Application Note

High Quality Low-Dropout Regulator Measurement Techniques

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ABSTRACT

This application note details the best practices for capturing quality measurements of Low Dropout (LDO) regulators. This document highlights measurements including line and load transients as well as additional information regarding proper oscilloscope setup.

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1 Introduction

The *Low Dropout (LDO) regulator* regulates a higher input voltage to a lower output voltage, similar to a switching regulator. Unlike the switching regulator, an LDO works as a noise filter device and shows to be much simpler to implement in modern designs. To learn more about how an LDO operates, refer to the *Learn the Basics of Linear and Low Drop-Out Regulators (LDOs) video*. With the increasing demand for low-noise parts in high-frequency power system applications, the LDO plays a significant role in meeting demand. The result of fulfilling this role means that more basic measurements are taken for debug purposes, and understanding how to make proper high-quality measurements becomes increasingly important. Taking measurements can be a challenging task, pay close attention to hardware setup and device configuration before taking a measurement. Typical measurements include, but are not limited to, load transients, line transients, short-circuit tests, and brownouts.

1.1 Oscilloscope Basics

While taking an oscilloscope measurement, remember these key fundamentals:

1. Turn the oscilloscope on, which can take a significant amount of time. For example, some oscilloscopes can take 30 minutes or more to reach specified accuracy.
2. Before taking a measurement, understand the measurement being attempted. What are the conditions and what channels are being used?
   a. Identify the conditions to measure, such as V_{IN}, V_{OUT}, loading, and so forth.
   b. Add labels to the channels on the oscilloscope to help with simple identification of each channel. Users are most likely showing the waveforms collected to other users, and making a habit out of labeling the waveforms on each channel helps others understand the information.
3. Connect the LDO terminals to each oscilloscope channel as desired. Setting the channels to high impedance termination mode (1MΩ) is a good starting point - unless the signal to be measured is also terminated with a 50 ohm termination, high impedance mode is appropriate. Determine whether AC coupling or DC coupling is appropriate for each channel - is the signal to be measured a 10mV AC signal superimposed on a 10V DC signal? If so, the 10mV signal can be difficult to view with DC coupling, and AC coupling is appropriate in this case. Choose probes that are matched to the oscilloscope's bandwidth for transient measurements. Verify that each oscilloscope channel shows the correct voltage and current levels in accordance to what levels are being set with the LDO.
   a. Choosing an oscilloscope probe for a measurement can be a difficult task, so, when choosing an oscilloscope probe, choose the correct probe for the correct measurement. Refer to Choosing an Oscilloscope Probe for additional information on choosing an oscilloscope probe.
   b. Be cautious when connecting a probe with long wires. Long return paths from the probe tip back and through the ground clip back to the probe can pick up additional noise, which affects measurement readings. Refer to *Implications of Parasitics* to learn more about the affects of parasitics in a circuit.
4. Once the oscilloscope is turned on, the previously configured oscilloscope conditions for the horizontal system time scale and the vertical system voltage scale show on the screen. Adjust the horizontal time scale (seconds/div) to zoom in or zoom out on the time scale.
   a. Adjusting the horizontal time scale zooms in or zooms out of a waveform, which helps to show the full waveform around the desired signal activity. For example, if users are measuring the impulse response of a control loop that has approximately 100kHz bandwidth, then setting the time scale to 10µs/div is a good starting point. For an example of incorrect oscilloscope scaling, refer to *Visualization*.
   b. Consulting the oscilloscope's user guide can help make setup adjustments to align with the measurement.
5. Determine the signal that makes the most sense to trigger the oscilloscope capture. For LDOs, it's often the case that the signal that triggers the transient behavior of interest is the rising or falling edge of the enable (EN) signal, or perhaps a change in the load current. When the triggering signal has been determined, go to the trigger settings in the oscilloscope and select the channel corresponding to the trigger signal. Then, set the trigger to detect the edge of the signal (this can be a rising or falling edge, depending on the test being

performed) at a voltage or current level that is roughly halfway between the minimum and maximum values. For example, if the EN signal rises from 0V to 2V, set the trigger to detect the rising edge on the channel corresponding to the EN waveform when the voltage crosses 1V.

6. Once the oscilloscope is configured and triggered, is the desired measurement reached?
   a. If the desired measurement was not reached, then continue to adjust the vertical and horizontal scale, configure the Volts/div and the offset of each channel.
      i. Additionally, check for signal path compensation. If DC measurement accuracy is required, then running a self calibration is recommended. Oscilloscope manufacturers have recommendations for how often to perform a self calibration.
   b. Users can get more use of the screen space by implementing a horizontal delay (shifting the waveforms to the left, for example) instead of the triggering event capturing in the middle of the screen.
7. Refer to the oscilloscope user's guide for examples of taking a proper measurement.
   a. Additional resources are also available on the oscilloscope manufacturer's website. For example, if using a Teledyne Lecroy oscilloscope, refer to *Hands-On Guide to LeCroy Color Digital Oscilloscopes*.

