Linear Regulator Series (3-Terminal Regulator, LDO)

BA178xx Series Application Information

The information in this application note provides only suggestions for IC mounting. For this reason, the information should not be taken as a quality explanation or as a warranty for the IC. See the latest data sheet for the IC standard values. Also, note that the application circuits used in the explanations for each item have been simplified. Be sure to verify operations using the actual application.

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1 BA178xx series

After Fairchild (now Texas Instruments) released the µA7800 series in 1976, three-terminal voltage regulators became the industry standard for fixed positive voltage output regulators. The BA178xx series were developed as the second source of the µA7800 series. The µA7800 series is a long-selling product. If you search online you can find a dozen or more companies that make a second source. But because each of those companies uses a different manufacturing process, it is impossible to achieve compatibility with all of them. Manufacturing differences can be seen in variations in the package size, internal circuits, and constants. So before replacing the IC, be sure to perform evaluations to check for any potential problems.

Product name	Output
BA17805	5V, 1A
BA17806	6V, 1A
BA17807	7V, 1A
BA17808	8V, 1A
BA17809	9V, 1A
BA17810	10V, 1A
BA17812	12V, 1A
BA17815	15V, 1A
BA17818	18V, 1A
BA17820	20V, 1A
BA17824	24V, 1A

2 Typical application: fixed output voltage regulator

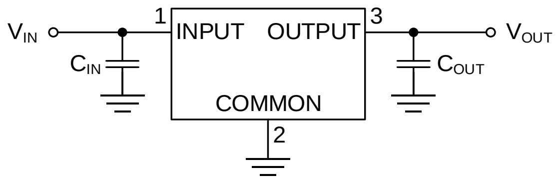
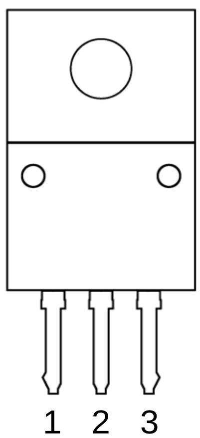


Figure 2-1. Typical application circuit (TO220CP-3 package)

Product name	BA178xxCP
Package	TO220CP-3
Pin layout Top View	

Pin number	Pin name	Function
1	INPUT	Input pin Power is supplied to the IC through the input pin. To stabilize the IC input, connect a capacitor between INPUT and COMMON. Place the capacitor near the pin. → See page 5.
2	COMMON	Common pin This is the COMMON pin of the regulator circuit. When using the unit as a fixed output voltage regulator, connect COMMON to the ground.
3	OUTPUT	Output pin Power is supplied to the load through the output pin. Connect a capacitor between OUTPUT and COMMON to prevent oscillations. → See page 5.
-	-	Heat radiation fins FIN is connected to the die via the lead frame. We recommend connecting it to a heatsink to improve heat dissipation efficiency. This package is completely covered with mold resin, so the metal parts on the back surface are not exposed. This means an insulation plate is unnecessary.

2 Typical application: fixed output voltage regulator

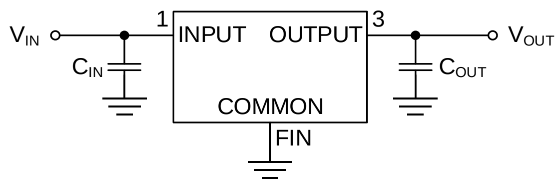
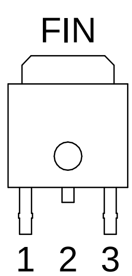


Figure 2-2. Typical application circuit (TO252-3 package)

Product name	BA178xxFP
Package	TO252-3
Pin layout Top View	

Pin number	Pin name	Function
1	INPUT	Input pin Power is supplied to the IC through the input pin. To stabilize the IC input, connect a capacitor between INPUT and COMMON. Place the capacitor near the pin. → See page 5.
2	N.C.	Unconnected pin Leave this open. This is connected with FIN via COMMON of the regulator circuit.
3	OUTPUT	Output pin Power is supplied to the load through the output pin. Connect a capacitor between OUTPUT and COMMON to prevent oscillations. → See page 5.
FIN	COMMON	COMMON pin and heat radiation fins FIN is connected to the die via the lead frame. We recommend soldering FIN to the COMMON plane with a wide copper foil area to improve heat dissipation efficiency. Also, FIN is electrically connected to COMMON inside the package. When using the unit as a fixed output voltage regulator, connect COMMON to the ground.

3 Input capacitor

The purpose of the input capacitor is to reduce the fluctuations in the potential of the power line during circuit operations. This stabilizes the IC input. In particular, when the input trace is long or when the input power impedance is high, the input capacitor effectively stabilizes the input power. Connect the capacitor between the INPUT and COMMON pins within 1 cm of the IC. The purpose of the input capacitor is to reduce the source impedance. We therefore recommend a ceramic capacitor with a small ESR. Connect a capacitor with a capacitance of 0.33 µF or greater. If the output current changes drastically, increasing the capacitance of the output capacitor will reduce the ripple voltage. However, if the momentary current supply capacity on the input current side is poor, the input voltage may drop due to the larger output capacitance. To prevent this, increase the capacitance of the input capacitor as well, so that it approximates the output capacitance. For the bulk capacitor, connect an aluminum electrolytic capacitor, etc. in parallel with the ceramic capacitor.

4 Output capacitor

To stabilize the loop, place the output capacitor between the OUTPUT and COMMON pins within 3 cm of the IC. Connect a capacitor with a capacitance of 0.1 µF or greater. If the capacitance is too small, oscillation may occur. Although there is no limit to the maximum value for the output capacitance, the following points must be considered. Increasing the capacitance will lengthen the charging time after the power is turned ON, and the discharging time after the power is turned OFF. It is possible that the IC can be damaged when turning OFF the power due to an input and output voltage inversion, which causes a large current to flow back into the IC. Therefore, connect a reverse current bypass diode or a reverse current protection diode.

Be careful using electrolytic capacitors. While they are inexpensive and offer a large capacitance, this capacitance may suddenly drop at low temperatures.

For a ceramic capacitor, we recommend using an X5R or X7R. These have good temperature characteristics. Do not use a Z5U, Y5V, or F. These have large capacitance variations. The capacitance value may be reduced due to the differences in tolerance, the temperature characteristics, and the DC bias characteristics. Set it so that the capacitance does not fall below the minimum value. For the DC bias characteristics, the capacitance tends to drop more with smaller sizes.

If the fluctuations in the load current are abrupt, a ripple voltage may occur in the output. To reduce the ripple voltage, increase the capacitance of the output capacitor. When the output capacitance is increased, the amount of electrical charge that charges the output capacitor from the input side increases. For this reason, if the load responsiveness of the input side power is bad, this may result in a voltage drop. To prevent this, use a larger input capacitor that is appropriate for the output capacitance.

The number of the operational conditions may be unlimited, depending on the circuits connected to the front and rear stages of the linear regulator. Regardless of capacitor type and capacitance value of the capacitor, make sure that there are no oscillations in the final product.

5 Load

This IC has the over current protection (OCP) characteristics resembling the number “7”. Therefore, if the load current during startup exceeds the IC output (supply) current, the output voltage will not rise and the IC will fail to start up. This is also the case when the load is a constant current source or the output voltage is negative during startup, or when a through current larger than the IC supply capacity flows in a logic circuit during startup.

For example, the IC will operate when the constant current load is turned ON after the IC output voltage rises to the specified value. But afterwards, if the thermal shutdown circuit operates and the output goes OFF, the IC cannot be restarted. Further, if the IC cannot be started, a constant current load will flow to the electrostatic breakdown protection diode (between OUTPUT and COMMON). Due to this, temperature of the chip may rise, depending on the current value. This may destroy the IC or melt the solder. For this reason, we do not recommend using a constant current load.

6 Efficiency

Efficiency can be calculated with the following equation.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times (I_{OUT} + I_b)} \times 100 \quad [\%] \qquad (6\text{-}1)$$

V_{IN}: Input voltage $[V]$
V_{OUT}: Output voltage $[V]$
I_{OUT}: Output current $[A]$
I_b: IC bias current $[A]$

Note that when $I_b \ll I_{OUT}$, the efficiency can be calculated with the following equation.

$$\eta = \frac{V_{OUT}}{V_{IN}} \times 100 \quad [\%] \qquad (6\text{-}2)$$

We can see from these equations that a smaller voltage difference between the input and output results in a better efficiency

7 Thermal design

To ensure highly reliable operations, it is necessary to make sure that the IC junction temperature does not exceed 150°C. The junction temperature estimate can be calculated using the following three methods.

1. When measuring the IC temperature by its surface temperature, use the thermal characteristic parameter ψ_{JT} for the calculation. If a thermocouple can be affixed firmly in the center of upper surface center, the temperature T_T at that point can be measured precisely. The junction temperature can be calculated precisely by using the thermal characteristic parameter.

$$T_J = T_T + \psi_{JT} \times P \quad [^\circ C] \qquad (7\text{-}1)$$

T_T: Temperature at the center of upper surface of package $[^\circ C]$
ψ_{JT}: Thermal characteristics parameter from junction to center of upper surface of package $[^\circ C/W]$
P: IC power consumption $[W]$

P is the IC power consumption. It can be calculated with the following equation.

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} + (V_{IN} \times I_b) \quad [W] \qquad (7\text{-}2)$$

V_{IN}: Input voltage $[V]$
V_{OUT}: Output voltage $[V]$
I_{OUT}: Output current $[A]$
I_b: IC bias current $[A]$

Note that when $I_b \ll I_{OUT}$, the power consumption can be calculated with the following equation.

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} \quad [W] \qquad (7\text{-}3)$$

Also, the peak output current that can flow constantly can be calculated with the following equation.

$$I_{OUT(MAX)} = \frac{T_{J(MAX)} - T_T}{(V_{IN} - V_{OUT}) \times \psi_{JT}} \quad [A] \qquad (7\text{-}4)$$

$T_{J(MAX)}$: Absolute maximum rating for junction temperature $[^\circ C]$
T_T: Temperature at the center of upper surface of package $[^\circ C]$
ψ_{JT}: Thermal characteristics parameter from junction to center of upper surface of package $[^\circ C/W]$
V_{IN}: Input voltage $[V]$
V_{OUT}: Output voltage $[V]$

2. The thermal resistance θ_{JA} can also be used to quickly calculate the junction temperature.

$$T_J = T_A + \theta_{JA} \times P \quad [^\circ C] \qquad (7\text{-}5)$$

T_A: Ambient temperature $[^\circ C]$
θ_{JA}: Thermal resistance between junction and ambient atmosphere $[^\circ C/W]$
P: IC power consumption $[W]$

Also, the peak output current that can flow constantly can be calculated with the following equation.

$$I_{OUT(MAX)} = \frac{T_{J(MAX)} - T_A}{(V_{IN} - V_{OUT}) \times \theta_{JA}} \quad [A] \qquad (7\text{-}6)$$

$T_{J(MAX)}$: Absolute maximum rating for junction temperature $[^\circ C]$
T_A: Ambient temperature $[^\circ C]$
θ_{JA}: Thermal resistance between junction and ambient atmosphere $[^\circ C/W]$
V_{IN}: Input voltage $[V]$
V_{OUT}: Output voltage $[V]$

3. The TO220 package can be equipped with a heatsink to reduce thermal resistance. The thermal resistance θ_{JC} is used to calculate the junction temperature.

$$T_J = (\theta_{JC} + \theta_{CH} + \theta_{HA}) \times P + T_A \quad [℃] \qquad (7\text{-}7)$$

θ_{HA} : Thermal resistance of heatsink $[℃/W]$

θ_{JC}: Thermal resistance between the junction and the case $[℃/W]$

θ_{CH}: Contact thermal resistance (e.g. silicone grease) $[℃/W]$

$$\theta_{CH} = \frac{t}{K \times L \times W} \quad [℃/W]$$

t: Thickness of silicone grease $[m]$

K: Thermal conductivity of silicone grease $[W/(m \cdot K)]$

L: Length of case contact surface $[m]$

W: Width of case contact surface $[m]$

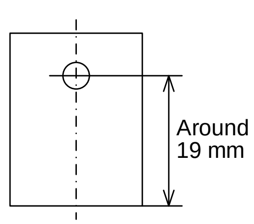
T_A: Ambient temperature $[℃]$

P: C power consumption $[W]$

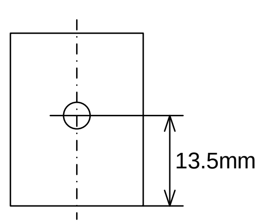
In addition, the thermal resistance θ_{HA} of the heatsink required for heat dissipation can be calculated with the following equation.

$$\theta_{HA} = \frac{T_J - T_A}{P} - \theta_{JC} - \theta_{CH} \quad [℃/W] \qquad (7\text{-}8)$$

Since the lead frame length of the TO220CP-3 package is different from that of the general TO220 package, the position of the heatsink mounting hole is also different. Note that some commercial heatsinks may not be used for this reason.



