Using Tracking LDOs as High-Side Switches (for Low-Current Applications)

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ABSTRACT

Many automotive subsystems such as electromagnetic relays, current controlled power rails, and other resistive, inductive, or capacitive loads require low-current high-side switches. This paper discusses an approach of using TI's automotive tracking LDOs (TPS7B4250-Q1, TPS7B4253-Q1, and TPS7B4254-Q1) for such applications, and the advantages of doing so.

These LDOs provide basic protection features as conventional automotive high-side switches, including overcurrent protection, overtemperature shutdown, reverse polarity protection, reverse-current and short-to-ground protection. In addition, the ADJ pin on these devices can be used for enable and disable control, programmable rise-time setting, as well as for clamping the output voltage while using the device for critical loads like ECU power supply. These LDOs can work with very small capacitors on the input and output. This paper includes test results for various output rise time settings, the effect of output capacitance, and the switching characteristics of the TPS7B4250-Q1 device.

Contents

List of Figures

List of Tables

1   Introduction

In many automotive subsystems, low-current high-side switches are required to supply power to small sensors or for battery-voltage monitoring. Conventionally, such a requirement is met using automotive-qualified high-side switches. The critical parameters are as follows

- Load dump protection for a 12-V battery system and support for a 12-V nominal battery supply
- Output rise time of the signal less than 0.5 ms at approximately 5-mA load
- Switch output that tracks the input voltage with very low error
- Built-in protection of the device and connected circuitry (ECU pins) under fault conditions

2   Circuit Description

Figure 1 is a typical schematic for a tracking LDO used as a high-side switch. The TPS7B4250-Q1 input (V_{IN}) can be connected directly to a 12-V battery. It is recommended to place a small ceramic capacitor between V_{IN} of the TPS device and GND to avoid line disturbances. The inductance of the wiring harness can produce voltage spikes during switching, and a long wiring harness can pick up noise. A capacitor in the range of 1 µF to 10 µF should be sufficient for most cases; however, this value can be further reduced if a TVS diode is used in parallel for transient protection.
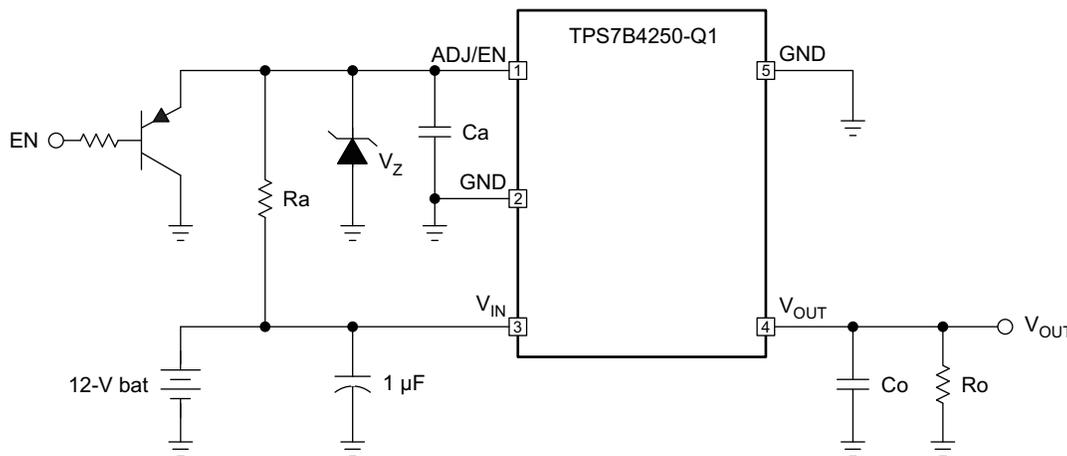
Figure 1. Schematic of the TPS7B4250-Q1 Device as a High Side-Switch

The complex load (resistive, capacitive, or inductive) is connected to the output pin V_{OUT}. The output-voltage rise and fall times are controlled during on and off transition to minimize emissions. Only a small ceramic capacitor of 10-nF value (C_O) is recommended to attenuate RF noise and stabilize the output after transitions.

A built-in current limit protects the device against destruction. TPS7B425x-Q1 devices can be switched on and off through the ADJ/EN pin. A voltage level greater than 1.5 V, enables the device. When the ADJ/EN pin voltage is pulled below 0.8 V, the device is in the OFF state with very low power consumption.

When the device is enabled, the output voltage tracks the ADJ/EN pin voltage with a worst-case accuracy of ±5 mV. However, while using these devices as high side switches, the ADJ/EN pin is tied to V_{IN} through a resistor (Ra). In this case, V_{OUT} = V_{IN} – Dropout voltage. Typically, the dropout voltage for these regulators is less than 150 mV under a light-load condition.

Because the ADJ/EN pin is directly pulled to the V_{IN} voltage through a resistor, V_{OUT} tracks the ADJ/EN pin voltage. The maximum recommended operating voltage for the ADJ/EN pin is 18 V; hence, a Zener clamp (with breakdown voltage less than 18 V) should be used if the input voltage is not regulated. Using a Zener diode also makes sure that output voltage is clamped to a required safe level while using the device for critical loads like ECU input.

