Keysight Technologies
Power Supply Control Loop Response (Bode Plot) Measurements

Using Keysight InfiniiVision X-Series Oscilloscopes

Application Note

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights

Introduction

The primary measurement tool used to test and characterize power supplies is an oscilloscope. Many of today's scopes, including Keysight's InfiniiVision X-Series, offer special power measurement options that can help automate many of the most important measurements. Figure 1 shows a list of the power supply characterization measurements that are available on Keysight's InfiniiVision 3000T, 4000, and 6000 X-Series oscilloscopes with the power measurements option (DSOX3PWR, DSOX4PWR, DSOX6PWR). Unique to Keysight's portfolio of measurements are frequency response measurements including Control Loop Response (Bode) and Power Supply Rejection Ratio (PSRR). These particular stimulus-response type measurements are typically performed using low-frequency network analyzers. But since Keysight's InfiniiVision X-Series oscilloscopes come with a built-in function/arbitrary waveform generator, they can also be performed using these scopes.

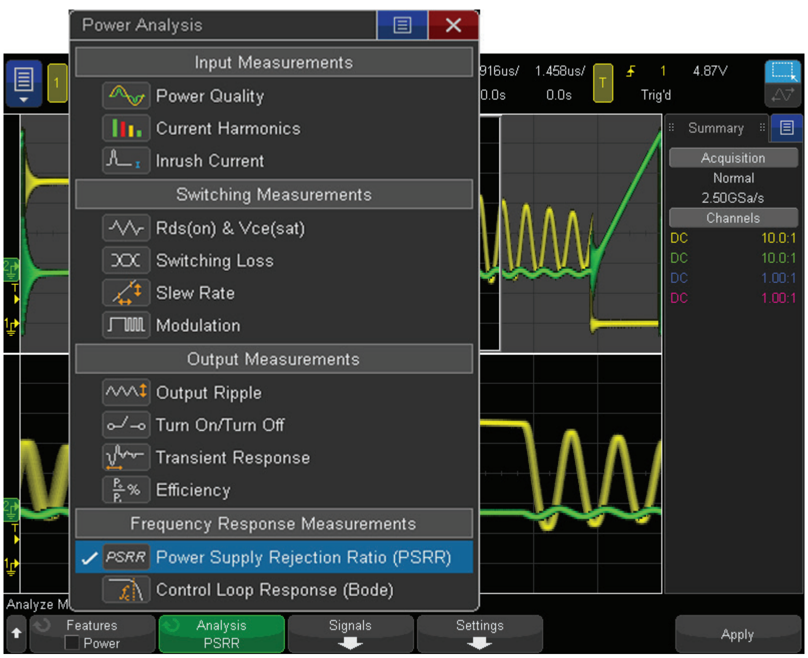

Figure 1: Power supply characterization measurements available in Keysight's InfiniiVision X-Series oscilloscopes.

Control Loop Response (Bode)

A power supply is actually an amplifier with a negative feedback control loop as shown in Figure 2. This means that although you may think of a power supply as a DC amplifier, it actually amplifies AC to react to changes in output conditions, such as load changes.

Performing a Control Loop Response test requires that you inject an error signal over a band of frequencies into the feedback path of the control loop. The resistive-divider network of R1 and R2 is the feedback path in this diagram. To inject an error signal, a small resistor must be inserted into the feedback loop. The 5-Ω injection resistor shown in this schematic is insignificant in comparison to the series impedance of R1 and R2. So you might consider designing in this low-value injection resistor (Rinj) permanently for test purposes. An injection transformer, such as Picotest's J2101A, is also required so that the AC disturbance signal is isolated and doesn't induce any DC bias.

The measurement system, in this case an InfiniiVision X-Series oscilloscope with its built-in WaveGen function/AWG generator, measures AC voltage levels at the top of the feedback network (Vin) as well as at the regulated DC output (Vout) of the power supply. The scope then computes gain as 20Log(Vout/Vin) at each frequency within the swept band. Also measured at the same time is the phase difference between Vin and Vout.