Position of heatsink mounting hole for general TO220



Position of heatsink mounting hole for TO220-CP3

The thermal characteristics parameter ψ_{JT} and thermal resistance θ_{JA} are values measured using a specific PCB. Heat dissipation is affected by PCB characteristics, copper foil layout, parts layout, chassis shape, the surrounding environment and so on. Therefore, the thermal characteristics parameter and thermal resistance will also be affected. Take into account that the values may differ from those of an actual equipment board.

Thermal characteristics parameters and thermal resistance of TO220CP-3 package

Configuration	ψ_{JT} (℃/W)	θ_{JA} (℃/W)
IC only	10	72.0

Configuration	θ_{JC} (℃/W)
Infinite heatsink *1	4

*1 : Water-cooled cold plate

Thermal characteristics parameters and thermal resistance of TO252-3 package

PCB type	ψ_{JT} (℃/W)	θ_{JA} (℃/W)
1 layer (1s)	13	132.2
2 layers (2s)	3	30.2
4 layers (2s2p)	2	23.3

Figures 7-1 through 7-13 and Tables 7-1 to 7-3 show the specifications for the PCB used in measurement.

TO252-3 package PCB specifications, 1 layer (1s)

Conforms to JEDEC standard JESD51-3/ -7

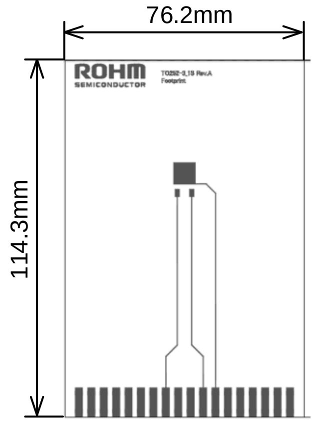


Figure 7-1. Top Layer Trace

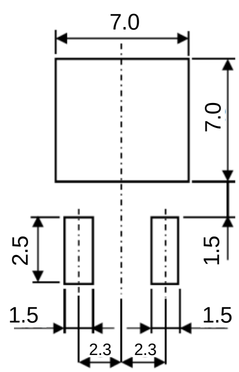


Figure 7-2. Footprint

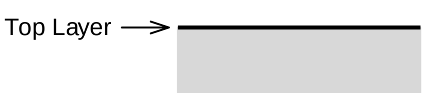


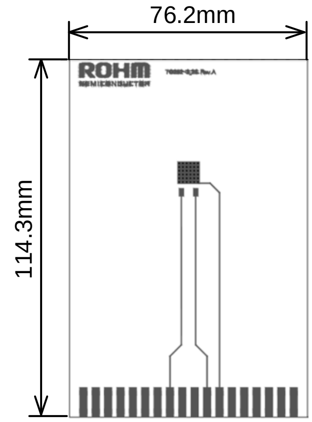
Figure 7-3. 1-layer board sectional view

Item	Value
Board thickness	1.57 mm
Board outline dimensions	76.2 mm × 114.3 mm
Board material	FR-4
Trace thickness (Finish thickness)	70 µm (2 oz)
Lead width	0.254 mm
Copper foil area	Footprint

Table 7-1. 1-layer PCB specifications

TO252-3 package PCB specifications, 2 layers (2s)

Conforms to JEDEC standard JESD51-3/ -5/ -7



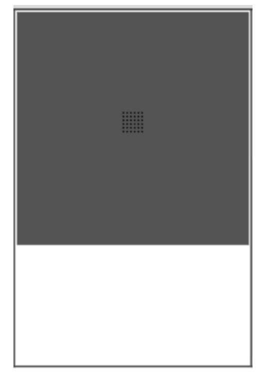


Figure 7-4. Top Layer Trace

Figure 7-5. Bottom Layer Trace

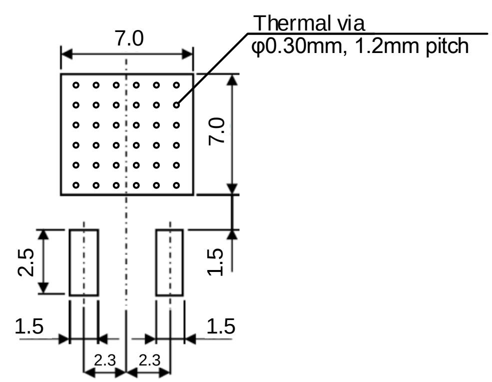


Figure 7-6. Footprint

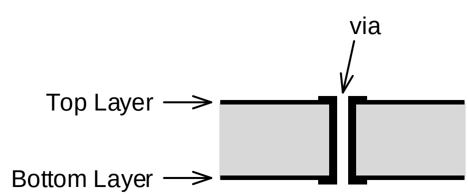


Figure 7-7. 2-layer board sectional view

Item		Value
Board thickness		1.60 mm
Board outline dimensions		76.2 mm × 114.3 mm
Board material		FR-4
Trace thickness (Finish thickness)	Top Bottom	70 µm (2 oz) 70 µm (2 oz)
Lead width		0.254 mm
Copper foil area	Top Bottom	Footprint 5505 mm^2 (74.2 mm × 74.2 mm)

Table 7-2. 2-layer PCB specifications

TO252-3 package PCB specifications, 4 layers (2s2p)

Conforms to JEDEC standard JESD51-3/ -5/ -7

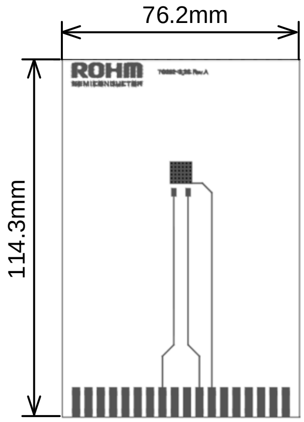


Figure 7-8.
Top Layer Trace

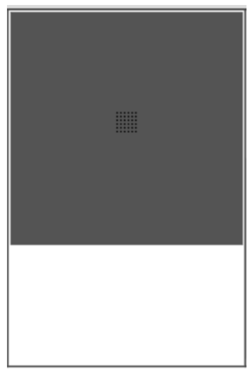


Figure 7-9.
Middle 1 Layer Trace

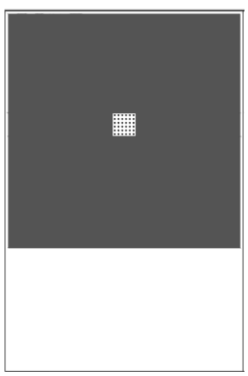


Figure 7-10.
Middle 2 Layer Trace

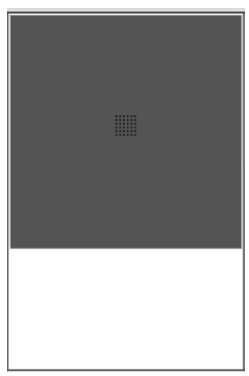


Figure 7-11.
Bottom Layer Trace

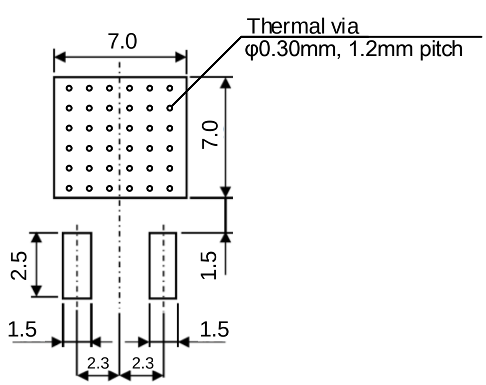


Figure 7-12. Footprint

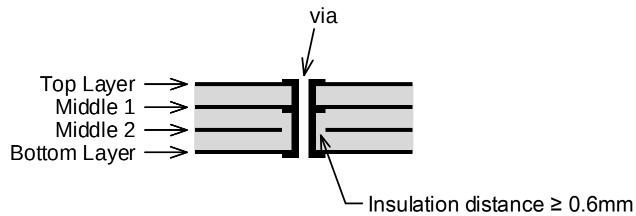


Figure 7-13. 4-layer board sectional view

Item		Value
Board thickness		1.60 mm
Board outline dimensions		76.2 mm × 114.3 mm
Board material		FR-4
Trace thickness (Finish thickness)	Top Middle 1 Middle 2 Bottom	70 µm (2 oz) 35 µm (1 oz) 35 µm (1 oz) 70 µm (2 oz)
Lead width		0.254 mm
Copper foil area	Top Middle 1 Middle 2 Bottom	Footprint 5505 mm^2 (74.2 mm × 74.2 mm) 5505 mm^2 (74.2 mm × 74.2 mm) 5505 mm^2 (74.2 mm × 74.2 mm)

Table 7-3. 4-layer PCB specifications

8 Terminal protection

If inverse or excess voltage is applied to the IC terminals, the device may be damaged or the output voltage may not rise. When the following conditions are anticipated, we recommend that the terminals be adequately protected.

1. When the input/output voltage conditions are reversed
   → reverse current bypass, reverse current prevention
2. When the output load is inductive → output reverse voltage protection
3. Possibility of input polarities connected in reverse → input reverse voltage protection
4. Hot-plugging → hot-plugging countermeasures
5. Load exists between disparate power sources → reverse current bypass
6. Positive-negative power source (both power sources)

1. When the input/output voltage conditions are reversed

When the capacitance of the output capacitor is large, and a load remains in the output capacitor even after the input power shuts down, or the speed that the input power shuts down is extremely fast, reverse current will flow from output to input via parasitic elements in the IC because the input/output voltage state will be inverted. Operation is not guaranteed for parasitic elements, and this can degrade or destroy elements.

As a countermeasure, connect a reverse current bypass diode externally (Figure 8-1) or insert a reverse current prevention diode into the input side (Figure 8-2), so that the reverse current does not pass through the inside of the IC. Note that when the input side is left open and the IC is powered down, no degradation or breakdown of parasitic elements will occur due to the reverse current value being a slight IC bias current only. Owing to this, countermeasures using the external diode is not necessary (Figure 8-3).

It is necessary for the bypass diode to turn ON before the parasitic elements inside the IC turns ON. As the ON voltage of the internal parasitic elements is approximately 0.7 V for the BA178xx series linear regulator, a lower forward voltage V_F is required. Select an inverse rated voltage that is larger than the input/output voltage difference to be used (80% derating or less). Select a forward direction rated current that is larger than the reverse rated current value (50% derating or less) to be used. From the above conditions, we recommend a rectifier diode or Schottky barrier diode; but as the inverse current of many Schottky barrier diodes is generally large, select one with a small value.

