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RENESAS

User's Manual

Usage of Three-Terminal Regulators

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1. INTRODUCTION

NEC Electronics produces a variety of ICs for power supplies that differ in their on-chip functions and usage. Within these, large quantities of three-terminal regulators have come to be used to configure stabilized power supplies easily using few external components.

However, the occurrence of unexpected irregularities when designing power supply circuits also has increased. Therefore, this manual starts with the basic structure of the main bipolar process that is used in ICs for power supplies and gives precautions pertaining to actual applications.

2. BASIC STRUCTURE OF A POWER SUPPLY IC

As mentioned in chapter 1, a power supply IC mainly uses a bipolar process. Understanding the structure of an IC that uses a bipolar process also is useful for applications.

2.1 Structure of a Bipolar IC

The following elements can be made into an IC in a general bipolar process.

NPN transistor
PNP transistor
Resistor
Capacitor

Figures 2-1 through 2-3 show the structure of each.

Figure 2-1. Structure of NPN Transistor and PNP Transistor

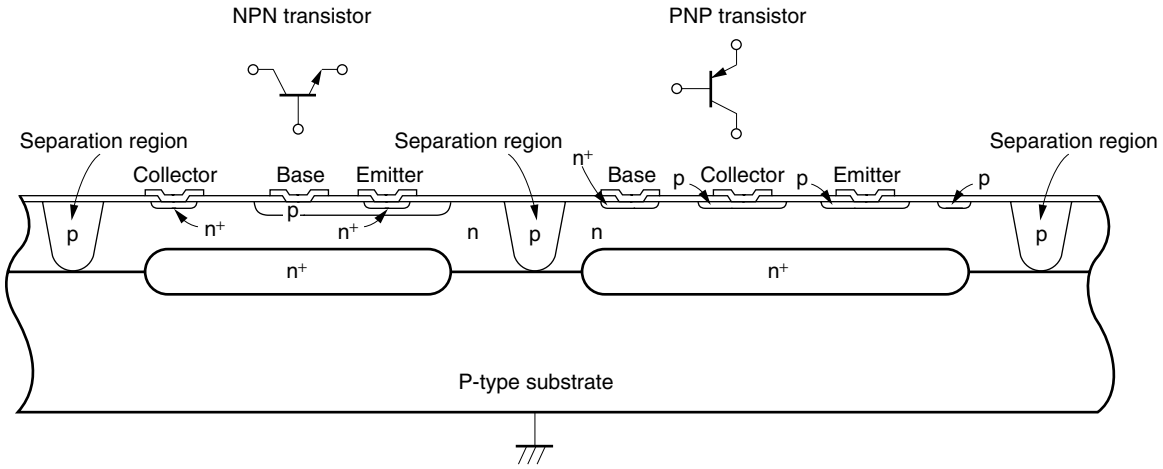


Figure 2-2. Structure of Resistor

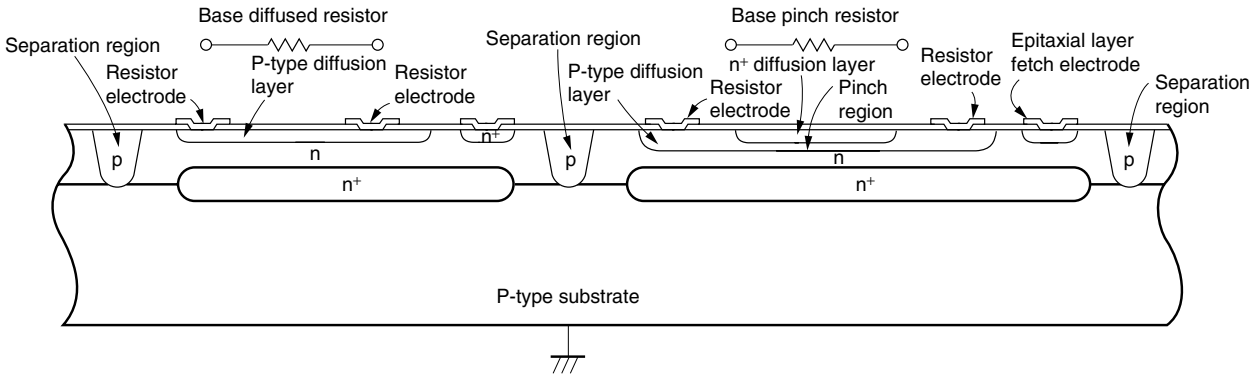
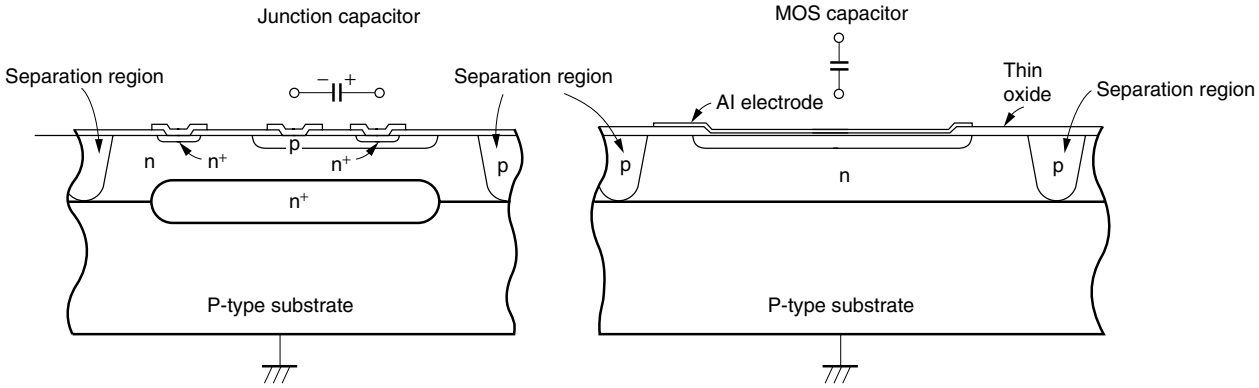


Figure 2-3. Structure of Capacitor



There is a point to heed in applying power supply ICs. It is that a method known as "junction separation" is used as the method of electrically separating each of the elements above. By connecting a separation region so that it is formed by a P-type semiconductor and is the same lowest potential as the substrate, the element region and the separation region are electrically separated and insulated by being in (PN junction) reverse bias states. If for some reason the potential of this separation region becomes a higher potential than the element region (for example the NPN transistor collector region in Figure 2-1), normal operation cannot be expected since the PN junction enters a forward bias state and the separation state between the elements cannot be maintained. For example, when using a positive output three-terminal regulator, the GND pin always must be made a lower potential than the potential of other pins.

2.2 About Power Supply IC Equivalent Circuits

Equivalent circuits that are shown in data sheets are so designated assuming the premise of the preceding section (that separation regions and substrate are made the lowest potential). Be careful not to reference these when this premise is violated.

3. BASIC CIRCUITS OF A POWER SUPPLY IC

3.1 Basic Circuits

Although the basic circuits that make up a power supply IC differ according to the product type, the following elements are necessary.

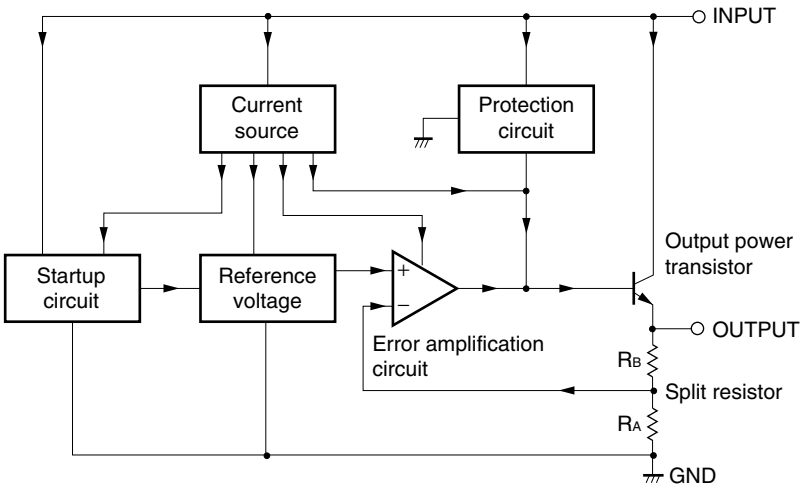
<1> Reference voltage circuit
<2> Error amplifier
<3> Active load (constant current circuit)
<4> Output stage power transistor
<5> Startup circuit

The following protection circuits also are on-chip.

<6> Overcurrent protection circuit
<7> Stable operation area (SOA or ASO) restriction circuit
<8> Overheat protection circuit

Figure 3-1 shows a block diagram of a power supply IC.

