

LDO Thermal Considerations

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INTRODUCTION

Battery-operated equipment (most notably cell phones and notebook computers) have created a strong demand for linear regulators in small packages. While such packages save space, they also have poor heat transfer characteristics. To minimize power dissipation, these regulators are designed to work with very low input/output voltage differentials, hence the name “low dropout regulators” or LDOs.

LDOs specify maximum output current and input voltage limits, but blindly operating the LDO within these limits will surely result in exceeding the maximum power dissipation capability.

DISSIPATING HEAT

Like other power devices, LDOs dissipate heat generated in the die by convection at rates determined by the thermal resistances in the system. Heat dissipation by convection is determined by the thermal resistance from the junction to ambient (Θ_{JA}). Typically, heat sinks and/or forced air techniques may be used to decrease Θ_{JA} , but not without impacting system size and cost.

In addition to convection, heat is also removed from the LDO by conduction (i.e., through any portion of the package that is in contact with the circuit board). In this case, increasing copper trace size and improving thermal interface (using thermal grease or films) significantly improves conduction cooling efficiency.

LDO POWER DISSIPATION

Determining the power dissipated by an LDO involves a straight forward calculation. The current entering the LDO can only go two places: through the pass device to the output (I_{OUT}); or through the internal bias circuitry to ground (I_{GND}). See Figure 1.

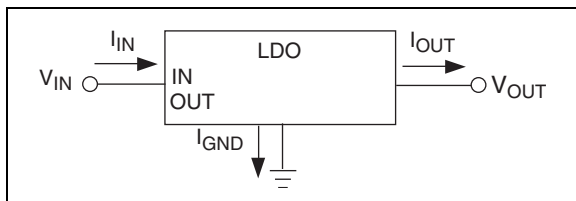


FIGURE 1: LDO Power Dissipation

The conservation of power, states that power in must equal power out. Consequently, input power is equal to the power delivered to the load plus the power dissipated in the LDO, (Equation 1):

EQUATION 1:

$$P_{IN} = P_{OUT} + P_{LDO}$$

The power dissipation of the LDO is expressed in Equation 2:

EQUATION 2:

$$P_D = (V_{IN} - V_{OUT}) \times I_{LOAD} + V_{IN} \times I_{GND}$$

When calculating power dissipation, it is critical that worst case conditions be used. This means maximum V_{IN} , I_{LOAD} , and I_{GND} , and minimum V_{OUT} values. Equation 2 is more accurately written as Equation 3.

EQUATION 3:

$$P_{DMAX} = (V_{INMAX} - V_{OUTMIN}) \times I_{LOADMAX} + V_{INMAX} \times I_{GNDMAX}$$

EXAMPLE 1:

The TC1264VAB-3.0 (0.8A LDO in a TO-220-3 package) is being used to regulate a 5V supply down to 3.0V. The 5V supply is specified to have an output tolerance of $\pm 5\%$. The maximum load on the 3.0V supply is 0.7A. The system operating temperature range is from 20°C to 70°C.

Given: Maximum supply current = 130 μ A

$$V_{INMAX} = (5V \times 1.05) = 5.25V$$

$$V_{OUTMIN} = 2.93V$$

Therefore, (Equation 4 and Equation 5).

EQUATION 4:

$$P_{DMAX} = (5.25V - 2.93V) \times 0.7A + 5.25V \times 130 \mu A$$

EQUATION 5:

$$P_{DMAX} = 1.62W$$

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THERMAL RESISTANCE

Heat flows from a high temperature (T_1) to a relatively lower one (T_2) at a rate determined by the thermal resistance (Θ_{12}) between the two points (see Figure 2).

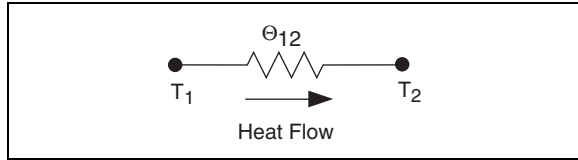


FIGURE 2: Thermal Resistance

The thermal resistance is the temperature rise (in $^{\circ}\text{C}$) for every watt dissipated for the system in question. Therefore, the expression in Equation 6 and Equation 7.

EQUATION 6:

$$T_1 - T_2 = P_D \times \Theta_{12}$$

EQUATION 7:

$$\Theta_{12} = (T_1 - T_2)/P_D$$

Where:

T_1 = Temperature of Point 1

T_2 = Temperature of Point 2

P_D = Power dissipated in the device

Relating this model to an IC, we can say that the device's thermal resistance from junction to ambient (Θ_{JA}) is equal to the junction temperature minus ambient, divided by power dissipation, or as expressed in Equation 8.

EQUATION 8:

$$\Theta_{JA} = (T_J - T_A)/P_D$$

The device junction temperature can be expressed as a function of power dissipation and thermal resistance by Equation 9.