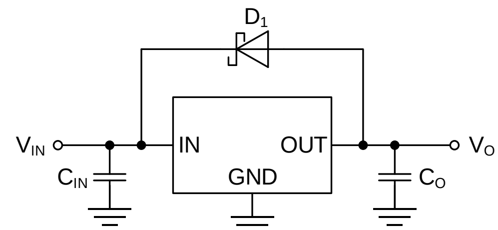


Figure 8-1. Reverse current bypass diode

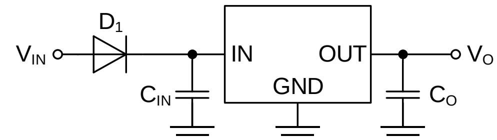


Figure 8-2. Reverse current prevention diode

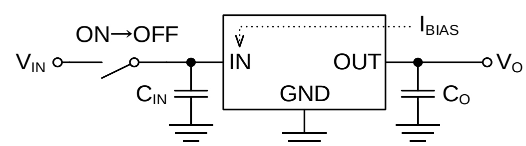


Figure 8-3. When the input is open

2. When the output load is conductive

When the output load is inductive, the energy stored in the inductive load at the instant the output voltage goes off will be discharged to the ground. A diode is used between the IC output pin and GND pin to prevent electrostatic breakdown. If a large electric current flows to this diode, the IC may break down. To prevent this, connect a Schottky barrier diode in parallel to the electrostatic breakdown prevention diode (Figure 8-4).

When the IC output pin and load are connected via a long wire, a conductive load may occur. Measure the waveform using an oscilloscope. Aside from this, when the load is a motor, a diode is necessary due to counter electromotive force in the motor, which causes the same kind of current to flow.

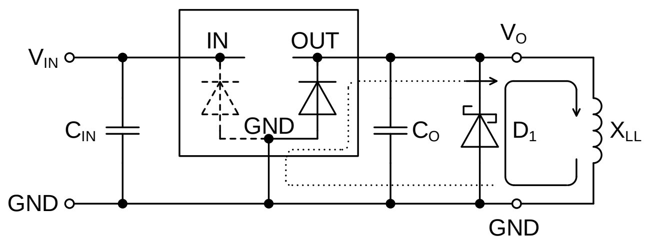


Figure 8-4. Conductive load current path (when output is off)

3. Possibility of input polarities connected in reverse

When connecting an input to the power supply, if the positive and negative terminals are connected in reverse due to careless error, a large electric current may flow into the parasitic diode between the IC input pin and the GND pin (Figure 8-5), causing the IC to break down. The easiest countermeasure against the reverse connection is to connect a Schottky barrier diode or a rectifier diode in series with the power supply, as shown in Figure 8-6. Using the correct connection, a power loss will occur in $V_F \times I_O$ due to a voltage drop in the forward voltage V_F of the diode, so this is not suitable for a battery-operated circuit. The V_F of a Schottky barrier diode is lower than that of a rectifier diode, so the loss will be somewhat smaller. Since the diode will generate heat, select a diode with a margin of power dissipation. When connected in reverse, current for the diode will flow in reverse, but the value will be slight.

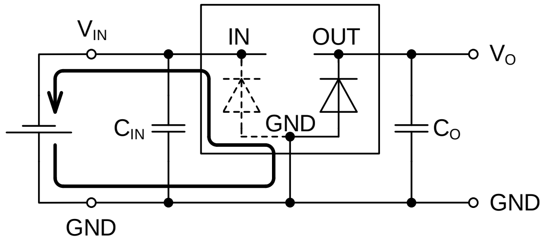


Figure 8-5. Current path when the input is connected in reverse

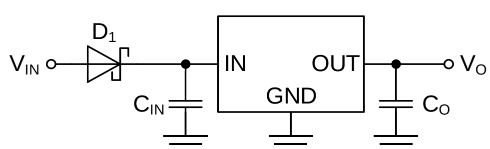


Figure 8-6. Countermeasure #1 against reverse connection

Figure 8-7 shows how to connect the diode in parallel with the power source. Since it is necessary for the diode to turn ON earlier than the parasitic diode inside the IC, use a Schottky barrier diode with a low V_F. Using the correct connection, this will operate in the same way as without the diode. Since the total current will keep flowing to the diode when connected in reverse, heat will occur, which may lead to breakdown if the current capacity in the previous stage is too large. The prerequisites for this circuit are either to protect the circuit from accidental mistakes over the short-term, or for an over current protection circuit to be present in the previous stage.

For placing greater emphasis on safety by using a protection circuit, connect the power source in series to the fuse. Although maintenance of the fuse is required, this will protect the circuit with even greater certainty (Figure 8-8).

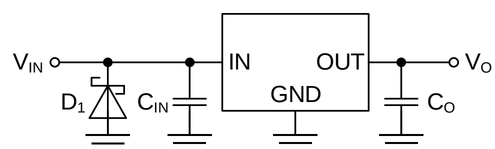


Figure 8-7. Countermeasure #2 against reverse connection

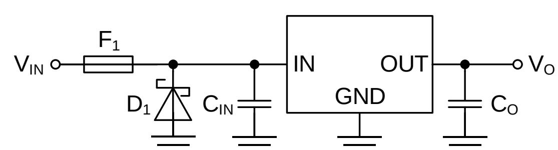


Figure 8-8. Countermeasure #3 against reverse connection

Figure 8-9 shows how to connect the P-ch MOSFET in series with the power source. The diode between the MOSFET drain-source is a body diode (parasitic element). Using the correct connection, the P-ch MOSFET will turn ON, and the voltage drop here will be the ON resistance of MOSFET times the output current I_O. As this is smaller than the voltage drop via diode (Figure 8-6), the power loss will be smaller. When connecting in reverse, MOSFET will not turn ON, so there will be no current flow.

When the voltage drop exceeds the rated voltage between MOSFET gate and source (in consideration of derating), divide between the gate and the source by inserting a resistor, and lower the gate-source voltage as shown in Figure 8-10.

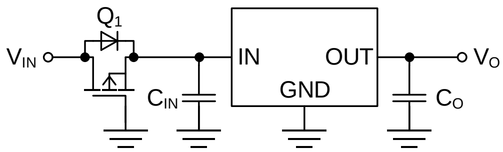


Figure 8-9. Countermeasure #4 against reverse connection

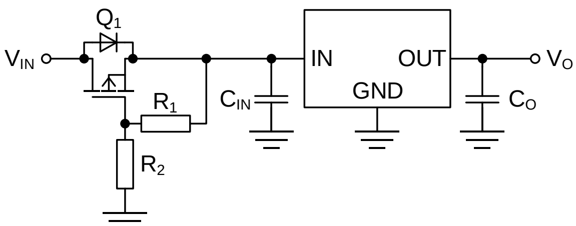


Figure 8-10. Countermeasure #5 against reverse connection

4. Hot-plugging (hot swapping)

When connecting a wire to the IC input while the supply side power is ON, a pulse waveform will be generated due to contact between the wiring inductance component and the metal of the connector plug. If this surge voltage exceeds the IC's absolute maximum rating, the IC may break down. Use a TVS (transient voltage suppressor) diode to absorb the surge, so that the surge voltage does not reach the IC input pin (Figure 8-11).

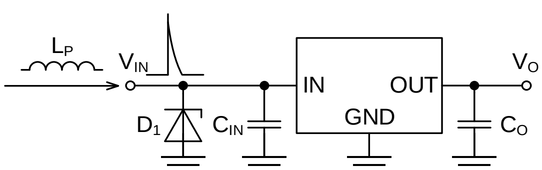


Figure 8-11. Hot-plugging countermeasure

5. Load exists between disparate power sources

As shown in Figure 8-12, when a load exists between disparate power sources, the timing for rises and drops are different, so current will flow to another power output terminal through the load. Reverse voltage will occur between IC inputs and outputs at this time, so a reverse current bypass diode is needed.

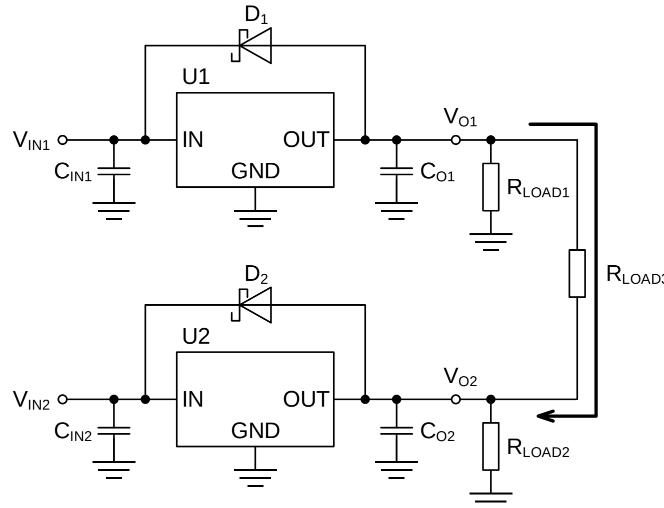


Figure 8-12. Current path and diode insertion for disparate power sources

6. Positive-negative power source (both power sources)

For positive-negative power supplies as shown in Figure 8-13, the speeds at which the power supplies rise are different. For this reason, when there is a load between positive and negative, the power source that started first pulls current from the other output through the load, which applies negative voltage to the output. Be sure to connect a Schottky barrier diode with a low V_F between the output and GND, to prevent damage to the IC and to prevent the output voltage from failing to rise.

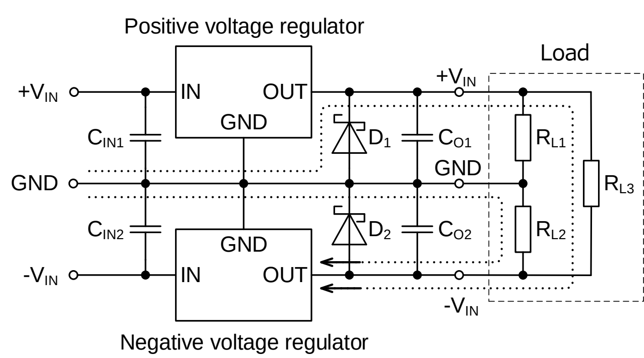


Figure 8-13. Diode insertion for positive-negative power supplies; current path when negative power supply regulator starts first

9 Sequence for turning power supply on

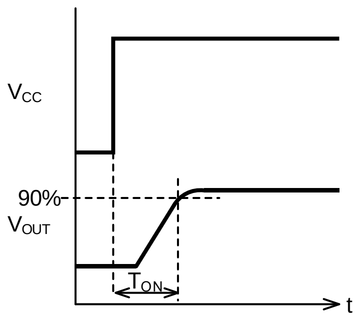


Figure 9-1.
When V_{CC} turns ON abruptly
When the output capacitor value is small

Figure 9-1 shows the startup characteristics when V_{CC} abruptly turns ON. The circuit begins operating at the time when V_{CC} starts up. When the capacitance of the output capacitor is small (at or below around several µF), the inrush current during startup remains lower than the value at which the over current protection circuit activates, and the current is not limited. Therefore, the output voltage increases with the rise time of the reference voltage inside the IC, regardless of the capacitance value of the output capacitor.

Figure 9-2 shows the startup characteristics when the output capacitor value on Figure 9-1 is large (around several dozens µF or more). Since the inrush current at startup time becomes longer and current is limited as a result of the over current protection circuit, the charging current to the capacitor will be limited, and the startup time will get longer as the capacitor's capacitance increases.

