Packaging Limits Range of Linear Regulators

Scot Lester — Linear Regulators, Power Management Products

ABSTRACT

The power limitations of the physical packaging for a linear regulator device can limit the total output current or the input-to-output voltage differential. This inherent limitation is not always apparent from the product data sheet and must be evaluated during the design phase. This application note shows how the package can limit the operating envelope of a linear regulator.

1 Introduction

Typically, engineers select linear regulators based on a few specifications listed on the front of the data sheet that outline the operating envelope of the regulator, such as input voltage range, output voltage, output current and dropout voltage. Then, these designers typically search for the smallest package size available, so that the overall solution size is minimized. This selection process, however, can lead to thermal problems in the end application or solution because the thermal characteristics of the device packaging can impose limits on the operating envelope described in the data sheet.

For example, the product data sheet for the TPS73401 linear regulator states the input voltage can range from 2.7 V to 6.5 V; the output voltage can be set to any value between 1.2 V and 6.3 V; and the device can provide up to 250 mA of output current. The data sheet also specifies that the device is available in either a 5-pin TSOT23 or 6-pin SON package.

Based on these specifications, the operating envelope of the linear regulator could be graphed as shown in Figure 1.

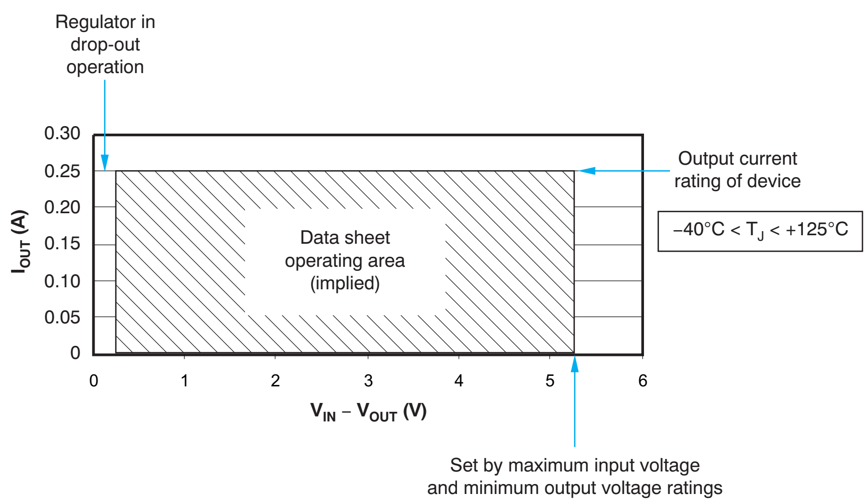

Figure 1. Implied Operating Area of a Linear Regulator Based on Data Sheet Specifications

The x-axis in Figure 1 is the input voltage minus the output voltage, or more simply, the voltage drop across the linear regulator. The lower end of the operating window x-axis is limited by the dropout voltage of the linear regulator, while the upper end is limited by both the maximum input voltage and the minimum output voltage that the regulator can support.

2 Procedure

The first step of the required thermal analysis is to determine the power dissipation of the linear regulator. Figure 2 illustrates a generic linear regulator with its relevant voltages and currents.

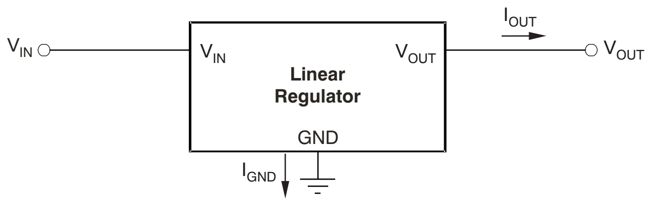

Figure 2. Generic Linear Regulator

The power dissipated by the linear regulator is calculated in a fairly straightforward manner. We have the power dissipated by the voltage drop across the regulator, and we multiply that value by the load current passing through the regulator. There is also an additional power loss as a result of the quiescent current required to operate the internal logic and control functions. This power loss is simply the quiescent current, or ground-pin current, multiplied by the input voltage. The equation for the total power dissipation of the regulator is given in Equation 1.

$$P_D = (V_{IN} - V_{OUT}) \bullet I_{OUT} + I_{GND}V_{IN} \quad (1)$$

The next step of the analysis is to determine the junction temperature of the linear regulator. The easiest method for this calculation is to multiply the power dissipation by the thermal impedance of the selected package; this step shows us the temperature increase. We can then add this value to the ambient temperature of the air surrounding the board to calculate the temperature junction. Equation 2 is the general formula to find the junction temperature (T_J) of a device at some ambient temperature (T_A). Most product data sheets provide the thermal impedance from the junction-to-(ambient) air as a numerical constant, θ_{JA} or *Theta-J*$_A$.

$$T_J = T_A + P_D\theta_{JA} \quad (2)$$

Theta-J_A is measured by every semiconductor manufacturer, with an industry-standard printed circuit board and established testing methods. Typically, though, the standard test board is not thermally representative of an end-user application board. Therefore, the possibility exists that the calculated temperature increase using Theta-J_A versus the actual temperature rise of the device in a real system will show large variations. The Theta-J_A number is best suited for making relative thermal performance comparisons between different device packages or device manufacturers, or as a good first estimate of the junction temperature rise.

