Application Report

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Limiting DDR Termination Regulators' Inrush Current

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ABSTRACT

The output voltage of DDR termination regulators tends to rise quickly after their VDDQ line is enabled. Most DDR terminators are specifically designed for fast start-up. They also require bulky output capacitors for a stable output voltage. This often results in a significant inrush current from DDR terminator voltage supply to charge the output capacitors and to provide current to the resistive loads. Inrush current in DDR terminators like LP2996, LP2997, LP2998 can preclude proper operation of the load circuitry. This application report addresses simple methods to achieve a monotonic, inrush current limited start-up in LP299x devices. It also describes the selection of output capacitor and option to replace the expensive electrolytic and tantalum capacitors with ceramics and ESR to compensate the regulator control loop.

Contents

1 Overview

The simplified block diagram of Figure 1 depicts basic functional blocks of LP299x devices. These devices support DDRI, DDRII, DDRIII and DDRIIIL VTT bus termination with VDDQ minimum of 1.35V. LP299x devices consist of high-speed operational error and reference amplifiers to provide excellent response to load transients.

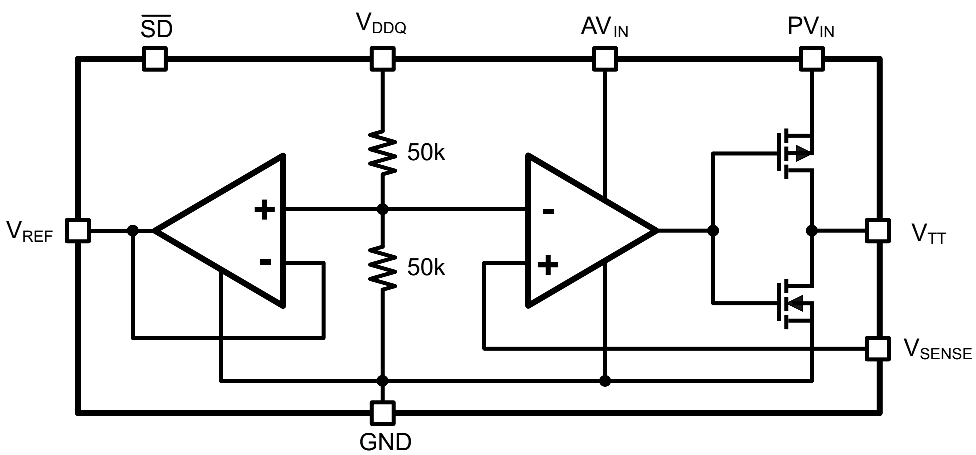

Figure 1. Simplified Functional Block Diagram

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2 Inrush Current

When VDDQ is enabled, the error amplifier senses that the output voltage is low and drives the pass element as hard as possible. The pass element pulls a large inrush current from the AVIN/PVIN power supply to charge the output capacitance and/or load abruptly after the push pull circuitry is activated. Inrush current is more common in DDR applications with large VTT capacitors. In most DDR memory termination circuitries, switching regulators are used to provide AVIN/PVIN voltage rails. The amount of inrush current often exceeds the switching regulator's maximum current limit which causes the supply voltage to droop and activates switching regulator's UVLO (if available).

There is a misconception about taming the inrush current in DDR termination regulators by using switching regulators for PVIN/AVIN with soft-start implementation. This doesn't always help in reducing inrush current because in most DDR memory applications the power supply for AVIN/PVIN is already enabled (sequenced up) before the V_{DDQ} rail is enabled. Figure 1 shows the implementation of LP2998 in DDRII termination configuration. LP299x devices are commonly used in automotive cluster designs to terminate the DDR memory and are capable of sourcing and sinking 1.5-A constant current.

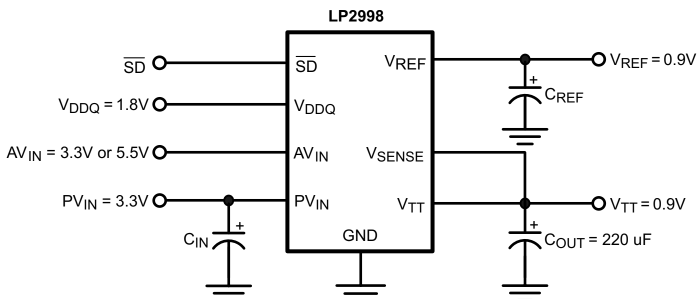

Figure 2. LP2998 DDRII Configuration

3 System Reset Caused by the Inrush Current

In this example the designer is using a fairly large capacitor at VTT (VDDQ/2 output). The AVIN/PVIN is 3.3 V provided by LM43001, 1-A buck converter. The 1.8-V VDDQ come from another regulator with very fast slew rate.