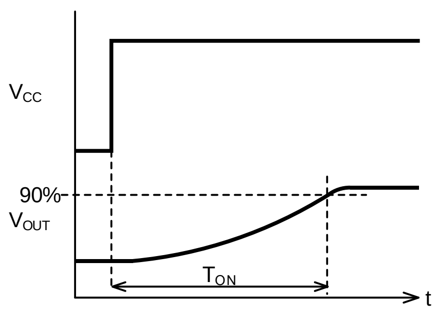


Figure 9-2.
When V_{CC} turns ON abruptly
When the output capacitor value is large

Typical values are shown below.

C_O (µF)	T_{ON}		
	BA17805	BA17812	BA17824
0.1 µF	6 µs	17 µs	27 µs
1 µF	6 µs	17 µs	30 µs
10 µF	12 µs	42 µs	200 µs
22 µF	30 µs	100 µs	500 µs
47 µF	80 µs	250 µs	1.3 ms
100 µF	180 µs	560 µs	2.8 ms
220 µF	390 µs	1.3 ms	5.8 ms

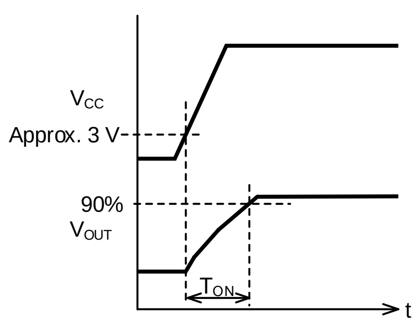


Figure 9-3.
When V_{CC} turns ON gradually
When the output capacitor value is small

Figure 9-3 shows the startup characteristics when V_{CC} turns ON gradually, and when the output capacitor value is small. The circuit begins operating and the output voltage rises at the time when the V_{CC} exceeds approximately 3 V. In addition, the point where the circuit begins operating is the same when the output capacitor is large, and the output voltage rise waveform will be as shown in Figure 9-2.

10 Sequence for turning power supply OFF

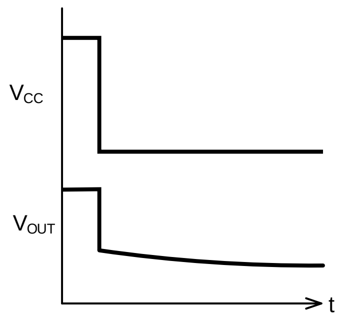


Figure 10-1.
When V_{CC} turns OFF abruptly

Figure 10-1 shows the power OFF characteristics when V_{CC} abruptly turns OFF. When V_{CC} abruptly turns OFF, the electrical charge of the output capacitor is discharged to the input side through the parasitic elements inside the IC due to the input/output voltage inversion. As a result, the output voltage abruptly falls following the input voltage; and when V_{CC} reaches 0 V, the output voltage starts falling gradually with the remaining ON voltage of the parasitic elements (approximately 0.5 V). Then, the voltage falls with the time constant of the load resistor.

For a load of a simple resistor, the output voltage falling time can be calculated with the following equation.

$$T_{OFF} = -C_O \times R_L \times \ln\left(\frac{V_C}{V_O}\right) \quad [sec] \tag{10-1}$$

C_O: Output capacitor $[F]$
R_L: Load resistance $[\Omega]$
V_O: Output voltage $[V]$
V_C: Final dropped voltage $[V]$

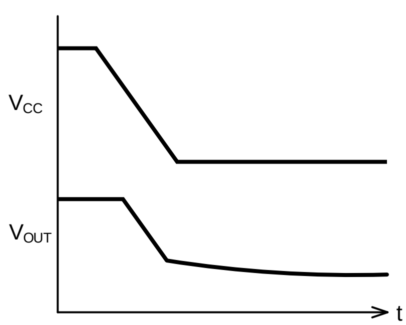


Figure 10-2.
When V_{CC} turns OFF gradually

Figure 10-2 shows the power OFF characteristics when V_{CC} gradually turns OFF. When V_{CC} falls and the input/output voltage reaches the inversion point, the electrical charge of the output capacitor is discharged to the input side through the parasitic elements inside the IC. As a result, the output voltage gradually falls following the input voltage; and when V_{CC} reaches 0 V, the output voltage starts falling further gradually with the remaining ON voltage of the parasitic elements (approximately 0.5 V). Then, the voltage falls with the time constant of the load resistor.

11 Inrush current

An inrush current flows to electrically charge the output capacitor of the IC during startup. Even if the output current value exceeds the maximum value of the recommended operating range, the over current protection (OCP) circuit limits the current, so there are no problems in operation. Note that it is necessary to make sure that the IC junction temperature does not exceed 150°C due to overcurrent. The junction temperature T_J during short-term over current can be estimated by the following equation using the transient thermal resistance Z_{TH}.

$$T_J = T_A + Z_{TH} \times P \quad [°C] \qquad (11\text{-}1)$$

T_A: Ambient temperature [°C]
Z_{TH}: Transient thermal resistance between junction and ambient environment [°C/W]
P: IC power consumption [W]

P can be calculated by the IC power consumption using the following equation.

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} + (V_{IN} \times I_b) \quad [W] \qquad (11\text{-}2)$$

V_{IN}: Input voltage [V]
V_{OUT}: Output voltage [V]
I_{OUT}: Output current [A]
I_b: IC bias current [A]

Note that when $I_b \ll I_{OUT}$, the power consumption can be calculated with the following equation.

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} \quad [W] \qquad (11\text{-}3)$$

In the TO220 package, considering that 1.5 A of inrush current flows for 1 ms at an ambient temperature of T_A = 60°C, the transient thermal resistance in 1 ms is 1.1°C/W from Figure 11-1.
The junction temperature Tj is calculated as follows.

$$T_J = 60\ °C + 1.1 \times (12V - 5.0V) \times 1.5A = 71.6°C$$

The junction temperature Tj is 150°C or less, so there is no problem.
In this way, since the rise in chip temperature is slight when the inrush current flows for a short time around 1 ms, problems with rising temperatures are minimal.

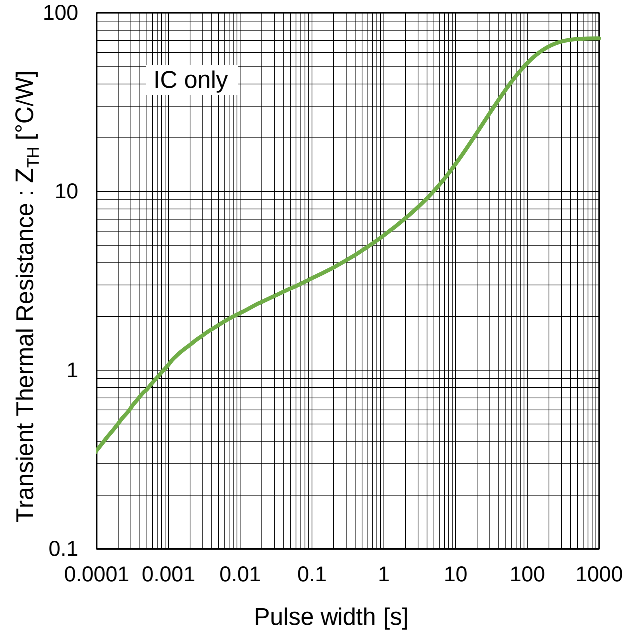


Figure 11-1. Transient thermal resistance of the TO220 package

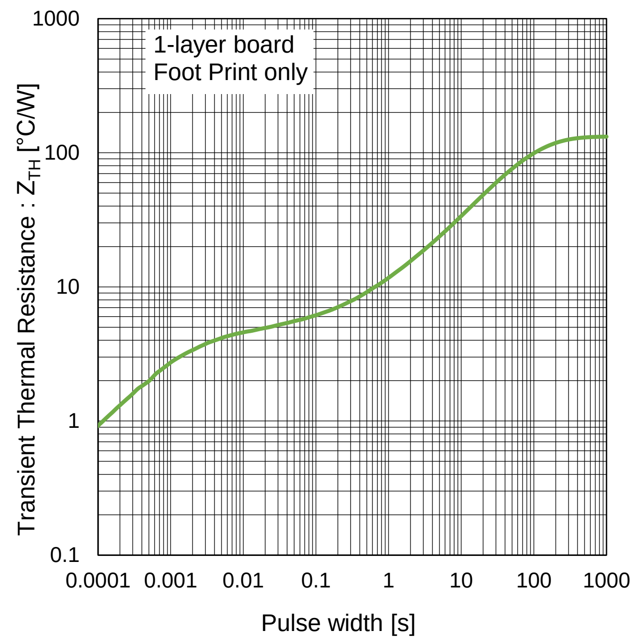


Figure 11-2. Transient thermal resistance of the TO252-3 package

12 Over current protection (OCP)

An over current protection circuit is included, in order to prevent IC breakdown due to overcurrent when the IC output shorts out the GND. This protective function prevents the IC from breaking down; thus, for the purpose of protection as per the original set, we consider using a fuse or other current limit devices.

The over current protection characteristics are as shown in Figure 12-1, and the characteristics look like a number "7" (or a "fold back characteristic" in English). Point A is the over current protection detection current with the reference value of approximately 1.5 A to 2 A. The lower limit value for variations in the detection current will not fall below the maximum value of the recommended output current. When overcurrent is detected, the current fold back circuit operates, and the output voltage drops. Along with the drop in output voltage, the circuit repeatedly works to limit the current, reaching point B. Point B is the output short circuit current. As for the power loss at point B, we can say that this is a safe protection circuit that protects the IC from breaking down, due to small power loss and a smaller degree of heat. Note that this condition will continue until the cause of the overcurrent is eliminated. The output voltage is automatically restored when the overcurrent condition is removed.

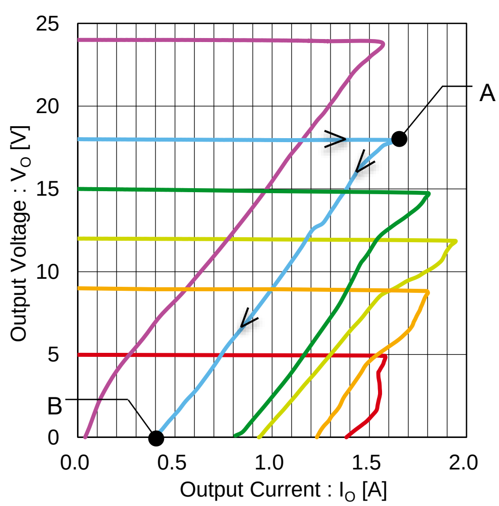


Figure 12-1. Characteristics of over current protection

In the region between the maximum value of the recommended output current and the over current protection detected value, the IC operates as a linear regulator. However, the electrical characteristics are not guaranteed. When continuing to operate beyond the power dissipation, the thermal shutdown circuit will activate and shut off the output.

13 Thermal shutdown (TSD)

Thermal shutdown protects the IC from damage due to overheating, which occurs when the IC chip temperature exceeds the junction temperature due to an output short or increased power loss. This is not intended to supplant the original thermal shutdown feature of the set.

When junction temperature exceeds the reference value of approximately 175°C, the thermal shutdown circuit turns off the regulator output turns off, shutting off the output current and lowering the chip temperature. If the chip temperature falls, TSD turns ON the output again and starts output current supply. The output will turn ON and OFF repeatedly until the cause of the rise in chip temperature is eliminated. If this condition continues, the IC will not break down right away, but continued operation should be avoided, as it will lead to degradation or breakdown.

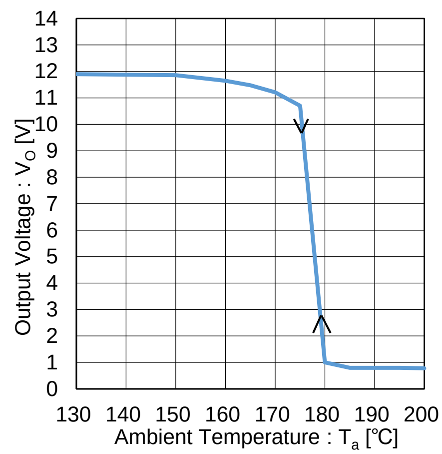


Figure 13-1. Thermal shutdown characteristics

14 Safe operating area (SOA) limiting circuit

The power area where power devices can operate without breaking down is referred to as the safe operating area. In the BA178xx series, a circuit is used for reducing the power loss by reducing the maximum output current according to the input/output voltage difference, to prevent the power loss from increasing as the input/output voltage difference increases. This circuit does not function to limit the power loss within the safe operating area in all conditions.

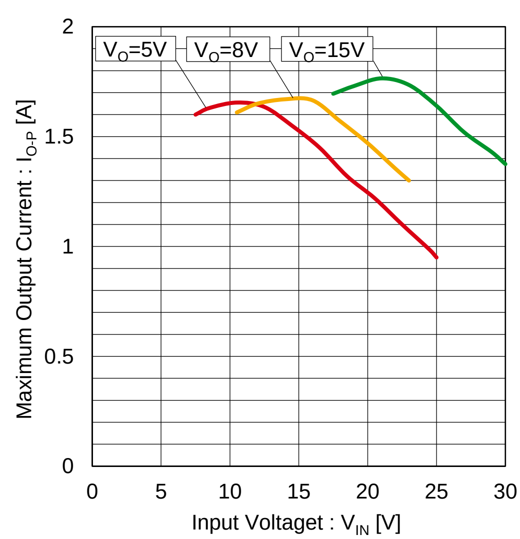
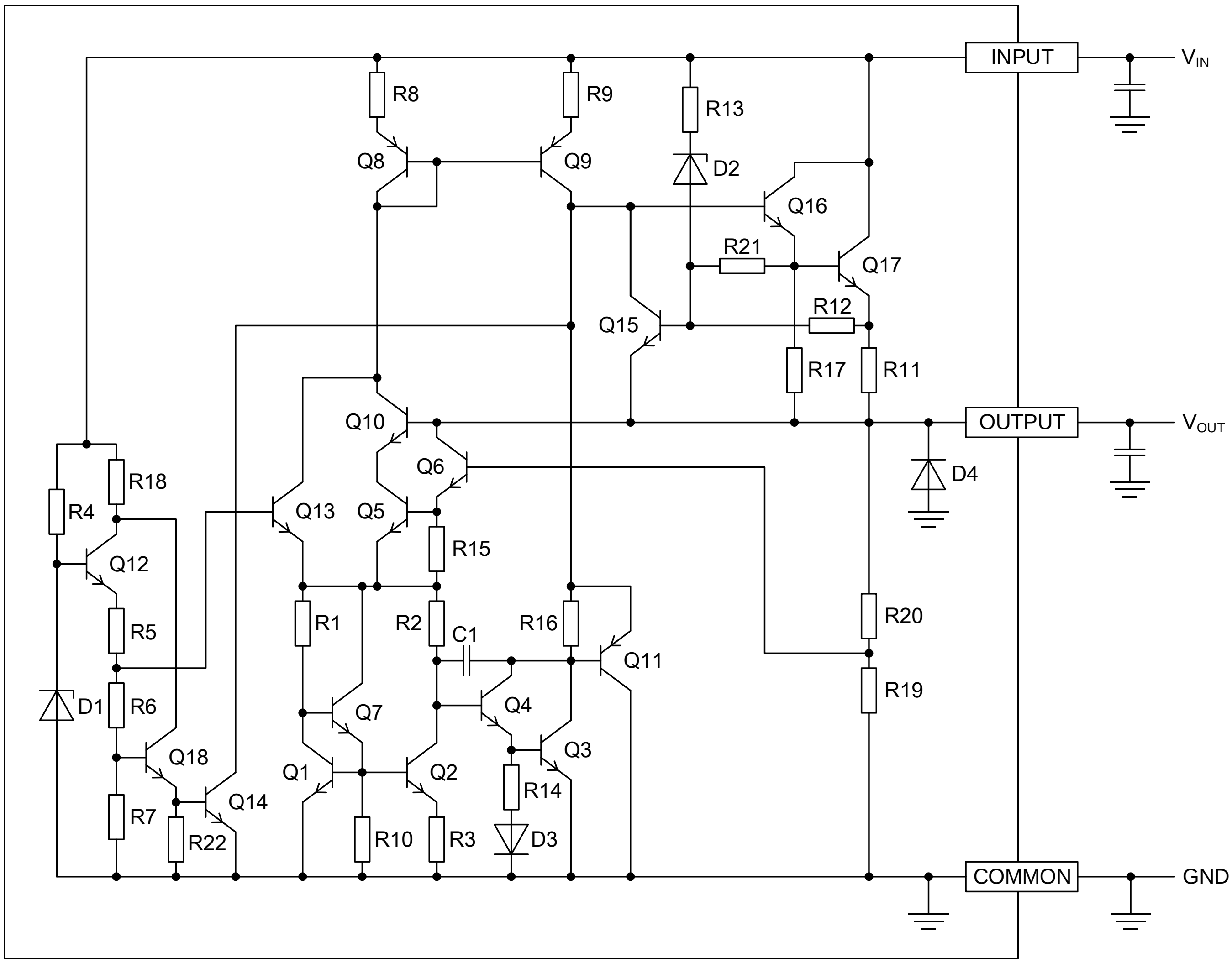


Figure 14-1. SOA limiting circuit characteristics

15 Internal equivalent circuit



Product name	R20 (kΩ)	R19 (kΩ)
BA17805	0	5
BA17806	1	5
BA17807	2	5
BA17808	3	5
BA17809	4	5
BA17810	5	5
BA17812	7	5
BA17815	10	5
BA17818	13	5
BA17820	15	5
BA17824	19	5

Figure 15-1. Internal equivalent circuit

16 Description of the internal circuit operation

The components of the internal circuit can be color-coded according to their functions as shown in Figure 16-1. The frames are overlapped at several locations because a single element can have multiple functions.

1. Bandgap voltage source

The green frame represents the bandgap voltage source, which generates a stable reference voltage within the operating temperature range. The yellow-green frame represents the error amp. As output circuits Q3, Q4, and Q6 are incorporated as a part of the bandgap reference voltage source, the error amp is integrated with the bandgap voltage source.

Figure 16-2 shows the bandgap voltage source described by Robert J. Widlar. This bandgap voltage source is often mentioned in books that deal with electronic circuits. The reference voltage V_{REF} is described by the following equations.

$$V_{REF} = V_{BE3} + \frac{R_2}{R_3}\Delta V_{BE} = V_{BE3} + \frac{R_2}{R_3} V_T \ln\frac{R_2}{R_1} \qquad (16\text{-}1)$$

$$\Delta V_{BE} = V_{BE1} - V_{BE2} = V_T \ln\frac{I_{C1}}{I_{C2}} = V_T \ln\frac{R_2}{R_1}$$

$$V_T = \frac{kT}{q} \cong 26 \text{ mV} \ \ (at\ 27°\text{C})$$

k: Boltzmann constant $1.3806 \times 10^{-23} [J/K]$

q: Elementary charge 1.6022×10^{-19} $[C]$

T: Absolute temperature, 300.15 [K] at 27°C

In addition, since the temperature characteristic of the reference voltage has a negative temperature coefficient for V_{BE3} (approximately -2 mV/°C), you can perform the temperature compensation by adjusting resistors R_2 and R_3 so that the term R_2/R_3 ΔV_{BE} becomes a positive temperature coefficient (approximately +2 mV/°C). The temperature coefficient of V_{REF} is obtained by differentiating Equation 16-1 by temperature. The result is given by the following equation.

$$\frac{\partial V_{REF}}{\partial T} = \frac{\partial V_{BE3}}{\partial T} + \frac{R_2}{R_3}\frac{k}{q}\ln\frac{R_2}{R_1} \qquad (16\text{-}2)$$

In this circuit, the temperature compensated V_{REF} is approximately 1.2 V.

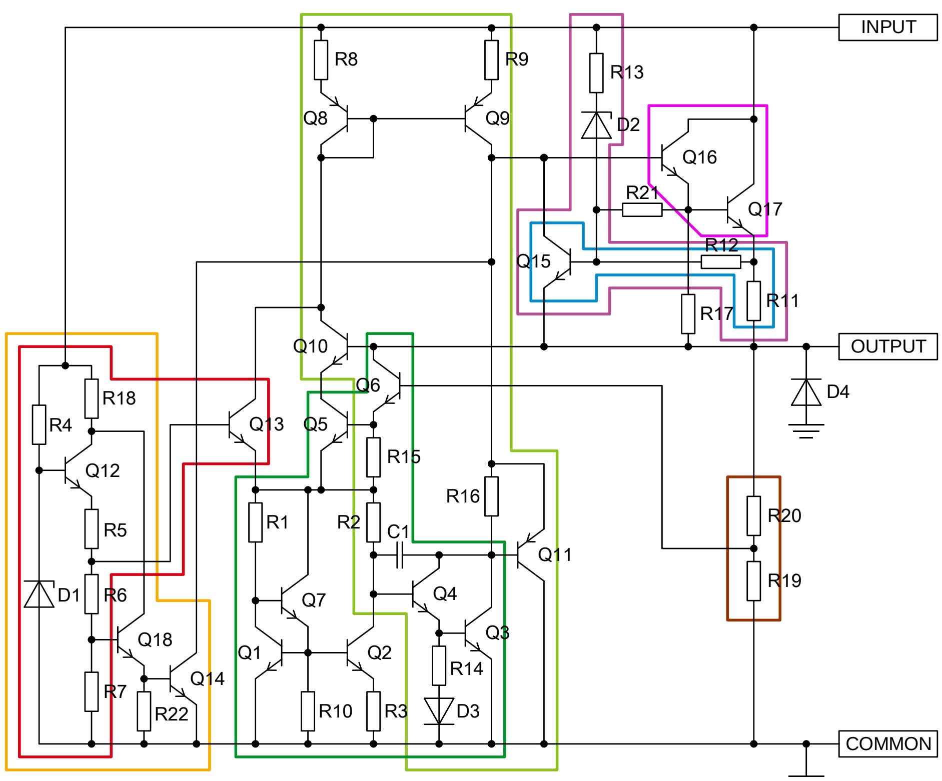


Figure 16-1. Components of BA178xx

Starter circuit (red), temperature protection (orange), bandgap voltage source (green), error amp (yellow-green), over current protection (blue), safe operating range limiting circuit (purple), output transistor stage (pink), and voltage divider (brown)

Returning to the circuit in Figure 16-1, the reference voltage of this bandgap voltage source is not 1.2 V but 5 V. To help explain the difference, Figure 16-3 shows the circuit with only its main elements displayed. While the route from the ground to V_{REF} passes through Q3 and R2 in the circuit in Figure 16-2, the route passes through Q3, Q4, R2, Q5, and Q6 with fourfold V_{BE} in Figure 16-3. This situation is described by the following equation, where the first term V_{BE} in Equation 16-1 is multiplied by 4.

$$V_{REF} = V_{BE3} + V_{BE4} + V_{BE5} + V_{BE6} + \frac{R_2}{R_3} V_T \ln\frac{R_2}{R_1} \qquad (16\text{-}3)$$

In addition, the temperature coefficient is given by the following equation.

$$\frac{\partial V_{REF}}{\partial T} = \frac{\partial V_{BE3}}{\partial T} + \frac{\partial V_{BE4}}{\partial T} + \frac{\partial V_{BE5}}{\partial T} + \frac{\partial V_{BE6}}{\partial T} + \frac{R_2}{R_3}\frac{k}{q}\ln\frac{R_2}{R_1} \qquad (16\text{-}4)$$

The increase in V_{BE} raises V_{REF} from 1.2 V to 5 V. However, because the negative temperature coefficient due to V_{BE} is also multiplied by 4, perform the temperature compensation by increasing the ratio R2/R3 to increase the positive temperature coefficient.

2. Error amp

Although the yellow-green frame represents the error amp, it is difficult to discriminate the components on the circuit diagram. Since the bandgap voltage source is integrated with the current feedback loop of the error amp, the components in the green and yellow-green frames are combined to serve as the error amp. When the output voltage is stable, the current feedback loop converges so that Q6/base reaches 5 V, and the collector current in Q9 takes a constant value. The extra current is discarded to the ground by Q11, and the voltage of output transistor Q17/emitter is stabilized. When the output voltage drops as the load current increases, the Q6/base voltage drops. Subsequently, the voltages on Q6/emitter, Q5/base, Q5/emitter, Q4/base, Q4/emitter, and Q3/base drop. This voltage drop decreases the Q3/collector current, thereby increasing the Q16/base and Q17/base voltages. Then, when Q17 is turned ON, the current is supplied to the output and the output voltage rises. Next, when the output voltage is increased, the Q6/base voltage rises. Subsequently, the voltages of Q6/emitter, Q5/base, Q5/emitter, Q4/base, Q4/emitter, and Q3/base rise. This voltage rise increases the Q3/collector current, thereby decreasing the Q16/base and Q17/base voltages. Then, when Q17 is turned OFF, the current supply to the output is stopped. This condition continues until the output voltage drops.

3. Output transistor stage

The pink frame represents the transistor stage. Q17 is the output transistor with a sufficient capacity to handle the load current. Q16 is the predrive stage to drive the base current of large transistor Q17.

4. Voltage divider

The brown frame represents the resistors for determining the output voltage. The reference voltage is divided to determine the output voltage.

$$V_{OUT} = \frac{R_{19} + R_{20}}{R_{19}} \times 5 \quad [V] \qquad (16\text{-}5)$$

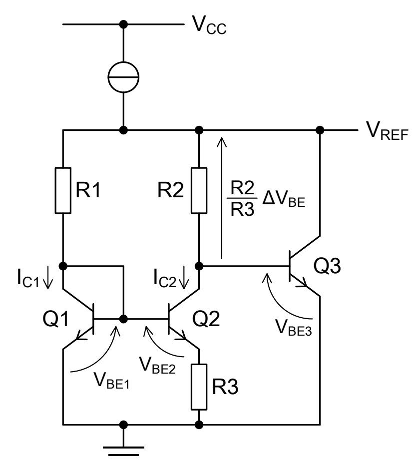


Figure 16-2. Bandgap voltage source described by Robert J. Widlar

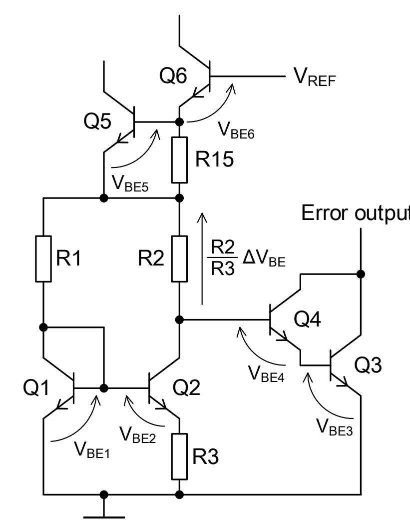


Figure 16-3. Bandgap voltage source of BA178xx

Only the main elements of the circuit are displayed.

5. Starter circuit

The red frame represents the starter circuit. When a voltage is applied to INPUT, a voltage is generated in Q12/base, Q12/emitter, and Q13/base in this order, and Q13 is turned ON. The Q13/collector current serves as the start current, and the entire circuit is started up when the current is supplied to the bandgap voltage source and the current feedback loop of the error amp. When the circuit is started up, Q13 is turned OFF because the voltage becomes higher in Q13/emitter than in Q13/base, and then the function of the starter circuit is stopped.

6. Temperature protection

The orange frame represents the temperature protection circuit. The reference voltage generated in D1 is supplied to Q14/base via Q12 and Q18. Normally, the Q14/base voltage is set to a low value and Q14 is in the OFF state. When the temperature rises, Q14 is turned ON because its V_{BE} has a negative temperature coefficient (approximately -2 mV/°C). Then, since the Q14/collector completely absorbs the driving current of the output transistor, the output transistor is turned OFF.

7. Over current protection

The blue frame represents the over current protection circuit. As the output current increases, the voltage generated across R11 also increases. When this voltage exceeds the V_{BE} voltage of Q15, Q15 is turned ON and decreases the base current of output transistors Q16 and Q17. In this way, the output transistors reduce the power loss by reducing the output current as the output current increases.

8. Safe operating range limiting circuit

The purple frame represents the safe operating range limiting circuit. As the voltage difference between INPUT and OUTPUT increases, the voltage difference across D2 also increases. When this voltage exceeds the breakdown voltage of D2, the current passes through INPUT, R13, D2, R12, R11, and OUTPUT in this order. This current increases as the difference between the input and output voltages increases. At the same time, the voltage generated across R12 and R11 also increases. When this voltage exceeds the V_{BE} voltage of Q15, Q15 is turned ON and decreases the base current of output transistors Q16 and Q17. In this way, the output transistors reduce the power loss by reducing the output current as the difference between the input and output voltages increases.

17 Application information

17-1. Fixed output regulator

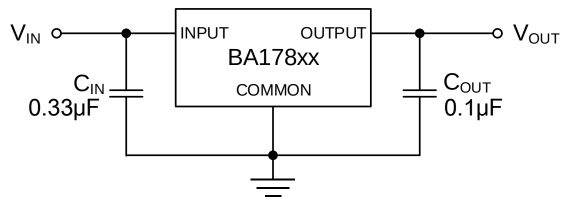


Figure 17-1-1. Fixed output regulator

The unit functions as a fixed output type voltage regulator when the COMMON pin is connected with the ground. The “xx” section of the product name represents the output voltage. Increase the capacitances of input and output capacitors C_{IN} and C_{OUT} according to the conditions of the load current and the ripple voltage.

17-2. Variable output regulator 1

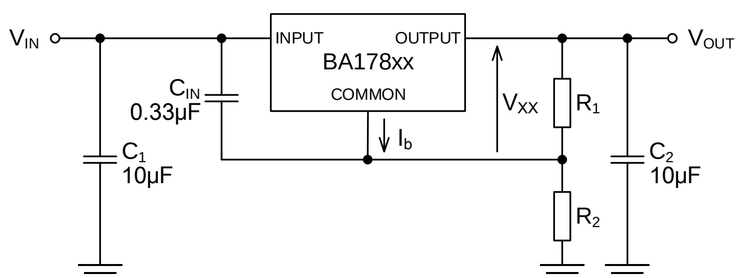


Figure 17-2-1. Variable output regulator 1

Figure 17-2-1 shows a circuit that varies the output voltage using resistors. The output voltage can be calculated with the following equation. In addition, the ranges of the input and output voltages are as follows.

$$V_{OUT} = \left(\frac{R_1 + R_2}{R_1}\right) V_{XX} + I_b R_2 \quad [V]$$

V_{XX}: Voltage in the “xx” section of the product name $[V]$
I_b: IC bias current $[A]$

Input voltage range V_{IN}: Between the “Min” and “Max” voltages described in “Operating range” of the data sheet
Output voltage range V_{OUT}: $V_{IN(MIN)}$ - 2.5 V to $V_{IN(MAX)}$ - 2.5 V
Input/output voltage difference: 2.5 V or greater

Since IC bias current I_b flows to the ground via R_2, a voltage by I_b is generated across R_2. The larger is the value of R_2, the larger is the effect on the output voltage. In addition, it is necessary to consider that the fluctuation or variation in I_b can affect the output voltage. When R_2 is reduced, the effect on the output voltage decreases, but the reactive current that flows from V_{OUT} to the ground via R_1 and R_2 increases. Increase the capacitance of input and output capacitors C_1 and C_2 according to the conditions of the load current and the ripple voltage.

Practical example

- Output voltage 13.5 V

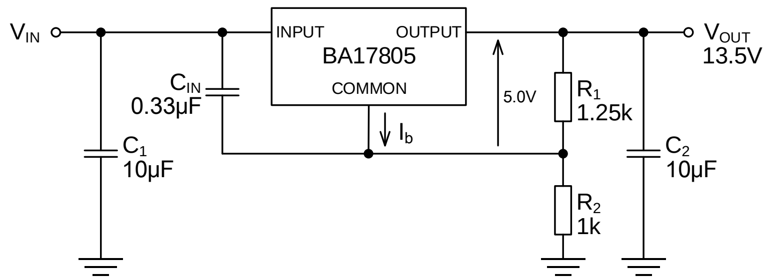


Figure 17-2-2. 13.5 V output circuit

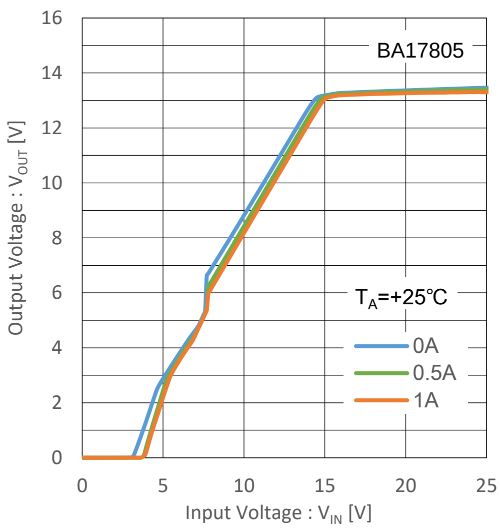


Figure 17-2-3. Input/output characteristics (output current)

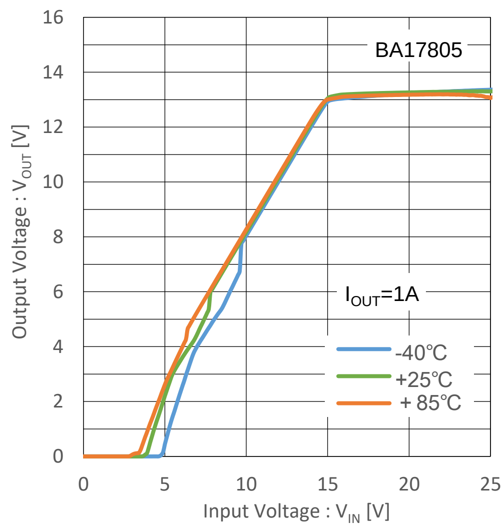


Figure 17-2-4. Input/output characteristics (temperature)

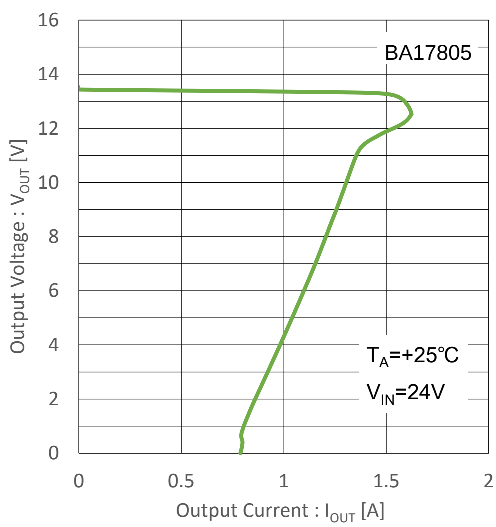


Figure 17-2-5. Over current protection characteristics

Practical example

- Output voltage 30 V

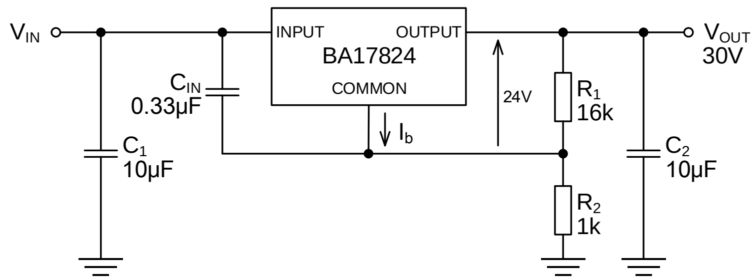


Figure 17-2-6. 30 V output circuit

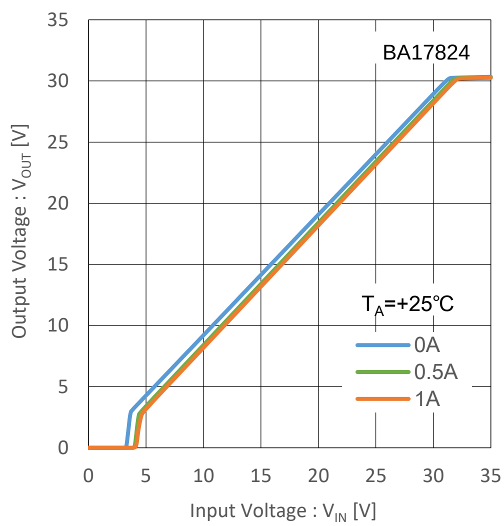


Figure 17-2-7. Input/output characteristics (output current)

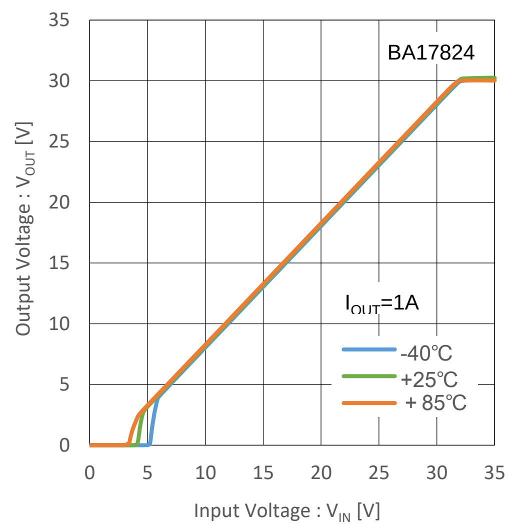


Figure 17-2-8. Input/output characteristics (temperature)

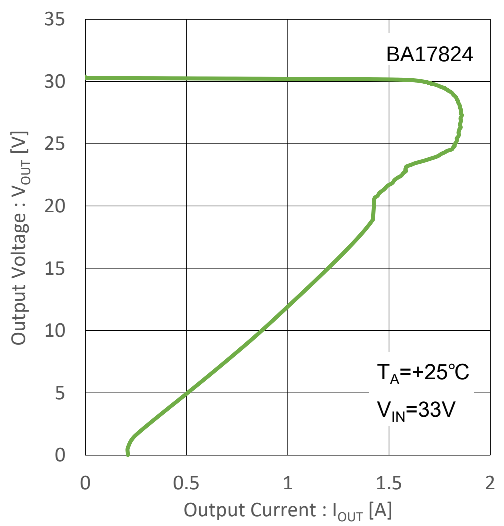


Figure 17-2-9. Over current protection characteristics

17-3. Variable output regulator 2

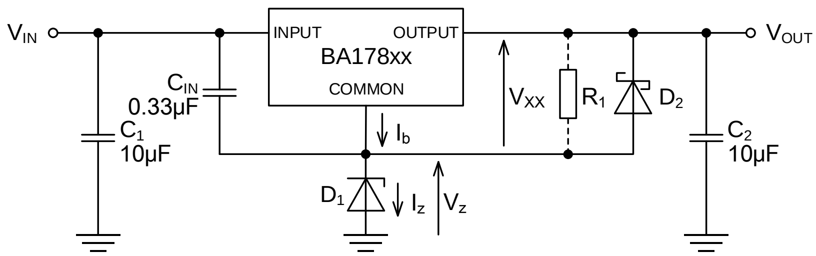


Figure 17-3-1. Variable output regulator 2

Figure 17-3-1 shows a circuit that varies the output voltage using a Zener diode. The output voltage can be calculated with the following equation. In addition, the ranges of the input and output voltages are as follows.

$$V_{OUT} = V_{XX} + V_Z \quad [V]$$

V_{XX}: Voltage in the “xx” section of the product name $[V]$
V_Z: Zener voltage of D_1 $[V]$

Input voltage range V_{IN}: Between the “Min” and “Max” voltages described in “Operating range” of the data sheet

Output voltage range V_{OUT}: $V_{IN(MIN)}$ - 2.5 V to $V_{IN(MAX)}$ - 2.5 V

Input/output voltage difference: 2.5 V or greater

Since IC bias current I_b flows to the ground via D_1, I_b acts as Zener current I_Z of the Zener diode. If the value of I_b is insufficient for the Zener current, add R_1 to supply the Zener current from V_{OUT}. At this time, the Zener current can be calculated with the following equation.

$$I_Z = \frac{V_{XX}}{R_1} + I_b \quad [A]$$

Since the Zener voltage varies due to the fluctuation or variation in I_b, it is necessary to consider that I_b can affect the output voltage. In addition, the temperature characteristics of the Zener voltage is added to that of the output voltage. These factors make the voltage precision of this regulator appear unreliable. Increase the capacitance of input and output capacitors C_1 and C_2 according to the conditions of the load current and the ripple voltage. Since the voltage between the COMMON and OUTPUT pins is inverted when the power supply is turned ON, D_2 is a Schottky diode to protect the terminals.

Practical example

- Output voltage 13.2 V

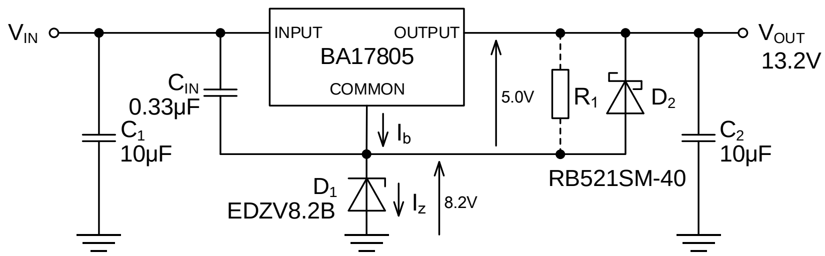


Figure 17-3-2. 13.2 V output circuit

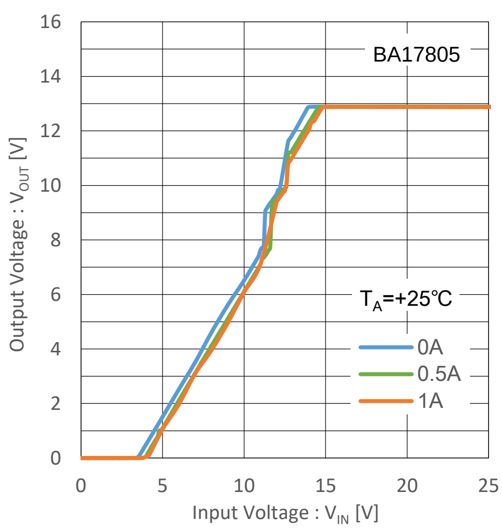


Figure 17-3-3. Input/output characteristics (output current)

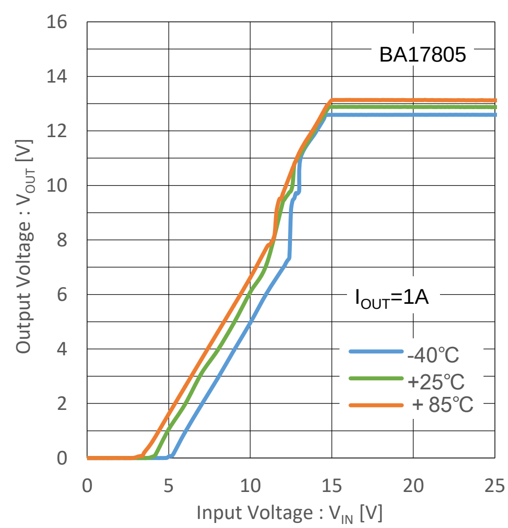


Figure 17-3-4. Input/output characteristics (temperature)

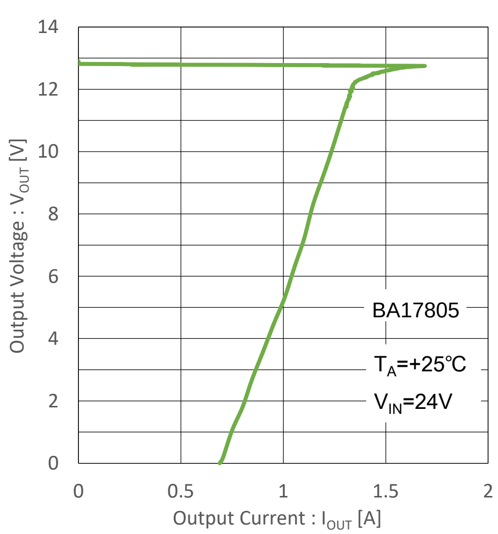


Figure 17-3-5. Over current protection characteristics

Practical example

- Output voltage 30.2 V

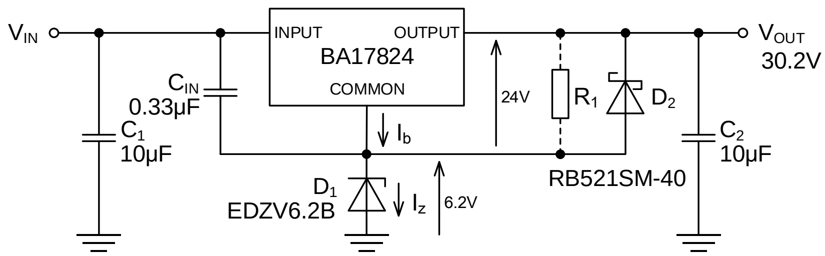


Figure 17-3-6. 30.2 V output circuit

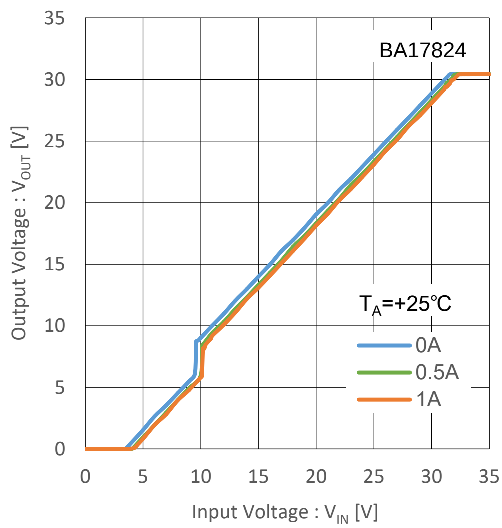


Figure 17-3-7. Input/output characteristics (output current)

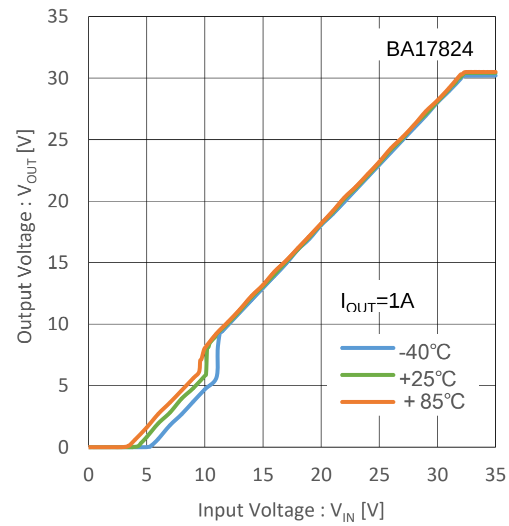


Figure 17-3-8. Input/output characteristics (temperature)

