Application Report
SLVA851–November 2016

Short-Circuit Reliability Test for TPS7B4250-Q1

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ABSTRACT

The tracking LDOs are widely used as short-circuit protection devices for off-board sensor power supply in automotive systems. Therefore, the robustness of the device under repetitive short-circuit stress is crucial for the entire system. The AEC Q100-012 is the most recognized qualification certificate in industry, which specifies the reliability of this type of device.

This application report describes the AEC Q100-012 specification and provides the test method and results for the TPS7B4250-Q1 device, a tracking LDO from Texas Instruments.

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1 AEC Q100-012 Introduction

1.1 Introduction

The Automotive Electronics Council (AEC) provides the AEC Q100-012 documentation, which specifies the short-circuit reliability test. The main purpose of this test is to determine the reliability of tracking LDO when operating in a continuous short-circuit condition. The AEC Q100-012 specification includes an equivalent test circuit, detailed test conditions, different reliability grade definitions, and other information.

1.2 Equivalent Test Circuit

Figure 1 shows the basic equivalent test circuit for a high-side device. The high-side device performs the repetitive short-circuit tests. The R_{SUPPLY} and L_{SUPPLY} are the input impedance from the voltage source side (VBB), and the R_{SHORT} and L_{SHORT} are the output impedance from the module board and the cables.

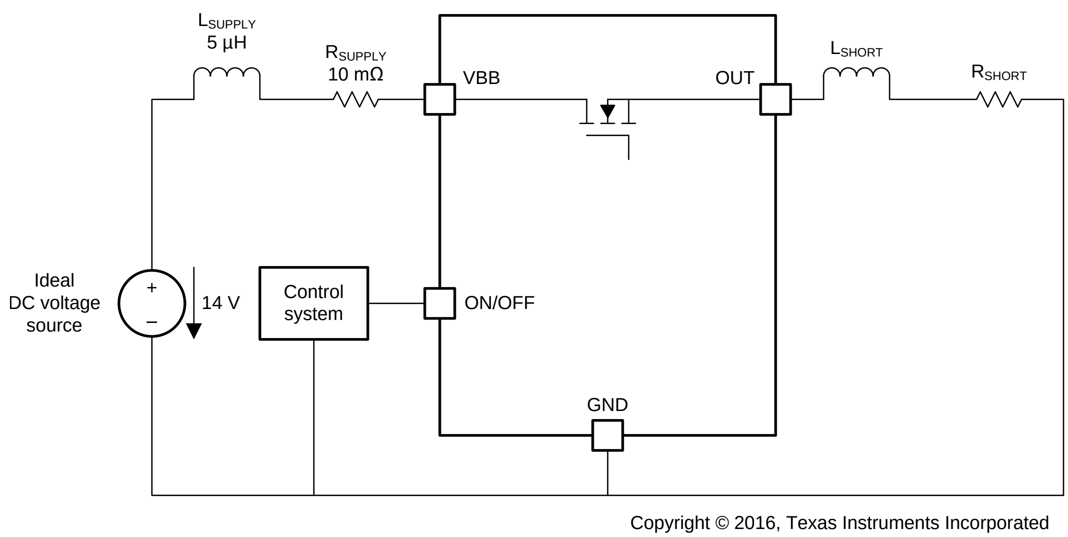

Figure 1. Equivalent Test Circuit for High Side Devices

2 Short-Circuit Test of TPS7B4250-Q1

2.1 Test Conditions

2.1.1 Supply Voltage

The supply is modeled by an ideal voltage source, V_{BAT}, which is 14 V ±2%.

2.1.2 Input Impedance

Considering the cable and device connection, a total resistance of R_{SUPPLY} = 10 mΩ ±20% and an inductance of L_{SUPPLY} = 5 µH ±20% are specified.

2.1.3 Output Impedance

The short circuit can occur anywhere on the output cable from the device to the load. Therefore, the output impedance may vary according to the cable length and diameter. Two types of short-circuit conditions are specified in the AEC Q100-012: the module terminal-direct short circuit and the long short circuit with an unassigned cable. For the terminal short circuit, AEC Q100-012 specifies that the module terminal, R_{SHORT} is 20 mΩ, and the parasitic inductance is smaller than 1 µH.

For the long short circuit, the specification assumes that the harness inductance is 1 µH/m, and specifies that the length is shorter than 5 m. Table 1 lists the output impedance parameters of the two the short-circuit types. The short-circuit current is specified by the internal current-limit value of the device. Based on the different current range, different impedance values are provided.