Figure 3 shows the startup of LP2998 device when VDDQ voltage line is enabled using a fast slew rate (~60 µs). The input current from LM46001 reaches ~5 A which exceeds the buck converter's current limit and consequently the input voltage droops down. The LM43001 has under voltage lock out (UVLO) and it shuts off, causing the whole system to restart.

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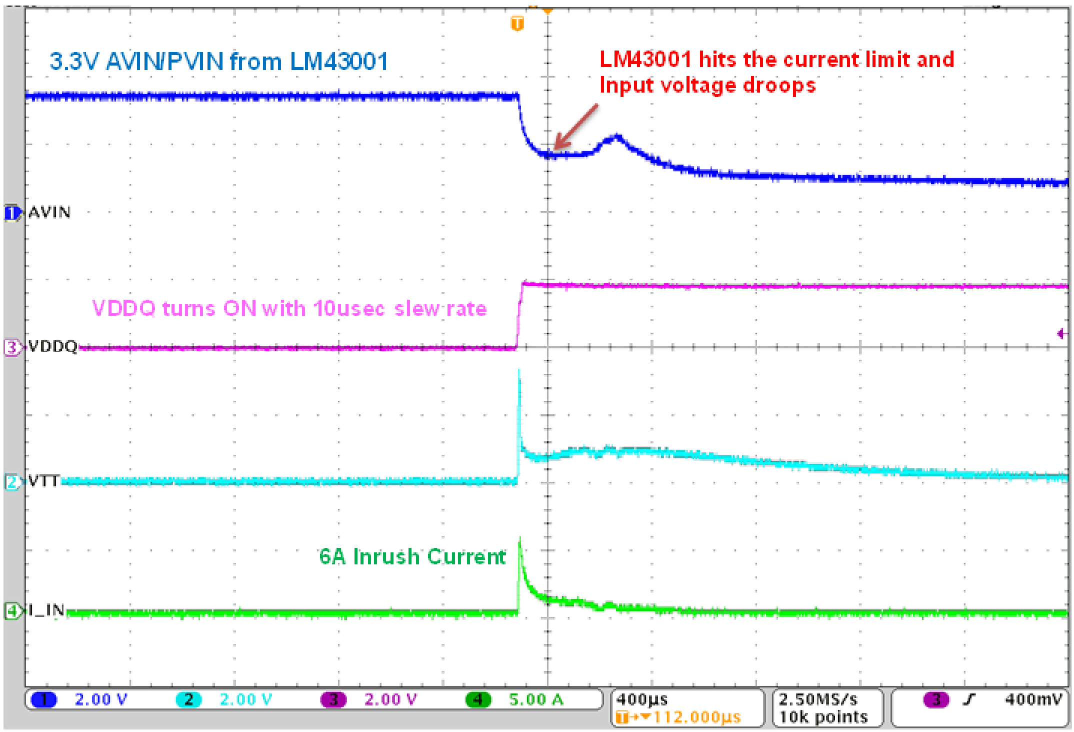

Figure 3. System Shutdown Due to Inrush Current

With no inrush-control circuitry in place, the input current is clamped to the regulator's current limit. When the AVIN/PVIN supply voltage droops, it signals the UVLO trigger. This causes the entire system to restart. Figure 4 shows an instrument cluster resetting over and over due to similar issue.