★ **Figure 3-1. Power Supply IC Block Diagram**



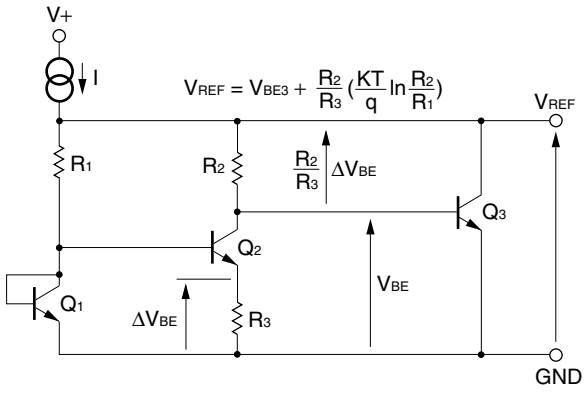
The operation of each block is explained in simple terms below.

<1> Reference voltage circuit

The reference voltage circuit, which determines the output voltage of the power supply IC, is an extremely important part within the circuit. The method for configuring this circuit is as follows.

- Band gap reference method: Use the forward characteristic between the base and emitter of the transistor. The possibility of making the reference voltage 2 V or less is a feature of this method.
  Figure 3-2 shows the principles of the band gap reference method. Figure 3-3 is a simple circuit diagram of the band gap reference reference voltage used in the μPC7800A Series.

Figure 3-2. Band Gap Reference Circuit



The reference voltage is as follows.

$$V_{REF} = V_{BE3} + (I_{C2} + I_{B3}) \times R_2$$

$$= V_{BE3} + \frac{R_2}{R_3}(\Delta V_{BE}) + I_{B3} \times R_2$$

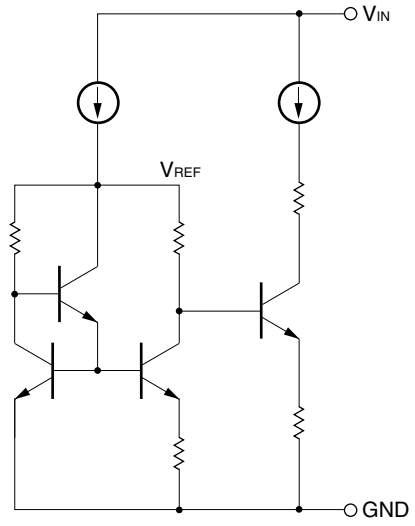
$$\fallingdotseq V_{BE3} + \frac{R_2}{R_3}\left[\frac{KT}{q} \ln \frac{R_2}{R_1}\right] \quad \cdots\cdots (3 - 3)$$

The temperature coefficient is as follows.

$$\frac{\partial V_{REF}}{\partial T} = \frac{\partial V_{BE3}}{\partial T} + \frac{K}{q} \times \frac{R_2}{R_3} \ln \frac{R_2}{R_1} \quad \cdots\cdots (3 - 4)$$

By optimally choosing the ratio of $\frac{R_2}{R_3} \times \frac{R_2}{R_1}$, a temperature compensated reference voltage is known to be obtained.

Figure 3-3. (Simplified) Band Gap Reference Circuit of μPC7800A Series



<2> Error amplifier

This circuit controls the output voltage by detecting and comparing the reference voltage created by the reference voltage circuit and the resistor split output voltage. If V_{OUT} is the output voltage and V_{REF} is the reference voltage (refer to Figure 3-1), the following relationship holds.

$$V_{OUT} = \frac{A}{\beta\ (1 + A)}\ V_{REF} \quad \text{..... (3 - 1)}$$

Here, A is the open loop gain of the error amplifier and $\beta = R_A / (R_A + R_B)$.

<3> Active load (constant current circuit)

Expression (3 - 1) becomes the following if the open loop gain A of the error amplifier is sufficiently large compared to 1.

$$V_{OUT} \fallingdotseq V_{REF} / \beta$$

A small bias current and high resistance are realized by using a constant current circuit in the error amplifier load to make A 60 to 80 dB.

<4> Output stage power transistor

The output stage power transistor supplies current to the load. Although normally a Darlington form NPN, the low saturation type of power supply IC uses a PNP single transistor.

<5> Startup circuit

A power supply IC has an on-chip constant current circuit for use as an error amplifier load or for biasing the reference voltage circuit. A constant current circuit, which consists of paired transistors, does not begin to operate as long as the diode connected transistors are not in a steady bias state. A startup circuit therefore is set up and it biases the active load at power-on to cause normal operation to begin whether the temperature of the transistors is low or high.

<6> Overcurrent protection circuit

This is a protection circuit for preventing the load current from exceeding the current capacity of the output stage power transistor. It restricts the base current of the output stage power transistor by biasing the current restriction transistor more deeply in accordance with the voltage drop in the current detection resistor inserted in the load current route.

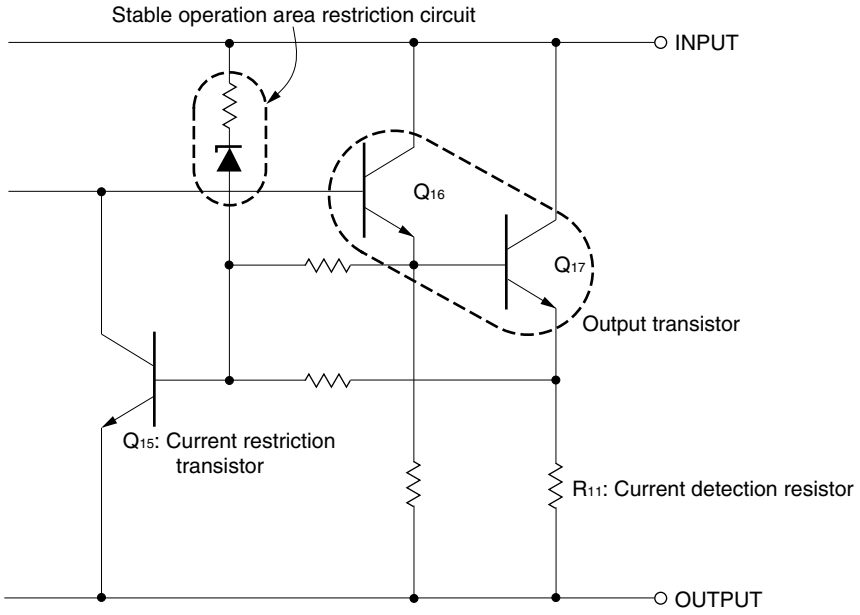
<7> Stable operation area (SOA or ASO) restriction circuit

The stable operation area restriction circuit operates to squeeze the output current if the voltage between input and output (voltage between the collector and emitter of the output stage power transistor) becomes large so that the stable operation area of the output stage power transistor is not exceeded.

If the voltage difference between input and output exceeds the breakdown voltage (7 to 8 V) of a Zener diode connected between input and output, it restricts the base current of the output stage power transistor by biasing the current restriction transistor more deeply using the breakdown current. Since the larger the voltage difference between input and output the more the base current of the output stage power transistor is restricted, the load characteristic is a "foldback" type drooping characteristic as a result.

Figure 3-4 shows the parts of a general overcurrent protection circuit and stable operation area restriction circuit.

Figure 3-4. Sample Overcurrent Protection Circuit and Stable Operation Area Restriction Circuit (μPC7800A Series)

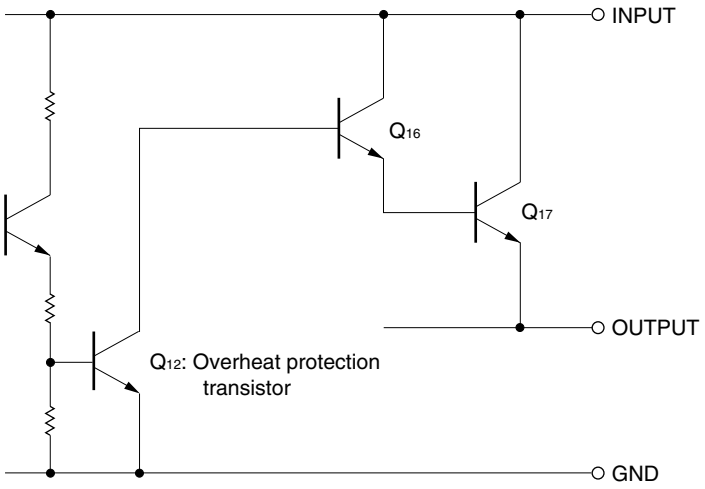


<8> Overheat protection circuit

The overheat protection circuit prevents destruction of the IC by cutting off output if the temperature of the chip itself increases too much.

Figure 3-5 shows the parts of an overheat protection circuit. Q_{12}, which is biased to the extent that it is not ON in a normal operating state, is completely ON at 150 to 200°C accompanying a decrease in V_{BE} when the temperature of the chip increases. When Q_{12} is ON, it cuts off the output voltage by absorbing the base current of the output stage power transistor.

Figure 3-5. Sample Overheat Protection Circuit (μPC7800A Series)



The overheat protection circuit is designed to operate at temperatures exceeding the absolute maximum rating (generally 150°C). Therefore, if the overheat protection circuit has operated, the IC should be considered to have been exposed to an abnormal state and positive use of the overheat protection circuit should be avoided (so a separate circuit is needed to perform power supply overheat protection).