Note

All channels in a modern oscilloscope share a common ground. Special attention is needed to avoid short circuits through the oscilloscope probe ground.

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2 Implications of Parasitics

When designing a circuit we often overlook parasitics, but in reality parasitics are always present and cause deviations from expected behavior, which can alter data collection. What happens when these unexpected effects occur? When designing a printed circuit board (PCB), the designer must keep in mind that all traces are slightly resistive, capacitive, and inductive. These effects are otherwise known as parasitics. Especially in high frequency measurements, designing with parasitics is incredibly important to verify the LDO works as expected. Resistive parasitics can cause gain errors, create DC voltage errors, and create mismatches at the inputs of the gain amplifier that is present in an LDO. Capacitive and inductive parasitics can cause unwanted noise and signal coupling to occur. Capacitive parasitics can also cause instability to occur in the circuit. Inductive parasitics can increase the return loop inductance and can create LC resonances that cause oscillations during transients.

For LDOs, noise coupling and instability is especially important when taking high frequency measurements. With parasitics present in a circuit, additional ringing, oscillation, and unwanted noise coupling through a ground plane of power supply can be present in high frequency measurements. Examples of where parasitics can be present in a circuit are:

1. Microstrip Copper Traces:
   a. Microstrip copper traces are transmission lines referenced to copper plane typically used for high frequency signals.
2. Parallel Copper Planes
   a. Parallel copper planes are large sections of copper in the PCB intended for power signals, which are meant to carry hundreds of miliamps to amps. Parallel copper planes are used as a low-impedance access to power or ground, but often create capacitive parasitics.
3. Vias
   a. Vias connect signals between different layers on a PCB, but often create capacitive and inductive parasitics.
4. Adjacent Copper Traces
   a. Adjacent copper traces allow for routing to related groups of signals around a PCB, but often creates capacitive and inductive parasitics and allows for coupling of signal between traces, otherwise known as cross talk. The closer the traces are to one another, the stronger the coupling.

Before taking a measurement, we highly recommend controlling inductive and capacitive parasitics. To control inductive and capacitive parasitics, cut out copper planes and traces under sensitive test nodes, and minimize the use of vias on critical signal traces. If vias cannot be avoided in a power trace, the use of multiple vias helps to reduce the parasitic effect. Additionally, use short, direct signal routing to minimize unwanted noise coupling, and place ground copper between adjacent traces to minimize cross talk, which is especially important when designing with dual input or dual output LDOs. To reduce inductance, the return path for high-frequency transient currents needs to be parallel to the current carrying trace, but this can add parasitic capacitance to the circuit. Finally, we recommend reducing cabling attached to the device under test (DUT).

3 Common Oscilloscope Issues

Oscilloscope set-up has significant influence on measurement accuracy, here are a few common measurement issues to be aware of.

3.1 Choosing an Oscilloscope Probe

Before taking a measurement, choose the correct type of oscilloscope probe for the measurement being taken. The true bandwidth of the oscilloscope and the probes must be at least the bandwidth of the signal to be measured to avoid distortions in the measurement. Since most oscilloscopes and probes are not specified as true bandwidth but as -3dB bandwidth, using an oscilloscope and probes with at least 10 times the bandwidth of the signal to be measured makes sure that the signal is not distorted. For example, a signal that rises linearly in 10ns has a bandwidth of 0.35/10ns = 35MHz (Bogatin), and so setting the oscilloscope to 350MHz or greater and using probes with bandwidth 350MHz or greater is sufficient.

When choosing oscilloscope probes, remember that probes are also susceptible to parasitics. Long probe cabling can give an inflated drop is transient tests. Capacitive 10X probes can add additional noise to the LDO's output signal. Additionally, introducing long ground loops while using a 10X probe can add unwanted noise to a measurement. 10X probes also effectively increase the signal to noise ratio because the probes divide the signal down by a factor of 10 and then the oscilloscope digitally gains the signal back up by a factor of 10. For this reason, when measuring small signals, sometimes using a 1X probe is appropriate. When using a 1X probe, remember that the voltage going into the oscilloscope channel is not divided down, so care must be taken to avoid exceeding the voltage rating of the oscilloscope channel.

In this section, two oscilloscope probes, a SMA probe and a probe with a ground clip are evaluated, while taking a load transient measurement.

Figure 3-1 shows a load transient measurement using a probe with a standard Alligator ground clip. Figure 3-2 shows the setup for a standard Alligator ground clip, where there are not convenient test points on which the probe tip and ground clip can be connected. The available banana connectors are used to run out wires to the probe. Figure 3-1 shows that while using a standard Alligator clip, the measurement looks visually very noisy, and users can conclude that the device appears to be much more noisy than the data sheet specifies.