To control rise time of the V_{OUT} voltage, use an additional capacitor, Ca, between the ADJ pin and GND. The Ra-Ca combination determines the rise time for the V_{OUT} voltage. For example, with Ra = 5 kΩ and Ca = 100 nF, rise time approximately equals 5 × 5 kΩ × 100 nF = 2.5 ms.

By connecting the FB pin to the GND pin as shown in Figure 2, the TPS7B4253-Q1 or TPS7B4254-Q1 device can also be used as a high-side switch. The switching on and off of the device is then controlled through the EN and ADJ pins.
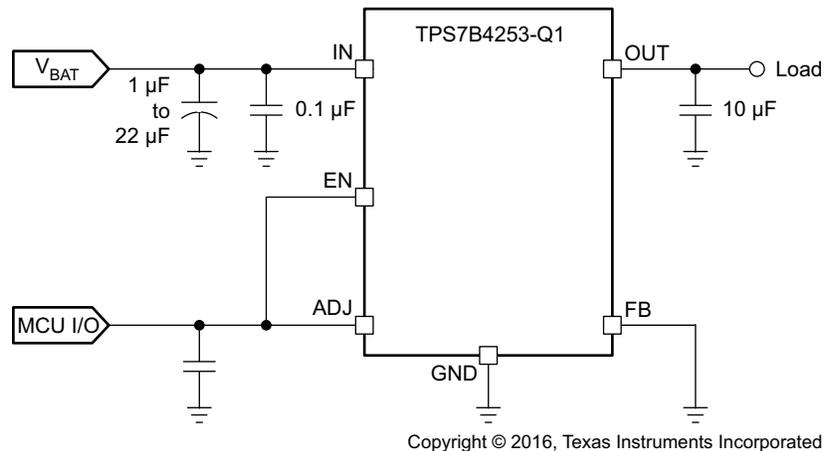

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Figure 2. High-Side Switch Application With the TPS7B4253-Q1 Device

Figure 3 shows the waveform of the high-side switch configuration of the TPS7B4253-Q1 device, with conditions of V_{IN}=14 V, EN and ADJ 5-V high-voltage level, and 100-mA load at the output.
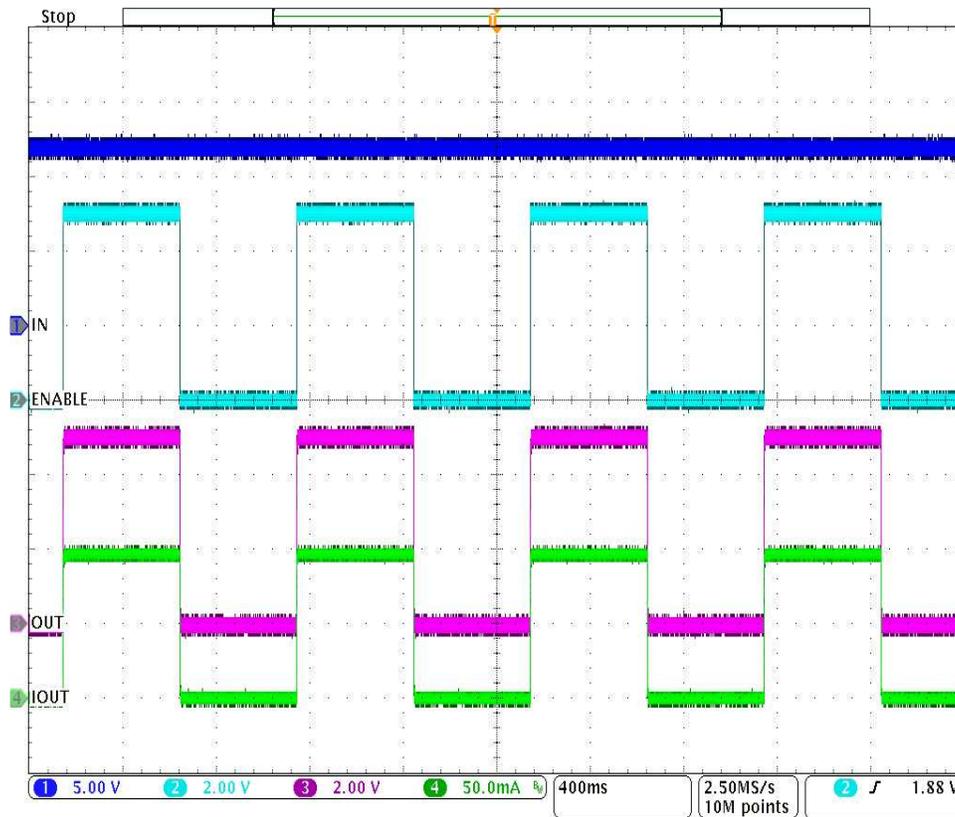
Figure 3. Waveform of a High-Side Switch Application

3 Comparison of Various Tracking LDOs as High-Side Switches

Table 1 lists and compares electrical characteristics and protection features of TPS7B425x-Q1 family of tracking LDOs.