Table 1. Output Impedance

SHORT CIRCUIT TYPE	DESCRIPTION	R_{SHORT} (mΩ) ±20%	L_{SHORT} (µH) ±20%
Terminal short circuit	Short at module	20	< 1
Long short circuit	Short at load, $I_{SHORT} \leq 20$ A	110 – R_{SUPPLY}	5
	Short at load, 20 A < $I_{SHORT} \leq 100$ A	100	5
	Short at load, $I_{SHORT} > 100$ A	50	5

The short-circuit current of the TPS7B4250-Q1 device is smaller than 20 A. Therefore, R_{SHORT} is 100 mΩ and L_{SHORT} is 5 µH.

2.2 Test Items

Based on the different application cases, three test modes are defined in the AEC Q100-012 specification to verify the reliability of the device. Table 2 lists the detailed ambient temperature, pulse duration, and cycle numbers.

Table 2. Test Requirements Summary

TEST ITEMS		TEST CONDITION	TEST CYCLES
Cold repetitive short-circuit test	Short pulse	–40°C, 10-ms pulse, cool down	100k
	Long pulse	–40°C, 300-ms pulse, cool down	100k
Hot repetitive short-circuit test		25°C, keeping short	100k

2.2.1 Cold Repetitive Short Circuit—Short Pulse

This test must be performed for all devices with status feedback, and for latching devices even if they provide no status feedback.

Cold repetitive short circuit testing refers to the condition of complete cooling between consecutive pulses. The smart power device is placed into short-circuit mode and turned on according to Table 1, and turned off with a delay of 10 ms (±20%) after receiving a status feedback or going into shutdown. The short pulse is intended to simulate a fast reaction of the system/microcontroller.

The time between the shutdown and the next activation must be long enough to ensure complete cooling down to the device test temperature. This sequence is repeated until a failure of the device is detected. The number of cycles to failure is recorded for statistical evaluation.

This test allows for the comparison of device performance without significant impact of boundary conditions. Latching devices need only be tested under the short pulse condition, even if they provide no status feedback as the long pulse test yields no difference in performance and the hot repetitive test is not feasible.

Even though the TPS7B4250-Q1 is a device without status feedback or latch, this application report still covers the short pulse test based on customer requirement and it passed the test.

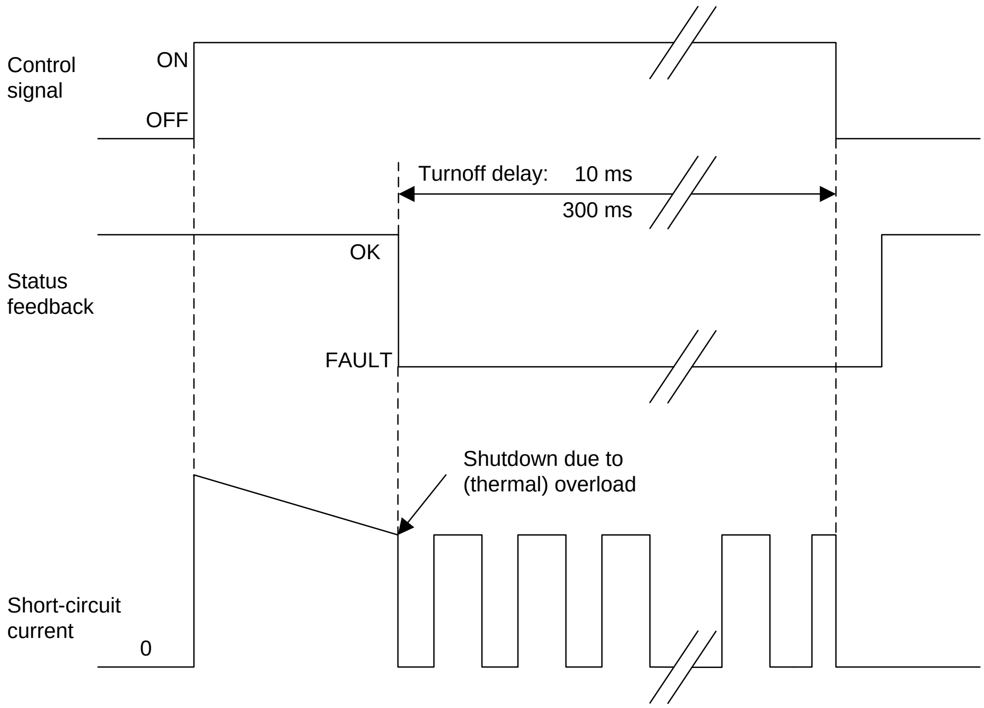

Figure 2. Timing Diagram of Cold Repetitive Short Circuit—Short Pulse

2.2.2 Cold Repetitive Short Circuit—Long Pulse

This test must be performed for all auto-restart devices.

