1. Protection Circuit

(1) Positive Voltage 3-Terminal Regulator (Fig. 1)

(1-1) Thermal Shut Down Circuit

The thermal shut down circuit cuts off the output voltage to drop down the temperature to the safe level when the junction temperature in the chip goes up to extreme high ($T_j=150$ to $200°C$).

The transistor $Q_4$ is biased off normally at room temperature. When the junction temperature in the chip goes high, the output pass transistor $Q_6$ and $Q_7$ become cut off because the decreased $V_{BE}$ turns on the transistor $Q_4$ then the transistor $Q_4$ makes a bypass of the base current of the transistor $Q_6$.

(1-2) Overcurrent Protection Circuit

The overcurrent protection circuit limits the current to protect the output pass transistor against the overcurrent like as accidental short-circuit, current overload.

When the output current increases, the voltage drop of the $R_{10}$ increases, the transistor $Q_5$ turns on because the $V_{BE}$ increases. Then the base current of the transistor $Q_6$ and the collector current of the transistor $Q_7$ (output current) are limited.

(1-3) Safe Operating Area Control Circuit

The safe operating area control circuit to protect the output pass transistor operation within the safe operating area by decreasing the output current when the input-output differential voltage increases.

When the input-output differential voltage increases over the breakdown voltage ($BV_z$) of zener diode $D_2$, the breakdown current flows from $V_{IN}$ to $V_{OUT}$ ($V_{IN}$→$R_7$→$D_2$→$R_9$→$R_{10}$→$V_{OUT}$).

As the input-output differential voltage increases, the $V_{BE}$ of the transistor $Q_5$ increases and the base current of the transistor $Q_6$ and the collector current of the transistor $Q_7$ (output current) are decreased. Then the output pass transistor operates within the safe operating area because the power consumption of the transistor $Q_7$ is decreased.

(2) Negative Voltage 3-Terminal Regulator (Fig. 2)

(2-1) Thermal Shut Down Circuit

The thermal shut down circuit cuts off the output voltage to drop down the temperature to the safe level when the junction temperature in the chip goes up to extreme high ($T_j=150$ to $200°C$).

When the junction temperature in the chip goes high, the output pass transistor $Q_9$, $Q_{11}$ and $Q_{12}$ become cut off because the decreased $V_{BE}$ of the transistor $Q_3$ turns on the transistor $Q_8$ then the transistor $Q_8$ makes a bypass of the base current of the transistor $Q_9$.

(2-2) Overcurrent Protection Circuit

The overcurrent protection circuit limits the current to protect the output pass transistor against the overcurrent like as accidental short-circuit, current overload.

When the output current increases, the voltage drop of the $R_{16}$ increases, the transistor $Q_8$ and $Q_7$ turn on because the $V_{BE}$ of the transistor $Q_8$ increases.

Then the base current of the transistor $Q_9$ and the collector current of the transistor $Q_{12}$ (output current) are limited.
3-TERMINAL VOLTAGE REGULATOR

(2-3) Safe Operating Area Control Circuit

The safe operating area control circuit to protect the output pass transistor operation within the safe operating area by decreasing the output current when the input-output differential voltage increases.

When the input-output differential voltage increases over the breakdown voltage (BV2) of zener diode D3, the breakdown current flows from COM to VIN (COM→Q10→D3→R12→R17→R16→VIN).

As the input-output differential voltage increases, the VBE of the transistor Q8 increases and the base current of the transistor Q9 and the collector current of the transistor Q12 (output current) are decreased. Then the output pass transistor operates within the safe operating area because the power consumption of the transistor Q12 is decreased.

Fig. 2 NJM7900/79M00 Series Circuit Function

Fig. 3 NJM79L00 Series Circuit Function

In the following explain only the positive regulator unless otherwise specified. However they can apply to the negative voltage regulator by easy change.

Typical Application

Current Boost Circuit (no short protection)

Output Voltage Boost Circuit

Constant Current Circuit

Positive/Negative Voltage Supply

note) In the above positive and negative power supply application, D₁ and D₂ should be connected. If D₁ and D₂ are not connected, either of positive or negative power supply circuit may not turns on.
3. **Note in Application Circuit**

   (1) If the higher voltage (above the rated value) or lower voltage (GND-0.5V) is supplied to the input terminals, the IC may be destroyed. To avoid such a case, a zener diode or other parts of the surge suppressor should be connected as shown below.

   ![Diagram 1](image1)

   (2) If the higher voltage than the input terminal is supplied to the output terminal, the IC may be destroyed. To avoid input terminal short to the GND or the stored voltage in the capacitor back to the output terminal, by the large value capacitor connecting to the output terminal application, the SBD should be required as shown below;

   ![Diagram 2](image2)

   * In case of negative voltage regulator, reverse the SBD and capacitor direction.