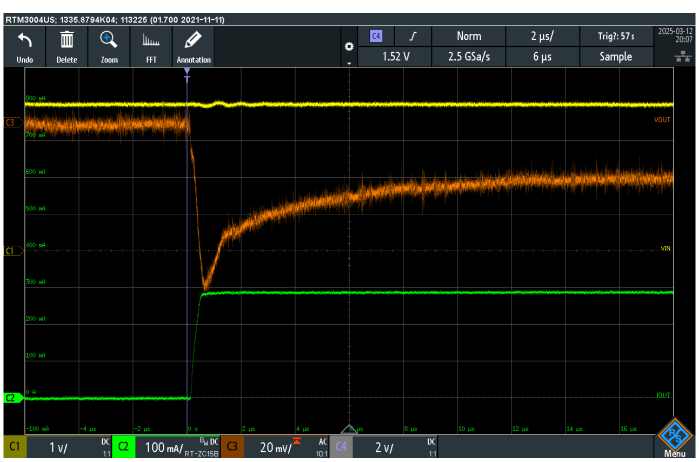

Figure 3-1. TLV773 Load Transient with Alligator Ground Clip Connection

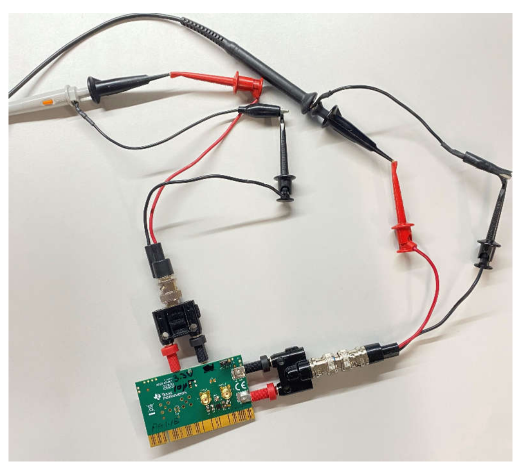

Figure 3-2. Probes with Alligator Ground Clip Setup on TLV773

Figure 3-3 shows a load transient while using a ground spring attachment for the oscilloscope probe. Figure 3-4 shows how to use the ground spring connector that comes with every oscilloscope probe. If there are no SMA connectors on the board, using this ground spring connector is the best way to get the shortest ground return path using a standard oscilloscope probe, and results in the least amount of noise coupling into the measurement. Figure 3-3 shows a much less noisy measurement using the ground spring connector.

Figure 3-3. TLV773 Load Transient with Ground Spring Connection

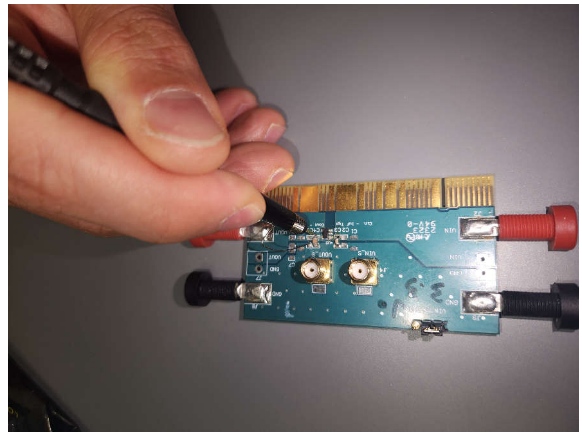

Figure 3-4. Probe with Ground Spring Setup on TLV773

Figure 3-5 shows a load transient with a SMA connector, and Figure 3-6 shows the setup for using an SMA connector. Figure 3-5 shows the least noisy measurement. SMA connectors are shielded which reduces noise coupled onto the cable, and the ground return loop is also minimized. The result is a very low-noise measurement. Whenever possible, TI recommends using SMA connectors for the lowest noise measurement capabilities. Many of TI's modern LDO EVMs employ SMA connectors for measuring critical nodes, such as the input and output voltages near the device pins.