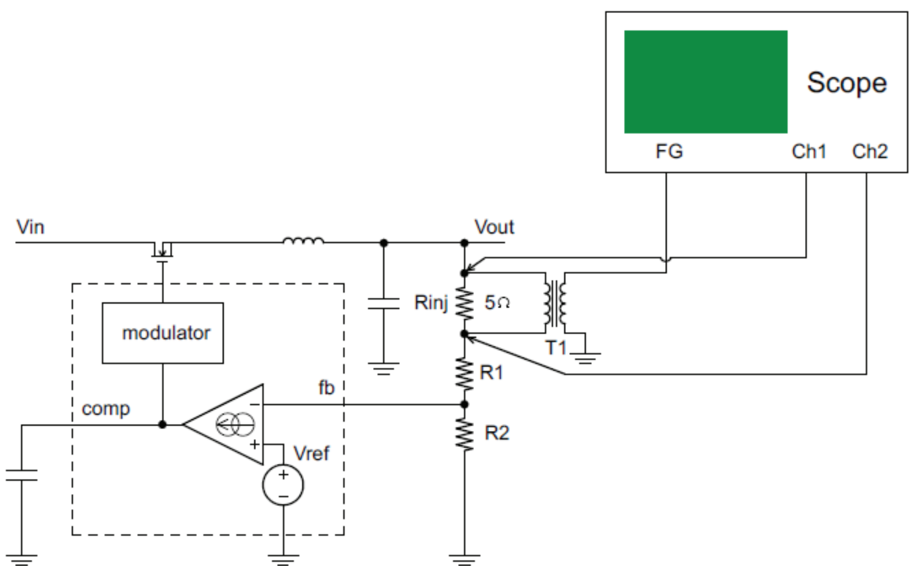

Figure 2: Power supply closed loop feedback network and oscilloscope connections for a Control Loop Response test.

Probing the Input and Output

Good probing techniques are required for a Control Loop Response measurement. Peak-to-peak amplitudes of both Vin and Vout can be really low (sub millivolts at some test frequencies). This means that 1:1 passive probes must be used for both input channels of the scope. In addition, properly grounding the probes is critical. If you use the standard ground lead that comes with your 1:1 passive probes, they will act as an antenna and pick up a significant amount of noise in the air and thereby reduce the dynamic range of your measurement. A short spring clip ground adapter (usually shipped as an accessory with the probe and shown in the inset image of Figure 3), or better yet, a soldered-in probe socket will provide the best low-noise signal fidelity.

Figure 3 shows a photo of actual test set up of a Control Loop Response measurement on a Picotest 3.3V linear regulator evaluation board using a Picotest J2101A injection transformer. Note the probe sockets used on the both the input and output probing points for solid ground connections (no antennas!).

Figure 3: Probing the DC-to-DC converter using two channels of the oscilloscope.

Performing the Control Loop Response Measurement

After making all connections to the DUT, first select the *Control Loop Response* measurement in the *Power Analysis* menu. In the *Signals* sub-menu, define which channels of the scope are probing the input and output. For example, Input = channel-1 and Output = channel-2. Next, select the *Settings* sub-menu and define the test parameters including *Start Frequency*, *Stop Frequency*, and *WaveGen* amplitude. Although a higher input disturbance signal amplitude can provide a higher dynamic range measurement, if the amplitude is set too high non-linear distortions can occur. In the Settings menu you can also define the maximum and minimum plot ratios in dB.

To begin the Control Loop Response measurement, simply touch *Apply*. During this one-sweep test, the scope triggers internally on the WaveGen signal for a very stable trigger. At each test frequency, the scope automatically optimizes vertical scaling of the input and output waveforms and takes eight averages at each frequency in order to eliminate random noise and provide maximum dynamic range. The measured amplitudes of both the input and output signals will often be sub-millivolt and buried in the scope's noise floor. As the test proceeds, the scope plots gain (in dB) across scope's display.

