TEXAS INSTRUMENTS

Application Report
SLVA709–June 2015

Short-Circuit Reliability Test for Smart Power Switch

ABSTRACT

Smart power switches are widely used as short-circuit protection devices 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 TPS1H100-Q1 device, a smart high-side switch from Texas Instruments.

Contents

List of Figures

List of Tables

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 smart-power switches 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 smart high-side switch (HSS). The HSS 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.

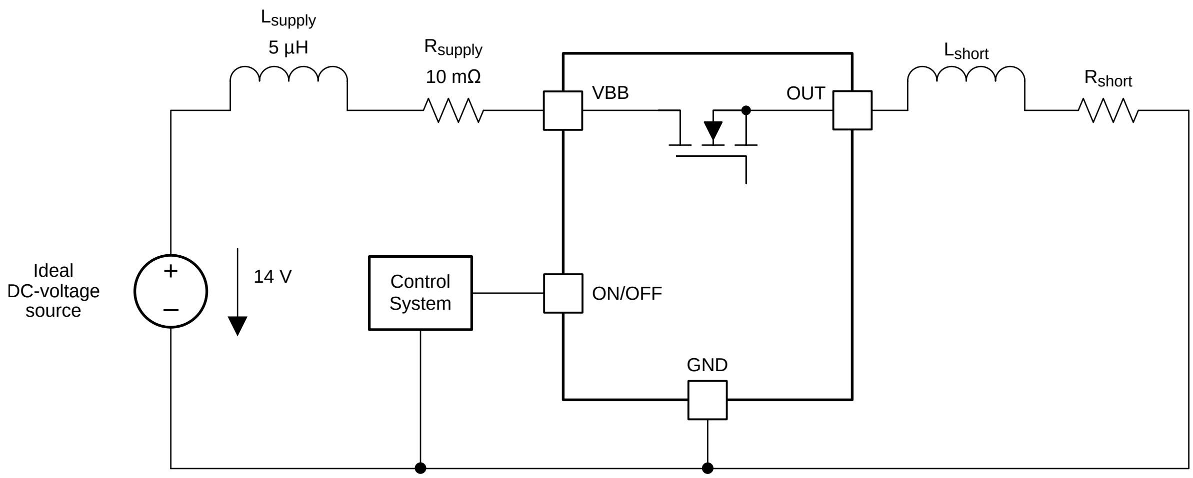

Figure 1. Smart HSS Short-Circuit Model

2 Short-Circuit Test of TPS1H100-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 TPS1H100-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	1 M
	Long pulse	–40°C, 300-ms pulse, cool down	1 M
Hot repetitive short-circuit test		25°C, keeping short	1 M

2.2.1 Cold Repetitive Short Circuit—Short Pulse

For TI's smart high-side switch, TPS1H100-Q1, a short-circuit fault can be reported on the current sense pin (CS) or the status output pin (ST). In general, the microcontroller turns off the channels when it receives the fault indication. After holding for enough cooling time, the system tries again. For high-power silicon, the stress of the sharp temperature variation should be considered, especially for the repetitive stress under extremely low temperature. The short pulse of the cold repetitive short-circuit is intended for this reliability.

Figure 2 shows the test sequence. The test sequence is as follows:

1. At point A, the short circuit occurs.
2. From point B to point E (10-ms pulse is specified in AEC-Q100-012), the internal thermal swing protection works to minimize the temperature variation.
3. From point C to point D is the thermal swing hysteresis cycle.
4. From point E to point F, the device turns off for enough time to ensure the device temperature goes back to –40°C. External sensors are required to monitor the device temperature.
5. At point F, the cycle counter increments by 1 and the next cycle occurs. Steps 1 through 4 repeat.