EQUATION 9:

$$T_J = (\Theta_{JA} \times P_D) + T_A$$

Heat is transferred from the die (heat source) to the air, through several material interfaces. The thermal resistance between these interfaces comprise the Θ_{JA} of the system. These interfaces are typically the die-to-package (Θ_{JC}), package-to-heat sink (Θ_{CS}), and heat sink-to-air (Θ_{SA}) (see Figure 3).

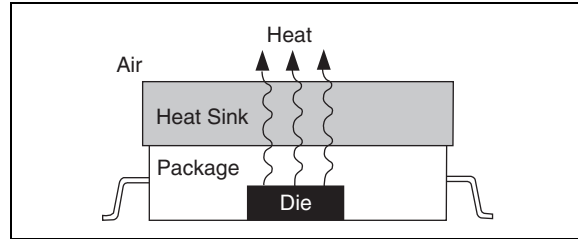


FIGURE 3: Heat transfer

The thermal resistance can now be written as shown in Equation 10.

EQUATION 10:

$$\Theta_{JA} = \Theta_{JC} + \Theta_{CS} + \Theta_{SA}$$

NO HEAT SINK

If no heat sink is used, thermal resistance from junction to case is typically provided.

EQUATION 11:

$$\Theta_{JA} = ^{\circ}\text{C}/\text{W}$$

EXAMPLE 2:

Given: TO-220-3 $\Theta_{JA} = 53^{\circ}\text{C}/\text{W}$

Maximum Junction Temperature = 150°C

and from Example 1:

$$P_{D\text{MAX}} = 1.62\text{W}$$

$$T_{A\text{MAX}} = 70^{\circ}\text{C}$$

We can calculate the junction temperature under these conditions by using Equation 9:

$$T_J = (\Theta_{JA} \times P_D) + T_A$$

$$T_J = 85.86^{\circ}\text{C} + 70^{\circ}\text{C}$$

$$T_J = 155.86^{\circ}\text{C}$$

This junction temperature is above the maximum limit. The highest power dissipation allowable in this case is:

$$P_{D\text{MAX}} = (T_{JA} - T_{J\text{AMAX}})/\Theta_{JA}$$

$$P_{D\text{MAX}} = (150^{\circ}\text{C} - 70^{\circ}\text{C})/53^{\circ}\text{C}/\text{W}$$

$$P_{D\text{MAX}} = 1.5\text{W}$$

WITH HEAT SINK

If a heat sink is used, thermal resistance can be expressed as:

$$\Theta_{JA} = \Theta_{JC} + \Theta_{JA} + \Theta_{SA}$$

EXAMPLE 3:

Given: $\Theta_{JC} = 3^{\circ}\text{C/W}$ (power circuitry)

$$\Theta_{CS} = 1.5^{\circ}\text{C/W}$$

Maximum Junction Temperature = 150°C

and from Example 1:

$$P_{D\text{MAX}} = 1.62\text{W}$$

$$T_{A\text{MAX}} = 70^{\circ}\text{C}$$

We can calculate the maximum thermal resistance that the heat sink can have, Θ_{SA} , and still hold the die temperature below 150°C .

$$\Theta_{SA} = (T_J - T_{A\text{MAX}})/P_D - (\Theta_{JC} + \Theta_{CS})$$

$$\Theta_{SA} = (150^{\circ}\text{C} - 70^{\circ}\text{C})/1.62\text{W} - (3.0^{\circ}\text{C/W} + 1.5^{\circ}\text{C/W})$$

$$\Theta_{SA} = 44.9^{\circ}\text{C}$$

Thus, the maximum thermal resistance of the heat sink needs to be less than 44.9°C/W .

VARYING SYSTEM REQUIREMENTS

The heat sink requirements vary with maximum power dissipation and maximum system temperature. Table 1 shows minimum acceptable heat sink requirements for Microchip's TC1264 LDO for various values of maximum power dissipation and system temperature.

TABLE 1: MINIMUM HEAT SINK THERMAL RESISTANCE REQUIREMENTS

Device No.	$I_{\text{OUT}}(\text{A})$	$P_D(\text{W})$	$\Theta_{SA} (^{\circ}\text{C/W})$	
			40°C	70°C
TC1264	0.2	0.46	234.6	169.4
TC1264	0.4	0.93	113.8	81.5
TC1264	0.6	1.40	74.1	52.6
TC1264	0.8	1.86	54.6	38.5

FORCED CONVECTION COOLING

Providing forced convection with a fan or blower will significantly improve heat sink efficiency while at the same time facilitating the use of smaller, lower cost heat sinks. Table 2 shows the effect of air flow on the volumetric efficiency of the heat sink. It can be seen that an airflow of 200 lfm will result in a 60-70% reduction in volumetric thermal resistance of the heat sink, over natural convection.