Table 1. Comparison of TPS7B425X-Q1 Devices

	TPS7B4250-Q1	TPS7B4254-Q1	TPS7B4253-Q1
Thermal shutdown	175ºC with 15ºC hysteresis	175ºC with 15ºC hysteresis	175ºC with 15ºC hysteresis
Nominal load current	50 mA	150 mA	300 mA
VDO	680 mV (at 50 mA)	240 mV (at 150 mA)	240 mV (at 150 mA)
Short-circuit protection	100 mA to 500 mA	151 mA to 520 mA	301 mA to 520 mA
Overvoltage protection	Adjustable	Adjustable	Adjustable
Operating voltage range	4 V to 40 V	4 V to 40 V	4 V to 40 V
Reverse current when voltage is applied at the output	–5 µA	–2 µA	–2 µA
Reverse current protection at negative input voltage	5 µA	10 µA	10 µA
Off-state input current	15 µA	2 µA	2 µA
Negative voltage clamp	Protected	Protected	Protected
Package	SOT-23	SO8 power PAD	SO-8, HTSSOP-20

Conventional high-side switches use a single MOSFET as shown in Figure 4. When voltage is applied at the output, very high reverse current can flow through device. The TPS7B425x-Q1 devices block the reverse current completely because of dual MOSFET architecture, as shown in Figure 5 and Figure 6.
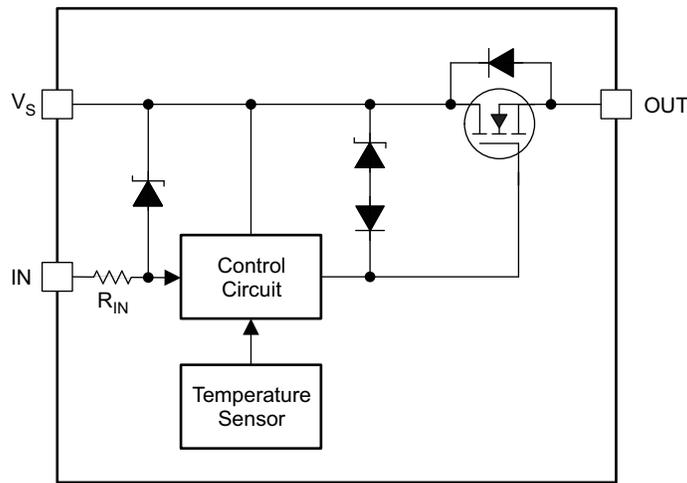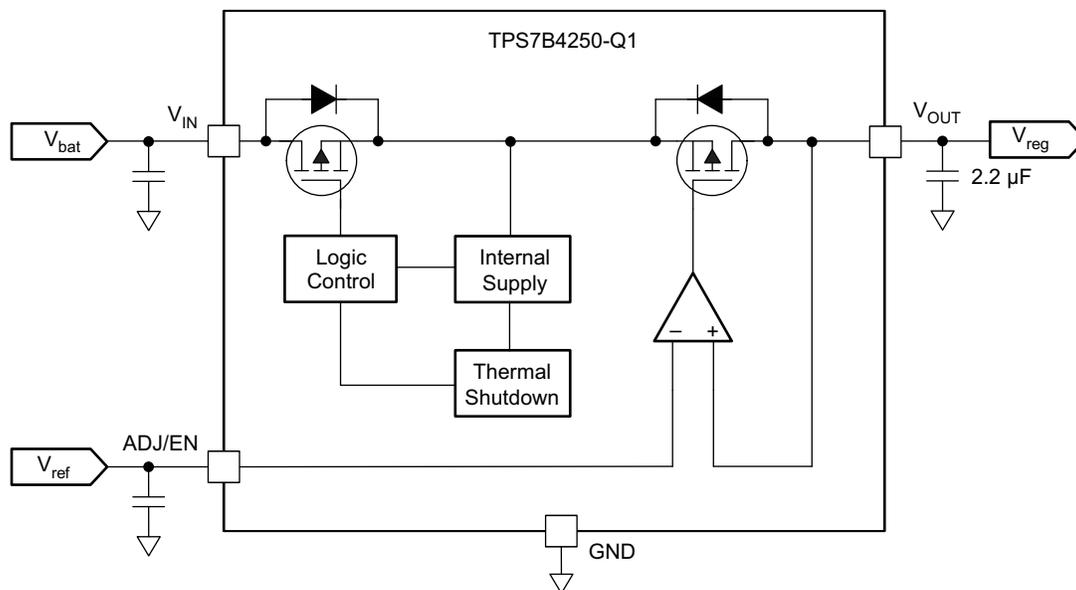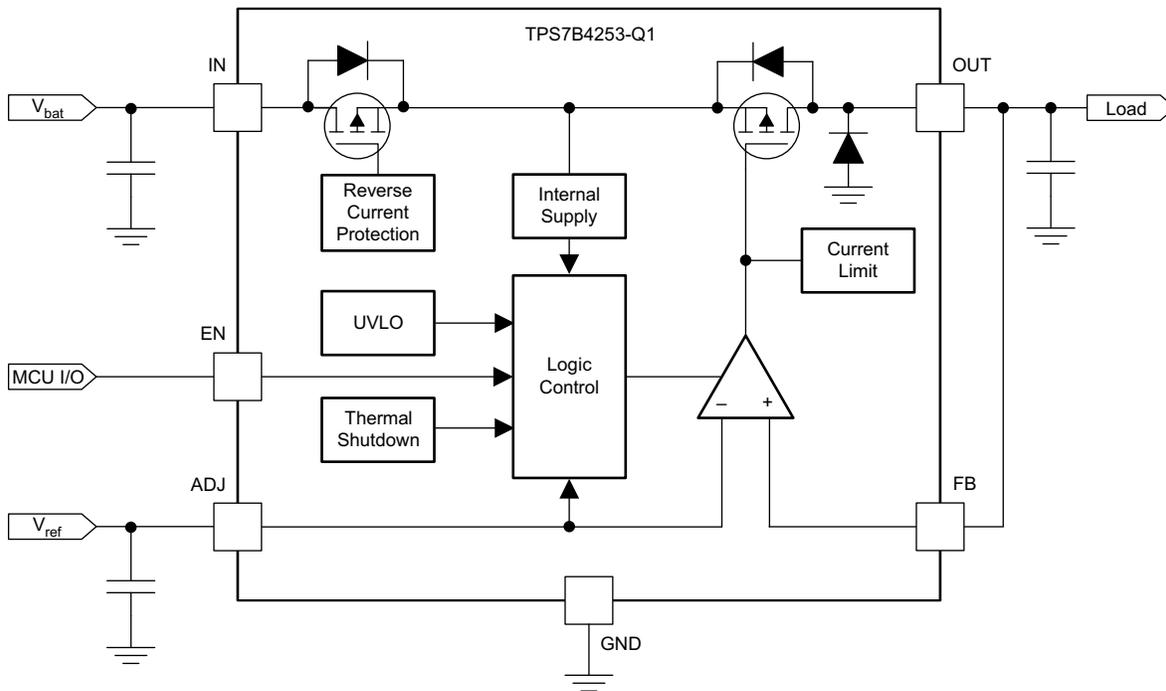

