Application Note AN-090477 Power Dissipation Considerations During Short Circuit Conditions

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Contents

Introduction

When selecting a Linear Voltage Regulator many parameters such as load and line regulation, maximum current, ripple rejection, functional features and maximum allowed junction temperature must be considered. To properly calculate this latter based on the appropriate thermal resistance, not only the power dissipation during normal operation must be considered, but also the power dissipation under overload conditions.

The example below shows how overload or short circuit conditions must be taken into consideration to properly calculate the junction temperature.

Even if the example considers a positive regulator, the explanation and the scope of this Application Note are still valid for negative-output regulators.

For the example developed here, let us consider a CHT-LDOP-150 (15V) supplied by an input voltage of 17V. Thus, the regulator's dropout (V_{in}-V_{out}) is 2V.

Power Dissipation Analysis

A simple typical application of a CISSOID Voltage Regulator is shown in Figure 1. This typical application is valid for both positive- and negative-output voltage regulators. In the typical application, an input voltage with a value higher than the output voltage is applied between nodes V_{in} and GND. The output voltage V_{out} is measured with respect to GND. The difference between V_{in} and V_{out} is called the regulator dropout.

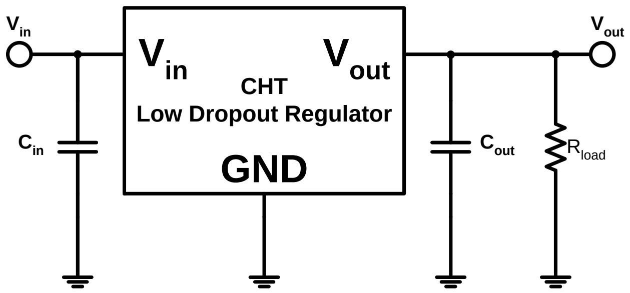

Figure 1. Typical application of a CISSOID Low Dropout regulator.

All parts from the CISSOID family of Voltage Regulators have a fold-back short circuit protection and this for both positive- and negative-output voltage regulators. Fold-back short circuit protections have short-circuit currents which are generally much lower than the maximum current that can be drawn from the regulator's output. Figure 2 shows a typical V_{out} versus I_{load} characteristic of a +15V CHT-LDOP regulator with a dropout (V_{in}-V_{out}) of 2V for several temperatures.

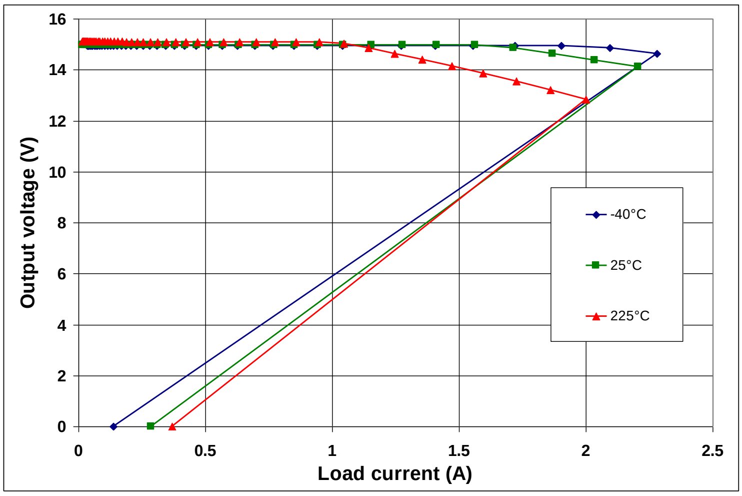

Figure 2. V_{out} vs I_{load} characteristic of CISSOID voltage regulators (V_{in}-V_{out} = 2V).

When the output is loaded with a R_{load}=30Ω, the output current is about 0.5A and the power dissipated by the regulator is

$$P_{reg} = V_{in} \cdot I_{GND} + (V_{in} - V_{out}) \cdot I_{load} = 17V \cdot 3mA + 2V \cdot 0.5A \cong 1W \qquad \textbf{Equation 1}$$

I_{GND} being the current through the ground pin.

Figure 3 shows the operation point for the 30Ω load. In this case the load line crosses the V-I characteristic in the flat region on which the load regulation is optimum.

