Three terminal regulators provide a simple, effective, and stable solution to power voltage regulation requirements. Some applications, however, require special techniques to deal with concerns about overheating. Lack of thorough consideration for thermal design may result in poor efficiency of the IC and shorter lives of semiconductors. This application note is a design guide for 3-terminal regulators used in combination with the TO220CP-3 package and a heatsink.

An input voltage range of 7.5-25 V and output current of 1 A can be found on the datasheet of a 5 V output regulator that belongs to the 78XX family of 3-terminal voltage regulators (Rohm model designation: BA78xx and BA178xx). If the regulator is configured to a 12 V input voltage and 1 A output current, for example, the calculation gives about 7 W of power dissipation (see Figure 1).

\[ P = (V_{IN} - V_O) \times I_O + (V_{IN} \times I_{CC}) \quad [W] \]
\[ = (12 - 5) \times 1 + (12 \times 4.5) = 7.054 \quad [W] \]

Where:

- \( I_{CC} \) = Current consumption of the IC [A]

Figure 1 Power Dissipation

Configuration without Heatsink

The datasheet provides information on the thermal resistance of the TO220CP-3 package, based on which junction temperature can be calculated. Figure 2 shows a thermal equivalent circuit model without a heatsink, which gives Equation (1) for the junction temperature calculation. The junction temperature \( T_J \) at the ambient temperature of 25°C is determined as follows.

\[ T_J = \theta_{JA} \times P + T_A \quad [^\circ C] \]
\[ = 62.5 \times 7 + 25^\circ C = 462.5 \quad [^\circ C] \]

Where:

- \( \theta_{JA} \) = Thermal resistance between the IC junction and ambient temperature \([^\circ C/W]\)
- \( P \) = Power loss of the IC \([^\circ C]\)
- \( T_A \) = Ambient temperature \([^\circ C]\)

The calculation proves that this configuration does not work since the maximum junction temperature rating is 150°C. Be sure to check the maximum rating of the junction temperature of the IC to be used on its datasheet because different ICs have maximum junction temperatures of their own.

Now, do the arithmetic to determine up to how much output current the circuit withstands if no heatsink is used. A maximum junction temperature rating of 150°C allows it to work for some time, however the behavior reliability is significantly sacrificed. It is commonly known that the junction temperature should be kept within 80% of its maximum rating for better circuit reliability. Another well-known fact is that the life of a device halves and the failure rate doubles per 10°C increase in the junction temperature. Therefore, circuits should be designed to operate at as low of a junction temperature as possible to reduce the failure rate.
Thermal Design for Three-Terminal Voltage Regulators

Parameters:
- Input voltage, $V_{IN} = 12 \text{ [V]}$
- Output voltage, $V_O = 5 \text{ [V]}$
- Maximum ambient temperature, $T_{A_{max}} = 60 \text{ [°C]}$
- Maximum junction temperature, $T_{J_{max}} = 120 \text{ [°C]}$ (80 % of rating)

Thermal resistance, $\theta_{JA} = 62.5 \text{ [°C/W]}$

\[ p = \frac{T_{max} - T_{A_{max}}}{\theta_{JA}} = \frac{120 - 60}{62.5} = 0.96 \text{ [W]} \]  
\[ I_O = \frac{p}{V_{IN} - V_O} = \frac{0.96}{12 - 5} = 0.137 \text{ [A]} \]

The calculation above proves that only 0.137 A of current are allowed per 1 A capacity, if no heatsink is used for the circuit.

Configuration with Heatsink

A heatsink mounted on an IC reduces thermal resistance. It achieves a lower junction temperature, which translates into efficient use of the IC. Figure 3 shows a thermal equivalent circuit model with a heatsink.

The power loss $P$ of the IC serves as the heat source that contributes to the increase in temperature at the die junction $T_J$. The TO220CP-3 package is designed to be fitted with a heatsink screwed to the back of the case. Heat from the die (junction temperature $T_J$) is transferred to the back surface of the case (case surface temperature $T_C$). The thermal resistance during this heat transfer is expressed as $\theta_{JC}$, which can be obtained from the datasheet.

Contact thermal resistance, $\theta_{CH}$

The thermal resistance in the region between the back of the case (case surface temperature $T_C$) and the heatsink (heatsink temperature $T_{hi}$) is expressed as $\theta_{CH}$, which represents the contact thermal resistance of the case and the heatsink. Flatness, contact area, and tightening strength are the factors that largely affect the contact thermal resistance at the case-to-heatsink interface. The variation in the thermal resistance becomes large if the heatsink is directly mounted onto the case surface without silicone grease at the expense of stability in flatness and contact area. The use of silicone grease or other suitable media applied to the contact surface is strongly recommended to secure stable and low thermal resistance.

Thermal resistance specific to silicone grease or silicone rubber sheet is available from the manufacturers. An approximate thermal resistance can be calculated using the specification value in product catalogs as follows.

The typical thermal resistance of a silicone grease falls within a range of 1 to 6 W/m-K, which can be usually referenced in a product catalog. Substitute the value for the silicone grease into the following equation.

\[ \theta = \frac{t}{K \times L \times W} \text{ [°C/W]} \]

Where:
- $t$ = Silicone grease thickness [m]
- $K$ = Thermal conductivity [W/m·K]
- $L$ = Length of the contact surface of the case [m]
- $W$ = Width of the contact surface of the case [m]

Example calculation

Parameters (Make sure each unit is correct.):
- Silicone grease thickness, $t = 0.1 \text{ [mm]}$
- Thermal conductivity, $K = 1 \text{ [W/m·K]}$
- Length of the contact surface of TO220CP, $L = 15 \text{ [mm]}$ (Available from the datasheet)
- Width of the contact surface of TO220CP, $W = 10 \text{ [mm]}$ (Available from the datasheet)
Thermal Design for Three-Terminal Voltage Regulators

Some of the calculated thermal resistances for different thicknesses of silicone grease are shown in Table 1, which indicates that thicker, uneven application of silicone grease contributes to an increase in the thermal resistance.

<table>
<thead>
<tr>
<th>Thermal Conductivity (W/m · K)</th>
<th>Thermal Resistance (°C/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t = 0.1 mm</td>
<td>0.11 - 0.67</td>
</tr>
<tr>
<td>t = 0.2 mm</td>
<td>0.22 - 1.33</td>
</tr>
<tr>
<td>t = 0.3 mm</td>
<td>0.33 - 2.0</td>
</tr>
</tbody>
</table>

Table 1 Silicone Grease Thickness and Thermal Resistance

Mica insulation plates are common material for case-to-heatsink insulation, however Rohm’s TO220CP-3 package (Figure 4), which has the entire surface coated in molded resin, has no metal parts exposed on the back, eliminating the need for an insulation plate.

Thermal resistance of heatsink, $\theta_{HA}$

The total thermal resistance from the heatsink to the ambient air is expressed as $\theta_{HA}$, and involves calculating the difference in the heat flow from the heatsink temperature $T_H$ to the ambient temperature $T_A$. For the sake of practicableness, the calculation uses actual measurements, since heatsink thermal resistance shows characteristics similar to a distribution constant that is not easily expressed in a formula. The specific thermal resistances of heatsinks are available from the manufacturers.

Below is the calculation of thermal resistance $\theta_{HA}$ required for the equivalent circuit model shown in Figure 3. Equations (6) and (7) are led for the equivalent circuit.

$$T_J = (\theta_{JC} + \theta_{CH} + \theta_{HA}) \times P + T_A \ [°C] \quad (6)$$

$$\theta_{HA} = \frac{T_J - T_A}{(V_{IN} - V_O) \times I_O + (V_{IN} \times I_{CC})} - \theta_{JC} - \theta_{CH} \ [°C/W] \quad (7)$$

Where:

$\theta_{HA} = \text{Thermal resistance of the heatsink} \ [°C/W]$

$\theta_{JC} = \text{Junction to Case thermal resistance} \ [°C/W]$

$\theta_{CH} = \text{Contact thermal resistance of silicone grease} \ [°C/W]$

$T_J = \text{Junction temperature} \ [°C]$

$T_A = \text{Ambient temperature} \ [°C]$

$V_{IN} = \text{Input voltage} \ [V]$

$V_O = \text{Output voltage} \ [V]$

$I_O = \text{Output current} \ [A]$

$I_{CC} = \text{Current consumption of the IC} \ [A]$

Here, we use the same parameters as the previous section.

Parameters:

- Input voltage, $V_{IN}$
- Output voltage, $V_O$
- Output current, $I_O$
- Current consumption of the IC, $I_{CC}$

(Available from the datasheet)

Ambient temperature, $T_A = 60 \ [°C]$

Junction temperature, $T_J = 120 \ [°C]$ (80% of rating)

Thermal resistance, $\theta_{JC} = 5.7 \ [°C/W]$

(Available from the datasheet)

Thermal resistance, $\theta_{CH} = 0.3 \ [°C/W]$

(Available from the manufacturer)

When the parameters are substituted into Equation (8), we get the following.

$$\theta_{HA} = \frac{120 - 60}{(12 - 5) \times 0.5 + (12 \times 4.5)} = \frac{5.7 - 0.3}{10.9} = 10.9 \ [°C/W]$$

From the manufacturer’s heatsink catalog, select a heatsink that has a thermal resistance no greater than the calculated 10.9°C/W. Without a heatsink, up to 0.137 A current was allowed per 1 A. Now, with a suitable heatsink, the allowable current increased to 0.5 A. Consider reducing the input voltage or output current if the calculated value is small, zero, or negative, as this indicates that the target junction temperature cannot be reached even when a heatsink is in use.