The smart power device is placed into short-circuit mode and turned on according to Table 1, and turned off with a delay of 300 ms (±10%) after receiving a status feedback (see Figure 3). If the device does not have status feedback, the device is to be turned off after 300 ms. The long pulse is intended to simulate a delayed reaction of the system or microcontroller.

The time between consecutive long pulses must be long enough to ensure the device cools sufficiently to reach –40°C for TPS7B4250-Q1. This sequence is repeated until a failure of the device is detected. The number of cycles to failure is recorded for statistical evaluation.

This test is representative of actual working conditions with a worst-case reaction time of the microcontroller. Boundary conditions can partially affect the rate of cooling.

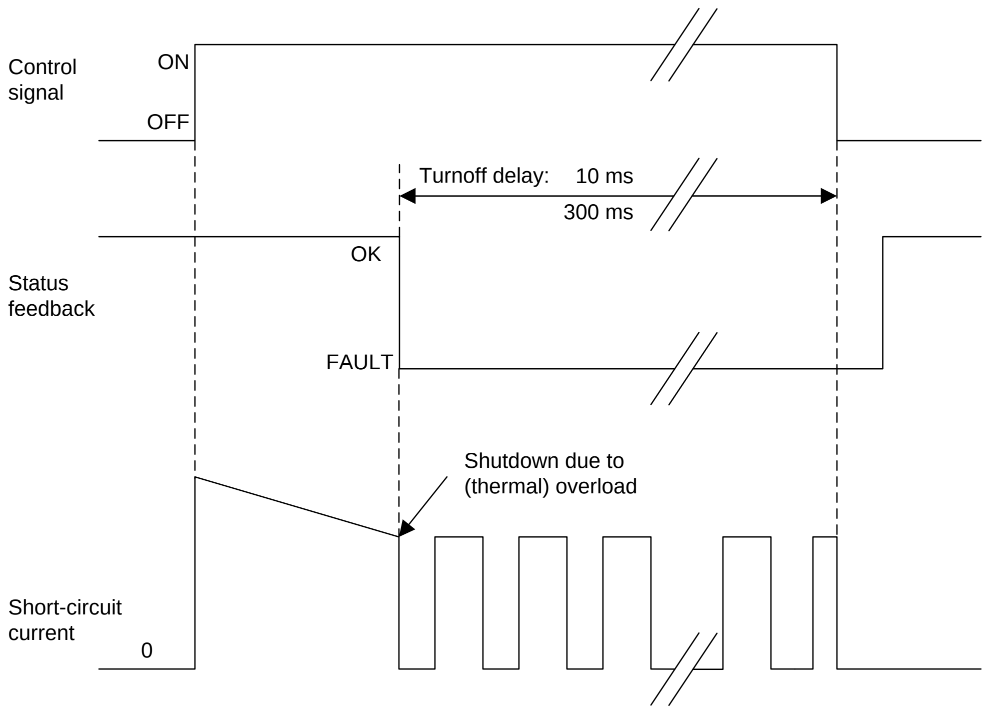

Figure 3. Typical Timing Diagram for Cold Repetitive Short-Circuit Device Signals

2.2.3 Hot Repetitive Short Circuit

The short pulses in the cold repetitive short-circuit scenario is the target for fault cases in applications with a microcontroller. However, some cases occur where the commands of the microcontroller return without any action or in applications without a microcontroller. In these cases, the hot repetitive short-circuit test is required. The enable signal remains active during a hot repetitive short-circuit. The device quickly enters thermal shutdown cycling then remains in the auto-retry mode with repetitive thermal cycling. A cooldown period for the device is not required. The hot repetitive test can depend on boundary conditions, but it is an important test as it allows evaluating how much time the device can support a short circuit if the system or microcontroller is not reacting. Also, the temperature variation occurs only at the first cycle and therefore room temperature at 25°C is acceptable.

