

**ATTACHMENT 6**

**AEC - Q101-006 REV-**

**SHORT CIRCUIT RELIABILITY CHARACTERIZATION  
OF SMART POWER DEVICES FOR 12V SYSTEMS**

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## Acknowledgment

Any document involving a complex technology brings together experience and skills from many sources. The Automotive Electronics Council would especially like to recognize the following significant contributors to the revision of this document:

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## SHORT CIRCUIT RELIABILITY CHARACTERIZATION OF SMART POWER DEVICES FOR 12V SYSTEMS

### 1. SCOPE

This document establishes a procedure for characterizing the short circuit reliability of Smart Power devices for 12V Systems. Different operating voltages (e.g., 28V, 42V) are currently outside the scope of this document.

#### 1.1 Purpose

The purpose of this specification is to determine the reliability of "protected" drivers when operating in a continuous short circuit condition. This document is not intended to address soft short circuit failures seen in incandescent lamp applications (e.g., external lighting). These applications will be considered in a separate document. Additional protection strategies and operating voltages that are currently outside the scope of this document are also being evaluated for future documents.

#### 1.2 Reference Documents

Not Applicable

#### 1.3 Terms and Definitions

##### 1.3.1 Smart Power Device

Smart power devices in the context of this document are defined as semiconductor devices that supply power to an external load and provide embedded protective functions against system malfunction due to short circuit of that load.

##### 1.3.2 Latching Protection

A device that is permanently shut down by its protective function after detecting an overload condition is called a "latching device" in the context of this document. The latched protection has to be reset by a system/firmware interaction (e.g., turning the device off or clearing a fault flag in a register) before the device may be turned on again.

##### 1.3.3 Auto-Restart Protection

A device that is shut down by its protective function after detecting an overload condition, but automatically restarts (after a given time period or removal of the fault condition; e.g., after cooling down) is called an "auto-restart device" in the context of this document. When exposed to a continuous short circuit condition, the device will generally operate in a periodic cycle of shutting down and restarting ("togglng").

##### 1.3.4 Over-Temperature Protection

A device that shuts down when a certain maximum junction temperature is reached is called "over-temperature protected". Other protection mechanisms (e.g., current limitation, pulse width modulation) may limit power dissipation to a safe value before thermal shutdown occurs. For such devices, the worst-case stress condition is generally given at minimum specified ambient temperature, causing the maximum temperature rise before thermal shut down.

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## 1.3.5 Status Feedback

A device that provides a dedicated signal informing the user (e.g., microcontroller) that an overload condition is present is called a "device with status feedback" in the context of this document.

### 1.3.5.1 Without Status Feedback

A device that performs protective functions against overload conditions, but provides no dedicated signal informing the system (e.g., microcontroller) is called a "device without status feedback" in the context of this document.

## 1.3.6 Supply Voltage

12V Systems refer to a nominal battery voltage of 12V with a range of 9V to 16V, depending on the alternator and loads. 14V is considered to be a standard average battery voltage for continuous operation. Therefore, all short circuit reliability testing will be performed at 14V.

## 1.3.7 Short Circuit

Within the scope of this document, a short circuit is defined as a constant overload condition in the load circuit that: (a) would draw a current in excess of the device's over-current limit, unless the power device under test reacts according to its embedded protective functions; or (b) results in excessive device current that triggers one (or more) embedded device protection functions. The device may also be turned on and off by external control depending on selected test conditions (see Section 3).

## 1.3.8 Soft Short Circuit

A constant overload condition in the load circuit that does not trigger the latching or auto-restart protection mechanism of the device.

## 2. EQUIPMENT

Not Applicable

## 3. PROCEDURE

### 3.1 Repetitive Short Circuit Characterization

#### 3.1.1 Test Circuit for High Side Devices

The test circuit for a high side device is shown in Figure 1. The supply is modeled by an ideal voltage source  $V_{BAT} = 14V \pm 2\%$ , a total resistance of  $R_{supply} = 10m\Omega \pm 20\%$  (including cabling and device connections), and an inductance of  $L_{supply} = 5\mu H \pm 20\%$ .

The short circuit may occur anywhere on the output cable from the device to the load. Therefore, the resistance and the inductance corresponding to this cable length may vary. They are also influenced by the diameter and geometry of the cable harness. For the purpose of short circuit reliability testing, two extreme cases are defined in Section 3.2 (see also Table 1).