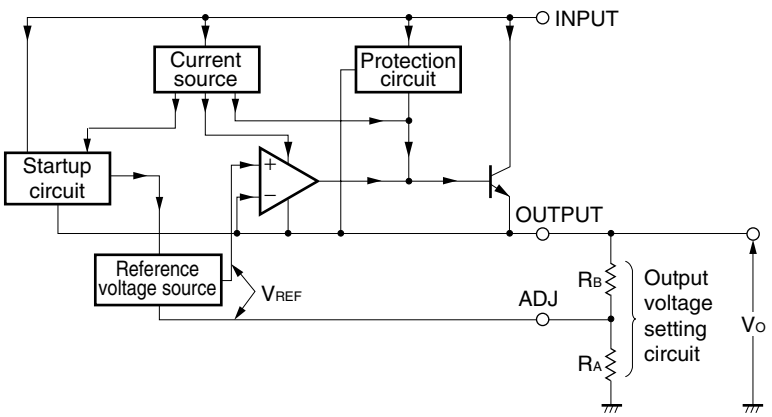
3.2 Operating Principles of Variable Output Types

A variable output type (μPC317, μPC337) differs from a fixed output voltage type in that it uses a method for configuring an output voltage setting voltage circuit externally so that an arbitrary output voltage can be set externally.

Figure 3-6 is the block diagram of a variable output voltage type. The output voltage is controlled by comparing the voltage between external resistors R_A and R_B and the reference voltage V_{REF} in the error amplifier.

Moreover, each block is connected between INPUT and OUTPUT and the current needed in each block (circuit operating current) is output from the OUTPUT pin. Therefore, the outflow current from the ADJ pin becomes negligible and its affect on the output voltage value can be ignored.

Figure 3-6. Variable Output Type Block Diagram

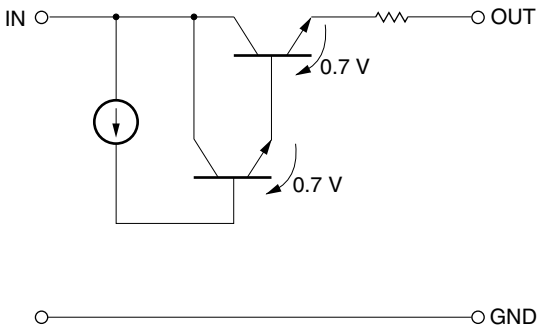


3.3 Operating Principles of Low Saturation Types

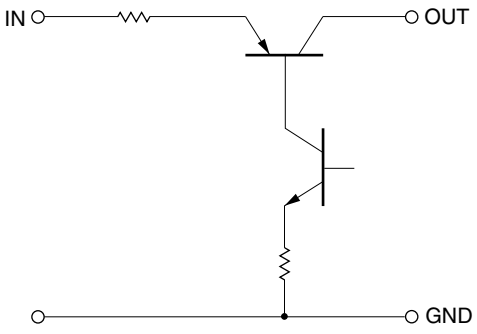
All of the power supply ICs discussed so far use Darlington connected NPN type transistors in the output stage. Therefore, the voltage difference between input and output that is needed to operate these power supply ICs cannot be lower than the voltage between the base and emitter of the Darlington connected output transistor (0.7 V × 2 = 1.4 V). A low saturation type power supply IC makes it possible to operate with a small voltage difference between input and output by using a PNP transistor as the output stage transistor (refer to Figure 3-7).

Figure 3-7. Differences Between General Power Supply IC and Low Saturation Type Output Stage Configurations

(a) General power supply IC

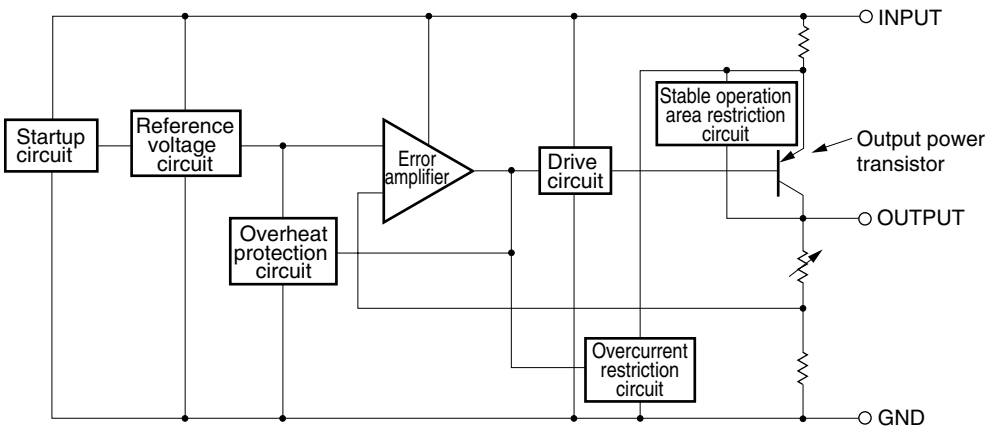


(b) Low saturation type power supply IC



Configurations other than this are nearly identical to a general power supply IC. Figure 3-8 shows a block diagram.

★ **Figure 3-8. Low Saturation Type Block Diagram**



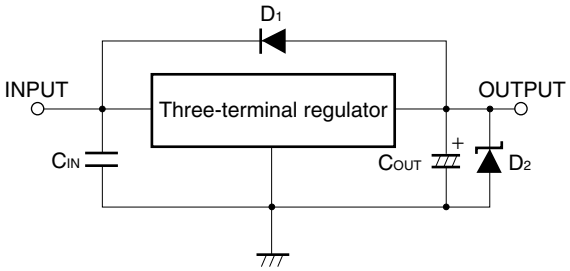
4. POWER SUPPLY IC APPLICATION CIRCUITS

4.1 Standard Circuit Connection

<1> Fixed output voltage type

Figure 4-1 shows an example of a standard circuit connection. Check the data sheet for each product type for the values of input and output capacitors.

★ **Figure 4-1. Sample Standard Circuit Connection (Single Power Supply Output)**



C_{IN}: Set this value according to the length of the line between the regulator and INPUT pin. Be sure to connect C_{IN} to prevent parasitic oscillation. Use of a film capacitor or other capacitor with excellent voltage and temperature characteristics is recommended. If using a laminated ceramic capacitor, it is necessary to ensure that C_{IN} is 0.1 μF or higher for the voltage and temperature range to be used.

C_{OUT}: Be sure to connect C_{OUT} to prevent oscillation and improve excessive load regulation. Place C_{IN} and C_{OUT} as close as possible to the IC pins (within 2 cm). Also, use an electrolytic capacitor with low impedance characteristics if considering use at sub-zero temperatures.

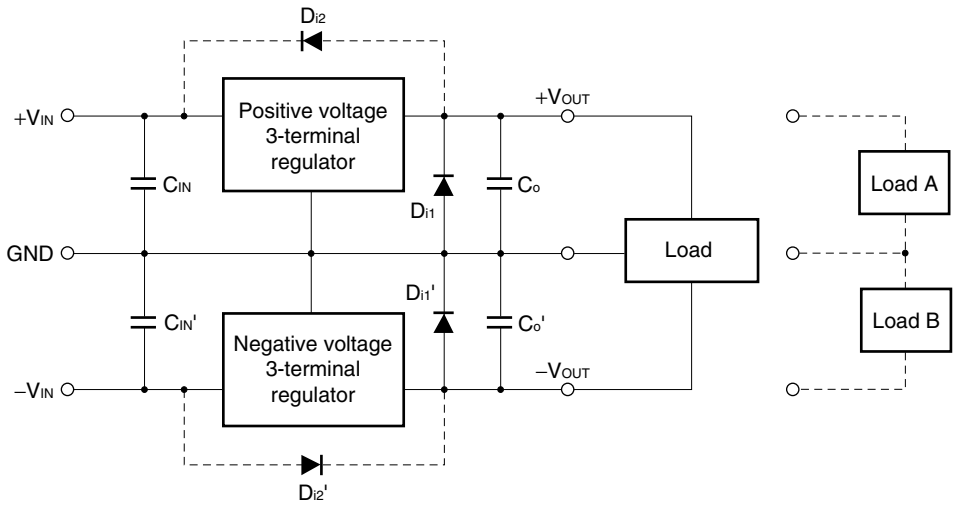
D_1: If the OUTPUT pin has a higher voltage than the INPUT pin, connect a diode.

D_2: If the OUTPUT pin has a lower voltage than the GND pin, connect a Schottky barrier diode.

Caution Make sure that no voltage is applied to the OUTPUT pin from external.

Figure 4-2 is an example of a standard connection for obtaining a positive and negative power supply. The diodes between output and GND are for preventing latchdown at startup and are absolutely necessary in the case of loads shown by solid lines. Without the diodes, current flows in the separation regions between elements as described in chapter 2 and the output voltage does not rise (refer to Figure 4-3).

Figure 4-2. Sample Standard Circuit Connection (Dual Power Supply Output)



★ C_{IN}, C_O, C_{IN}', C_O': As in the sample circuit for a single power supply load, these are needed.