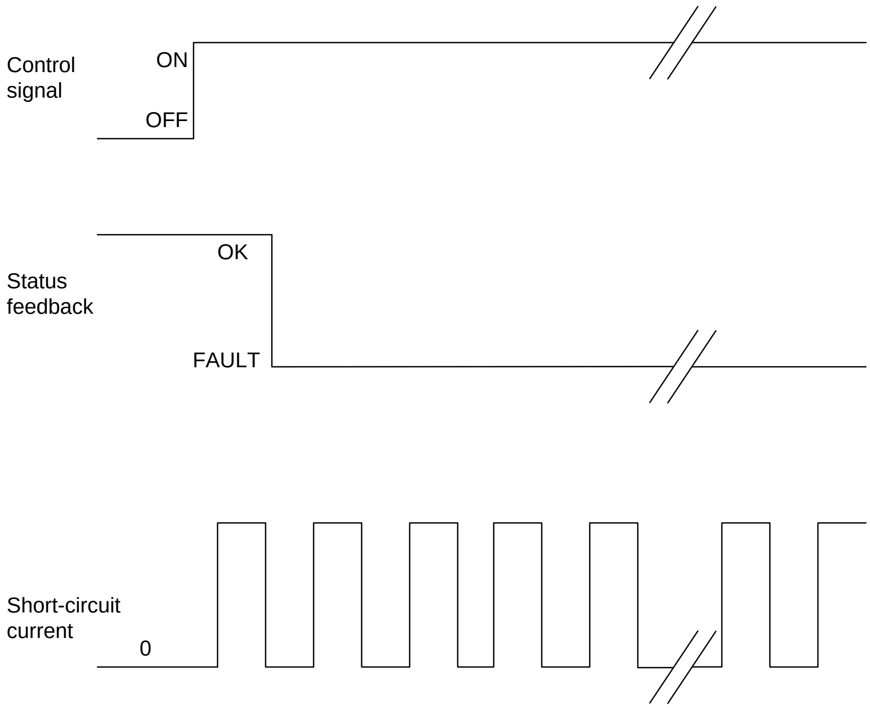

Figure 4. Typical Timing Diagram for Hot Repetitive Short-Circuit Device Signals

2.3 Block Diagram

The AEC Q100-012 standard requires at least 30 devices for a sufficient sample size. To ensure three test lots running in parallel, the system should accommodate a maximum of 40 devices under test (DUTs) simultaneously. All units have been tested for 100k cycles without any damage and parameter shift, which could meet the Grade C requirement.

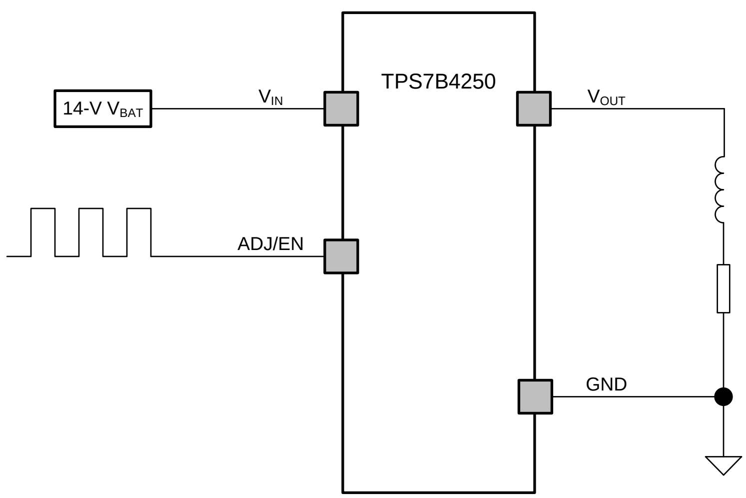

Figure 5. System Block Diagram

2.4 Test Setup

Three main sections are implemented in the test control system. These sections include the power and driver boards, the oven and the oven board, and the PC host system.