Figure 3-5. TLV773 Load Transient with SMA Connection

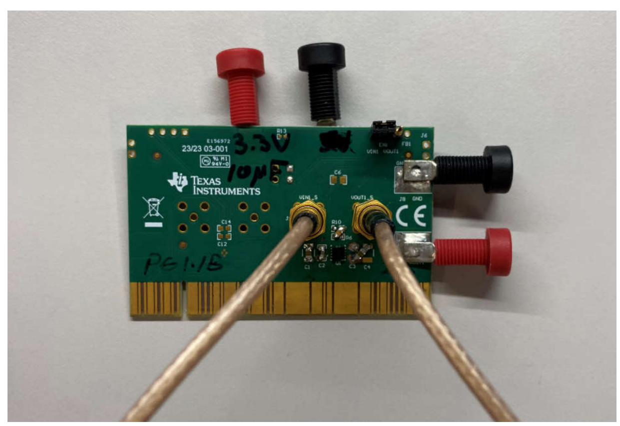

Figure 3-6. SMA Setup on TLV773

3.2 Sufficient Sampling

When taking measurements on the oscilloscope, sufficient sampling must be present for peak transients. When insufficient sampling is present while taking a waveform measurement, aliasing can occur in the measurement, which can cause inconsistent data collection. Aliasing can affect the trigger and can shift the waveform position horizontally. To learn more about aliasing please see *Teledyne Lecroy Oscilloscope Basics: Sampling Rate*. Insufficient sampling can show false peaks when conducting transients, which can give incorrect measurement data. Insufficient sampling can also cause a lack of information to appear for data collected at the peaks of certain signals, as shown in Figure 3-7.

When sufficient sampling is not present in a waveform, each channel is more difficult to visualize. Comparing the following images, Figure 3-7 with 500 samples and Figure 3-8 with 50k samples, Figure 3-7 with 500 samples is significantly more difficult to visualize each channel.

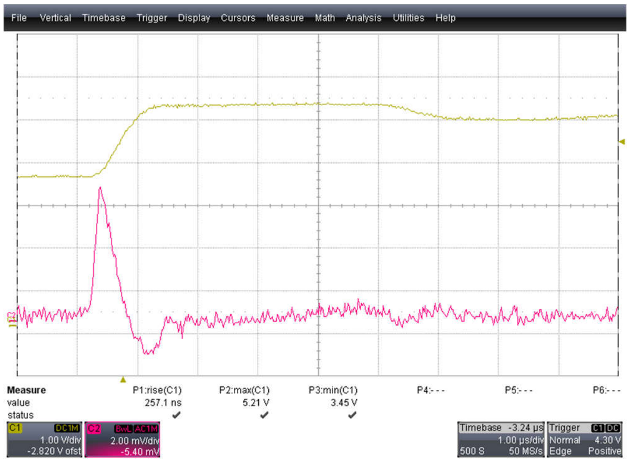

Figure 3-7. 500 Samples

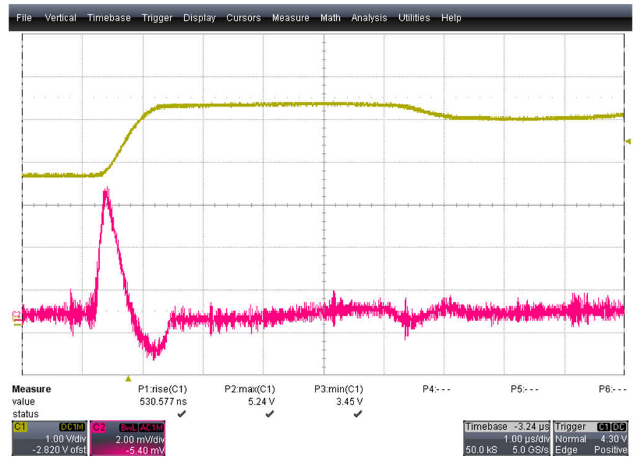

Figure 3-8. 50k Samples

Note

Not each oscilloscope is the same! There are oscilloscopes where the effective bandwidth and/or sampling is divided across channels, and can decrease when using more channels.

3.3 Visualization

Oscilloscopes have the capability to zoom between several orders of magnitude, from 1s/div down to 500ps/div, or even smaller in high-performance oscilloscopes. This makes choosing an appropriate time scale important to effectively visualize the waveforms captured. When a waveform is not in visual focus, there can be difficulty distinguishing data at the rising and falling edges. When a waveform is illegible, the details of the electrical behavior can be lost. Taking a measurement with improper visualization can lead to concerns when debugging a measurement for future development. Figure 3-9 shows a load transient measurement which is displayed on a time scale that is too zoomed out for the measurement to be legible. Figure 3-10 shows a load transient measurement with a corrected timebase to account for distinguishing data on the rising edge. Figure 3-10 is an acceptable image for visualization.