Figure 4. Functional Block Diagram of a Conventional HS Switch

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Figure 5. Functional Block Diagram of a TPS7B4250-Q1 Device

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Figure 6. Functional Block Diagram of a TPS7B4253-Q1 Device

4   Test Results

4.1   *Input-to-Output Delay and Rise-Time Setting*

Figure 7 shows the performance of the TPS7B4250-Q1 device with the V_{IN} voltage continuously at 12 V. When the ADJ/EN pin voltage exceeds 1.5 V, the device starts tracking the input voltage. Note that the output reaches the 12-V level at 30-mA load with a 100-nF output capacitor (Co) within 160 µs after the ADJ/EN voltage exceeds 1.5 V.
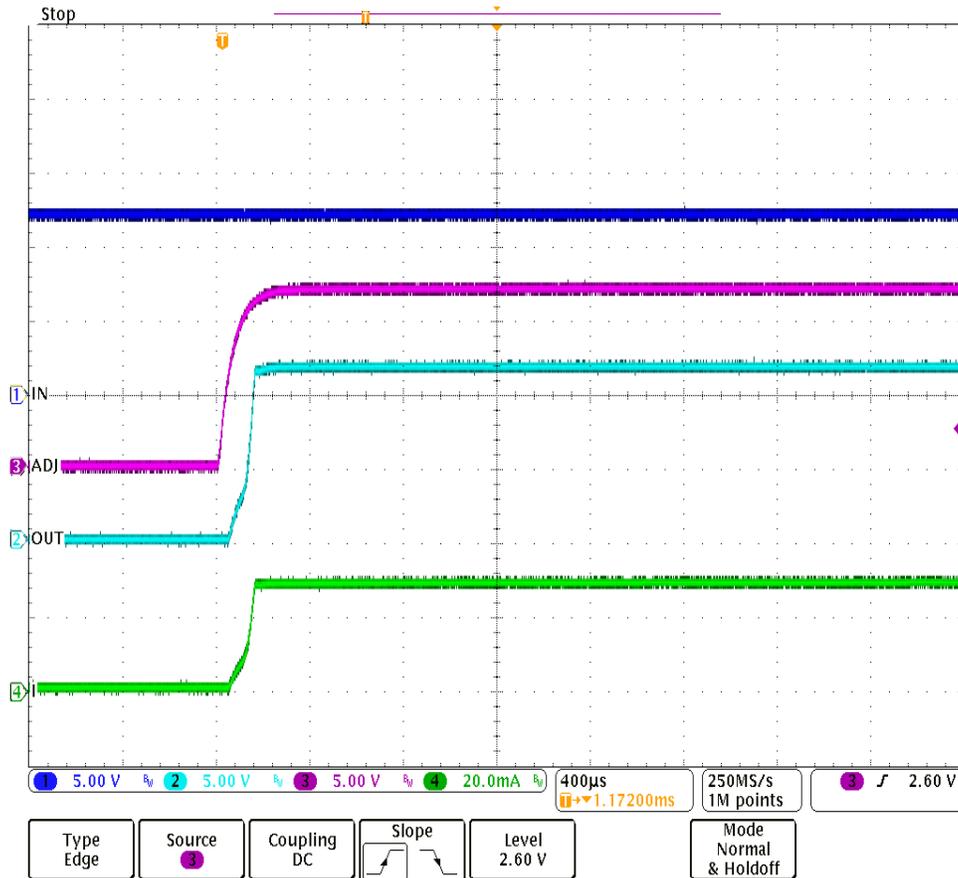