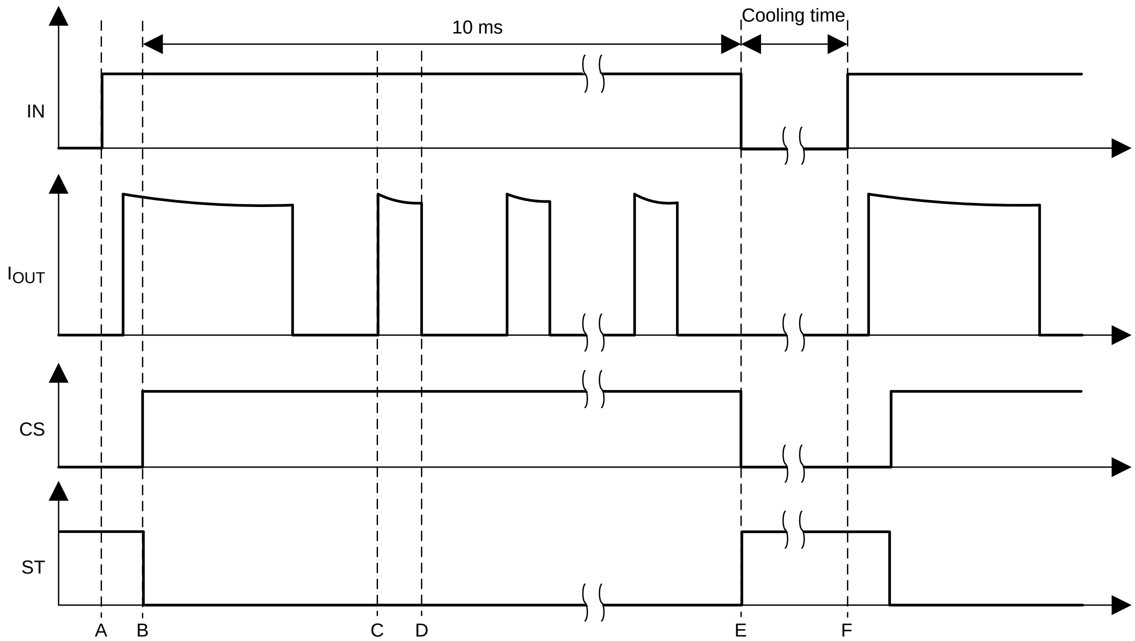

Figure 2. Timing Diagram of Cold Repetitive Short Circuit—Short Pulse

2.2.2 Cold Repetitive Short Circuit—Long Pulse

The short pulse described in Section 2.2.1 is intended to simulate the 10-ms scenario in which the microcontroller reacts; the thermal swing of the dynamic temperature protection is active. However, in some cases, the response time of the microcontroller is difficult to estimate (for example, the RC filtering delay or the conflict with higher priority interrupt). When the short-circuit cycle time increases, the device enters the absolute temperature protection region, the repetitive cycling of thermal shutdown. To verify the device reliability under this condition, the cold repetitive short-circuit long-pulse test is required. Similar to the short pulse, the start point of –40°C is the worst case.

Figure 3 shows the test sequence. The test sequence is as follows:

1. At point A, the short circuit occurs.
2. From point B to point G (300-ms pulse is specified in AEC-Q100-012), thermal swing protection is active first then thermal shutdown occurs.
3. From point E to point F is the thermal-cycling hysteresis time with half of the normal current limit value which is internally fixed.
4. From point G to point H, the device turns off for enough time to ensure that the device temperature goes back to –40°C. External sensors are required to monitor the device temperature.
5. At point H, the cycle counter increments by 1 and the next cycle occurs. Steps 1 through 4 repeat.