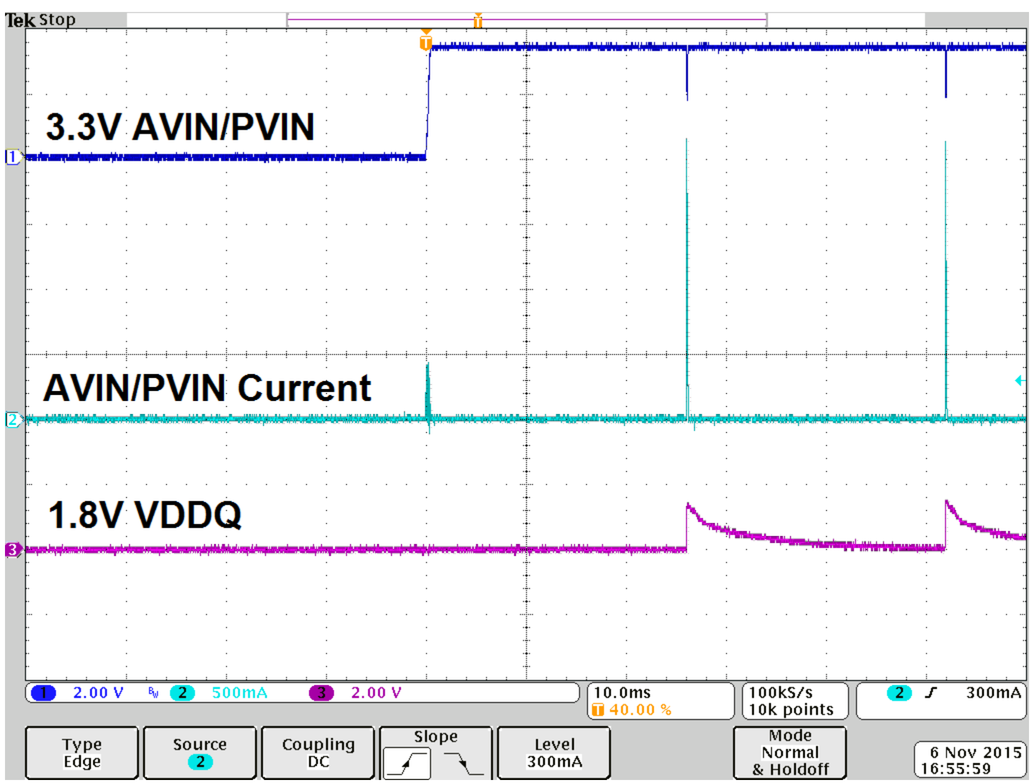

Figure 4. Instrument Cluster DDRII Fault Condition Due to Inrush Current

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4 Solution 1: VDDQ Soft-Start

VDDQ is the input used to create the internal reference voltage for regulating V_{TT}. The reference voltage is generated from a resistor divider of two internal 50-kΩ resistors. This ensures that V_{TT} will track VDDQ / 2 precisely

The following relationship predicts the DDR terminator's required input current at start-up for a given V_{TT} rise time, T_{RISE}, where C_{OUT} is the termination regulator's output capacitance.

$$I_{INRUSH} = C_{OUT} \times \frac{V_{TT}}{T_{RISE}} \quad (1)$$

Thus, we can see an inverse relationship between the V_{TT} voltage rise time and inrush current. In LP299x DDR terminations, the V_{TT} rise time depends on VDDQ slew rate. Therefore, the simplest solution can be achieved by implementing a soft-start for VDDQ power supply. If VDDQ start-up slew rate is ≥300 µs, the inrush current can be reduced by 90% as shown in Figure 5.