Figure 7. Input-to-Output Response Characteristic of the TPS7B4250-Q1 Device,
Co = 100 nF, Ro = 400 Ω, Ra = 5 kΩ, Ca = 10 nF

Figure 8 shows the response of the TPS7B4250-Q1 device with a 2.5-ms rise-time setting on the ADJ/EN pin using 5-kΩ Ra and 100-nF Ca. Output of the LDO, V_{OUT}, tracks the ADJ/EN voltage with a small delay.
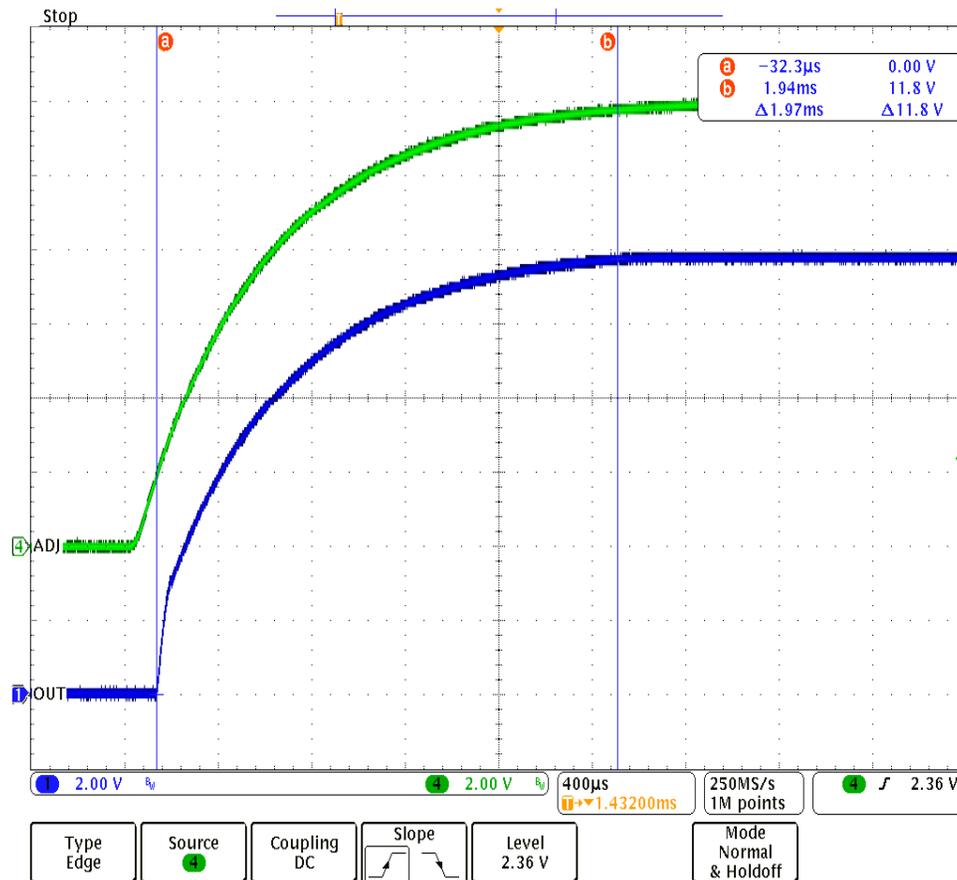
Figure 8. Rise-Time Setting Using the ADJ Pin,
Ra = 5 kΩ, Ca = 100 nF, Ro = 2.7 kΩ, Co = 100 nF

4.2 Effect of Output Capacitance

This section analyzes the effect of an output capacitor on output stability. Figure 9 and Figure 10 compare the response of the TPS7B4250-Q1 device at no load with no output capacitor and with a 1-nF output capacitor, respectively. Including a small 1-nF capacitor improves the stability of the output during turnon operation.