Figure 4 shows the results of a Control Loop Response gain plot using an InfiniiVision X-Series oscilloscope. This test was performed using a swept frequency from 100 Hz up to 10 MHz. The amplitude of the input disturbance signal was set at 130 mVpp, but the amplitude of this input signal was reduced by the low input impedance of the injection transformer to approximately 13 mVpp across the 5-Ω injection resistor. At the completion of the swept measurement, the 0 dB cross-over point was measured at approximately 6.6 kHz.

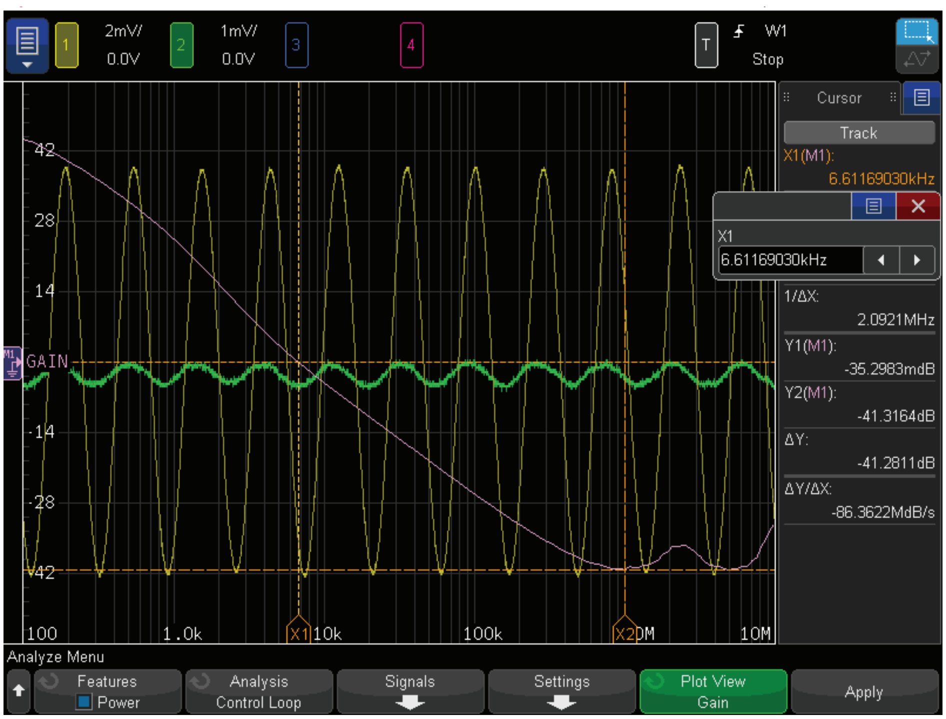

Figure 4: Control Loop Response gain measurement using an InfiniiVision X-Series oscilloscope.

After the completion of the gain measurement, the phase plot can be viewed as shown in Figure 5. But as you can see in this measurement, phase has only been plotted from approximately 800 Hz up to 100 kHz. In order to measure phase, the amplitude of both Vin and Vout must be approximately 1 mVpp or greater. With the cursor placed at the 6.61 kHz, 0 dB cross-over frequency, the scope measures a phase margin of approximately 56 degrees. Due to the low level input of this measurement, it was not possible to measure gain margin.