Figure 6. Instruments

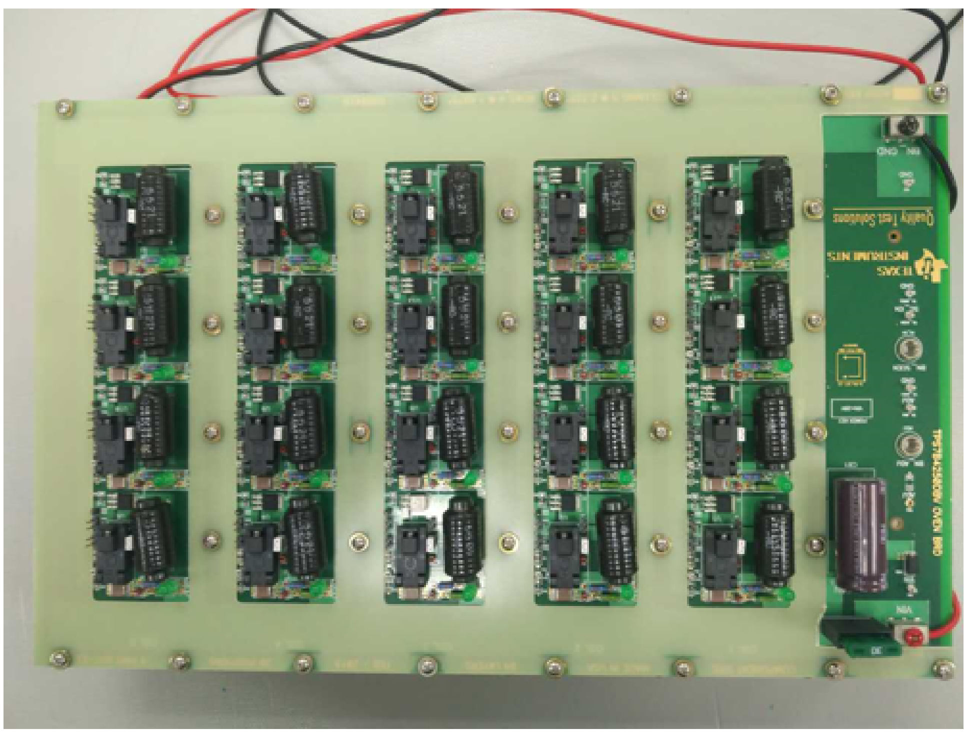

Figure 7. Oven Board

2.5 Test Procedure

2.5.1 Testing 1: Cold Repetitive Short-Circuit Test—Short Pulse

Testing 1 is tested according to section AEC Q100-012 3.4.1 with the following testing conditions:

1. The input of TPS7B4250-Q1 is connected to a 14-V battery with a 100-µF capacitor applied between VIN and GND.
2. VOUT of TPS7B4250-Q1 is short to GND.
3. A PWM waveform is applied at the ADJ/EN pin with 10 ms ON and 990 ms OFF. The 990 ms OFF is for the device to cool down (see Figure 8 and Figure 9). Figure 8 shows that the output current waveform is the same for every cycle with a 420-mA maximum transient current, which indicates that the device has completely cooled down.

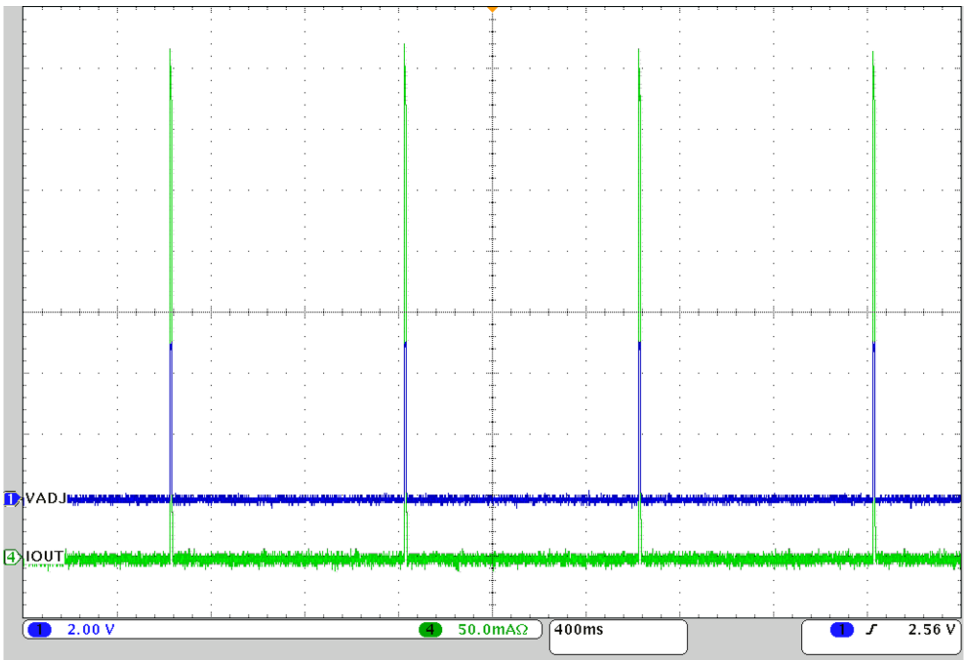

Figure 8. PWM Waveform on ADJ/EN Pin (AEC Q100-012 3.4.1 Testing)