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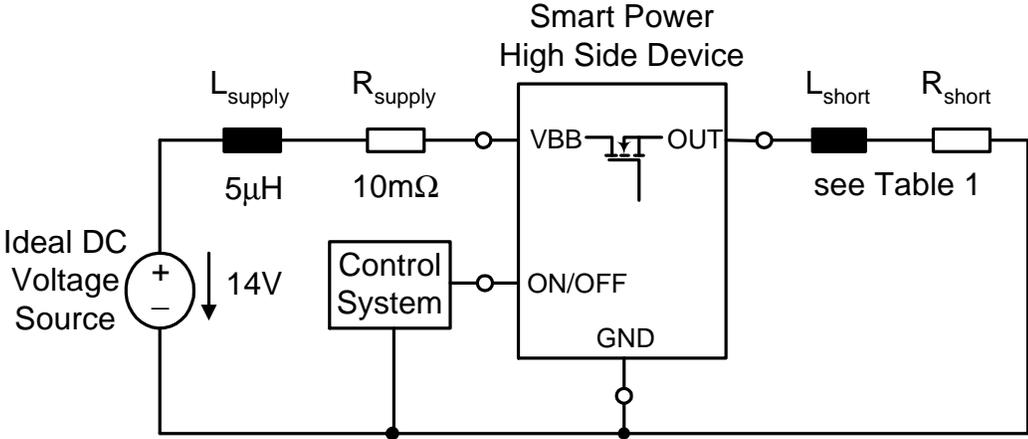


Figure 1: Equivalent Test Circuit for High Side Devices

3.1.2 Test Circuit for Low Side Devices

The test circuit for a low side device is shown in Figure 2. Since there is only one power circuit, separate impedances for supply and short circuit need not be considered. The supply and load impedances are modeled as shown in Figure 2, with the values as defined in Section 3.2 (see also Table 1).

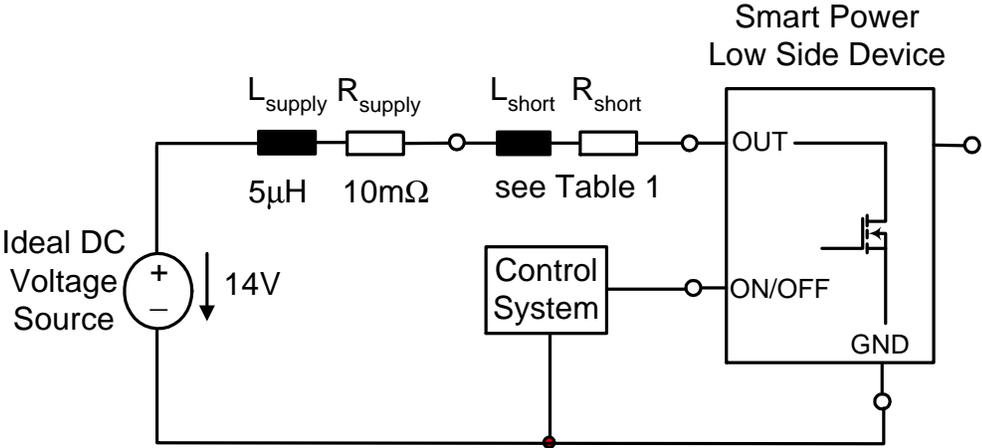


Figure 2: Equivalent Test Circuit for Low Side Devices

3.2 Operating Points for Short Circuit Testing

Actual short circuit impedances vary depending on PCB and connector resistance, cable length and diameter, and fault resistance. Two standardized worst-case conditions must be applied for short circuit reliability testing, see Table 1.

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**3.2.1 Terminal Short Circuit (TSC)**

A short circuit occurring directly on the system terminals close to the device, modeled by  $L_{short} < 1\mu H$  and  $R_{short} = 20m\Omega$ . The TSC impedances correspond to that of the PCB traces, connector and fault resistance. The wiring inductance must not exceed  $1\mu H$ .

\* **Note 1: TSC testing is not required for outputs with  $I_{short} \leq 20A$ .**

**3.2.2 Load Short Circuit (LSC)**

A short circuit occurring at the end of a cable connecting the device with the load, modeled by  $L_{short} = 5\mu H$  and  $R_{short}$  depending on device specification:

$R_{short} = 100m\Omega$  for specified short circuit current  $20A < I_{short} \leq 100A$

$R_{short} = 50m\Omega$  for specified short circuit current  $I_{short} > 100A$

The LSC impedances correspond to a cable harness of approximately 5 meters in length and  $1mm^2$  or  $2mm^2$  cross-sectional area with a low-ohmic ground path.

**3.2.2.1 Supply Voltage Compensation**

To compensate for connection resistances (e.g., due to socketing, cabling, connectors, etc.) encountered when performed LSC testing, the supply voltage may require adjustment to maintain the desired voltage drop across the load and test device. The compensated supply voltage can be calculated by using the following equation:

$$V_{supply} = R_{total} * I_{short} \quad \text{where}$$

$$R_{total} = 110m\Omega + R_{device} + R_{parasitic}$$

$$110m\Omega = R_{short} + R_{supply}$$

$R_{device}$  = Device resistance while in short circuit

$R_{parasitic}$  = Cumulative resistance of all the connections, cabling, etc..

**Table 1: Definition of Impedances for Short Circuit Characterization**

Operating Point	Description	$R_{short}$ (mW) $\pm 20\%$	$L_{short}$ ( $\mu H$ ) $\pm 20\%$
Terminal Short Circuit	Short at module	20	< 1
Load Short Circuit	Short at load, $I_{short} \leq 20A$	See Section 3.2.2.1	5
Load Short Circuit	Short at load, $20A < I_{short} \leq 100A$	100	5
Load Short Circuit	Short at load, $I_{short} > 100A$	50	5

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### 3.3 Test Set-up Materials and Conditions

Printed circuit board design, connectors, test sockets, and materials are all important for the validity and repeatability of Short Circuit test results. Proper test setup precautions need to be taken. The devices under test have to be mounted and wired in an appropriate way to ensure:

- a. Low-ohmic electrical contact according to the requirements stated in Table 1.
- b. Cooling conditions as recommended for their application by the supplier.
- c. No performance degradation due to mounting conditions.

The performance of short circuit reliability testing and the relationship of the results to the application in the field depend on the cooling rate of the part under test, the cooled temperature at the moment of the subsequent trigger pulse and the starting (or ambient) temperature of the test setup. The cooling rate is dependent on heat sinking and materials used in the test setup. The cooled temperature at the moment of the subsequent trigger pulse is dependent on the time between pulses.

### 3.4 Selection of Test Conditions

The following test conditions have to be selected according to the protection concept, including status feedback, of the smart power device:

#### 3.4.1 Cold Repetitive Short Circuit Test - 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 10ms ( $\pm 20\%$ ) after receiving a status feedback or going into shutdown (see Figure 3). 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 (see Section 3.4.3). This sequence is repeated until a failure of the device is detected. The number of cycles to failure is recorded for statistical evaluation (see Section 4).

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.

#### 3.4.2 Cold Repetitive Short Circuit Test - Long Pulse

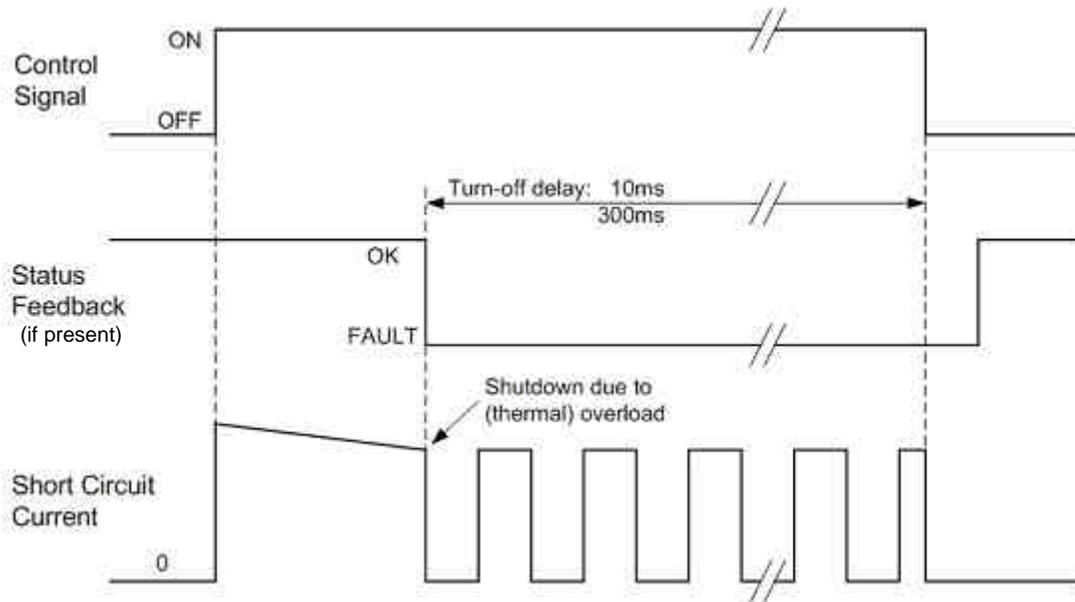
This test must be performed for all auto-restart devices.

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

The time between consecutive long pulses must be long enough to ensure the device cools sufficiently to reach the test temperature (see Section 3.4.3). This sequence is repeated until a failure of the device is detected. The number of cycles to failure is recorded for statistical evaluation (see Section 4).

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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**

### 3.4.3 Device Test Temperature for Cold Repetitive Short Circuit Testing

For over-temperature protected devices (see Definition 1.3.4), repetitive short circuit testing must be performed at minimum specified device test temperature (generally  $-40^{\circ}\text{C}$  for automotive devices). For other protection concepts not involving over-temperature shutdown, the worst-case device test temperature must be evaluated by performing repetitive short circuit testing at minimum and maximum specified ambient temperature. If another device test temperature is required for application characterization,  $25^{\circ}\text{C}$  is recommended as a standard condition.

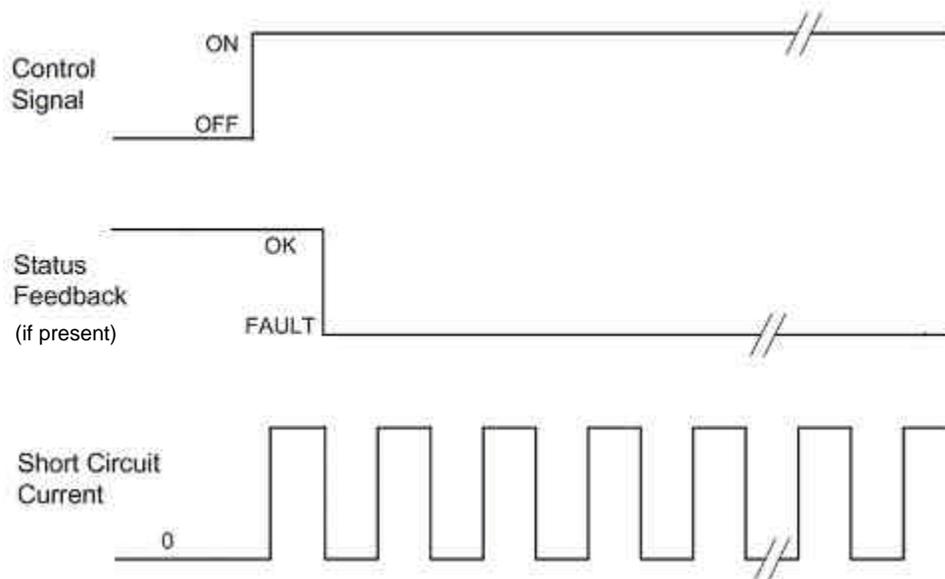
### 3.4.4 Hot Repetitive Short Circuit Test

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

"Hot" repetitive short circuit testing refers to the condition of a toggling operation close to the shutdown temperature. The smart power device is placed into short circuit mode and turned on according to Table 1, and left on to operate in auto-restart mode until a failure of the device is detected (see Figure 4). For this test, the ambient temperature is set to  $25^{\circ}\text{C}$ . The devices shall be exposed to a forced air flow to provide sufficient cooling conditions. The number of cycles to failure is recorded for statistical evaluation (see Section 4).

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/microcontroller is not reacting.

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**Figure 4: Typical Timing Diagram for Hot Repetitive Short Circuit Device Signals**

### 3.5 Practical Implementation of Test Pulses

Cold repetitive test pulses, described in Sections 3.4.1 and 3.4.2, can be implemented in two ways:

#### 3.5.1 Status Feedback Signal Detection

For devices providing a status feedback signal, it is recommended that the test equipment be capable of detecting and reacting to the status feedback signal provided by the device under test with a maximum delay of 5ms.

#### 3.5.2 No Status Feedback Signal Detection

If the test equipment is not capable of detecting the status feedback signal, the total pulse width may be determined offline by measuring the maximum time required to provide the status feedback signal for the given sample of devices under test, and adding the specified delay (10ms or 300ms, respectively) to achieve the worst-case pulse width, which shall then be applied for all devices. If this procedure yields less than 20% difference of total pulse widths for the tests defined in Sections 3.4.1 and 3.4.2, only the longer pulse width of Section 3.4.2 shall be used.

#### 3.5.3 Test Implementation Example

Consider a sample of devices that deliver their status feedback between 1500ms and 2000ms after turn on and are placed into short circuit. The devices will be tested with the following pulse widths applied to the device control inputs:

- a. Equipment Capable of Feedback Detection:
  - Short Pulse = 1510 ... 2010ms
  - Long Pulse = 1800 ... 2300ms (individually controlled by test equipment)
- b. Equipment Not Capable of Feedback Detection:
  - Short Pulse = 2010ms - not tested, < 20% difference to long pulse
  - Long Pulse = 2300ms (test equipment set to maximum for all devices)

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### **3.6 Detection of Failures**

Failures related to short circuit operation may occur in two ways:

- Device incapable of turning off (electrical short)
- Device incapable of turning on (open circuit)

The test procedure must ensure that both failure modes are detected. When device failures are detected, care must be taken to avoid having device failures influence or damage other devices under test.

Short circuit stress causes a degradation of physical properties of devices under test and consequently a shift of electrical parameters (e.g., on-resistance). Drift of electrical parameters beyond specified limits can therefore be used as an alternative failure criterion in cases where conventional (open/short) failures cannot be observed in a reasonable testing time.

### **3.7 Sample Size**

Samples for short circuit testing must be drawn from 3 independent lots. The sample size must be large enough to guarantee the statistical validity of the data. At least 10 samples per lot per test are recommended.

### **3.8 Multiple Output/Channel Devices**

When testing devices with multiple outputs/channels, it is acceptable to test one device output/channel that is representative of other "like" outputs/channels. A "like" output/channel is defined as having the same electrical characteristics (e.g., drive current, protection circuitry, etc.) as other device outputs/channels. For example, an 8 channel device with four 0.5A outputs/channels, two 1A outputs/channels, and two 2A outputs/channels would require three separate short circuit test groups - one for the 0.5A outputs/channels, one for the 1A outputs/channels, and one for the 2A outputs/channels.

### **3.9 Test Termination Criteria**

A repetitive short circuit test as described in this document shall be terminated by one of the following two conditions:

- a. At least 50% of all devices tested at a given condition have failed according to the criteria defined in Section 3.6.
- b. If an insufficient number of failures are observed for statistical evaluation, the test may be terminated after a pre-defined testing time. At least 100 hours (Hot Repetitive Testing) or 100,000 switching cycles (Cold Repetitive Testing) are recommended.

If the test is terminated before at least 50% of all devices under test have failed, the remaining parts must be characterized to the parametric limits of the device specification or datasheet to prove that they are within specifications.

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## 4. EVALUATION AND REPORTING OF TEST RESULTS

### 4.1 Description of Test Conditions

A report of repetitive short circuit test results shall contain the following minimum information:

- a. Specification of test circuit including impedance values and supply voltage
- b. Device test temperature
- c. Pulse width and repetition rate (if applicable)
- d. Sample size
- e. Test results in the form described in Sections 4.2 or 4.3.

### 4.2 Statistical Evaluation of Failure Data

If a sufficient number of failures have been observed for statistical evaluation, the cumulative failure distribution of failed components versus the number of cycles to failure (CTF) can be fitted numerically to a Lognormal or Weibull distribution (see Figure 5 for an example of a distribution fitted to measured data).