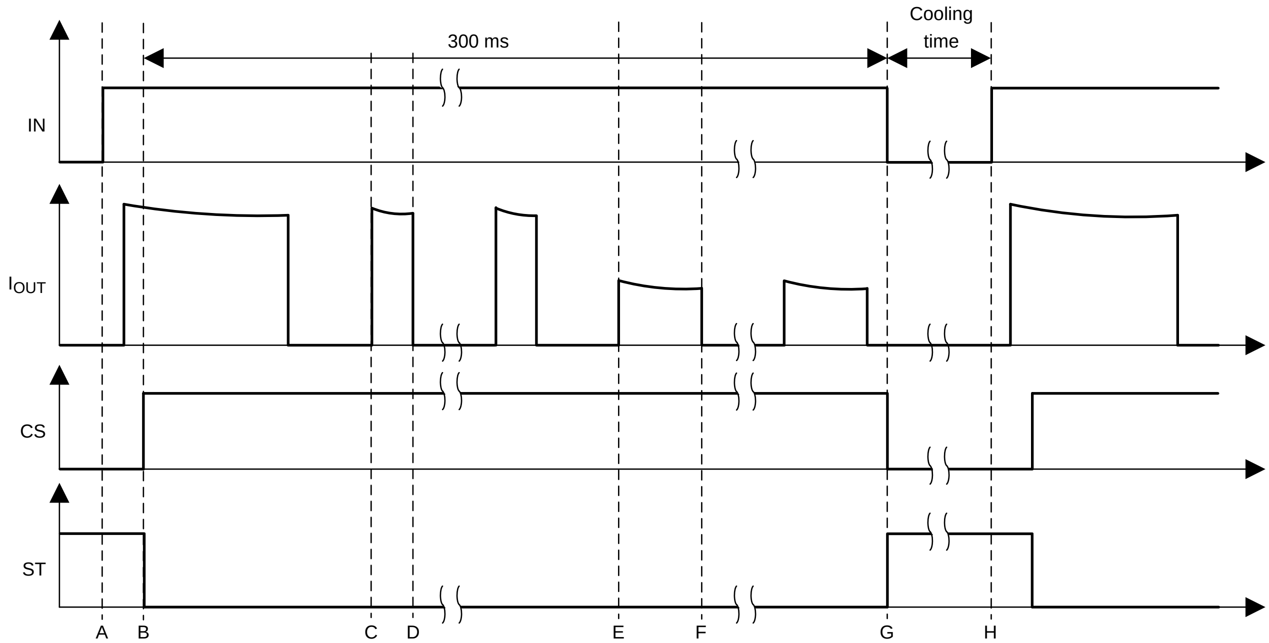

Figure 3. Timing Diagram of Cold Repetitive Short Circuit—Long Pulse

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 cool-down period for the device is not required. Also, the temperature variation occurs only at the first cycle and therefore room temperature at 25°C is acceptable.

Figure 4 shows the test sequence. The test sequence is as follows:

1. At point A, the short circuit occurs.
2. From point B to point F, thermal swing protection is active first then thermal shutdown occurs.
3. The short-circuit condition continues.

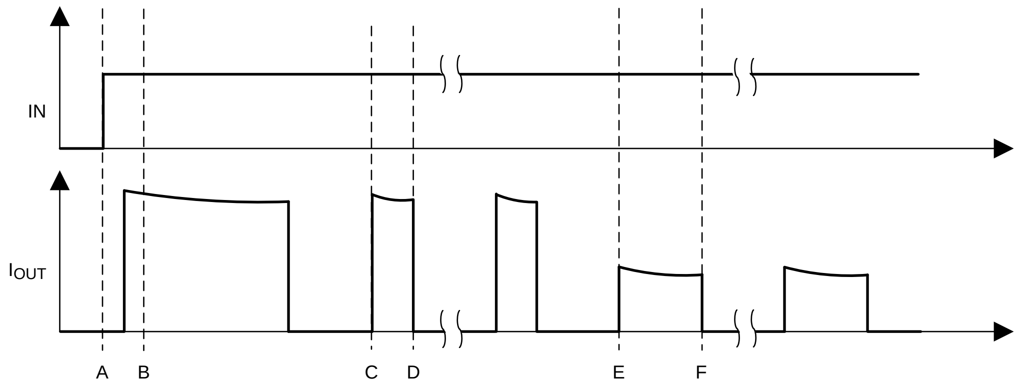

Figure 4. Timing Diagram of Hot Repetitive Short Circuit for Devices With Automatic Restart

2.3 Block Diagram

The AEC-Q100-012 standard requires at least 30 devices for a sufficient sample size. To ensure 3 test lots running in parallel, the system should accommodate a maximum of 40 devices under test (DUTs) simultaneously. System control relies on a central PC host which is linked to a PXI bus system with PXI-6509 and PXI-6224 cards. The PXI-6509 and PXI-6224 cards generate the control signals and process the feedback signals of the test. All DUTs are processed individually and independently. The PWR_IN_Sx signal enables the current-monitor device. The SC_EN_Sx signal turns on the short-circuit resistor, R_{short}. The PWR_CS_Sx signal is the short-circuit current feedback signal. The IN_Sx signal enables the HSS and triggers the short circuit.

Some power sequences are required to ensure that the test functions correctly. Follow these power sequences:

1. Power on the monitor device with the PWR_IN_Sx signal.
2. Turn on the N-MOS R_{short} with the SC_EN_Sx signal.
3. Turn on the IN_Sx signal to force the device into short-circuit mode.
4. Read back the PWR_CS_Sx signal and process it with a software algorithm.