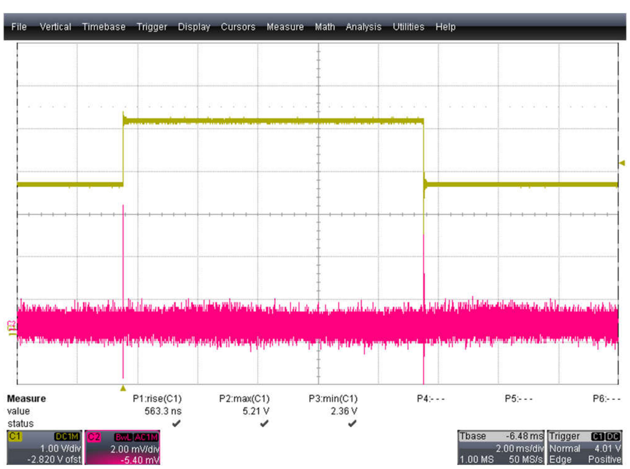

Figure 3-9. Poor Visualization

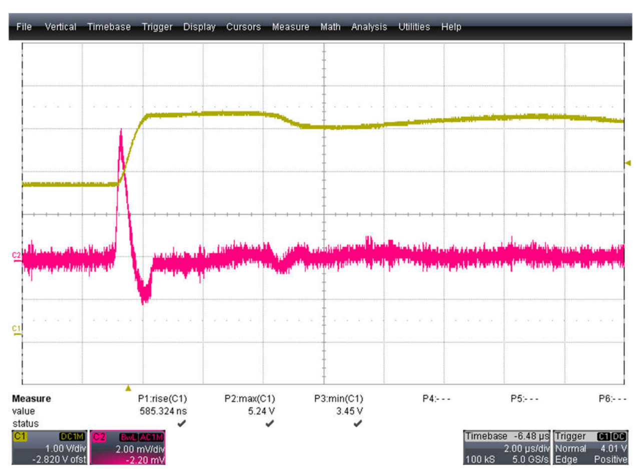

Figure 3-10. Focus on the Rising Edge

3.4 Measuring Currents Using Current Probes

Another common measurement for LDOs is to measure the input and output current using a current probe. Measuring current can be difficult to do with a current probe because the current probe requires that the current path is run through the probe. To accomplish this, sometimes a wire needs to be run out to create a loop around which the current probe can be connected, which introduces parasitic inductance. Any amount of parasitic inductance affects the shape of transient waveforms, and enough parasitic inductance can cause large resonant voltage spikes that distort the real behavior of the device. Load transient measurements were taken using the TPS793 device with a current probe which displays the output current on Channel 4 (green) in Figure 3-11. This load transient was collected with long cabling, which introduces significant parasitics. The additional parasitic inductance caused large resonant voltage spikes on the output of the device. Figure 3-12 shows a load transient measurement that includes significantly less cabling and minimal inductance, which leads to more accurate measurement data. Figure 3-12 shows the true device response to the load step, while Figure 3-11 does not.

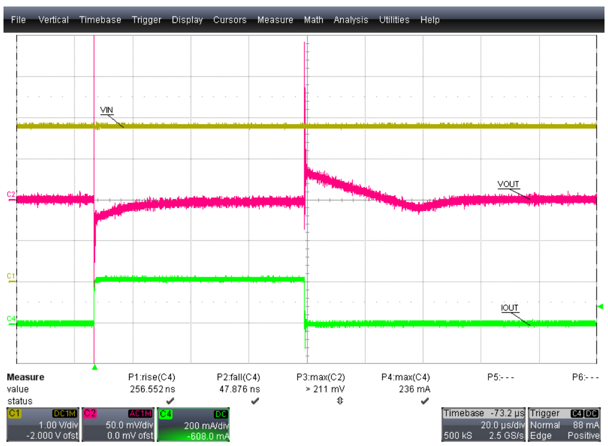

Figure 3-11. Current Probe Measurement with Long Cabling

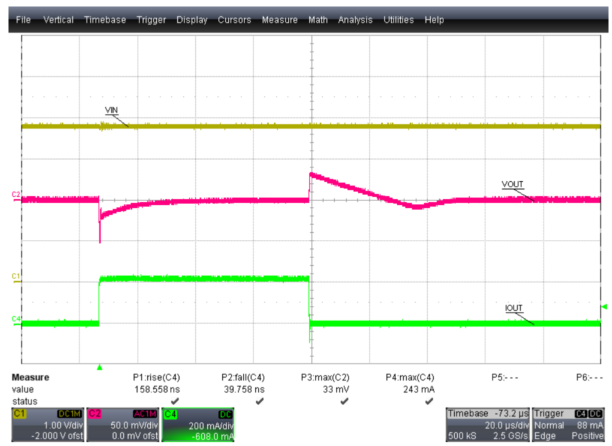

Figure 3-12. Current Probe Measurement with Shortened Cabling

3.5 Bandwidth Limiting and Averaging

Bandwidth limiting and averaging can be useful tools to reduce the amount of noise in a measurement, but must be used with caution. Both of these tools have advantages if used appropriately, but can give false impressions if used without consideration of the measurement being taken.