D_{i1}, D_{i1}' : **Absolutely necessary for loads shown by solid lines, in which a load current flows from $+V_{OUT}$ toward $-V_{OUT}$.**

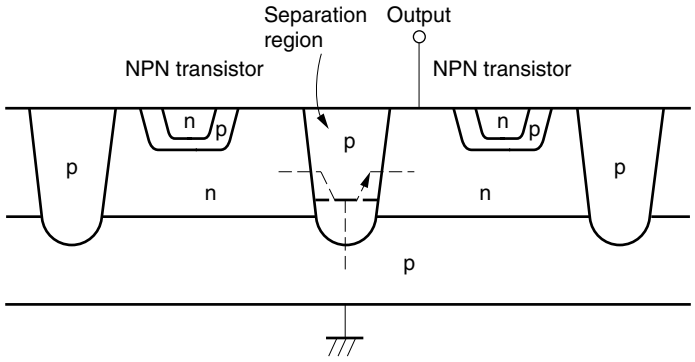
This is to prevent regulator output on either side from being latched down by differences occurring in the rise of regulator output voltage due to smoothing circuit capacitor capacity differences or the like.

Note that these are not specifically needed in the case of only those loads shown by dashed lines.

D_{i2}, D_{i2}' : **As in the sample circuit for a single power supply load, these sometimes are needed depending on the application circuit.**

If the output pin becomes a lower potential than GND, the P-type separation region and n type output pin (NPN transistor) enter a forward bias state and the "parasitic transistor" shown with dashed lines is formed. When this occurs, it is connected to the adjacent transistors and does not operate normally.

Figure 4-3. Sample Power Supply IC Cross Section Diagram (Latchdown)



★ **<2> Variable output voltage type**

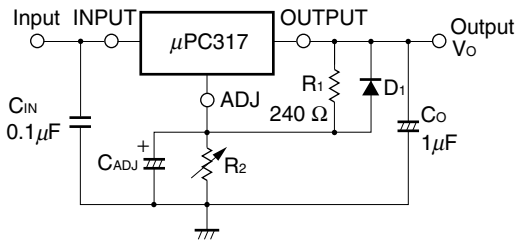
When a voltage not included in a fixed output voltage type is needed or the output voltage is to be adjusted and used, even a fixed output voltage type can be used by floating the GND (In a low saturation type case, it cannot do.) as described later, but voltage precision and drift become a problem. A variable output voltage type is useful in such cases.

Figure 4-4 shows an example of the standard connection. Since a bias current for the operation of each block inside the IC flows from INPUT to OUTPUT as described in section 3.2, be careful of the load current. By selecting 240 Ω as R1 as in the sample standard connection even when there is no load, no problems arise since a current of

1.25 V / 240 Ω = 5.2 mA

flows to OUTPUT.

Figure 4-4. Sample Standard Connection Circuit (Variable Output Power Supply)



Remark This example is for a positive voltage.
For a negative voltage (μPC337), D_1 and capacitor polarity are reversed.

C_{IN} : Since there may be oscillation if the wire leading from a smoothing circuit to a three-terminal regulator is long (15 cm or more), add a capacitor near the input pin.

C_O : For an application in which the load current changes suddenly, add a 10 μF or more capacitor for output voltage transient response improvement (and add 10 μF to C_{ADJ} at the same time).

C_{ADJ} : Connecting a 10 μF capacitor parallel to R_2 can improve the ripple removal rate (approximately 20 dB) and increase oscillation stability.
In this case, diode D_1 is needed for to prevent application of backward voltage on an output short circuit.

R_1, R_2 : These are resistors for setting the output voltage. The output voltage V_O is determined as follows.

$$V_O = \left(1 + \frac{R_2}{R_1}\right) \times V_{REF} + I_{ADJ} \times R_2$$
$$\fallingdotseq \left(1 + \frac{R_2}{R_1}\right) \times V_{REF}$$

Table 4-1 shows the relationship between typical output voltages and R_2.

Table 4-1. Settings of Output Voltage Setting Resistor R_2

Output Voltage V_O (V)	R_2 Setting[Note] (Ω)
2.5	240
5.0	720
12	2064
24	4368
30	5520

Note TYP. values

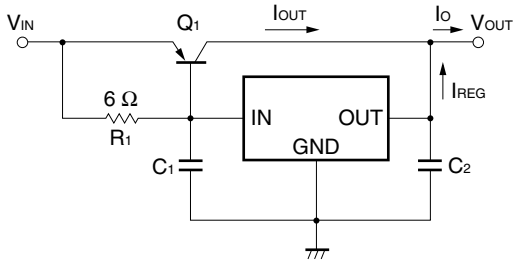
<3> Low saturation type

The standard method of use is the same as for a general fixed output voltage type (see Figure 4-1). However, the capacitor connected to the output must have a greater capacity than in a general power supply IC. In addition, note that the output voltage cannot be adjusted by inserting a resistor or the like in the GND pin as described later.

★ 4.2 Application Circuit Set

This circuit set mainly is filled in for positive output voltage three-terminal regulators. However, the circuits also can be applied to negative voltage three-terminal regulators by changing the polarity of parts employed. In the case of the circuit which has connected an element to GND pin, it is inapplicable to a low saturation type.

1. High output current circuit (without short circuit protection)



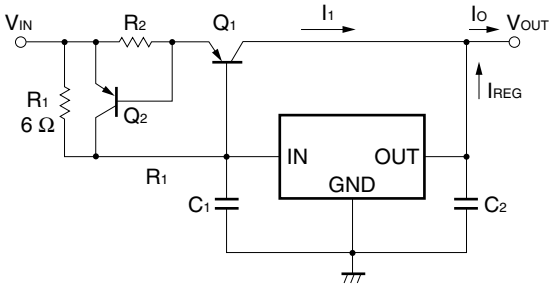
Drives the base of an external transistor using a three-terminal regulator.
Here R_1 is determined as follows.

$$R_1 = \frac{V_{BE1}}{I_{REG(MAX.)} - \frac{I_{OUT}}{h_{FEI(MIN.)}}} \quad \cdots\cdots (4.1)$$

$$I_O = h_{FE1(MIN.)} \left(I_{REG(MAX.)} - \frac{V_{BE1}}{R_1} \right) + I_{REG(MAX.)} \quad \cdots (4.2)$$

In this circuit, the output current has an actual range that is 5 to 6 times the three-terminal regulator rating.

2. High output current circuit (with short circuit protection)



This is an expansion of circuit 1. Current detection is performed using R_2.
Therefore, since the current at Q_1 is restricted by

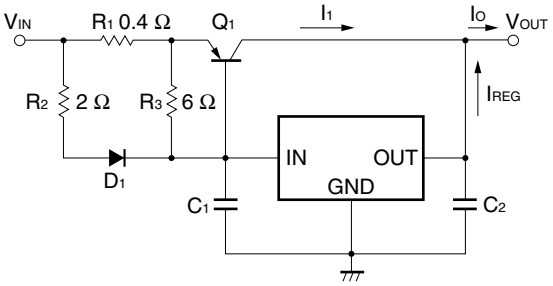
$$I_{1(MAX.)} = \frac{V_{BE2}}{R_2}$$

the output current is as follows.

$$I_{O(MAX.)} = I_{1(MAX.)} + I_{REG(MAX.)}$$

$$= \frac{V_{BE2}}{R_2} + I_{REG(MAX.)} \quad \cdots\cdots (4.3)$$

3. High output current circuit (with short circuit protection)



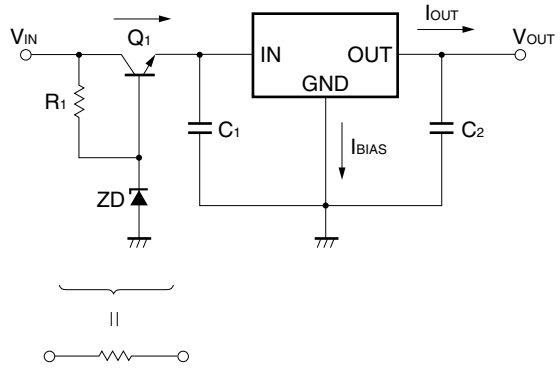
D_1 cancels V_{BE} at Q_1.
Q_1 and three-terminal current distribution is determined by R_1 and R_2.

$$\frac{R_2}{R_1} = \frac{I_1}{I_{REG}} \quad \cdots\cdots (4.4)$$

$$I_{O(MAX.)} = \frac{R_1 + R_2}{R_1} \times I_{REG(MAX.)} \quad \cdots\cdots (4.5)$$

Caution Absolutely do not connect output pins in parallel to increase the current capacity of a three-terminal regulator. If the output voltage becomes unbalanced, certain ICs operate in a restricted current vicinity and current hardly flows in certain ICs, and furthermore the current may flow in reverse. Also refer to 15. Wired OR.