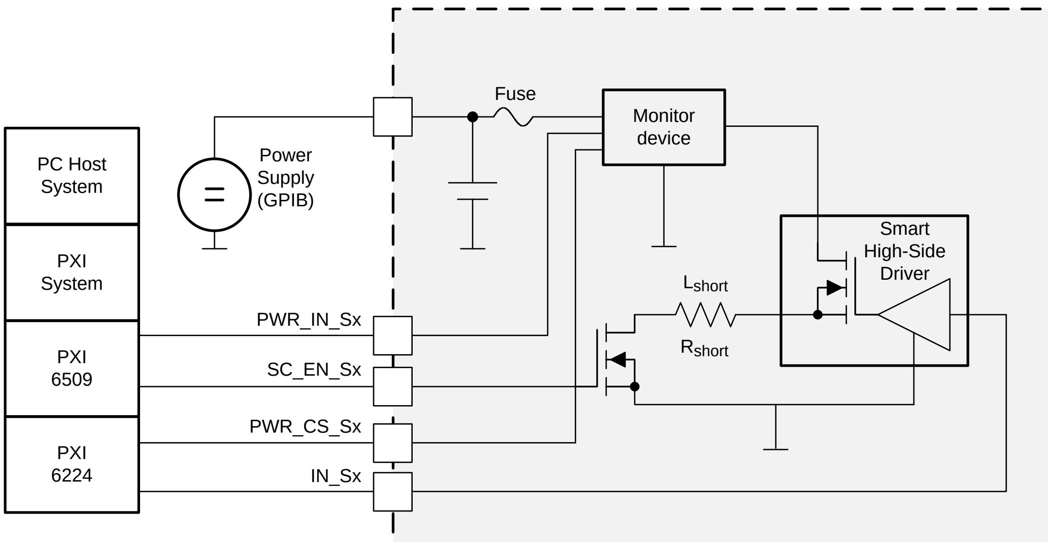

Figure 5. System Block Diagram

2.4 Test Set Up

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 shows the layout of one cell on the driver board and includes the monitor device and the connectors with the oven boards.

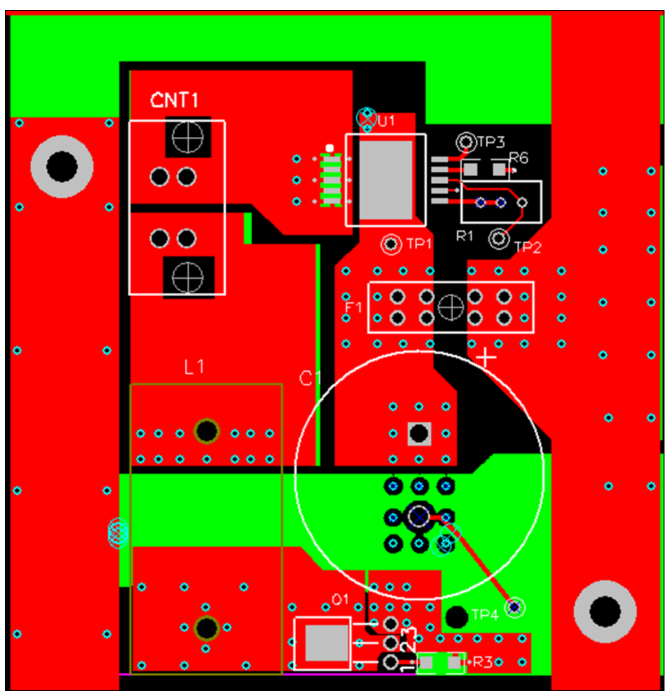

Figure 7. Layout of Driver Board

Figure 8 shows the layout of the oven board. The DUTs are placed on this board, which consists of 20 individual cells. This oven board is placed inside the oven for different temperature tests.

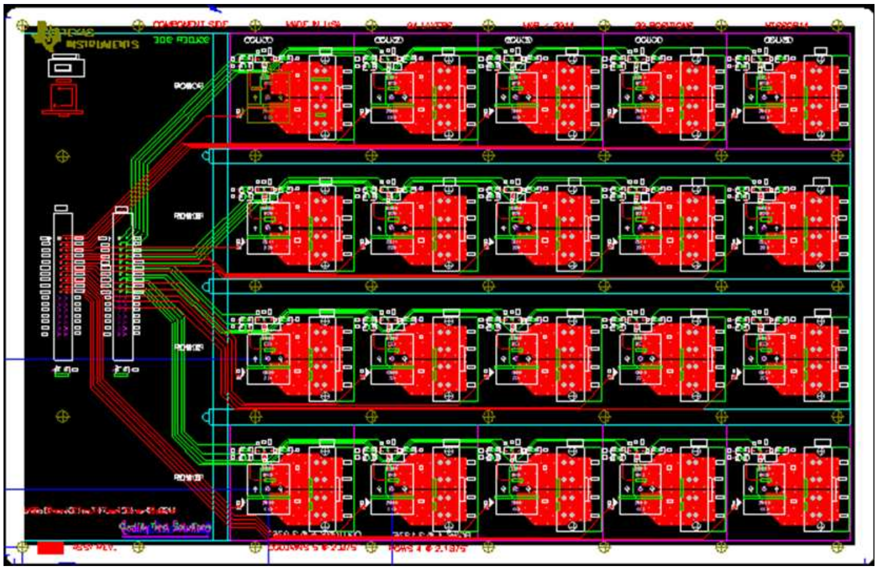

Figure 8. Layout of Oven Board

Figure 9 shows the graphical user interface (GUI) in the PC host system and how different test modes and conditions can be configured easily by the end user. The DUT status, test cycles, and waveforms can be monitored from this interface.