TABLE 2: THERMAL RESISTANCE VERSUS AIR FLOW

Air Flow (lfm)	Volumetric Resistance (in $^{\circ}\text{C/W}$)
Natural Convection	30-50
200	10-15
500	5-10

HEAT SINK ORIENTATION

Heat sink fins should be vertically oriented to take full advantage of free air flow in natural (non-forced air) convection applications. Space should be provided to allow air to circulate to and from the heat sink. In addition, full advantage of radiation heat transfer should be taken by using a heat sink with an anodized or painted surface.

Air flow should be parallel with the fins in forced convection cooled heat sink applications. A minimal amount of forced air will aid natural convection, so heatsink orientation with respect to the airstream should take priority. The width of the heat sink in the direction perpendicular to air flow has a greater effect than does heat sink length. Therefore, a wider heat sink should be chosen over one with longer fin length. See Figure 4.

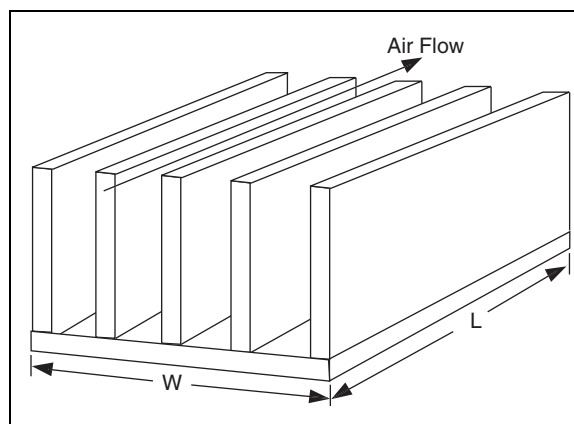


FIGURE 4: Heat Sink Orientation

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MOUNTING THE HEAT SINK

Care should be taken to select a heat sink with a base plate close in size to the device it is used with. This ensures generated heat is evenly distributed over the surface of the heat sink. A size mismatch will increase the spreading resistance which can result in an increase in the heat sink's thermal resistance by as much as 30%.

The thermal resistance between the device and the heat sink (Θ_{CS}) depends on many variables such as type of interface material, interface material thickness, dry or grease filled joints, mounting force (clip load, screw torque), contact area, and surface flatness. Material or heat sink manufacturers will generally specify interface thermal resistances.

ALTITUDE

Lower air pressures at higher altitudes result in lower air density. Consequently, heat sinks need to be derated by approximately 10% for every mile above sea level.

DISTRIBUTING POWER DISSIPATION

The TC1264 will have a dropout voltage of 1.3V at 0.8A. If a 5.0V $\pm 5\%$ supply is being regulated to 3.0V $\pm 2.5\%$, all the power is dissipated across the LDO. A resistor can be inserted in series with the input to share some of the power dissipation burden. See Figure 5

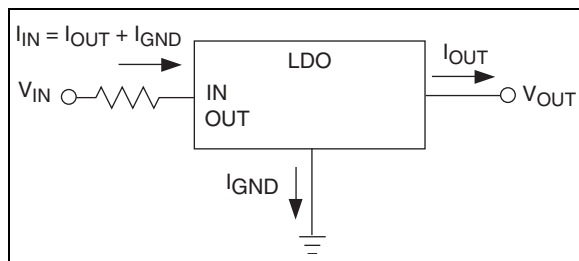


FIGURE 5: *Distributing Power Dissipation*

This resistor should be selected so the IR drop across it, (the worst case drop across the LDO) does not exceed the head room restraints of the system. R can be selected by using the equations:

$$V_{INMIN} - V_{OUTMAX} = (I_{OUTMAX} + I_{GNDMAX}) \times R_{MAX} + V_{DROPOUTMAX}$$

$$R_{MAX} = (V_{INMIN} - V_{OUTMAX} - V_{DROPOUTMAX}) / (I_{OUTMAX} + I_{GNDMAX})$$

$$R_{MAX} = (4.75V - 3.08V - 1.3V) / (0.8A + 13 \mu A)$$

$$R_{MAX} = 463 \text{ m}\Omega$$

The power drop across R_{MAX} is:

$$P_D(R_{MAX}) = (I_{OUT} + I_{GND})^2 \times R_{MAX}$$

$$P_D(R_{MAX}) = 0.30W$$

The power savings allows the use of smaller heat sink with a higher thermal resistance. The benefits of this series resistor are magnified as the output load and the input to output voltage differential increases.

SUMMARY

System thermal management considerations are not a trivial task. Many issues are involved in selecting the proper component, heat sink and air flow source. These issues need to be considered early in the design cycle to insure all options are available to implement the lowest cost, and most efficient thermal management solution.

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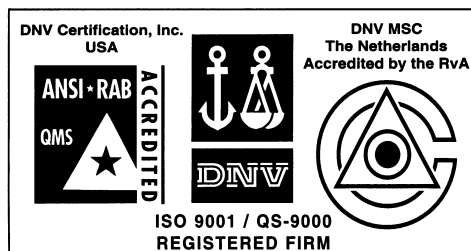
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