**4. Package**

(1) **SOT-89 Package**

   SOT-89 is a surface mount type package for low power 3-terminal voltage regulator.

   (1-1) **Features**

   1. Ultra miniature size
   2. Surface mount type
   3. Apply to the automatic mounter

   (1-2) **Structure**

   Refer to "IC PACKAGE DATA BOOK".

   (1-3) **Applied product Line up**

   1. NJM78L00UA/79L00UA
   2. NJM431U
   3. NJU7201U/7221U series
   4. NJU7202U/7222U series
   5. NJU7211U series
   6. NJU7212U series

   ![Power Dissipation Graph](image3)
(2) TO-220F Package
TO-220F is fully covered plastic mold package of TO-220 for middle and high power 3-terminal voltage retulator, and is compatible with TO-220 package.

(2-1) Features
TO-220F has some features as follows, because of fully covering the own radiation fin by high thermal conductive epoxy resin.
1. No Insulator between IC and heat sink is required.
2. Increase the power dissipation itself.
3. High density mounting.

(2-2) Structure
Refer to "IC PACKAGE DATA BOOK".

(2-3) Mounting Method
Refer to the following figure.

(2-4) Recommended Bolt Tighten Torque
recommended bolt tighten torque ≤ 0.6N·m

(3) Applied Product Line-up

<table>
<thead>
<tr>
<th>Type No.</th>
<th>V_{OUT} [V]</th>
<th>Polarity</th>
<th>I_{OUT} [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NJM78M00FA Series</td>
<td>5, 6, 8, 9, 12 15, 18, 20, 24</td>
<td>Positive</td>
<td>0.5</td>
</tr>
<tr>
<td>NJM7800FA Series</td>
<td>5, 6, 8, 9, 12 15, 18, 20, 24</td>
<td>Positive</td>
<td>1.5</td>
</tr>
<tr>
<td>NJM79M00FA Series</td>
<td>5, 6, 8, 9, 12 15, 18, 24</td>
<td>Negative</td>
<td>0.5</td>
</tr>
<tr>
<td>NJM7900FA Series</td>
<td>5, 6, 8, 9, 12 15, 18, 24</td>
<td>Negative</td>
<td>1.5</td>
</tr>
</tbody>
</table>
5. Thermal Design

(1) Heat Producing

There are two kinds of heat producing (P\textsubscript{LOSS-1}, P\textsubscript{LOSS-2}) in three terminal regulator and the sum of them is total heat producing of the IC (P\textsubscript{LOSS}).

(1-1) P\textsubscript{LOSS-1} : heat producing by own operation

Input voltage (V\text{IN}) and quiescent current (I\text{Q}) produce the heat mentioned below equation.

\[ P\textsubscript{LOSS-1} = V\text{IN} \times I\text{Q} \quad \text{(W)} \]

(1-2) P\textsubscript{LOSS-2} : heat producing by output current and the input-output differential voltage Internal power transistor produces the heat mentioned following equation.

\[ P\textsubscript{LOSS-2} = (V\text{IN} - V\text{OUT}) \times I\text{OUT} \quad \text{(W)} \]

Therefore, the total heat producing P\textsubscript{LOSS} is:

\[ P\text{LOSS} = P\text{LOSS-1} + P\text{LOSS-2} = V\text{IN} \times I\text{Q} + (V\text{IN} - V\text{OUT}) \times I\text{OUT} \quad \text{(W)} \]

(2) Thermal Resistance

(2-1) Definition of Thermal Resistance : \(\theta\)

Thermal resistance (\(\theta\)) is a degree of heat radiation mentioned following equation.

\[ \theta = \frac{(T_1-T_2)}{P} \quad \text{°C/W} \]

Heat Producing Quantity : \(P\) (W)

Ambient Temperature : \(T_2\) (°C)

Heat Source Temperature : \(T_1\) (°C)

(2-2) Thermal resistance of TO-220

There are two kinds of thermal resistance of TO-220. One is "\(\theta ja\)" for the application with the heat sink, the other is "\(\theta ja\)" for the application without the heat sink.

"\(\theta ja\)" : thermal resistance between IC chip (junction point) and the package back side contacting with the heat sink

"\(\theta ja\)" : thermal resistance between IC chip (junction point) and ambience

(2-3) Thermal resistance of TO-92

Thermal resistance of TO-92 is only \(\theta ja\) because of the no heat sink required.

There are two measurement methods of \(\theta ja\) mentioned following equation.

1. Calculation by the data of ambient temperature vs. power consumption

\(\theta ja\) is calculated by the ratio of changes of ambient temperature \(\Delta T_a\) and the changes of power consumption \(\Delta P_D\), which called temperature decrease curve, in the ambient temperature (Ta) vs. power dissipation (P\text{D}) figure.

