Thermal Stress in Current Limit and Circuit Breaker Mode – TPS2660 eFuse

Power Dissipation in Current Limit:

TPS2660 operating in active current limiting will limit current and V_{OUT} will drops lower than V_{IN}. Power dissipated by the device in current limit is

$$P_D = I_{LIMIT} * (V_{IN} - V_{OUT}).$$

Power Dissipation in Circuit Breaker:

In circuit breaker mode, device allows current greater than I_{LIMIT} for 4ms only and device will turn off. Power dissipated by the device in circuit breaker mode is

$$P_D = I_{LIMIT}^2 * R_{ON}.$$

Junction Temperature Rise:

P_D will heat the device based on thermal resistance θ_{JA}. Junction temperature will increase by

$$T_J = T_A + \theta_{JA} * P_D.$$

Current Limit Example:

Let us say current limit is set to 2A and if the load tries to take more current than 2A, TPS2660 will limit current and V_{OUT} will drop based on power drawn by the load.

For 24V V_{IN}, let us assume the power drawn by the load is 24W i.e., 1A load (effective R_{LOAD} of 24ohm). If the load changes to 60W i.e., 2.5A (effective R_{LOAD} of 9.6ohm), TPS2660 will limit current to 2A and V_{OUT} will droops to

$$V_{OUT} = I_{LIMIT} * R_{LOAD\_EFFECTIVE}$$

$$= 2 * 9.6 = 19.2V$$

$$P_D = 2 * (24 – 19.2) = 2 * 4.8 = 9.6W$$

For a device is operating at ambient 25°C, device junction temperature will increase by

$$T_J = 25 + 38.6 * 9.6 = 395.56°C.$$

Here '38.6' is TPS2660's TSSOP package thermal resistance θ_{JA}. Junction temperature T_J is more than TSD of 157°C and the device will enter thermal shutdown and turn off.

Time taken to enter thermal shutdown:

Time taken for junction temperature to rise is based on the power dissipated and the operating temperature of the device as shown in Figure 1. Refer to the "Thermal shutdown limit plot" tab in design calculator sheet http://www.ti.com/lit/zip/slvc668.

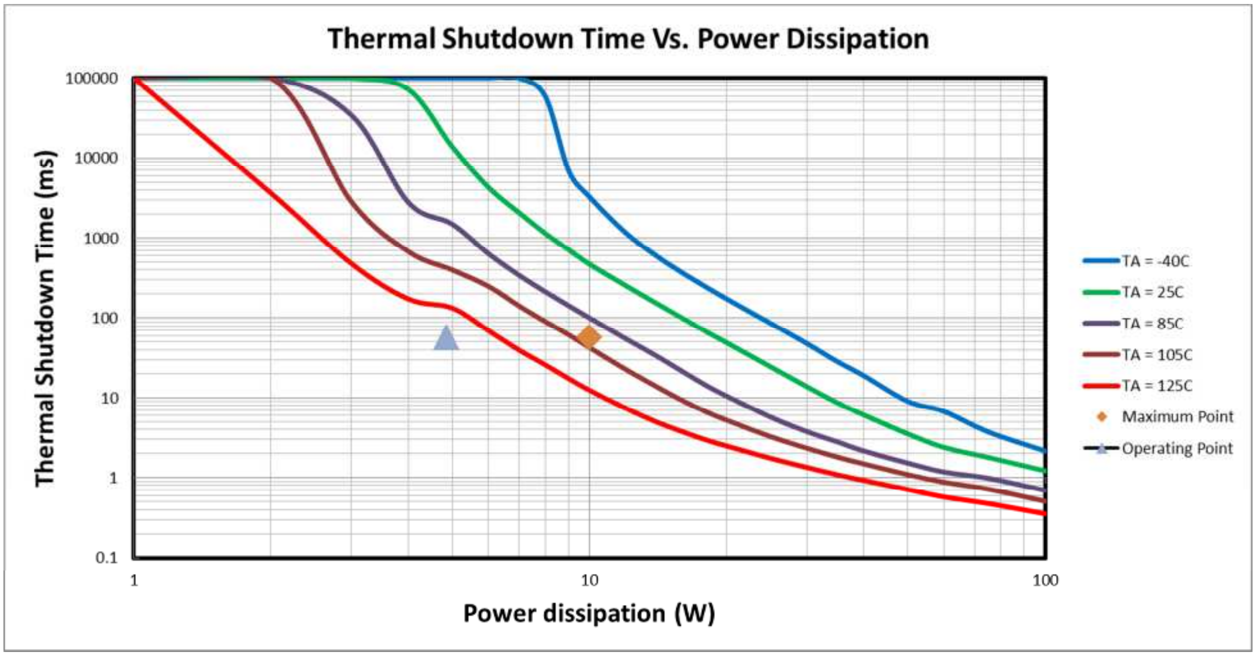

Figure 1: Thermal Shutdown Time (ms) Vs. Power Dissipation (W)

For example, at 25°C ambient operating temperature, with 10W of P_D the device takes 472ms to turn off due to TSD.

Circuit Breaker Example:

For example, if circuit breaker limit is set to 2.22A and the load tries to draw more current than 2.22A, TPS2660 will allow that current for 4mS as long as it is lower than fast-trip threshold. For 2.22A circuit breaker threshold, fast trip threshold is 3.996A (2.22 * 1.8). For a worst case thermal stress during 4ms, assume that load tries to draw close to 3.9A, power dissipation is

$$P_D = 3.9^2 * 0.16 = 2.43W$$

If the device is operating at ambient 25°C, device junction temperature will increase by

$$T_J = 25 + 38.6 * 2.43 = 118.8°C$$

This T_J is less than TSD of 157°C and the device will not enter thermal shutdown.

If the device is operating at 70°C, then T_J will be 163.8°C and it is greater than TSD. According to the design calculator, it will take more than a minute to turn off the device. Though T_J > TSD, TPS2660 will not enter thermal shutdown as the circuit breaker turns off the device within 4ms.

Auto-Retry Mode:

In auto-retry mode, device will attempt to restart after 540ms. Current limiting device in auto-retry mode will be hot until it hits TSD and after TSD it will retry after 540ms i.e., cools down.

Average junction temperature of a device operating in current limiting with auto-retry will settle at a value based on the duty cycle. For the current limit example discussed above, P_D is 9.6W and it takes about 590ms to enter TSD according to the design calculator. Average junction temperature increase, as the device keeps auto-retrying in current limit is

$$T_{J\_CL\_AR} = T_A + (T_J - T_A) * T_{DUTYCYCLE}$$

$$= 25 + (157-25) * 590 / (590 + 540) = 94°C.$$

Similarly, a device operating in circuit breaker with auto-retry, average junction temperature is

$$T_{J\_CB\_AR} = 25 + (157-25) * 4 / (4 + 540) = 26°C.$$

Summary:

TPS2660 operating in current limit experiences more thermal stress than a device operating in circuit breaker mode. Device auto-retrying in current limit will remain warm.