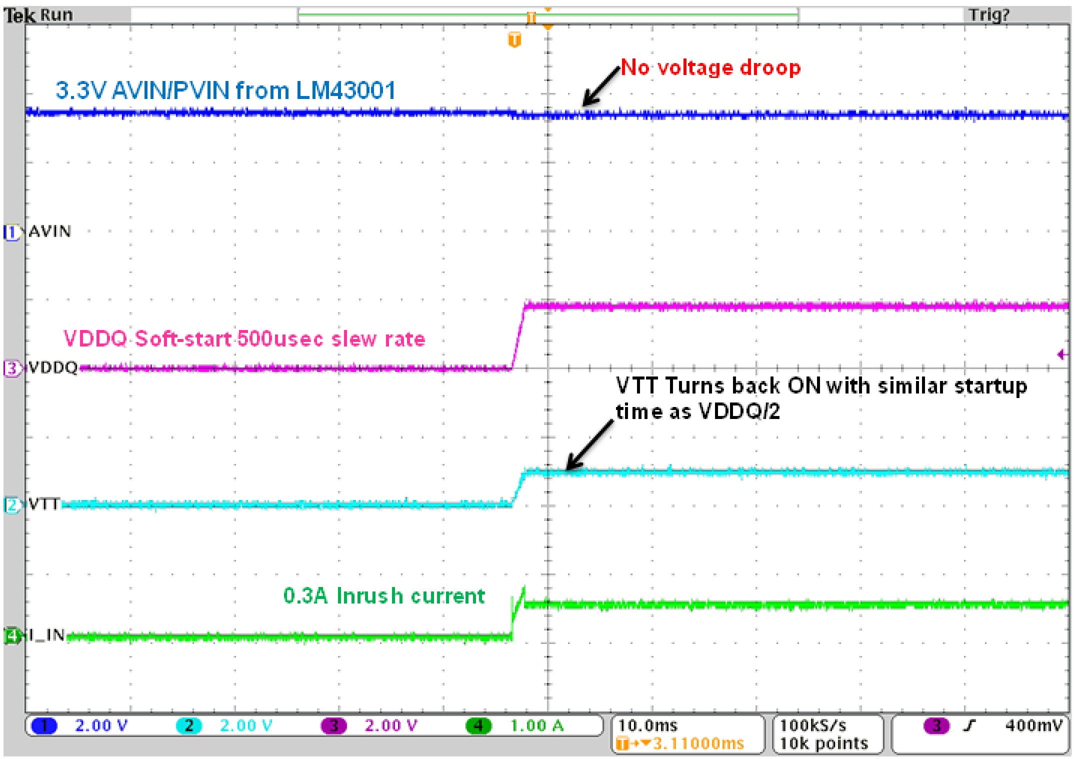

Figure 5. Inrush Current Controlled by Increasing VDDQ Slew Rate

The output current in Figure 5 is 500 mA, and VDDQ is enabled with 300-µs slew rate. The inrush current is reduced from ~6 A in Figure 5 to less than 0.3 A, which is a significant improvement.

5 Solution 2: Soft-Start with RC Filter Implementation

In some cases the system designers have very little to no control over the VDDQ voltage supply slew rate, whether using linear or switching regulators. Some step down voltage regulators don't have soft start feature. VDDQ voltage source requires only 18uA current to enable the DDRII termination voltage. Therefore placing an RC filter at VDDQ pin can conveniently increase the output voltage slew rate, allowing a slow rise in capacitor charge current. In order to keep the VDDQ voltage losses minimum, the resistor value should be chosen carefully. Figure 6 shows DDRII terminator configuration using LM2998 with RC filter to minimize the amount of inrush current.

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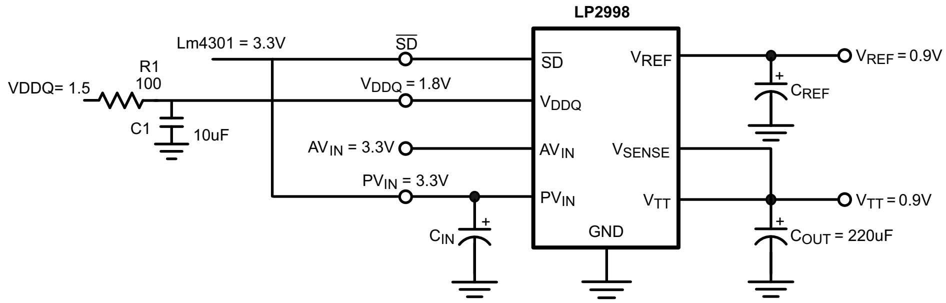

Figure 6. Inrush Current Controlled by RC Filter

In Figure 6, R1 is 100-Ω resistor which keeps the VDDQ supply voltage losses down to 1.8 mV, since the current through VDDQ is only 18 µA for DDRIII configuration. Figure 7 shows the rise time of the VDDQ voltage with the additional RC circuitry for I OUT = 500 mA. The measured rise time is slightly above 2 ms.