Although bandwidth limiting significantly reduces high-frequency noise present in a waveform, bandwidth limiting can also attenuate or filter components of the waveform that are important to see for debug, such as overshoot and undershoot. This can lead to inaccurate measurement readings, as seen in Figure 3-13 and Figure 3-14. If there are no expected high-frequency components in the intended measurement, bandwidth limiting can be used to get a clearer picture of the electrical behavior of the circuit with less noise, but in some cases there are unexpected high-frequency signals due to noise coupling or resonances from underdamped filters or parasitics. We recommend starting with full bandwidth and only limit the bandwidth after some confidence has been developed that the measurement does not have important high-frequency components.

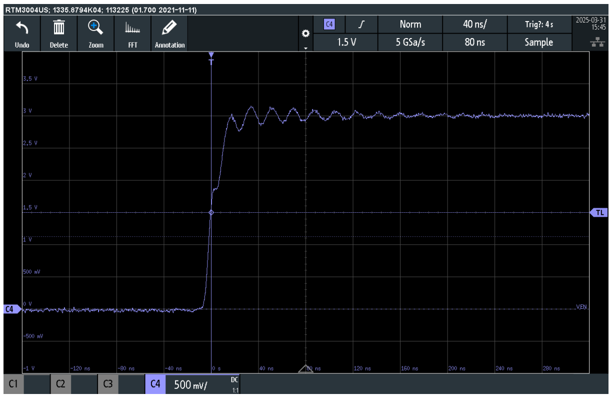

Figure 3-13. Full Bandwidth (500MHz) Rising Edge Signal

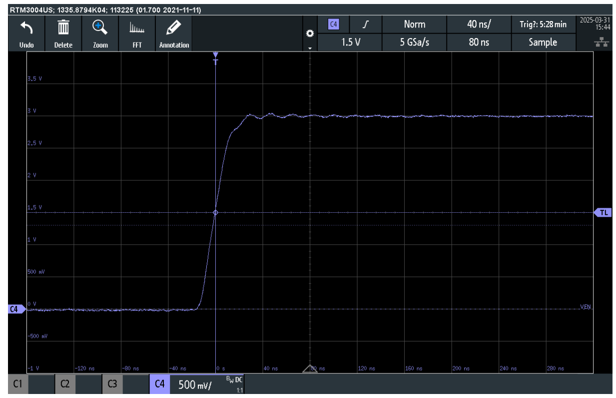

Figure 3-14. Bandwidth Limited (20MHz) Rising Edge Signal

Averaging can be a useful tool when there is no easy way to reduce noise through long measurement wires. This method requires that the waveform to be measured is consistent between measurements. Figure 3-16 shows how the noise in the measurement shown in Figure 3-15 is reduced by averaging 5 samples on the load transient shown on Channel 3.

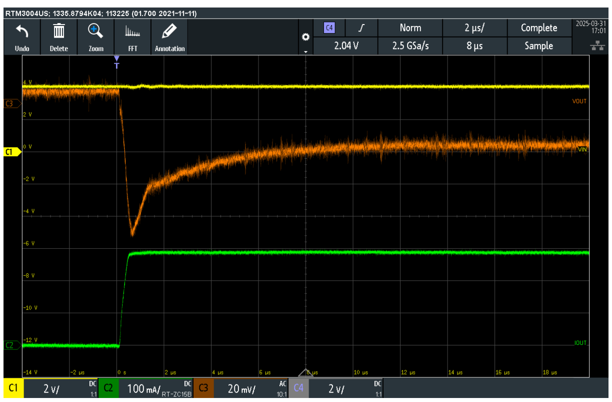

Figure 3-15. Load Transient with No Averaging

Figure 3-16. Load Transient with 5 Sample Average

4 Parasitic Effects on Common Measurements

4.1 Load Transients

A load transient is a sudden change in the load current, and an LDO response to a load transient is an important characteristic of the LDO. Load transient response is influenced by the LDO internal compensation, the dynamic bandwidth of the internal error amplifier, and by both output capacitance and parasitics. A poor load transient response (excessive undershoot, overshoot, or ringing) can impact the operation of components to which the LDO provides power. For additional information on load transients, refer to Understanding the Load-Transient Response of LDOs analog design journal.

In the following section, two load transient setup conditions are described. Conditions were tested using the device TPS7A57, which is a high speed LDO. With a high speed LDO, additional circuit inductance becomes apparent in a transient measurement. One condition has significant trace parasitics due to long cabling, while the other condition has limited trace parasitics and a closer connection to the DUT.