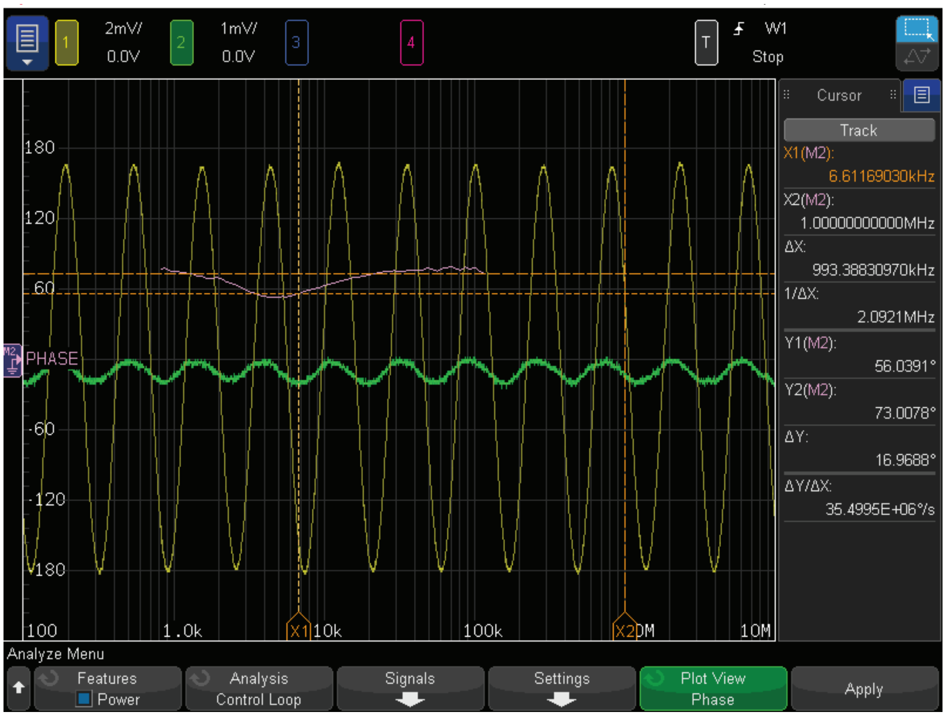

Figure 5: Measuring the phase margin at the 0 dB cross-over frequency.

Summary

Oscilloscopes are the primary measurement tools used today by engineers to test and characterize their power supply designs. But most scopes have significant limitations when it comes to performing frequency response measurements such as Control Loop Response. Keysight's InfiniiVision X-Series oscilloscopes are the first scopes on the market that can perform a Control Loop Response measurement automatically. Although the dynamic range and accuracy is certainly not as good as using a low-frequency network analyzer, it is often good enough. Side-by-side testing with a Keysight network analyzer shows that the gain and phase measurements of the InfiniiVision X-Series oscilloscope track very closely when characterizing linear power supplies with low-noise DC outputs.

System Requirements

A Control Loop Response test on a Keysight InfiniiVision 3000T, 4000, 6000 X-Series oscilloscope requires that the scope be licensed with the power measurements option (DSOX3PWR, DSOX4PWR, DSOX6PWR). The WaveGen option is not required. The scope will automatically turn on the WaveGen for the one-time Control Loop Response measurement. Two 1:1 passive probes, such as the N2870A, are recommended for probing the low-level input and output signals. Coupling and isolating the input disturbance signal from the scope's WaveGen output into the power supply's feedback network requires an isolation transform such as Picotest's J2101A Injection Transformer. For more information about this product, contact Picotest at **www.picotest.com**.

In addition to the above listed minimum system requirements, your 3000T or 4000 X-Series oscilloscope must be running on firmware version 4.06 or greater, and your 6000 X-Series oscilloscope must be running on firmware version 6.10 or greater.

Related Literature

Publication Title	Publication Type	Publication Number
InfiniiVision 3000T X-Series Oscilloscopes	Data sheet	5992-0140EN
InfiniiVision 4000 X-Series Oscilloscopes	Data sheet	5990-1103EN
InfiniiVision 6000 X-Series Oscilloscopes	Data sheet	5991-4087EN
InfiniiVision X-Series Power Measurements Options	Data sheet	5990-8869EN
InfiniiVision Oscilloscope Probes & Accessories	Data sheet	5968-8153EN
Power Supply Rejection Ratio (PSRR) using Keysight InfiniiVision X-Series Oscilloscopes	Application note	5992-0594EN
Switch Mode Power Supply Measurements	Application note	5991-1117EN
Making Your Best Power Integrity Measurements	Application note	5992-0493EN
Tips and Techniques for Making Power Supply Noise Measurements with an Oscilloscope	Application note	5989-6755EN
Evaluating Oscilloscope for Low-power Measurements	Application note	5991-4268EN
New Probing Technology Enables High Sensitivity, Wide Dynamic Range Current Measurement	Application note	5991-1951EN

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