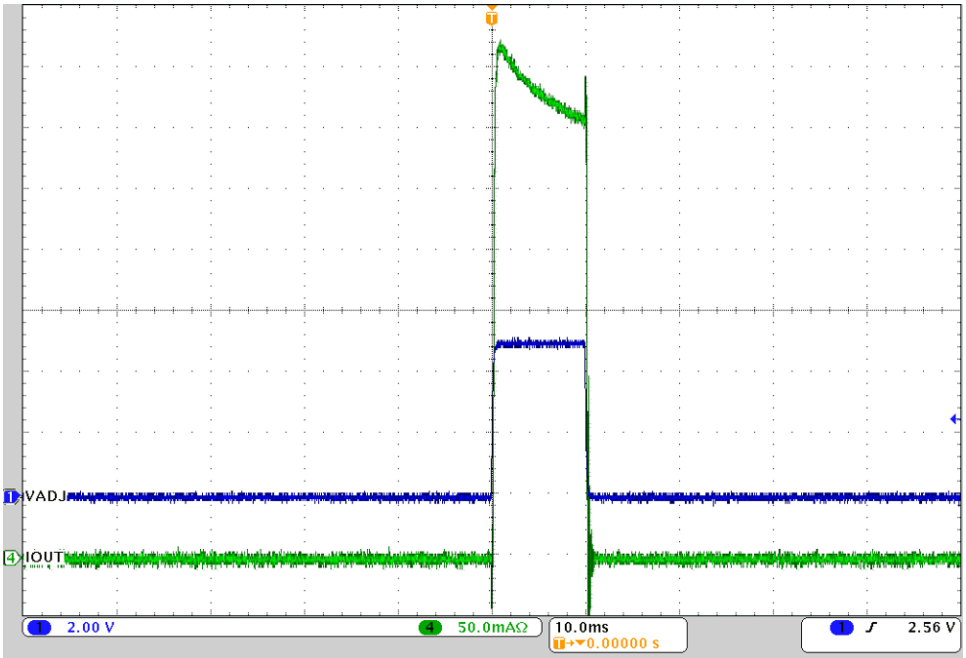

Figure 9. Zoomed PWM Waveform on ADJ/EN Pin (AEC Q100-012 3.4.1 Testing)

2.5.2 Testing 2: Cold Repetitive Short-Circuit Test—Long Pulse

Testing 2 is tested according to section AEC Q100-012 3.4.2 with the following testing conditions:

1. The input of TPS7B4250-Q1 is connected to a 14-V battery with a 100-µF capacitor applied between VIN and GND.
2. VOUT of TPS7B4250-Q1 is short to GND.
3. A PWM waveform is applied at ADJ/EN pin with 300 ms ON and 5700 ms OFF. The 5700 ms OFF is for the device to cool down (see Figure 10 and Figure 11). Figure 11 shows that the output current waveform is the same for every cycle with a 420-mA maximum transient current, which indicates that the device has completely cooled down.