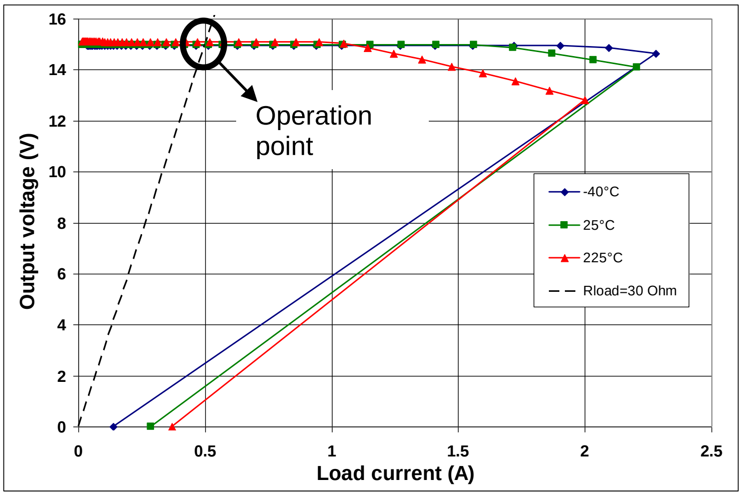

Figure 3. V_{out} vs I_{load} showing operation point with a 30Ω load resistor.

Figure 4 shows the possible operation points for several load resistors. Notice that below a given load resistor value, the voltage regulator enters into current fold-back mode.

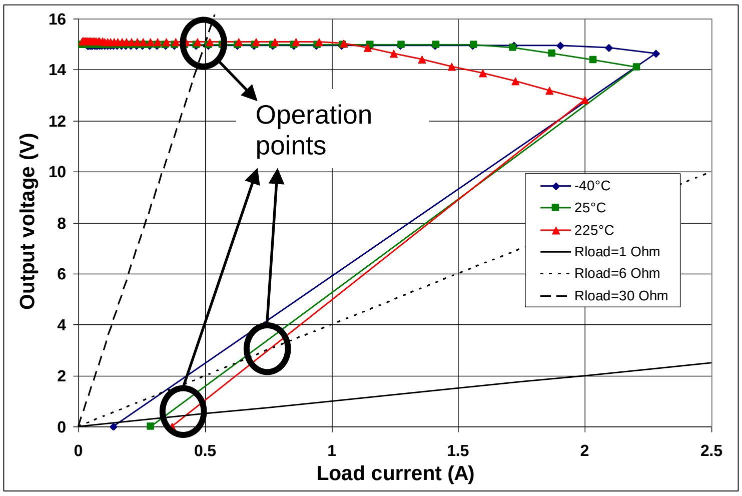

Figure 4. V_{out} vs I_{load} showing operation point with several load resistors.

If a perfect short circuit (Rload ≅ 0Ω) is established, then the power dissipated at 225°C (I_{SC}=0.37A) is about 6.3W (17V x 3mA + 17V x 370mA).

When the load resistor is swept down from, say, 1kΩ, the voltage regulator passes for three well differentiated regions. The first one, for high-load resistors and current values below the nominal maximum, is the liner region where the full set of electrical specifications is respected. In the second region, the regulator cannot sustain a constant output voltage and it starts decreasing its output voltage in a linear manner as current increases till the absolute maximum output current is reached. Then the regulator enters into the third region which is fold-back limitation.

Figure 5 shows the power dissipated by the voltage regulator and the corresponding output voltage when R_{load} is swept from 1kΩ to less than 1Ω. Notice that maximum power dissipation is obtained for a load resistor setting the output voltage at about the middle of the fold-back region.