Precautions for Heatsink Mounting

- A minimum of 0.05 mm flatness is required for the mounting surface, including burrs and sagging at holes for mounting screws. Insufficient flatness may result in damage to the case or die, and poor adhesion between the case and the
Thermal Design for Three-Terminal Voltage Regulators

- Lower the contact thermal resistance by applying silicone grease from the IC case to the heatsink interface or putting a silicone rubber sheet in-between them.

- Heads of tightening screws must be round, pan, truss, binding, or flat.

- DO NOT use self-tapping screws. Tightening torque may exceed the allowable maximum.

- DO NOT use countersunk screws. They allow excess stress to be applied to the device.

- Fasten screws at the specified tightening torque to ensure sufficient heat dissipation effect. Insufficient contact between the case and heatsink increases the contact thermal resistance. Applying a torque higher than specified may result in damage to the IC. Use a torque screwdriver that assures torque is set within the optimum range.

<table>
<thead>
<tr>
<th>Package</th>
<th>Tightening Torque [N · m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TO220CP-3</td>
<td>0.4 - 0.6</td>
</tr>
</tbody>
</table>

![Figure 5 Heatsink Mount Structure](image)

- Heatsink.

- DO NOT use self-tapping screws. Tightening torque may exceed the allowable maximum.

- DO NOT use countersunk screws. They allow excess stress to be applied to the device.

- Fasten screws at the specified tightening torque to ensure sufficient heat dissipation effect. Insufficient contact between the case and heatsink increases the contact thermal resistance. Applying a torque higher than specified may result in damage to the IC. Use a torque screwdriver that assures torque is set within the optimum range.
**Notes**

1) The information contained herein is subject to change without notice.

2) Before you use our Products, please contact our sales representative and verify the latest specifications:

3) Although ROHM is continuously working to improve product reliability and quality, semiconductors can break down and malfunction due to various factors. Therefore, in order to prevent personal injury or fire arising from failure, please take safety measures such as complying with the derating characteristics, implementing redundant and fire prevention designs, and utilizing backups and fail-safe procedures. ROHM shall have no responsibility for any damages arising out of the use of our Products beyond the rating specified by ROHM.

4) Examples of application circuits, circuit constants and any other information contained herein are provided only to illustrate the standard usage and operations of the Products. The peripheral conditions must be taken into account when designing circuits for mass production.

5) The technical information specified herein is intended only to show the typical functions of and examples of application circuits for the Products. ROHM does not grant you, explicitly or implicitly, any license to use or exercise intellectual property or other rights held by ROHM or any other parties. ROHM shall have no responsibility whatsoever for any dispute arising out of the use of such technical information.

6) The Products are intended for use in general electronic equipment (i.e. AV/OA devices, communication, consumer systems, gaming/entertainment sets) as well as the applications indicated in this document.

7) The Products specified in this document are not designed to be radiation tolerant.

8) For use of our Products in applications requiring a high degree of reliability (as exemplified below), please contact and consult with a ROHM representative: transportation equipment (i.e. cars, ships, trains), primary communication equipment, traffic lights, fire/crime prevention, safety equipment, medical systems, servers, solar cells, and power transmission systems.

9) Do not use our Products in applications requiring extremely high reliability, such as aerospace equipment, nuclear power control systems, and submarine repeaters.

10) ROHM shall have no responsibility for any damages or injury arising from non-compliance with the recommended usage conditions and specifications contained herein.

11) ROHM has used reasonable care to ensure the accuracy of the information contained in this document. However, ROHM does not warrant that such information is error-free, and ROHM shall have no responsibility for any damages arising from any inaccuracy or misprint of such information.

12) Please use the Products in accordance with any applicable environmental laws and regulations, such as the RoHS Directive. For more details, including RoHS compatibility, please contact a ROHM sales office. ROHM shall have no responsibility for any damages or losses resulting from non-compliance with any applicable laws or regulations.

13) When providing our Products and technologies contained in this document to other countries, you must abide by the procedures and provisions stipulated in all applicable export laws and regulations, including without limitation the US Export Administration Regulations and the Foreign Exchange and Foreign Trade Act.

14) This document, in part or in whole, may not be reprinted or reproduced without prior consent of ROHM.

Thank you for your accessing to ROHM product informations.
More detail product informations and catalogs are available, please contact us.

ROHM Customer Support System

http://www.rohm.com/contact/