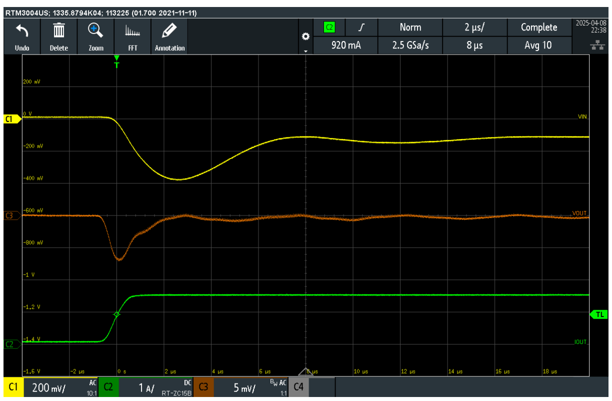

Figure 4-1. TPS7A57 Load Transient with Additional Parasitics at the Input and Output

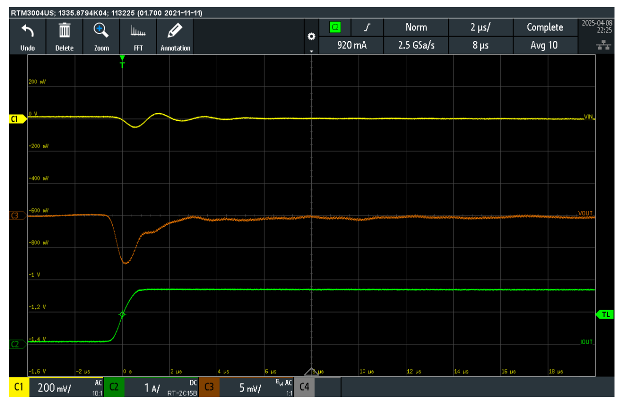

Figure 4-2. TPS7A57 Load Transient with Minimum Parasitics at the Input and Output

4.2 Power Supply Rejection Ratio

Power Supply Rejection Ratio (PSRR) for LDOs is a measure of how well a small-signal ripple on the input is attenuated at the output. To learn more about PSRR and how to take a PSRR measurement, please see *LDO PSRR Measurement Simplified*.

In the following section, we review two PSRR measurement setup conditions taken with the TPS793 device, shown throughFigure 4-3. Condition one, shown with the red trace, shows a PSRR measurement taken with significantly longer cabling, while condition two, shown with the green trace, shows a PSRR measurement taken with significantly shorter cabling. When parasitics are introduced in a PSRR measurement, as shown with red trace, the PSRR measurement data collected at higher frequencies seems to be lower. At higher frequency measurements, especially for PSRR, the output capacitor characteristics significantly affects the measurement. With more parasitics tied to the output capacitor, the data collected at high frequencies shows the capacitor characteristics with those parasitics introduced.

