R0637,1.01.01.20R2
DMM I In: Siglent Technologies,SDM3065X,SDM36FAX1R0084,3.01.01.07
DMM V Out: Siglent Technologies,SDM3055,SDM35FAC3R0135,1.01.01.20R2
DMM I Out: Siglent Technologies,SDM3065X,SDM36FAX1R0083,3.01.01.07
Total Steps: 101
Start: 0.0
Stop: 10.0
Increment: 0.1
Start-->:SOURCE:CURRENT:LEVEL 0.0
Load: 0.000000
Vin Setting: 5.0
Vin at DUT: +4.84649260E+00
DUT Vin Error: 0.153507399999999963
Adjusted Vin: 5.1535074
SDMVin: +5.00046023E+00
SDMIIn: +1.35293625E-01
Pin: 0.6765303911850338
SDMVoutMeas: +1.49570581E+00
SDMIoutMeas: +7.38562773E-06
Pout: 1.1046726306258111e-05
Pd: 0.67651934444587275
Eff: 0.00%

Step 2 -->:SOURCE:CURRENT:LEVEL 0.1
Load: 0.100000
Vin Setting: 5.1535074
Vin at DUT: +4.96860100E+00
DUT Vin Error: 0.031399000000000004
Adjusted Vin: 5.1849064
SDMVin: +5.00074402E+00
SDMIIn: +1.63302482E-01
Pin: 0.8166339103126576
SDMVoutMeas: +1.49536316E+00
SDMIoutMeas: +9.33043810E-02
Pout: 0.13952393401400395
Pd: 0.6771099762986537
Eff: 17.09%

Step 3 -->:SOURCE:CURRENT:LEVEL 0.2
Load: 0.200000
Vin Setting: 5.1849064
Vin at DUT: +4.96677129E+00
DUT Vin Error: 0.0332287100000000038
Adjusted Vin: 5.21813511
SDMVin: +5.00083737E+00
SDMIIn: +1.93319630E-01
Pin: 0.9667600300585731
SDMVoutMeas: +1.48485282E+00

```

This program uses the auto-ranging measurement function of each instrument, which can add time to each measurement. For proper DC measurements, there needs to be some time delay at each step value to ensure a stable reading. We have programmed sufficient delays for most DUTs, but you may need to tweak delays to meet your specific test needs. Upon completion, the program will indicate that it is complete and write a CSV file to the folder where the Python program is located.

Power Measurements Capabilities

```
*Python 3.6.5 Shell*
File Edit Shell Debug Options Window Help

Step 99 -->:SOURCE:CURRENT:LEVEL 9.8
Load: 9.800000
Vin Setting: 5.3015664199999999
Vin at DUT: +4.99945203E+00
DUT Vin Error: 0.00054797000000003973
Adjusted Vin: 5.3021143899999999
SDMVIn: +5.00010549E+00
SDMIIn: +3.10342924E+00
Pin: 15.51747358075053
SDMVoutMeas: +1.46351300E+00
SDMIoutMeas: +9.10822651E+00
Pout: 13.33000790432963
Pd: 2.1874656764208993
Eff: 85.90%

Step 100 -->:SOURCE:CURRENT:LEVEL 9.9
Load: 9.900000
Vin Setting: 5.3021143899999999
Vin at DUT: +5.00011296E+00
DUT Vin Error: -0.00011296000000000508
Adjusted Vin: 5.3020014299999999
SDMVIn: +5.00005695E+00
SDMIIn: +3.10398565E+00
Pin: 15.520105021982767
SDMVoutMeas: +1.46344890E+00
SDMIoutMeas: +9.10971299E+00
Pout: 13.331599454531212
Pd: 2.1885055674515552
Eff: 85.90%

Step 101 -->:SOURCE:CURRENT:LEVEL 10.0
Load: 10.000000
Vin Setting: 5.3020014299999999
Vin at DUT: +5.00005321E+00
DUT Vin Error: -5.3209999999914714e-05
Adjusted Vin: 5.3019482199999999
SDMVIn: +5.00001587E+00
SDMIIn: +3.10438393E+00
Pin: 15.52196891657297
SDMVoutMeas: +1.46350731E+00
SDMIoutMeas: +9.11028471E+00
Pout: 13.33296826926623
Pd: 2.18900064730674
Eff: 85.90%

Sweep Complete. Data saved in Test1.csv
```

Power Measurements Capabilities

Find the CSV file, copy columns A - I:

A	B	C	D	E	F	G	H	I
Iload	VIn	IIn	Pin	VOut	IOut	POut	Pd	Efficiency
0	5.00E+00	1.34E-01	0.671997	1.20E+00	5.91E-06	7.07E-06	0.67199	0.00%
0.1	5.00E+00	1.57E-01	0.784052	1.20E+00	9.33E-02	0.111594	0.672458	14.23%
0.2	5.00E+00	1.81E-01	0.904555	1.20E+00	1.94E-01	0.231516	0.673039	25.59%
0.3	5.00E+00	2.05E-01	1.026208	1.20E+00	2.94E-01	0.351182	0.675026	34.22%
0.4	5.00E+00	2.29E-01	1.147281	1.20E+00	3.94E-01	0.471095	0.676186	41.06%
0.5	5.00E+00	2.54E-01	1.268324	1.20E+00	4.94E-01	0.590596	0.677729	46.57%
0.6	5.00E+00	2.78E-01	1.389602	1.20E+00	5.94E-01	0.710075	0.679527	51.10%
0.7	5.00E+00	3.02E-01	1.511199	1.20E+00	6.94E-01	0.829753	0.681445	54.91%
0.8	5.00E+00	3.27E-01	1.633044	1.20E+00	7.94E-01	0.949343	0.683701	58.13%
0.9	5.00E+00	3.51E-01	1.755042	1.19E+00	8.94E-01	1.068669	0.686373	60.89%
1	5.00E+00	3.75E-01	1.877324	1.19E+00	9.95E-01	1.188238	0.689087	63.29%
1.1	5.00E+00	4.00E-01	2.000184	1.19E+00	1.09E+00	1.30772	0.692464	65.38%
1.2	5.00E+00	4.25E-01	2.122919	1.19E+00	1.19E+00	1.427102	0.695818	67.22%
1.3	5.00E+00	4.49E-01	2.245653	1.19E+00	1.29E+00	1.546399	0.699253	68.86%
1.4	5.00E+00	4.74E-01	2.36933	1.19E+00	1.40E+00	1.665803	0.703527	70.31%
1.5	5.00E+00	4.99E-01	2.49273	1.19E+00	1.50E+00	1.785083	0.707647	71.61%
1.6	5.00E+00	5.23E-01	2.616812	1.19E+00	1.60E+00	1.904417	0.712395	72.78%
1.7	5.00E+00	5.48E-01	2.741666	1.19E+00	1.70E+00	2.023564	0.718101	73.81%
1.8	5.00E+00	5.73E-01	2.866866	1.19E+00	1.80E+00	2.142845	0.724021	74.75%
1.9	5.00E+00	5.98E-01	2.992312	1.19E+00	1.90E+00	2.261874	0.730438	75.59%
2	5.00E+00	6.24E-01	3.118952	1.19E+00	2.00E+00	2.381115	0.737837	76.34%
2.1	5.00E+00	6.49E-01	3.245237	1.19E+00	2.10E+00	2.500116	0.745121	77.04%
2.2	5.00E+00	6.74E-01	3.37153	1.19E+00	2.20E+00	2.618698	0.752832	77.67%

Open a copy of the file Efficiency Template.xls included in the program folder, and paste the results to plot the curve:

