Tech Note

Determining Mission Profile Compatibility for LDOs

A commonly asked question for automotive-grade LDOs is whether a particular mission profile is sufficiently fulfilled by a vendor's qualification tests. This tech note will illustrate how to compare a given mission profile against a standardized stress test as well as highlight other considerations to keep in mind.

AEC-Q100 standards

In order to standardize the minimum qualification requirements for reliability in automotive applications, the Automotive Electronics Council created a dedicated document (AEC-Q100 Rev. H) that stipulates the various stress tests with respective conditions that should be successfully completed prior to a broad release to market.

Included amongst those tests is High Temperature Operating Life (HTOL), also known colloquially as a 'life test'. HTOL is used to determine the reliability of a device at high temperature while under operating conditions in an effort to accelerate the lifecycle of a device in a shorter amount of time. Customer mission profiles are typically compared against HTOL tests to determine sufficiency.

The duration and stress conditions for HTOL depend on the temperature grade of the device. Table 1 details the temperature and duration stress conditions for each grade.

Table 1. AEC-Q100 temperature grades

Temp. Grade	Ambient Operating Temp. Range (T_A)	HTOL stress conditions
0	-40°C to +150°C	+150°C T_A for 1000 hours
1	-40°C to +125°C	+125°C T_A for 1000 hours
2	-40°C to +105°C	+105°C T_A for 1000 hours
3	-40°C to +85°C	+85°C T_A for 1000 hours

Temperature Range

It is important to note that although an LDO may be qualified per a particular temperature grade (ex. Grade 1), the operating junction temperature (T_J) of the LDO (e.g. -40°C to +150°C) may, and often does, exceed the operating ambient temperature range (T_A) (e.g. -40°C to +125°C).

The reason for this is practical. LDOs dissipate power as part of regulation. That dissipation raises the temperature of the junction as per the well-known thermal equation:

$$T_J = T_A + P_D \times R_{\theta JA} \tag{1}$$

The wider range associated with operating junction temperature allows for the device to account for heat rise from dissipation without violating the operating ambient temperature range. As an example, assume the TPS7B81-Q1 (DGN package) operating from a 12 V battery, regulating 5 V and sourcing up to 50 mA in a 125°C environment:

$$T_J = 125°C + 0.35W \times 63.9°C/W \tag{2}$$

$$T_J = 147.4°C \tag{3}$$

As shown, the junction temperature exceeds the 125°C limit of the operating ambient temperature range while still being within the operating junction temperature range. (It's important to note that the operating junction temperature range is not governed by the AEC-Q100 qualification.)

Acceleration and equivalency

Although a Grade 1 qualified device is stressed to +125°C for 1000 hours, this is unlikely to be the exact condition that the device will undergo in its final application. Typically, the conditions, or mission profile, are listed in tabular fashion as seen in Table 2:

Table 2. A typical mission profile

T_A (°C)	Number of hours
0	100
25	4000
85	3400
100	500

Equivalency must be calculated through the acceleration model known as the Arrhenius equation:

$$A_f = e^{[\frac{E_a}{k_B}\times\left(\frac{1}{T_u}-\frac{1}{T_t}\right)]} \tag{4}$$

where:

- E_A is the activation energy (typically 0.7 eV)
- k_B is Boltzmann's constant (8.61733×10^{-5} eV/K)
- T_u is the application temperature (in K units)
- T_t is the over stress temperature (in K units)

By calculating the acceleration factor (A_f) for each temperature in the table, it is possible to determine the equivalent number of hours for stressing the part at +125°C by dividing the hours by the A_f.

Table 3. Determining accelerated testing

T_A (°C)	Number of hours	Acceleration Factor	Equivalent number of hours
0	100	11349.30	≪1
25	4000	937.19	4.3
85	3400	9.76	349.3
100	500	3.92	127.5

Per Table 3, 480.1 hours of HTOL testing at +125°C is equivalent to the mission profile. Since this is less than the standard 1000 hours of +125°C testing, a Grade 1 LDO would be adequately adapted for this mission profile.

This, however, doesn't take into account additional heating as the result of dissipation across the LDO. Therefore, the mission profile must be modified to incorporate self-heating. Using the previous example, the mission profile and acceleration factors can be recalculated, as shown in Table 4:

Table 4. Including power dissipation

T_J (°C)	Number of hours	Acceleration Factor	Equivalent number of hours
22.4	100	1194.95	0.1
47.4	4000	140	28.6
107.4	3400	2.57	1320.9
122.4	500	1.15	436.5

With dissipation included, the total number of equivalent stress hours at +125°C is 1786.1. (Notice that the junction temperature was used instead of the ambient temperature.) This exceeds the 1000 hours tested for a Grade 1 device.

Exceeding AEC-Q100 test conditions

When the stress conditions of an HTOL test are exceeded there are a few options to evaluate.

One of the quickest is determining if there is another package or a different device that will lower the effective thermal resistance. This will, in effect, lower the junction temperature rise and increase the acceleration factor(s).

Referring to the previous example, the TPS7B81-Q1 is also available in a TO-252 package which reduces the thermal resistance from 63.9°C/W to 31.1°C/W. This also reduces the factors as shown in Table 5:

Table 5. Optimizing thermal resistance

T_J (°C)	Number of hours	Acceleration Factor	Equivalent number of hours
10.9	100	3630.13	≪1
35.9	4000	358.94	11.1
95.9	3400	5	680
110.9	500	2.12	236.2

With the thermal resistance reduced, the total number of equivalent stress hours is 927.4. Now a Grade-1 HTOL test sufficiently fulfills the mission profile.

In a similar vein, the device and package can remain the same but modifications to the PCB can lower the thermal resistance. This topic is covered in another application note.

If moving to another device, package or PCB modification isn't an option, a higher temperature grade LDO is also a means of widening coverage. A grade-0 device, for example, increases the acceleration factor by virtue of being tested at 150°C. Unfortunately, the market for Grade-0 devices remains limited.

In some cases, supplementary HTOL testing by the vendor can be conducted to adequately satisfy a mission profile that exceeds the standard testing. This, however, requires negotiation between vendor and customer.

Conclusion

The standard HTOL testing in accordance with AEC-Q100 rev. H provides a useful means of determining the reliability of a device over its lifetime. By using the Arrhenius calculations, a mission profile can be compared to a stress test to determine its viability. Furthermore, thermal impedance can be lowered or a more severe stress testing can be used to fulfill a mission profile that goes beyond standard testing.

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