4. High input voltage circuit

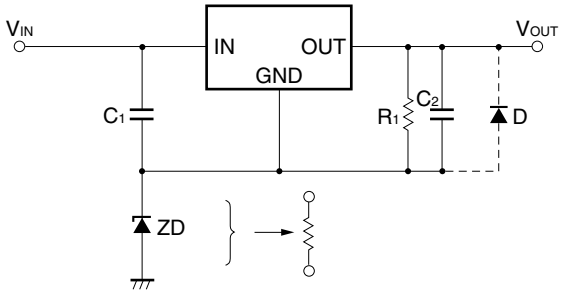


This circuit can be used when the input voltage exceeds the rating.

$$R_1 = \frac{V_{IN} - V_{ZD}}{\dfrac{I_{OUT(MAX.)} + I_{BIAS(MAX.)}}{h_{FE1(MIN.)}}} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (4.6)$$

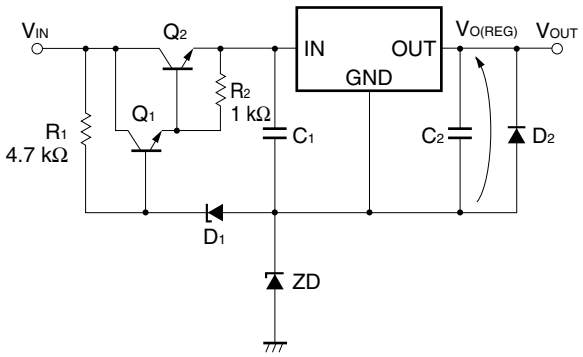
Moreover, if the load current changes little, a resistor can be used.

5. High input, high output voltage circuit (without short circuit protection)



Using the fact that the current flowing out from the GND pin of the three-terminal regulator is practically constant, add Zener diode to the GND pin to raise only the Zener portion of the voltage. R_1 supplies idling to the Zener. It also is possible to use a resistor, but this is inferior to the Zener from a stability standpoint.
D is needed as load short circuit protection. In addition, the input voltage must be set within a range that holds the voltage difference between input and output to the ratings even on a short circuit.

6. High input, high output voltage circuit (with short circuit protection[Note])



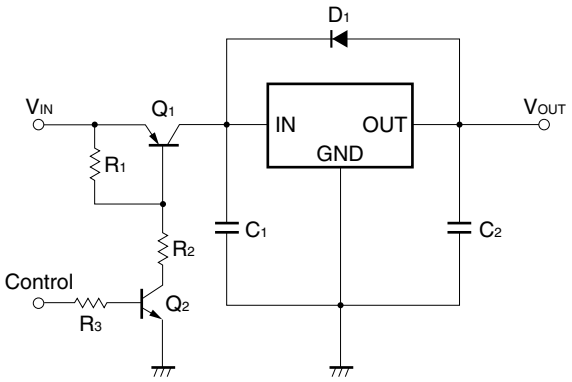
This circuit combines circuits 4 and 5. The circuit made up of Q_1, Q_2, and D_1 is a preregulator.
The output voltage is as follows.

$$V_{OUT} = V_{O(REG)} + V_{ZD} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (4.7)$$

D_2 protects against reverse bias in the GND and OUT pins on a load short circuit.

Note D_1 or ZD must be selected so that the voltage difference between input and output of the three-terminal regulator is kept within ratings even on a load short circuit.
In addition, D_2 must have low forward voltage.

7. Remote shutdown circuit



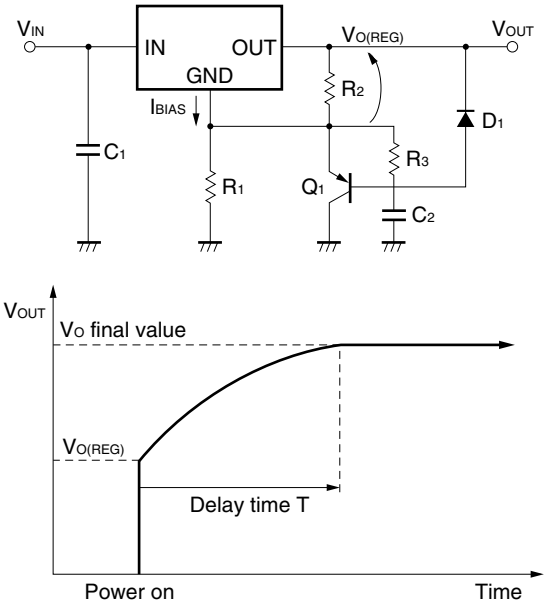
Control the output voltage using a preregulator set up ahead of the three-terminal regulator.
The control input is as follows.

At H: Output
At L: Output interruption

In addition, D_1 is added to prevent reverse bias between the input and output pins of the three-terminal regulator.

Remark H: High level, L: Low level

8. Slow startup circuit (without short circuit protection)



This circuit moderates the rise time of the output voltage. At power-on, this is the three-terminal regulator's specific output voltage, after which it gradually rises to its final value.
The initial output voltage is

$$V_{O1} = V_{O(REG)} \quad \text{..... (4.8)}$$

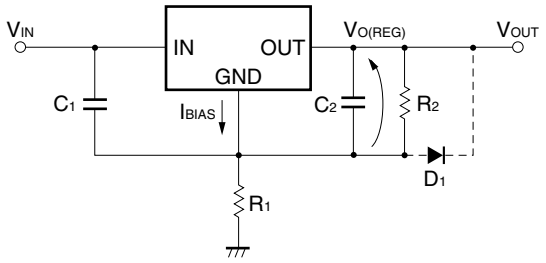
The output voltage after stabilization is

$$V_{O2} = V_{O(REG)} + R_1 \left[I_{BIAS} + \frac{V_{O(REG)}}{R_2} \right] \quad \text{..... (4.9)}$$

Furthermore, the delay can be represented as follows if expecting up to 99% of the final value.

$$T \fallingdotseq -CR \ \ln 0.01 \ [s] \quad \text{..... (4.10)}$$

9. Variable output voltage circuit (without load short circuit protection)



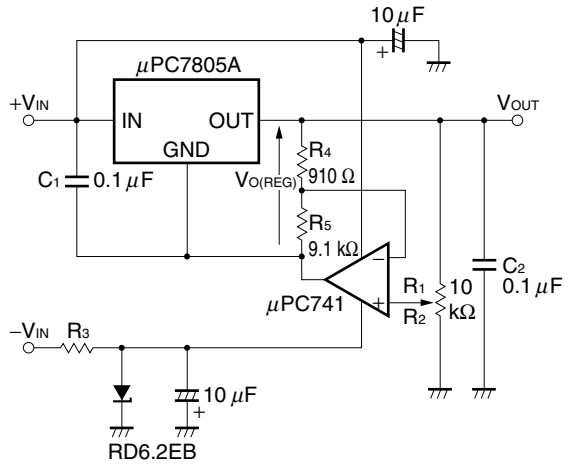
Note that applications using the variable output three-terminal regulator μPC317 are superior in output voltage precision and stability.

The Zener diode in the circuit shown in 5 is replaced by a resistor.

$$V_{OUT} = V_{O(REG)} + R_1 \left[I_{BIAS} + \frac{V_{O(REG)}}{R_2} \right] \quad \text{..... (4.11)}$$

Use a voltage difference between input and output that is within the three-terminal regulator ratings.
For a load short circuit or capacity load, the diode shown using dashed lines is needed and in particular a low forward voltage is needed.

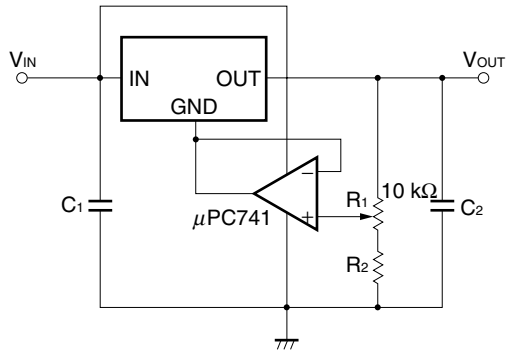
10. Variable output voltage circuit (0.5 to 10 V, without short circuit protection)



Splits the fixed output voltage $V_{O(REG)}$ of the three-terminal regulator using R_4 and R_5 and compares with the output voltage V_{OUT} value split using R_1 and R_2. The output voltage can be represented as follows.

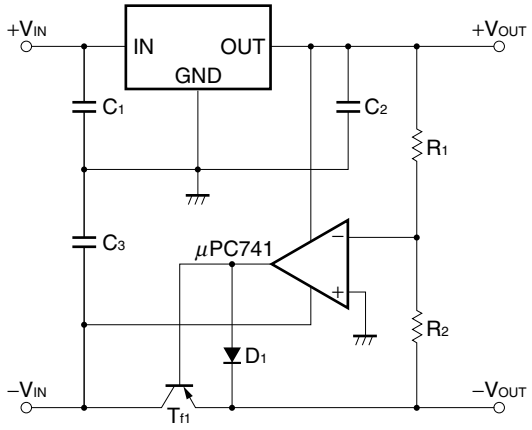
$$V_{OUT} = \frac{R_4}{R_4 + R_5} \times V_{O(REG)} \times \frac{R_1 + R_2}{R_1} \quad \ldots\ldots\ldots\ldots \quad (4.12)$$

11. Variable output voltage circuit (7 to 30 V)



This is analogous to the circuits shown in 5 and 8. Since it uses op amplifier μPC741 with a single power supply, the lowest value of the output voltage can be no lower than the sum of the output saturated voltage of the μPC741 and the output voltage of the three-terminal regulator.

12. Tracking regulator circuit

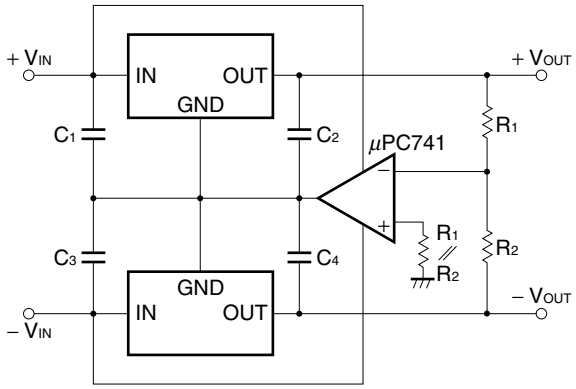


A tracking regulator is configured using a power transistor with one positive voltage three-terminal regulator.
The positive voltage is the fixed voltage of the three-terminal regulator. The negative voltage can be changed arbitrarily by the split ratio of R_1 and R_2. Thus the negative voltage output is as follows.

$$-V_{OUT} = \frac{R_2}{R_1} \times V_{OUT} \quad \ldots\ldots\ldots\ldots \quad (4.13)$$

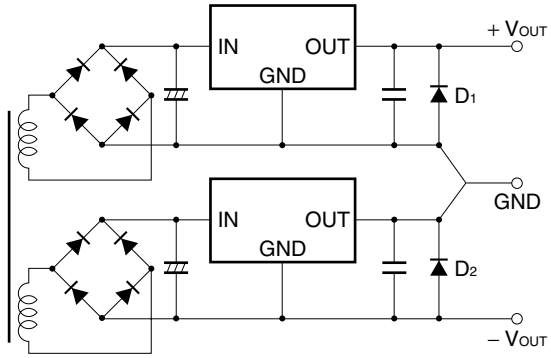
D_1 protects against reverse bias between the base and emitter of the transistor at power-on.

13. Tracking regulator circuit



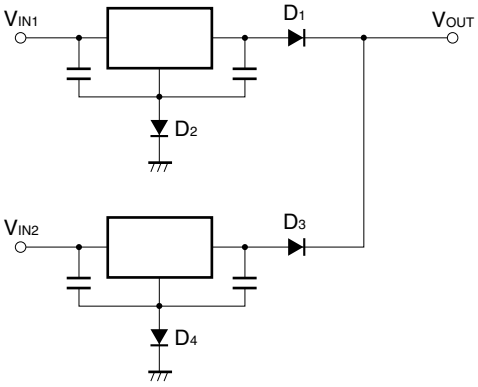
This power supply has superior tracking characteristics due to using an operational amplifier and one positive and one negative voltage three-terminal regulator.
The GND pin of each three-terminal regulator is driven in common by the operational amplifier output.
Favorable tracking characteristics are obtained by making $R_1 = R_2$. Moreover, bias current errors also can be canceled if the resistor $R_1//R_2$ is added between the non-inverting pin of the operational amplifier and GND.

14. Positive and negative dual power supply circuit (using positive voltage three-terminal regulators)



This is a positive and negative dual power supply that uses two positive voltage three-terminal regulators.
D_1 and D_2 are low forward voltage diodes that are absolutely necessary. They prevent output voltage pulldown due to discrepancies in the startup timing of each regulator.

15. Wired OR



When connecting the outputs of two or more three-terminal regulators, do it so that voltage from outside is not added to the regulator output at D_1 and D_3.
D_2 and D_4 are connected to compensate for the lowering of output by D_1 and D_3.

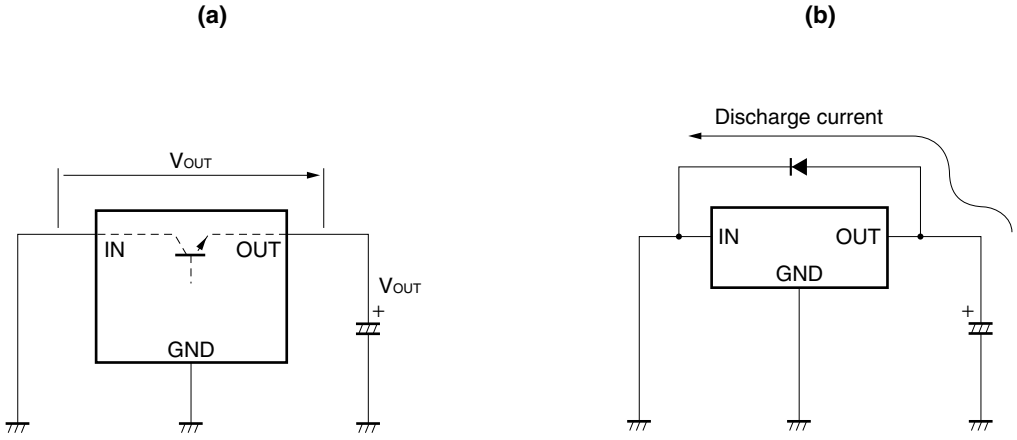
5. PRECAUTIONS ON APPLICATION

Do not use a three-terminal regulator under temperature conditions or voltage conditions that exceed the ratings. Other precautions that are specific to three-terminal regulators are shown below.

5.1 Shorting Input Pins and Ground Pins

When a capacitor with a large capacity is connected to the load of a three-terminal regulator, if the input pin is shorted to GND or the power supply is turned OFF, the voltage of the capacitor connected to the output pin is applied between the output and input pins of the three-terminal regulator.

Figure 5-1



The withstand voltage between the output and input pins of a three-terminal regulator is approximately 0.7 V for a low current with the output transistor base-emitter voltage.

Therefore, a diode like the one in Figure 5-1 (b) is effective against the reverse bias of the input and output pins.

Figure 5-1 (b) is for a positive voltage regulator. The diode direction is reversed for negative voltage.

5.2 Floating Ground Pins

Do not make the GND pin of a three-terminal regulator floating in the operating state. If it is made floating, an input voltage that has not been stabilized is output unchanged. This is because the output stage power transistor is biased by an overvoltage protection Zener or current mirror transistor leakage current. Since IC internal overheat protection and the like do not operate normally in this case, there is a possibility of destruction if the load is short-circuited or on an overload.

Be particularly careful when using a socket.

5.3 Applying Transient Voltage to Input Pins

A three-terminal regulator is destroyed if a higher voltage than the rating or a voltage more than 0.5 V lower than the GND pin is applied to the input line. In cases in which such voltages are superimposed on the line, add a surge suppressor using a Zener diode or the like.

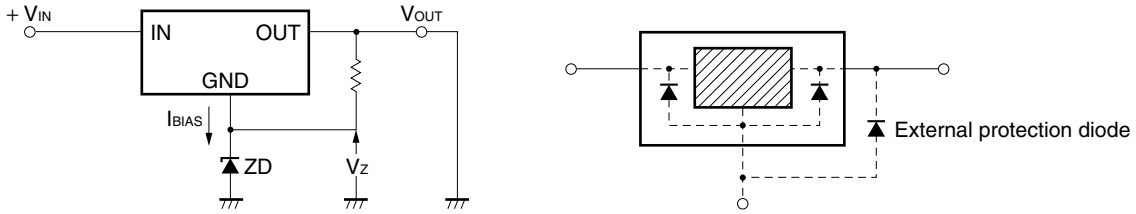
Figure 5-2

(a) **(b)**

5.4 Reverse Bias Between Output Pin and GND Pin

Figure 5-3

(a) **(b)**



In the sample application shown in Figure 5-3 (a), the voltage of the Zener diode is applied between the output and GND pins of the three-terminal regulator when the load is short-circuited.

Inside the three-terminal regulator, a diode like that shown in Figure 5-3 (b) apparently is formed, but if a current flows in this part, the three-terminal regulator is sometimes destroyed. Therefore, when using a GND like that shown in Figure 5-3 (a) in a floating state, it is necessary to add a low forward voltage diode from the GND pin of the three-terminal regulator toward the output pin.

5.5 Precautions Related to Low Saturation Types

Since a low saturation type of power supply IC uses a PNP transistor in the output stage, particular care is needed. In a low input state before the output voltage enters regulation state (such as at startup), a large circuit current flows because the output stage transistor is saturated. Depending on the product, the circuit current is decreased at startup by an on-chip rushing current prevention circuit, but even in this case a relatively large circuit current flows compared to normal operation (For details, refer to the "Circuit operating current at startup $I_{BIAS(S)}$" rating of each product). Thus, care is needed in the following matters.

- On startup, be careful of the output capacity of the power supply on the input side and the output impedance, since a circuit operating current flows in the input superimposed on the load current.
- It is not possible to adjust the output voltage by inserting a resistor or the like in the GND. This is because the circuit operating current increases at startup.

Be sure to connect a low impedance type capacitor to the output to increase stability against abnormal oscillation.

5.6 Thinking on Various Protection Circuits

NEC Electronics power supply ICs, which have on-chip overcurrent protection circuits, stable operation area restriction circuits, and overheat protection circuits, are very difficult to destroy in their normal operating state.

Nonetheless, you should not design circuits that put too much confidence in these protection circuits. These protection circuits are for protection against sudden accidents. To the best of your ability, avoid operating protection circuits for long stretches of time. In particular, be careful using the overheat protection circuit since this is like operating at a temperature exceeding the absolute maximum rating.

6. POWER SUPPLY IC DATA SHEET APPEARANCE AND DESIGN METHODS

6.1 Absolute Maximum Ratings

This item shows values that must not be exceeded even momentarily under any usage conditions or test conditions. Moreover, it is a mistake to think that use at the absolute maximum ratings is possible. Design should be performed so that even in an abnormal state the equipment being considered leaves room for the absolute maximum ratings.

In addition, it is assumed that GND is the lowest potential in the case of a positive output power supply and that INPUT is the lowest potential in the case of a negative output power supply (see chapter 2).

6.2 Recommended Operating Conditions

If used under these conditions, it is possible to obtain output voltage precision as expected. Think of this as a criterion for selecting a power supply IC.

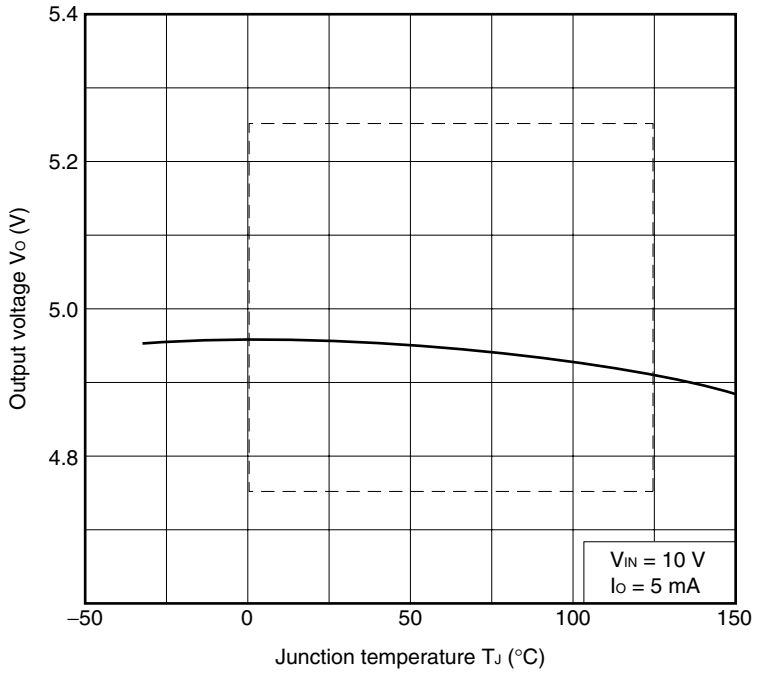
6.3 Electrical Specifications

NEC Electronics guarantees the minimum values and maximum values of electrical characteristics at the time of shipment. Therefore, whether or not it is possible to satisfy the specifications of the power supply to be designed must be determined by adequately investigating each rating and condition in each item of the electrical characteristics. Each item of the electrical characteristics is described below (Since the explanations below are mainly for positive output power supply ICs, reread them while reversing polarities for negative power supply ICs).

<1> Output voltage V_O

This item is the most important rating in using a power supply IC. Pay attention to measurement conditions. If power supply specifications are within this range of conditions, the expected precision (for example ±5%) is obtained (see Figure 6-1).

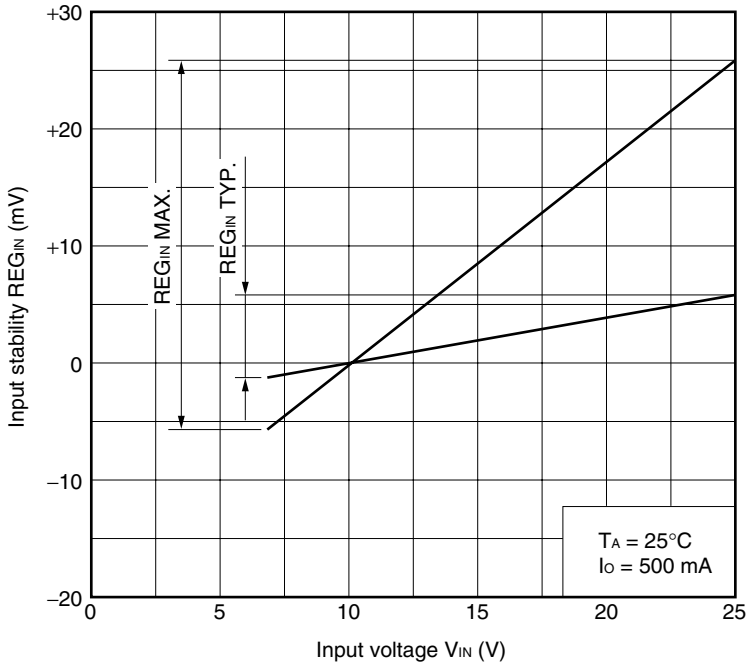
Figure 6-1. Output Voltage Conceptualization (For μPC7805AHF) Guaranteed Range Inside Broken Lines



<2> Input stability REG_{IN}

When the input voltage increases, the output voltage also increases. This item shows how much the output voltage changes when the input voltage V_{IN} is varied within the measured conditions. As shown in Figure 6-2, output voltage changes nearly linearly with respect to input voltage. Therefore, it is possible to infer how much the output voltage will change from the initial period when the initial input voltage is changed to a given input voltage.

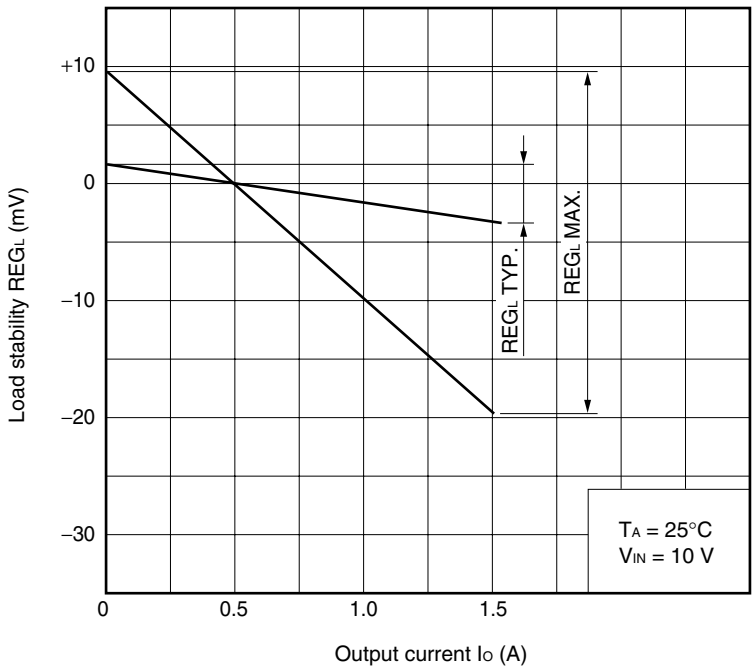
Figure 6-2. Input Stability REG_{IN} Conceptualization (For μPC7805AHF, V_{IN} = 10 V Standard)



<3> Load stability REG_L

Whereas REG_{IN} is the change in output voltage with respect to input voltage, load stability REG_L shows the change in output voltage with respect to load current (output current). When load current increases, output voltage decreases nearly linearly. The output voltage for an arbitrary load current can be inferred in the same way as REG_{IN} (see Figure 6-3).

Figure 6-3. Load Stability Conceptualization (For μPC7805AHF, I_O = 500 mA)



<4> Circuit operating current I_{BIAS}

This is the bias current needed for each internal block of a power supply IC to operate. It flows from input toward GND. Applications that adjust output voltage by inserting a resistor in GND take this item into account.

<5> Circuit operating current change ΔI_{BIAS}

This shows the change in I_{BIAS} when the input voltage or load current changes.

<6> Ripple removal rate R • R

The ripple voltage that appears in the output when a 120 Hz sine wave (minimum value and maximum value of sine wave are noted in measured conditions) is input in the input is represented by the following expression.

$R \bullet R = 20 \log (V_{IN}/V_{Oripple})$ [dB]

If the frequency increases, R • R decreases mainly due to the frequency characteristics of the internal error amplifier of the IC.

<7> Output noise voltage V_n

This shows the noise that occurs inside a power supply IC (mainly thought to be thermal noise).

★ **<8> Peak output current I_{Opeak}**

This is the current at which the overcurrent protection circuit operates. It is defined as the output current when the output voltage is lowered by 2 or 5% from its initial value.

As described in chapter 3, the overcurrent protection circuit operates together with the stable operation area. Moreover, note that I_{Opeak} decreases as temperature increases (negative temperature characteristic). Figure 6-4 shows the I_{Opeak} - (V_{IN} - V_O) characteristics of the μPC7800A Series. For a nonlinear load such as a motor or lamp, select a power supply IC that has sufficient leeway (50% or less of normal characteristic graph).