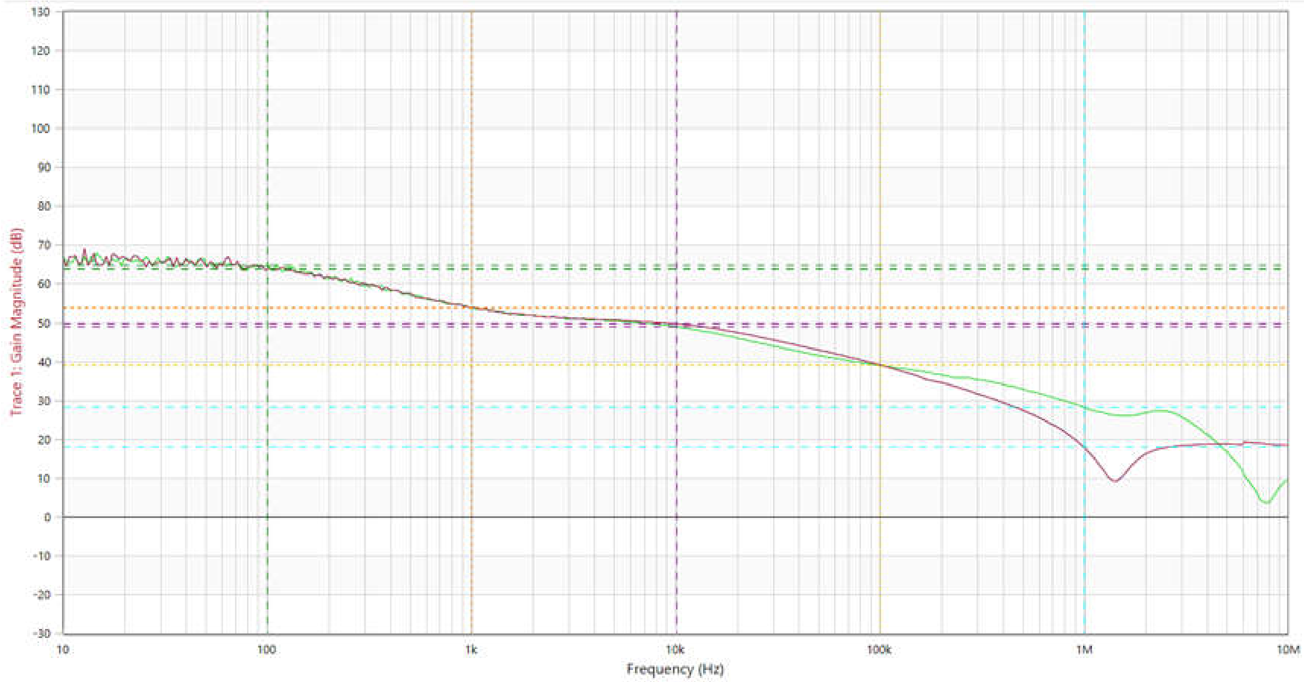

Figure 4-3. TPS793 PSRR with Additional Parasitics

4.3 Output Noise Voltage

Output noise voltage is the RMS output noise voltage over a given range of frequencies, typically 10HZ to 100kHz. Noise is measured under the conditions with constant output current and a ripple-free input voltage. To learn more about output noise voltage and how to take an LDO noise measurement, please see *How to Measure LDO Noise*.

The following sections reviews two noise measurement setup conditions. Conditions were tested on the TPS793 device. Figure 4-4 shows a noise measurement taken with significantly longer cabling, while Figure 4-5 shows a noise measurement taken with significantly shorter cabling. When more cabling is introduced in a noise measurement as seen with Figure 4-4, parasitics are introduced, which means more noise is present in the measurement, which corresponds to the resulting data collection. With parasitics the noise collected in Figure 4-4 was found to be 69.9uVrms, while Figure 4-5, which has minimal parasitics shows data to be 68.9uVrms. Although for this specific application, the noise did not seems to change significantly, only 1uVrms, but with lower noise applications 1uVrms can have a significant impact on how the device can perform.

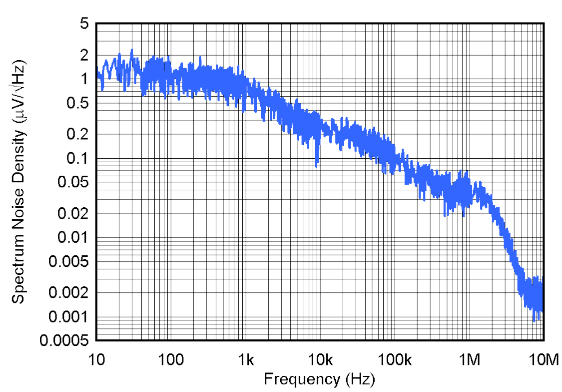

Figure 4-4. TPS793 Output Voltage Noise with Additional Parasitics

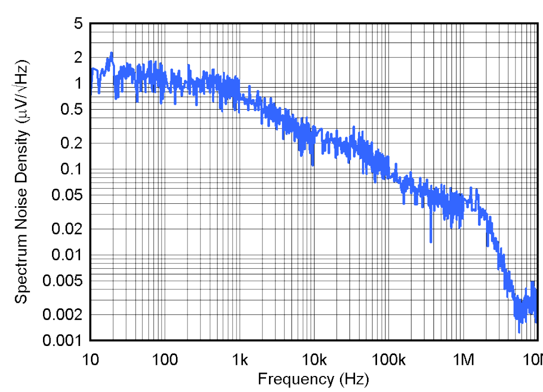

Figure 4-5. TPSS793 Output Voltage Noise with Parasitic Limiting

5 Summary

Measurement setup is important when verifying LDO device specification accuracy. Before taking a measurement, be aware of certain measurement conditions which can give inaccurate or distorted measurement data. Be sure to use sufficient sampling to avoid aliasing and poor visualization. Limit circuit inductance with shortened cabling to reduce resonant ringing. Finally, make sure that the oscilloscope is properly adjusted to best display the measurements by adjusting the horizontal and vertical scales appropriately. Please verify measurement setup before taking a measurement on an LDO device.

6 References

- Teledyne LeCroy, *Oscilloscope Basics: Sampling Rate*.
- Texas Instruments, *Understanding the Load-Transient Response of LDOs*, technical article.
- Texas Instruments, *Understanding the Terms and Definitions of LDO Voltage Regulators*, application note.
- Texas Instruments, *LDO PSRR Measurement Simplified*, application note.
- Texas Instruments, *How to Measure LDO Noise*, application note.
- Bogatin, Eric. “Back to Basics: Bandwidth and Rise Time.” *Signal Integrity Journal*, Signal Integrity Journal, 29 July 2020, www.signalintegrityjournal.com/blogs/12-fundamentals/post/853-back-to-basics-bandwidth-and-rise-time.

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (February 2025) to Revision A (July 2025)	Page
• Updated document to reflect technical correctness	1

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