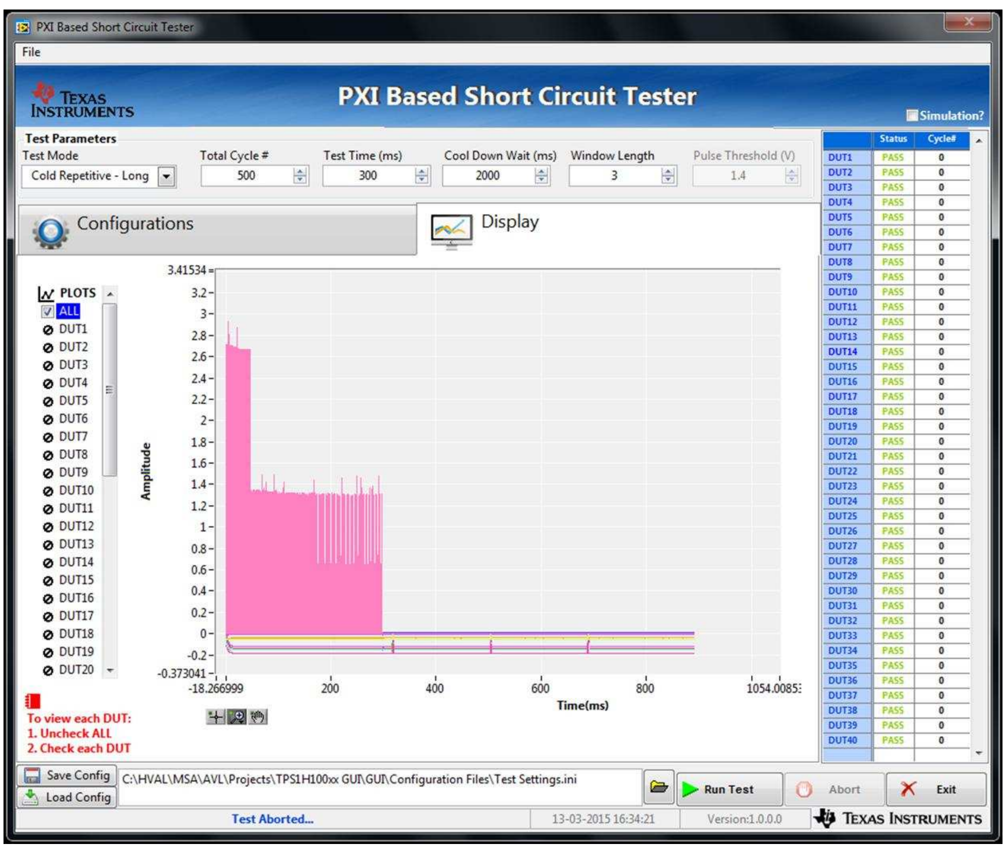

Figure 9. User Interface

2.5 Failure Check

Two types of failure checks are conducted for each device: the real-time monitor and the pre-test data and post-test data check.

2.5.1 The Real-Time Monitor

The DUT failures are under real-time monitoring, including the open load and short circuit. If either failure is detected, the number of cycles undergone by the DUT is recorded as a device failure. The two failures are defined as:

Short-circuit failure — If the PWR_CS_Sx signal reaches the maximum set value, the short-circuit failure of the DUT is detected. The controller shuts down the corresponding site and records the number of cycles that have been performed on that site.

Open-load failure — If the PWR_CS_Sx signal reaches zero for the set time, it is recognized as an open-load failure DUT. The controller shuts down the corresponding site and records the number of cycles that have been performed on that site.

2.5.2 The Pre-Test and Post-Test Data Check

Pre-test and post-test data are only checked for each device on the automatic test equipment (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 TPS1H100-Q1 device which are based on the previously listed test conditions and setup. No failure was detected after the 1-millionth 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 result shows that the TPS1H100-Q1 device fulfills 1 million times of test without a failure. Therefore, the device is qualified as Grade A, the highest short-circuit reliability certificate in the industry.

3 References

- *AEC - Q100-012 - REVSHORT CIRCUIT RELIABILITY CHARACTERIZATION OF SMART POWER DEVICES FOR 12V SYSTEMS* (Automotive Electronics Council, 2006)
- *TPS1H100-Q1 40-V, 100-mΩ Single-Channel Smart High-Side Power Switch* (SLVSCM2)

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