#### 4.2.1 Cumulative Lognormal distribution:

$$F(CTF) = \Phi\left(\frac{\log(CTF) - \log CTF_{mean}}{\log s}\right)$$

$\Phi$  = cumulative normal distribution function  
 $\log CTF_{mean}$  = logarithmic CTF mean value  
 $\log \sigma$  = logarithmic standard deviation

#### 4.2.2 Cumulative Weibull distribution:

$$F(CTF) = 1 - \exp\left(-\left[\frac{CTF}{CTF(63\%)}\right]^g\right)$$

CTF(63%) = cycles for 63% failures  
 $g$  = Weibull exponent

#### 4.2.3 Distribution data may be reported in the following forms:

- a. Statistical parameters of the chosen distribution as specified above.
- b. A table of cycles to failure for given cumulative failure rates. At least 100ppm and 1000ppm values are recommended.

4.2.4 For Hot Repetitive Short Circuit Testing, the toggling/re-triggering frequency of the device must be reported to enable the calculation of a time to failure.

### 4.3 Grade Level Description of Test Results

If the conditions of Section 3.9 for test termination have been met, test results may be reported in the form of a grade level according to Table 2. The grade level shall either be determined by the number of cycles until the first observed failure, or by the total number of tested cycles, if no failure occurs within a sample during the duration of the test.

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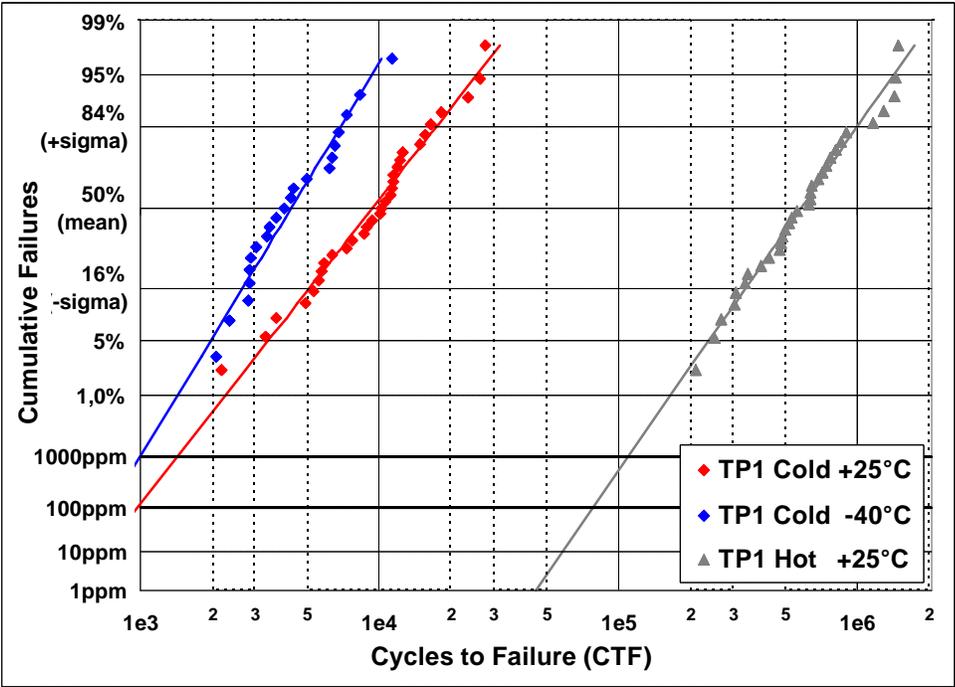
**Table 2: Cycle Capability Grades**

Grade	# Cycles	Lots/Samples per lot	# 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	>3,000 – 10,000	3/10	0
G	>1,000 – 3,000	3/10	0
H	300 – 1,000	3/10	0
O	< 300	3/10	0

If a sufficient number of failures have been observed, it is recommended that the statistical evaluation (see Section 4.2) be performed and the distribution parameters reported, as this yields the most complete information to the customer.

Grade levels (see Section 4.3) can always be specified even in the case of insufficient failure data (e.g., due to robust performance of tested products or economical constraints on testing time), but they contain less information for the purpose of reliability calculation.

**Figure 5: Example of a Log-Normal Data Plot**



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**Revision History**

<u>Rev #</u>	<u>Date of change</u>	<u>Brief summary listing affected sections</u>
-	Sept. 14, 2006	Initial Release