We can combine Equation 1 and Equation 2 to create one equation that uses all of the relevant variables. If the ground-pin current is neglected, we use these two equations to make Equation 3. This single equation links the linear regulator operating points to the package thermal characteristics and the junction temperature.

$$T_J = T_A + (V_{IN} - V_{OUT}) \bullet I_{OUT}\theta_{JA} \quad (3)$$

Equation 3 can be used with data sheet parameters to determine the thermally-safe operating area of a linear regulator for different package types and temperature rises. For example, using the TPS73401 again, the data sheet states the following parameters:

- V_{IN}: 2.7 V to 6.5 V
- V_{OUT}: 1.2 V to 6.3 V (adjustable)
- I_{OUT}: 250 mA
- T_J: +125°C (recommended maximum operating junction temperature)
- θ_{JA}: 200°C/W (TSOT23-5 package, high-K board)
- θ_{JA}: 65°C/W (SON-6 package, high-K board)

The TPS73401 comes in two different package types: a 5-pin TSOT23 and a 6-pin SON. Each package has a different Theta-J_A. These values can be used along with Equation 3 to create a graph of the thermal-safe operating area for an ambient temperature of +85°C, as Figure 3 shows.

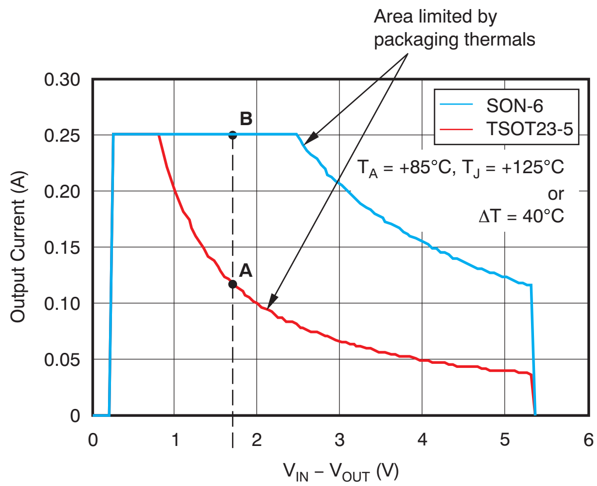

Figure 3. Thermal-Safe Operating Area for +85°C in Ambient Air

This new operating envelope graph shares the same lower and upper limits as the operating envelope implied by the data sheet (see Figure 1). However, the upper right-hand corner of the envelope is now limited by the thermal performance of the package type. Operating conditions with high output current or a high-voltage drop across the linear regulator may fall outside the thermal-safe operating area, which means that the junction temperatures will exceed the maximum safe operating temperature.

Continuing with our example, we can use the graph to pick an appropriate package type for a 5.0-V to 3.3-V dc-to-dc conversion with the linear regulator. The operating point on the x-axis is then (5.0 V – 3.3 V), or 1.7 V. Looking at Figure 3, both packages have safe operating areas with $V_{IN} - V_{OUT}$ = 1.7 V. However, we can also see from Figure 3 that if the load current of the TSOT23 package goes above 115 mA (point ***A*** on the graph), the device is no longer in the thermally-safe area for the package, and junction temperatures will exceed the recommended operating maximum. The SON-6 package (point ***B*** on the graph) remains in the safe operating range, so this package can supply the full-load current desired while maintaining safe junction temperatures. If the design absolutely requires using the TSOT23 package and full output current, the designer must either lower the voltage drop across the regulator to less than 0.8 V, or reduce the ambient temperatures that the system is expected to see.

3 Conclusion

When selecting a linear regulator, the designer must consider the package thermal performance, in addition to the obvious selection criteria such as input voltage, output voltage, and output current. When a linear regulator is available in several different package options, the smallest package may be desirable from a perspective of total board space, but that package may also limit the regulator operating range.

4 References

- TPS73401 linear regulator product data sheet: TPS73401

For more information about low-dropout (LDO) linear regulators and packaging ranges, see the LDO page on the TI website at www.ti.com/ldo.

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