**Figure 9. Effect of Output Capacitance Under a No-Load Condition,
Ra = 3.3 kΩ, Ca = 1 nF, Ro = open, Co = open**
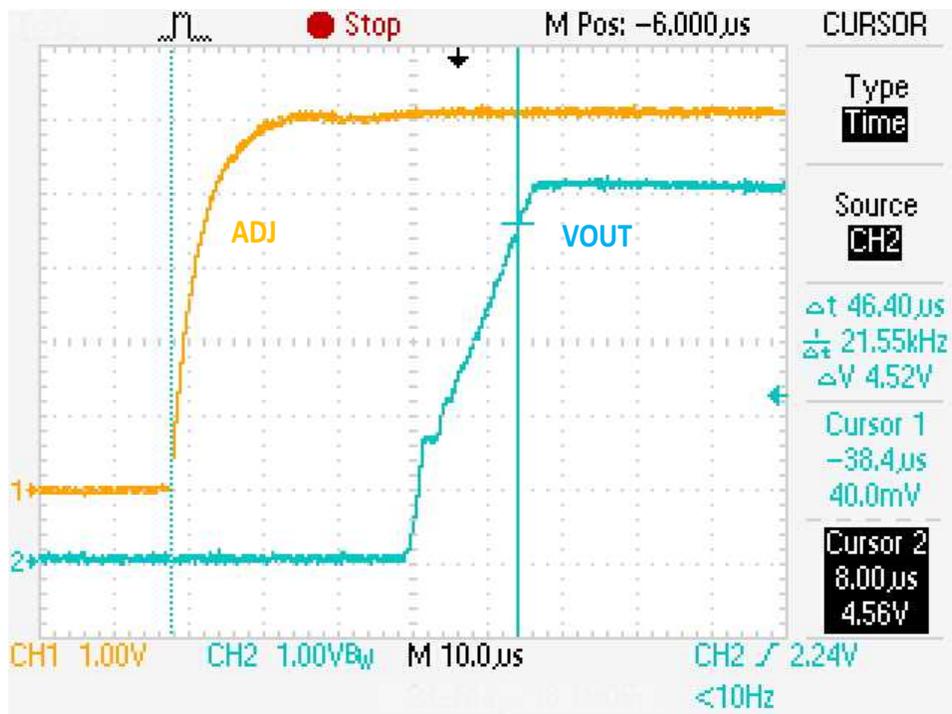
**Figure 10. Effect of Output Capacitance Under a No-Load Condition,
Ra = 3.3 kΩ, Ca = 1 nF, Ro = open, Co = 1 nF**
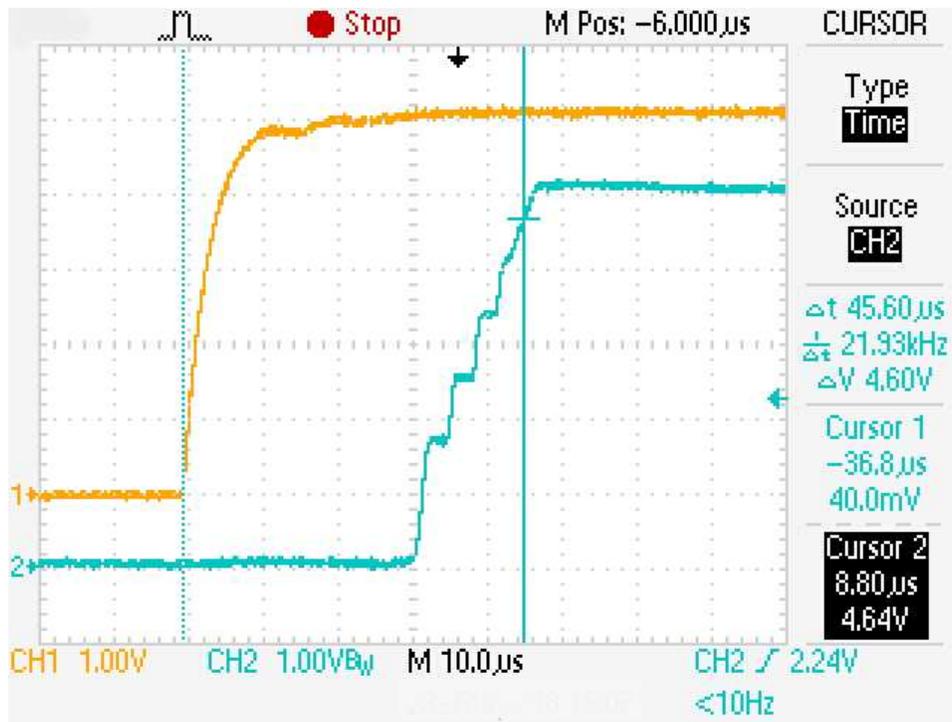
There is a stable response with a 1-nF output capacitor. Testing the circuit with a small load of 1.5 mA, and with a 1-nF output capacitor (Figure 11), there is an 880-mV glitch at the output. When output capacitance is increased to 3 nF (Figure 12), the output glitch amplitude reduces to 480 mV. And