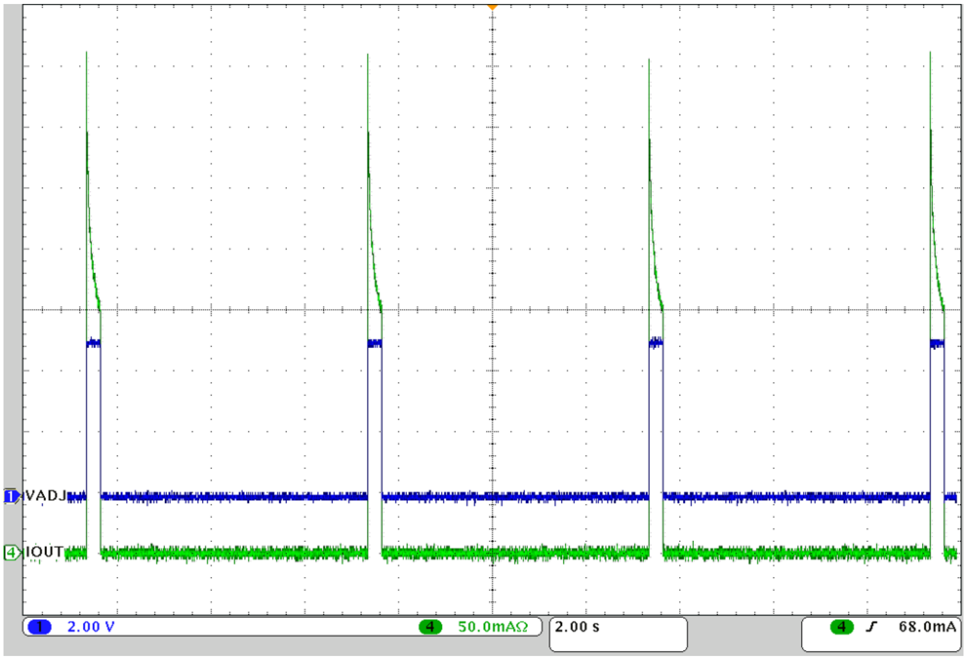

Figure 10. PWM Waveform on ADJ/EN Pin (AEC Q100-012 3.4.2 Testing)

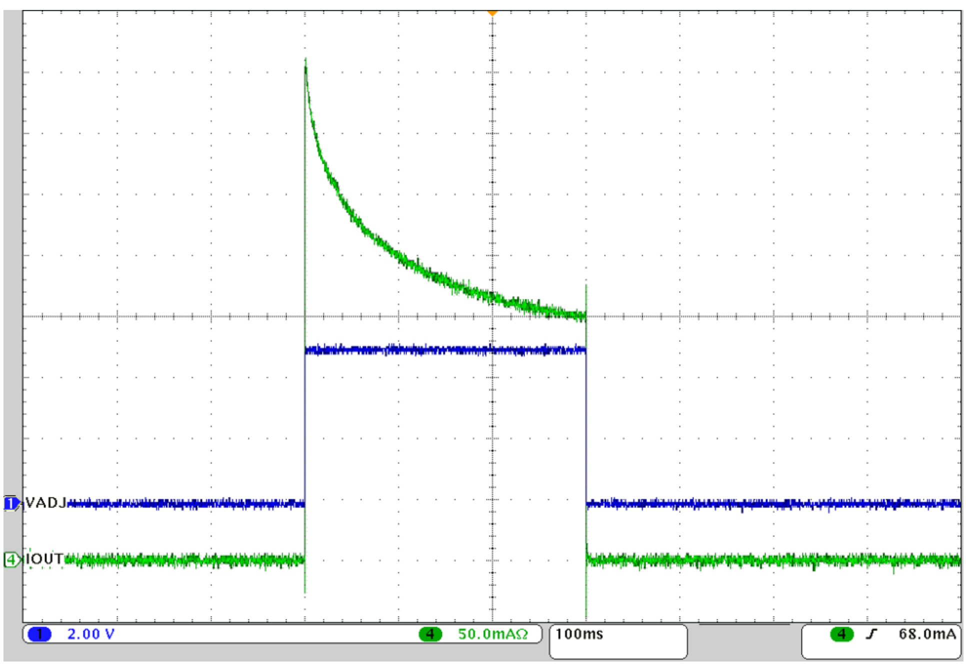

Figure 11. Zoomed PWM Waveform on ADJ/EN Pin (AEC Q100-012 3.4.2 Testing)

4. The bench is set up according to the schematic in Figure 5.
5. The testing is done in the chamber and ambient temperature is set to –40.3°C.
6. The entire testing period lasts for 170 hours, and the 10 units are tested on ATE after that. No damage or parameter shift were found.

2.5.3 Testing 3: Hot Repetitive Short-Circuit Test

Testing 3 is tested according to section AEC Q100-012 3.4.4 with the following testing conditions:

1. The input of TPS7B4250-Q1 is connected to a 14-V battery with a 2.2-µF capacitor applied between VIN and GND.
2. VOUT of TPS7B4250-Q1 is short to GND.
3. VADJ/EN is connect to a 5-V power rail.
4. Room temperature, 25°C.

The output current waveform of TPS7B4250-Q1 is shown in Figure 12, which shows that the device is in repeat thermal shutdown with about 13-ms periods.