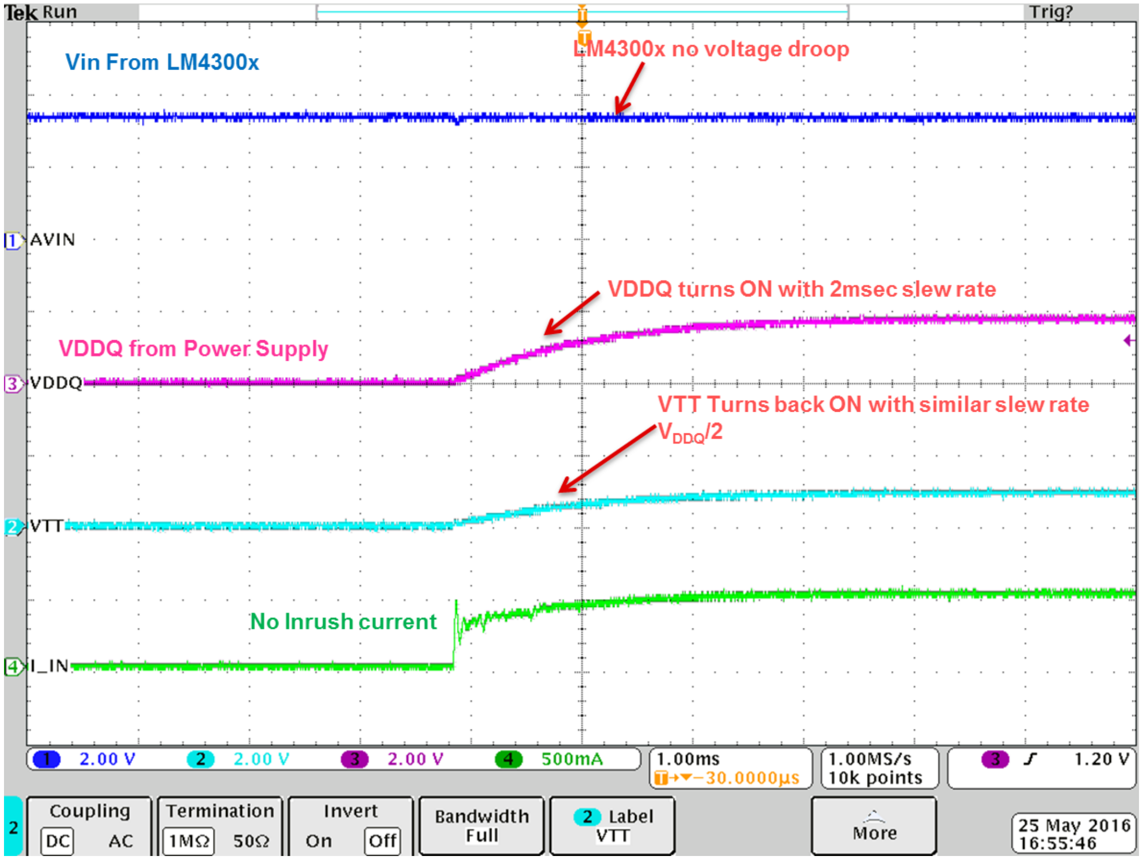

Figure 7. Inrush Current Controlled by RC Filter

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6 VTT Capacitor Guidelines for LP299x Devices

6.1 Electrolytic and Tantalum Capacitors

A bypass capacitor should be placed on the VTT line for stability. However, the size of VTT capacitor will not affect stability, but larger values will improve the transient response and should be sized according to the design requirements. Electrolytic and tantalum capacitors have parasitic resistance known as ESR. Most linear regulators have stable range of ESR values which the output capacitor must meet to ensure stable regulator operation. This makes electrolytic and tantalum more effective in linear regular based devices. However, their cost is significantly higher than ceramic capacitors which makes them a difficult choice in cost sensitive designs. Good news is that the unique design of LP299x devices allows a greater stability with ceramic capacitors combined with ESR and reduces overall system cost.

6.2 Ceramic Capacitors

Ceramic capacitors do contain some parasitic ESR, but for capacitance values greater than 1 uF, the value of ESR is usually in the range of a few mΩ at high frequencies. . This makes ceramic capacitors extremely attractive for bypassing high frequency noise and supporting rapidly changing load transients. But it also makes them unsuitable for use with linear regulator based devices, which were designed to rely on the output capacitor's ESR for the loop compensation zero. When using ceramic capacitors at the output large load steps can cause ringing on VTT as shown in Figure 8.