with a 10-nF output capacitance (Figure 13), the output is stable with peak-to-peak noise less than 15 mV as shown in Figure 14.
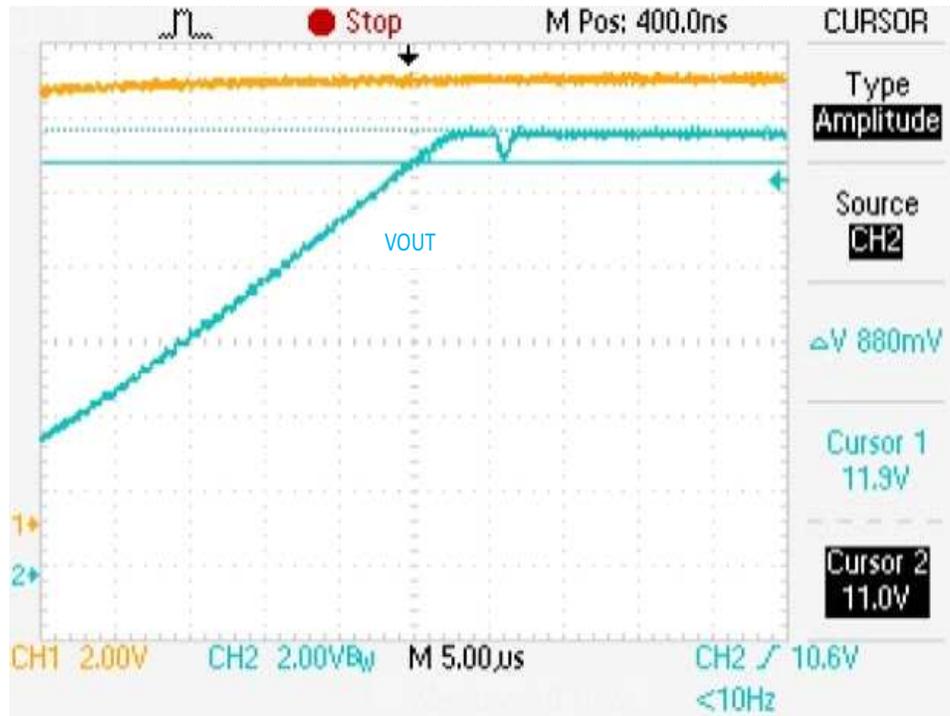
Figure 11. Effect of Output Capacitance Under a Light Load Condition,
Ra = 10 kΩ, Ca = 1 nF, Ro = 3.3 kΩ, Co = 1 nF
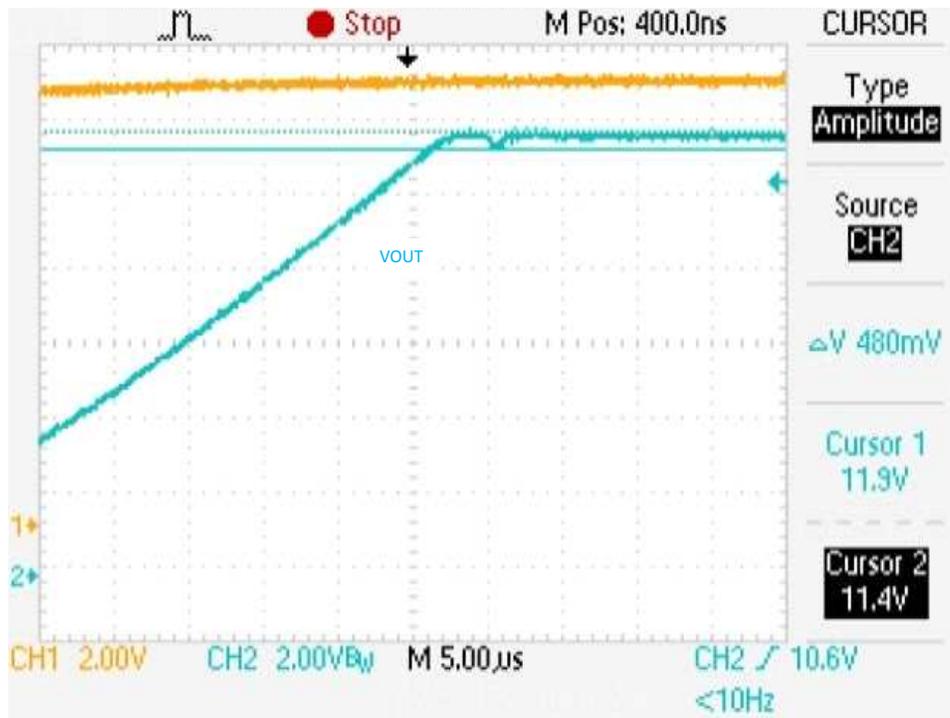
**Figure 12. Effect of Output Capacitance Under a Light Load Condition,
Ra = 10 kΩ, Ca = 1 nF, Ro = 3.3 kΩ, Co = 3 nF**
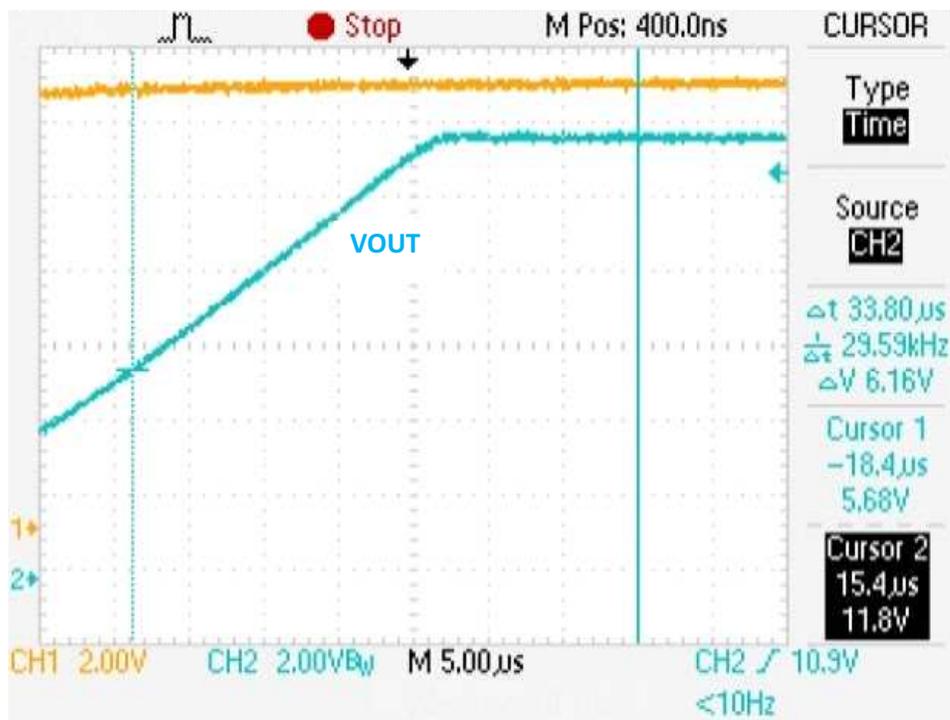
**Figure 13. Effect of Output Capacitance Under a Light Load Condition,
Ra = 10 kΩ, Ca = 1 nF, Ro = 3.3 kΩ, Co = 10 nF**