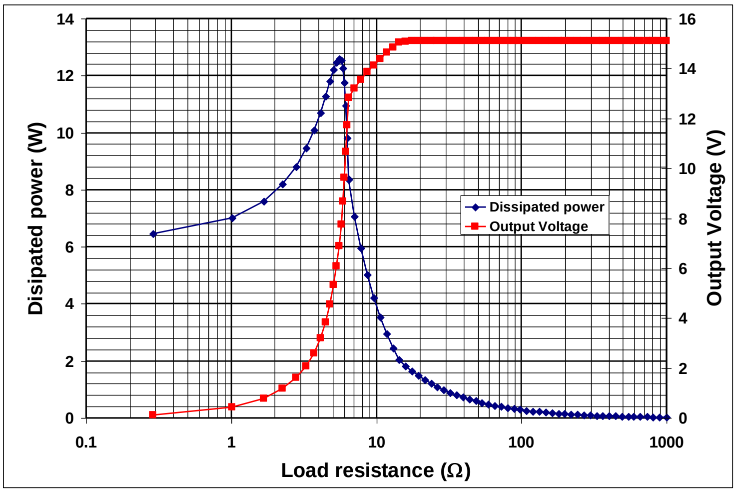

Figure 5. Power dissipated by the regulator and V_{out} versus R_{load} (V_{in}=17V and V_{out}=15V).

Thermal Considerations

When the junction-case or junction-ambient thermal resistance is considered, the importance of the dissipated power becomes evident.

The junction temperature T_j of the die can be calculated, depending upon the know variables available, according to the following equations

$$T_j = T_a + P_{reg} \cdot R_{thja}$$ **Equation 2**

$$T_j = T_c + P_{reg} \cdot R_{thjc}$$ **Equation 3**

where T_j is the junction temperature, Ta is the ambient temperature, T_c is the case temperature, Preg is the power dissipated by the voltage regulator (see equation 1), Rthja is the junction-to-ambient thermal resistance and Rthjc is the junction-to-case thermal resistance.

The ambient temperature can be calculated as

$$T_a = T_j - P_{reg} \cdot R_{thja}$$ **Equation 4**

For a CHT-LDOP-150 in TO-254 metal package, the junction-to-case thermal resistance is R_{thjc}=5°C/W whereas that the junction-to-ambient is R_{thja}=50°C/W. Supposing that the CHT-LDOP-150 is assembled without heat sink and on still air, using equation 3 and considering that a permanent short circuit with a 1Ω resistor is produced (P_{reg}=7W), the maximum acceptable ambient temperature allowing the junction temperature to remain below the Absolute Maximum Rating of 250°C would be

$$T_{a\_max} = 250°C - 7W \cdot 50°C/W = -100°C$$

The result above shows that the voltage regulator must be used with a heat sink or under an air stream flow, otherwise a steady short circuit would cause a permanent damage on the part as its effective junction temperature would be well above the Absolute Maximum Rating.

If a heat sink is used, this one must be designed so that T_j does not go above the Absolute Maximum Rating of 250°C. Hence, using equation 3 to calculate T_c it is obtained

$$T_{c\_max} = 250°C - 7W \cdot 5°C/W = 215°C$$

In the example above we have not considered the worst case of the power dissipation, which takes place for a load resistance of about 5.5Ω. Also we have supposed that the short circuit current was stable for any increase of the temperature. This is true for temperatures below the Absolute Maximum Rating of 250°C. Above T_j = 250°C, the short circuit current increases with temperature which can produce a thermal runaway and heat the part well above 300°C.

Conclusions

When analyzing the thermal requirements for a voltage regulator, the following choices and parameters must be taken into account:

- Input voltage and standard operating load conditions.
- Regulator dropout conditions.
- V_{out}-I_{load} regulator characteristic.
- Maximum power dissipation under normal operation conditions ($I_{load} \leq I_{nom\_max}$).
- Maximum power dissipation during short-circuit and ambient conditions under which the short-circuit needs to be sustained.
- Junction-to-case and junction-to-ambient thermal resistances.

CISSOID offers extremely reliable and robust voltage regulators able to operate under very hard environmental and electrical conditions with enough design margin to sustain limited operation above the Maximum Nominal operating conditions. Nevertheless frequent or extended exposure to operating conditions at or above the Absolute Maximum Rating may permanently affect product reliability.

Contact & Ordering

CISSOID S.A.

Headquarters and contact EMEA:	CISSOID S.A. – Rue Francqui, 3 – 1435 Mont Saint Guibert - Belgium T : +32 10 48 92 10 - F: +32 10 88 98 75 Email: sales@cissoid.com
Sales Representatives:	**Visit our website: http://www.cissoid.com/contact**

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