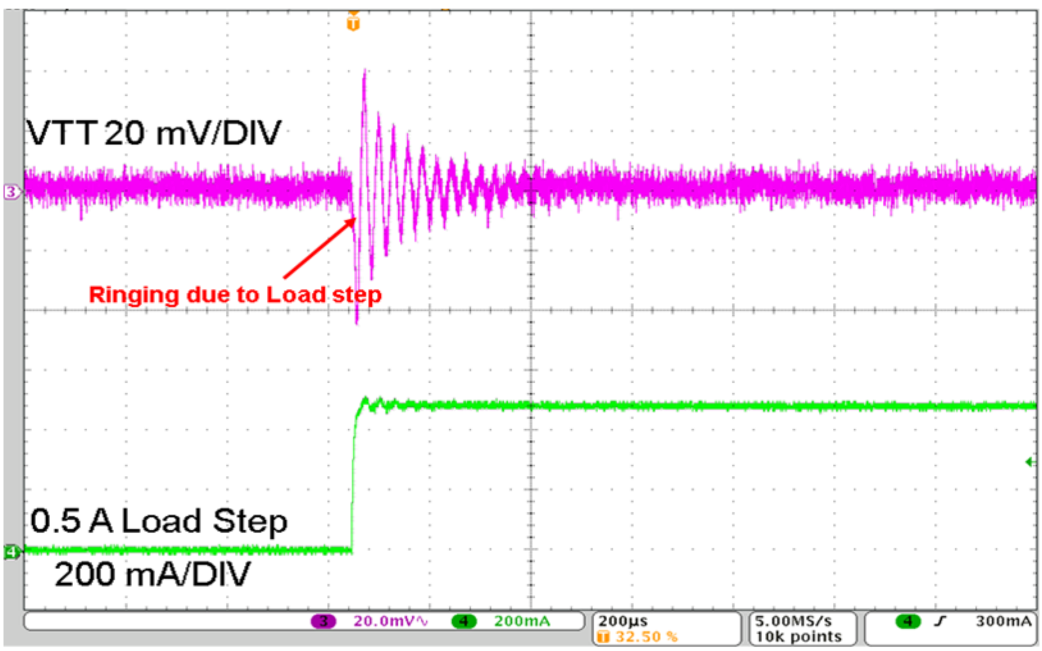

Figure 8. Ringing at VTT of LP2998 with 100uF Ceramic Capacitor

Although the amount of undershoot was reduced by ceramic capacitor, the absence of sufficient ESR caused the VTT ringing. Adding an external resistor in series with the VTT capacitor can compensate the loop and eliminate the ringing. To calculate the value of ESR, first measure the ringing frequency and use the following equation to calculate the amount of ESR needed for loop compensation.

$$ESR = \frac{1}{2\pi f C_{VTT}}$$

In most cases if a 100uF to 300uF capacitor is used for VTT line, using an ESR in 50mΩ to 100mΩ range will stabilize the VTT voltage completely as shown in Figure 9.

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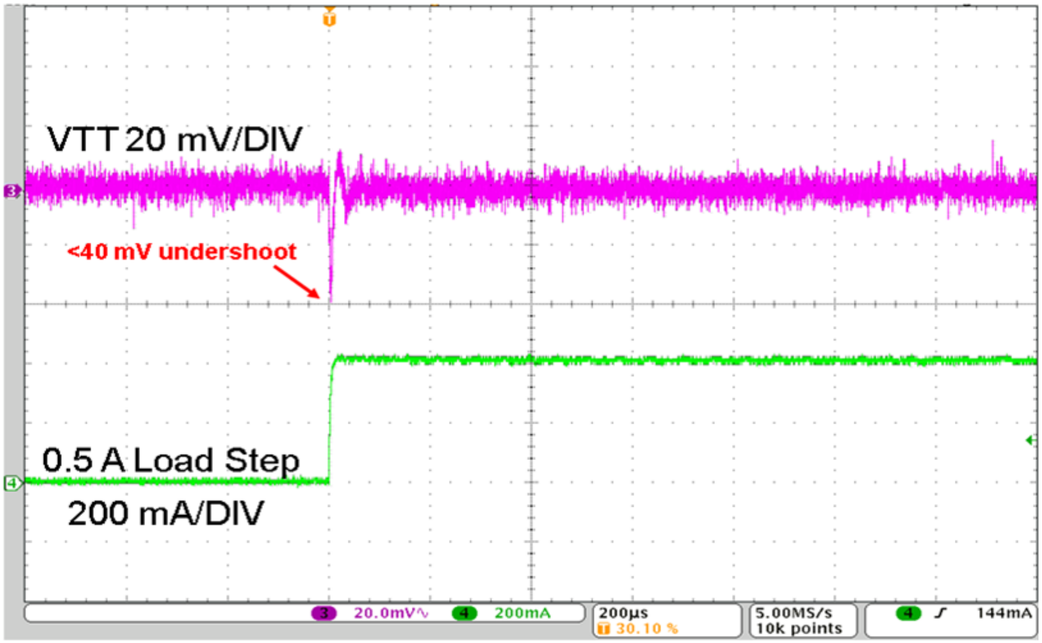

Figure 9. Stabilized VTT with 100mΩ ESR in series with 100uF Capacitor

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