**Figure 14. Effect of Output Capacitance Under a Light Load Condition,
Ra = 10 kΩ, Ca = 1 nF, Ro = 3.3 kΩ, Co = 10 nF**

4.3 Switching Characteristics

Figure 15 and Figure 16 show the switching characteristics of the TPS7B4250-Q1 device with a 50-mA load. Note that the total of output rise time and propagation delay is approximately 120 μs (Figure 15). During turnoff (Figure 16), output voltage tracks the ADJ/EN pin voltage until the ADJ pin voltage is above 0.8 V. When the ADJ/EN pin voltage falls below 0.8 V, the device is disabled, and the output capacitor discharges through the load.
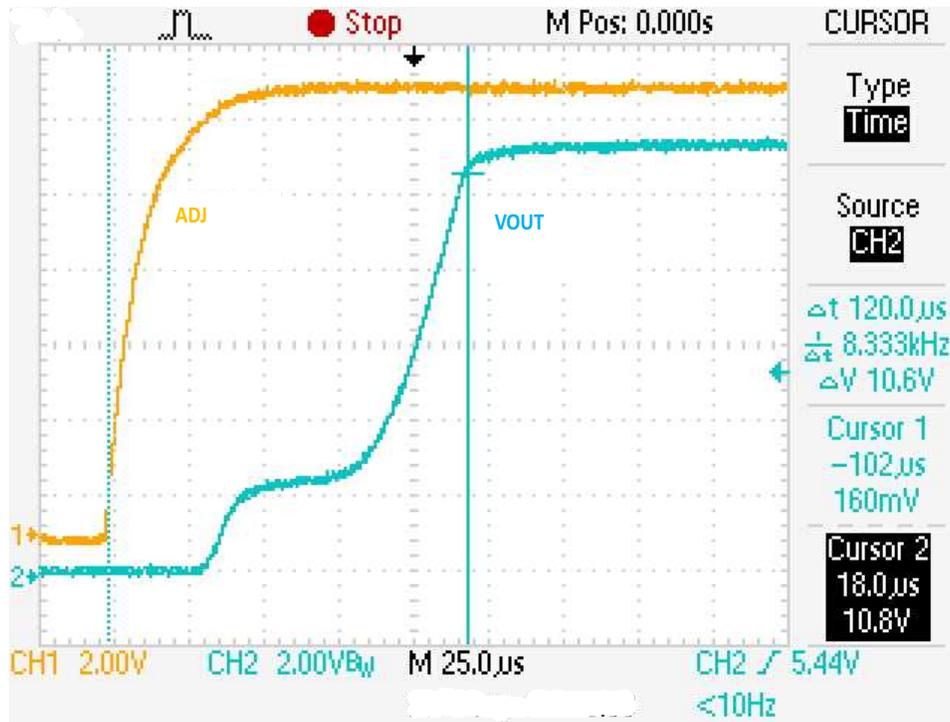
**Figure 15. Switching Characteristics of the TPS7B4250-Q1 Device During Start-Up With a 50-mA Load,
Ra = 10 kΩ, Ca = 1 nF, Ro = 240 Ω, Co = 10 nF**

**Figure 16. Switching Characteristics of the TPS7B4250-Q1 Device During Shutdown With a 50-mA Load,
Ra = 10 kΩ, Ca = 1 nF, Ro = 240 Ω, Co = 10 nF**

4.4 Conclusion

The analysis presented in this paper demonstrates that the TPS7B425x-Q1 tracking LDO devices can be used as high-side switches in automotive applications. These devices not only offer the protection required in automotive sub-circuits (as conventional high side switches), but also have added advantage of reverse-current blocking and rise-time control using the ADJ or ADJ/EN pin.

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