The testing is lasted for one day which means more than 6M times thermal shutdown are triggered, after testing the device on ATE, no damage was found

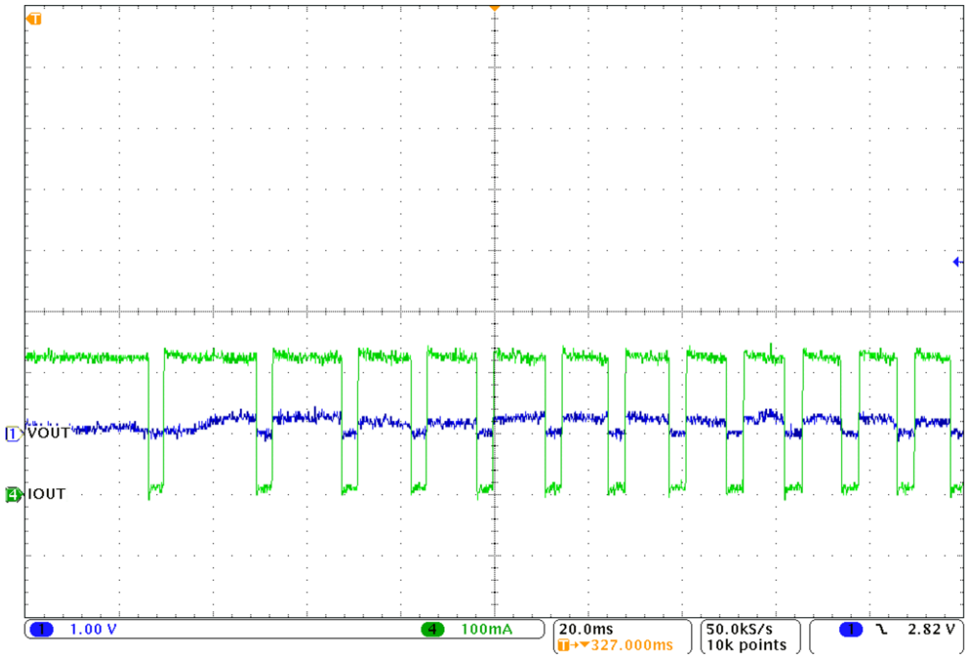

Figure 12. Output Current Waveform of TPS7B4250-Q1 With VOUT Short to GND

2.5.4 Pre-Test and Post-Test Data Check

Pre-test and post-test data are only checked for each device on the ATE. Any value outside of the device specification listed in the data sheet is regarded as a test failure.

2.6 *Results and Conclusion*

Different grade levels are specified according to the pass cycles in the AEC Q100-012 specification. Samples for short-circuit testing must be drawn from three independent lots. The sample size must be large enough to ensure the statistical validity of the data. At least 10 samples per lot per test are recommended. Table 3 lists the number of cycles and fails and lots for these grade levels.

Table 3. Grade Level Table

GRADE	NUMBER OF CYCLES	LOTS/SAMPLES PER LOT	NUMBER OF FAILS
A	> 1 000 000	3/10	0
B	> 300 000 – 1 000 000	3/10	0
C	> 100 000 – 300 000	3/10	0
D	> 30 000 – 100 000	3/10	0
E	> 10 000 – 30 000	3/10	0
F	> 3000 – 10 000	3/10	0
G	> 1000 – 3000	3/10	0
H	300 – 1000	3/10	0
O	< 300	3/10	0

Table 4 summaries the test results of the TPS7B4250-Q1 device, which are based on the previously listed test conditions and setup. No failures were detected after the 100k stress for each of the three test items.

Table 4. Test Result Summary

TEST PROCEDURE	LOTS/SAMPLES PER LOT	TEMPERATURE	CYCLES	FAILURE	ATE TEST
Cold repetitive short pulse	3/10	–40℃	1 000 000	0	Pass
Cold repetitive long pulse	3/10	–40℃	1 000 000	0	Pass
Hot repetitive pulse	3/10	25℃	1 000 000	0	Pass

With the robust silicon, after the strict test following with AEC Q100-012, the results show that the TPS7B4250-Q1 device fulfills 100k times of test without a failure. Therefore, the device is qualified as Grade C, the highest short-circuit reliability certificate in the industry.

3 References

1. Automotive Electronics Council Component Technical Committee, *AEC - Q100-012 - REVSHORT CIRCUIT RELIABILITY CHARACTERIZATION OF SMART POWER DEVICES FOR 12V SYSTEMS* (Automotive Electronics Council, 2006)
2. Texas Instruments, *Short-Circuit Reliability Test for Smart Power Switch* (SLVA709)
3. Texas Instruments, *TPS7B4250-Q1 50-mA 40-V Voltage-Tracking LDO With 5-mV Tracking Tolerance* (SLVSCA0)

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