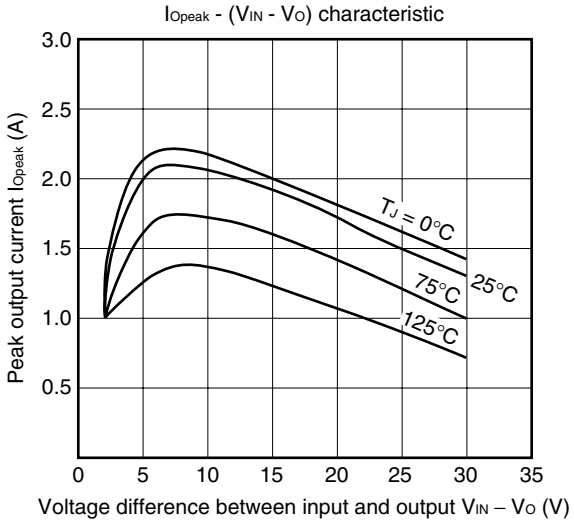
★ **<9> Output short circuit current I_{Oshort}**

This is the current that flows when output is short-circuited to GND. Since most NEC Electronics power supply ICs have an on-chip stable operation area restriction circuit, the following relation holds if input voltage is high.

$I_{Oshort} < I_{Opeak}$

Like I_{Opeak}, I_{Oshort} displays a negative temperature characteristic. Refer to Figure 6-4 for temperature characteristics of the output short circuit current and changes with respect to input voltage.

Figure 6-4. Sample I_{Opeak} Characteristics (μPC7800A Series)



6.4 Design Methods

(A) Input circuit design

Determine the capacity of a smoothing capacitor of an input circuit using an O.H. Shade graph or simulator so that the minimum value of the input voltage is not lower than the measurement conditions of output voltage.

At this time, connect a film capacitor between input and GND of the power supply IC separate from the smoothing capacitor to prevent abnormal oscillation (refer to the data sheet of each product type for capacitor values).

(B) Output circuit design

Check whether the load current used is a current no greater than the peak output current.

Connect a capacitor for abnormal oscillation prevention between output and GND of the power supply IC. If transient load stability becomes a problem, make sure the capacitor is connected in parallel.

(C) Radiation design

The junction temperature can be calculated using the following expression.

$$T_J = (R_{th(J-C)} + \theta_{C-HS} + \theta_{HS}) \times P_D + T_A \quad \text{..... (6.1)}$$

$R_{th(J-C)}$: Thermal resistance between junction and case

θ_{C-HS} : Contact thermal resistance (includes thermal resistance of insulation sheet when using insulation sheet)

θ_{HS} : Thermal resistance of radiator

P_D : Internal power consumption of IC ($P_D = (V_{IN} - V_O) \times I_O + V_{IN} \times I_{BIAS}$)

T_A : Ambient operating temperature

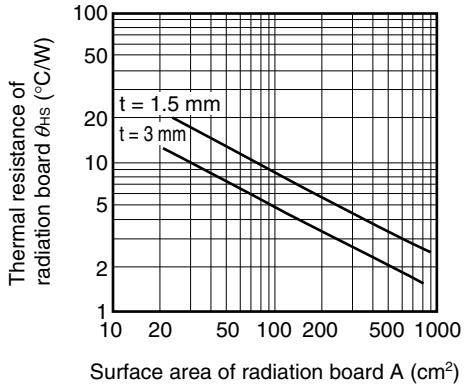
Expression (6.1) is the calculation expression when using a radiator. When not using a radiator, such as in the μPC78L00J Series, use the following expression.

$$T_J = R_{th(J-A)} \times P_D + T_A \quad \text{..... (6.2)}$$

Use the values in the data sheets for $R_{th(J-C)}$ and $R_{th(J-A)}$ in expressions (6.1) and (6.2).

Since T_J, $R_{th(J-C)}$, P_D, and T_A are given, find the thermal resistance of the radiator θ_{HS} from them using expression (6.1). Figure 6-5 shows the thermal resistance of an aluminum board. Since the makers of radiators produce radiators suited to power supply ICs, also consult the radiator maker.

Figure 6-5. Thermal Resistance of Aluminum Board



If T_J is not within the design values, return to (A) or (B) and recalculate. An example of radiator design is shown next.

<1> Design objectives

Positive power supply using μPC7805AHF

Maximum output current	$I_{O\ max.}$ = 0.6 (A)
Maximum voltage difference between input and output	$V_{DIF\ max.}$ = 6 (V)
Maximum ambient operating temperature	$T_{A\ max.}$ = 60 (°C)
Maximum junction temperature	$T_{J\ max.}$ = 100 (°C)

<2> Radiation board thermal resistance calculation

In a used state, the junction temperature T_J is the following.

$$T_J = (R_{th(J\text{-}C)} + \theta_{C\text{-}HS} + \theta_{HS}) \times P_D + T_A \quad \text{..... (6.3)}$$

$R_{th(J\text{-}C)}$: Thermal resistance between junction and case
$\theta_{C\text{-}HS}$: Thermal resistance between case and radiator
θ_{HS} : Thermal resistance of radiator
P_D : Power consumption

Here, $T_{J\ max.}$ = 100 (°C), $T_{A\ max.}$ = 60 (°C), $\theta_{C\text{-}HS} << 1$ (°C/W), and $R_{th(J\text{-}C)}$ = 5.0 (°C/W)
By substituting $P_{D\ max.} \fallingdotseq V_{DIF\ max.} \times I_{O\ max.}$ = 3.6 (W) in expression (6.3), find the thermal resistance θ_{HS} needed in the radiator.

$$\theta_{HS} = \frac{T_J - T_A}{P_D} - R_{th(J\text{-}C)} - \theta_{C\text{-}HS}$$

$$= 6.1\ (°C/W) \quad \text{..... (6.4)}$$

<3> Determination of size of radiation board

From expression (6.4), the design objectives can be satisfied using a radiator of 6.1 (°C/W).
Figure 6-5 shows the relationship between the thickness, surface area, and thermal resistance of an aluminum board.
By using a 3 mm thick 60 cm^2 aluminum board here, we know that the radiation board will have the necessary thermal resistance.

(Sample use without radiator)

The junction temperature T_J in the used state when not installing a radiation board is the following.

$$T_J = R_{th(J\text{-}A)} \times P_D + T_A \quad \text{..... (6.5)}$$

$R_{th(J\text{-}A)}$: Thermal resistance between junction and ambient air (still air ..... natural convection)
P_D : Power consumption
T_A : Ambient operating temperature

Setting T_J to 100°C or less in the used state is recommended.

Precautions when installing in a radiator

- **Make the convexity or concavity of the part installation surface of the radiator 0.05 mm or less.**
- **Spread silicon grease to a uniform thickness between the radiator and part. Determine the kind of grease on consulting the maker of the radiator.**
- **Painting the radiator black increases its effectiveness in radiating heat. However, if it is close to a heat source, it has the reverse effect of absorbing heat.**
- **Use one of the insulating board bushings shown in Table 6-2.**
- **Cut a screw in a radiator and absolutely do not use self-tapping screws to install one.**

When installing a radiator, if the tightening torque of a screw is too great, the fins can be distorted and the IC damaged. Drive screws using a torque driver that can manage the tightening torque.

★ **Table 6-1. Three-Terminal Regulator Tightening Torque**

Markings	Tightening torque (N•m)
TO-126	0.2 to 0.4
TO-220	0.3 to 0.5
MP-45G	0.3 to 0.5

Figure 6-6. Standard Installation Method for Radiation Board Insulation

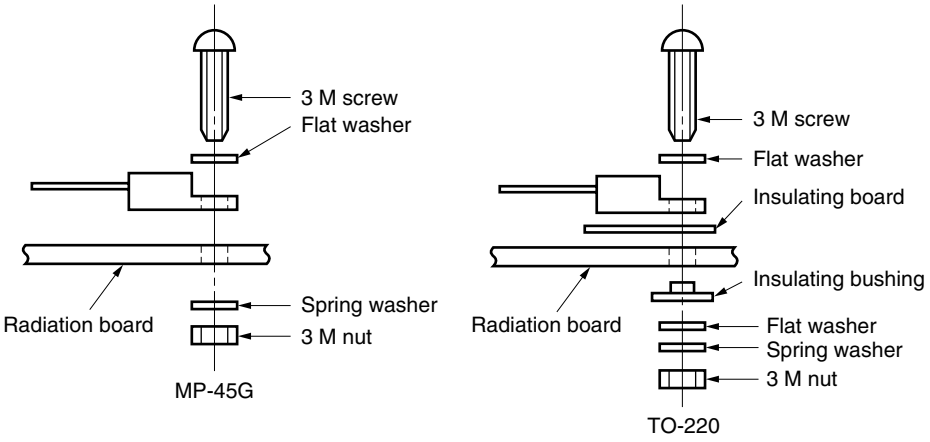


Table 6-2. Recommended Insulating Bushings and Insulating Board

	Code No.	Product Name	Quality of Materials		Incombustibility Grade
			Material	Color	
Insulating bushing	B-24	25K bushing U	Gelanex 3310	Light brown	UL 94V-0
Insulating board	S-7	MP-25 insulating board A	Polyester	Colorless, transparent	–

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