The start temperature of temperature decrease curve is 25°C normally, but some of them start from 50°C.

\[ \theta ja = \frac{\Delta T_a}{\Delta P_D} \quad \text{°C/W} \]
2. Calculation by the absolute maximum ratings

\( \theta_{ja} \) is calculated by the maximum power dissipation \((P_{D\text{max}} \text{ at } Ta=25°C)\) and the maximum junction temperature \((T_j \text{ max : apply the maximum storage temperature, } 125°C)\) as mentioned below.

\[ \theta_{ja} = \frac{(T_j \text{ max}-Ta)}{PD} \quad (^{\circ} \text{CW}) \quad Ta=25°C \]

Note) (2-3) 2. is applied only for the device which specified the temperature decrease curve starting from 25°C

**Typical Thermal Resistance Value**

<table>
<thead>
<tr>
<th>Thermal Resistance</th>
<th>TO-220</th>
<th>TO-220F</th>
<th>TO-92</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \theta_{ja} )</td>
<td>70</td>
<td>60</td>
<td>200</td>
<td>°C/W</td>
</tr>
<tr>
<td>( \theta_{jc} )</td>
<td>5</td>
<td>5</td>
<td>---</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

(3) Heat Radiation Balance

The heat produced in the IC is radiated to ambience through the package and the heat sink. The quantity of the heat radiation depends on the heat source temperature, ambient temperature and the thermal resistance of the package.

(3-1) TO-220 with heat sink

Heat radiation balance model of the TO-220 with heat sink is shown as below.

![Heat Radiation Model](image)

where

- \( \theta_{jc} \) : thermal resistance between IC chip (junction point) and the package backside connecting to the heat sink
- \( \theta_{js} \) : thermal resistance between IC chip (junction point) and package surface
- \( \theta_{CH} \) : thermal resistance between package backside and the heat sink including the condition of insulator, silicon grease and bolt tighten torque
- \( \theta_{HS} \) : thermal resistance of the heat sink
If the $\theta_{js}$ is large enough compare with other thermal resistance, the $\theta_{js}$ can be neglected and the heat radiation model can be mentioned as below.

![Fig. 4](image)

The relation between temperature and heat radiation quantity is shown below.

$$T_j = P_{\text{LOSS}} \times (\theta_{jc} + \theta_{CH} + \theta_{HS}) + T_a \quad (\degree C)$$

(3-2) 

Heat radiation balance model of the TO-92 is shown as follows. 

The relation between temperatures and heat radiation quantity is mentioned below.

$$T_j = P_{\text{LOSS}} \times \theta_{ja} + T_a \quad (\degree C)$$

Heat Source
(junction)

(4) 

Thermal Design

The heat radiation balance model of the TO-220 with the heat sink is shown as follows.

Heat radiation balance

$$T_j = P_{\text{LOSS}} \times (\theta_{jc} + \theta_{CH} + \theta_{HS}) + T_a \quad (\degree C) \quad (4-1)$$

$$P_{\text{LOSS}} = V_{IN} \times I_Q + (V_{IN} - V_{OUT}) \times I_{OUT} \quad (W) \quad (4-2)$$

Substituting "Eq. (4-2)" into "Eq. (4-1)" obtains

$$T_j = [V_{IN} \times I_Q + (V_{IN} - V_{OUT}) \times I_{OUT}] \times (\theta_{jc} + \theta_{CH} + \theta_{HS}) + T_a \quad (\degree C) \quad (4-3)$$

In Eq. (4-3), $V_{IN}, I_{OUT}, \theta_{CH}, \theta_{HS}, T_a$ depend on using condition. 

$T_j$, $I_Q$, $V_{OUT}$, $\theta_{jc}$ depend on IC specification. 

When $\theta_{CH}$, $I_Q$ and $T_j$ are assumed the following values, 

Eq. (4-3) becomes Eq. (4-4).

$$\theta_{CH} = 0.3 \text{ to } 0.4(\degree C/W) \quad \text{Insert the mica paper (0.1t) and thermal conduction silicon grease between the IC and heat sink and tighten them with the bolt by 4Kg-cm-min.}$$

Lower $V_{IN}$ and/or $I_{OUT}$ are required to limit the temperature rise. 

Smaller $\theta_{HS}$ is required for the effective heat reduce (i.e. using the large heat sink). 

In the thermal design, when fix the $V_{IN}$, $I_{OUT}$ and $T_a$, select the heat sink which $\theta_{HS}$ is smaller than the result of Eq. (4-4).

For more detail, please refer the heat resistance value mentioned in the specification of the heat sink supplier.