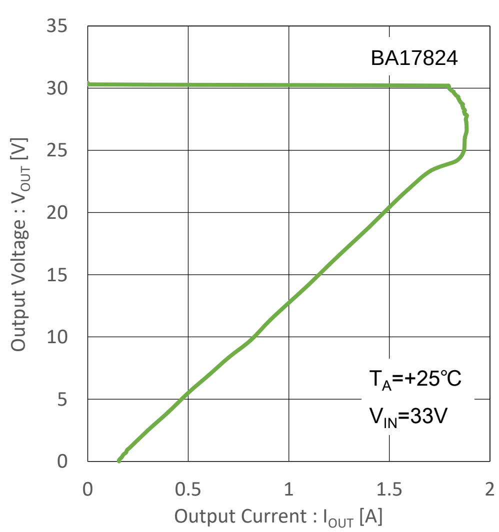


Figure 17-3-9. Over current protection characteristics

17-4. Variable output regulator 3

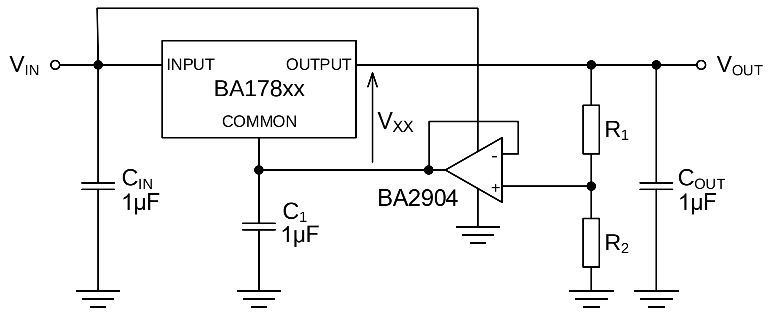


Figure 17-4-1. Variable output regulator 3

Figure 17-4-1 shows a circuit in which the effect of I_b variation on the output voltage of the regulator in Figure 17-2-1 is eliminated. The circuit is improved to eliminate the effect of I_b by connecting a voltage follower of an op-amp between voltage dividing resistors R_1 and R_2 that determine the output voltage and the COMMON pin. The output voltage can be calculated with the following equation. In addition, the ranges of the input and output voltages are as follows. Increase the capacitances of input and output capacitors C_{IN} and C_{OUT} according to the conditions of the load current and the ripple voltage.

$$V_{OUT} = \left(\frac{R_1 + R_2}{R_1}\right) V_{XX} \quad [V]$$

V_{XX}: Voltage in the "xx" section of the product name $[V]$

Input voltage range V_{IN}: Between the "Min" and "Max" voltages described in "Operating range" of the data sheet

Output voltage range V_{OUT}: $V_{IN(MIN)}$ - 2.5 V to $V_{IN(MAX)}$ - 2.5 V

Input/output voltage difference: 2.5 V or greater

Practical example

- Output voltage 13.5 V

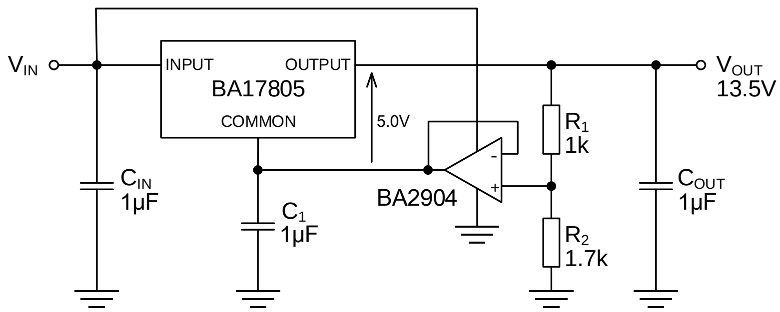


Figure 17-4-2. 13.5 V output circuit

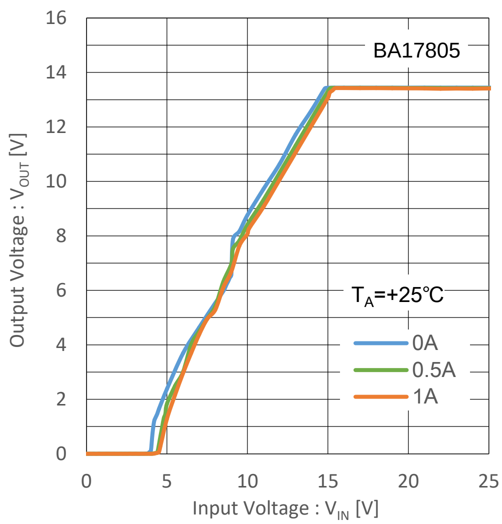


Figure 17-4-3. Input/output characteristics (output current)

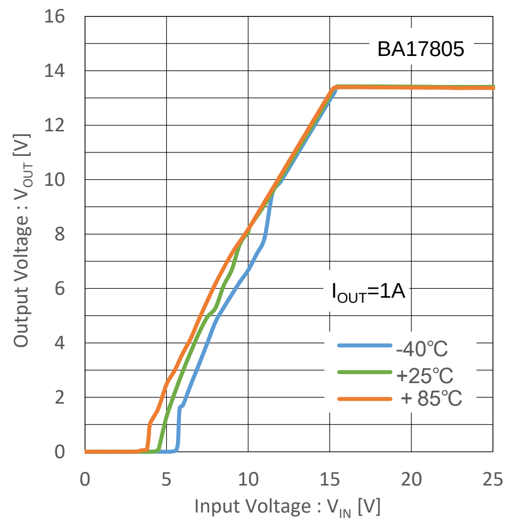


Figure 17-4-4. Input/output characteristics (temperature)

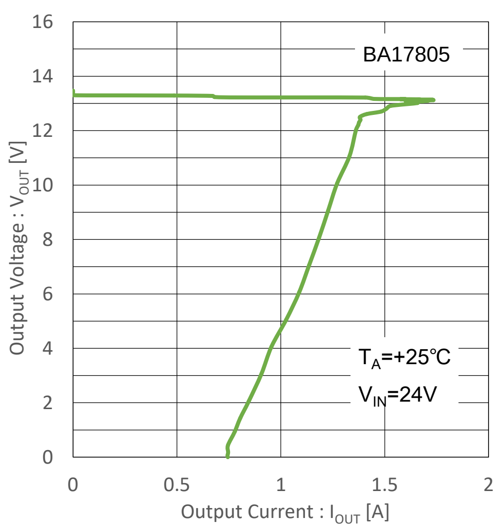


Figure 17-4-5. Over current protection characteristics

Practical example

- Output voltage 30 V

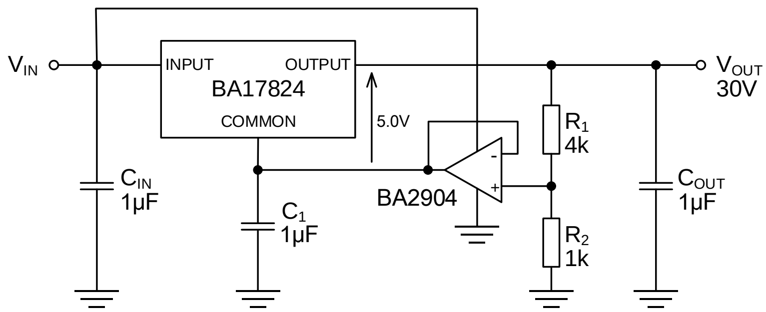


Figure 17-4-6. 30 V output circuit

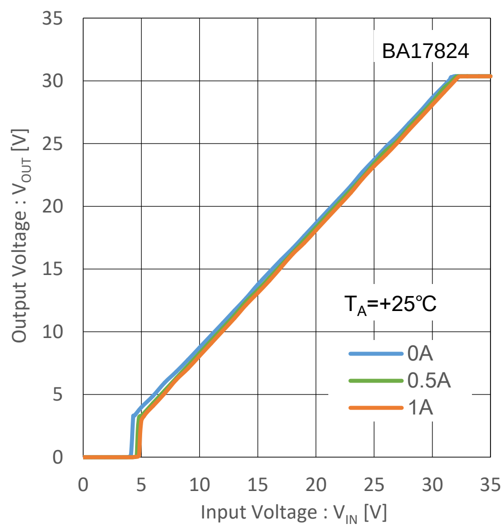


Figure 17-4-7. Input/output characteristics (output current)

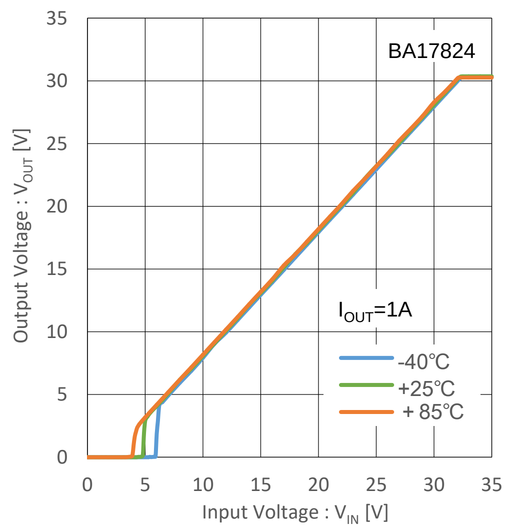


Figure 17-4-8. Input/output characteristics (temperature)

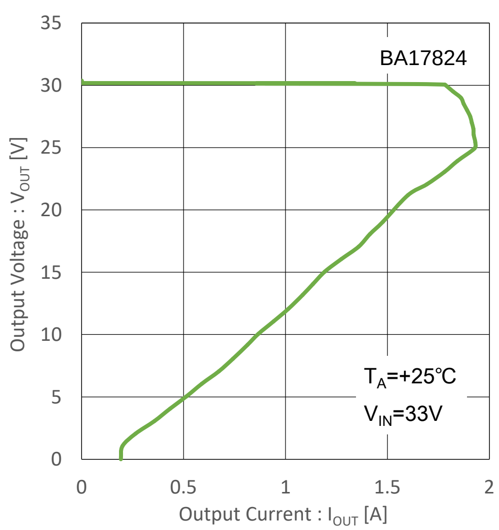


Figure 17-4-9. Over current protection characteristics

17-5. Current boost regulator

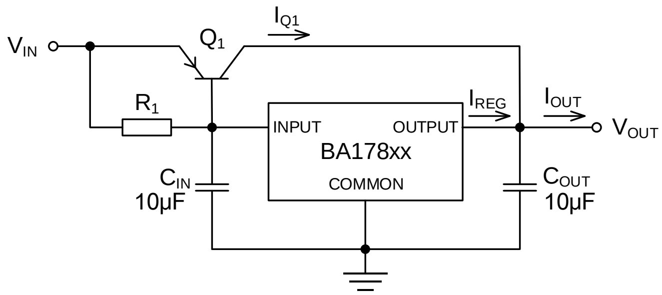


Figure 17-5-1. Current boost regulator

Installing power transistor Q_1 externally allows you to increase the output current. When load current I_{OUT} is small, a current is supplied from IC and Q_1 is in the OFF state. When the load current increases, the voltage generated in R_1 increases as well. Q_1 is turned ON when this voltage reaches V_{BE} of Q_1, and supplies current to the load. A power loss occurs in Q_1, which can be calculated with $(V_{IN} - V_{OUT}) \times I_{Q1}$. Therefore, a package that can withstand this power loss as well as heat radiation are required. For R_1, select a resistor that conforms to the rating because a power loss of $V_{BE(Q1)}^2/R_1$ occurs. The minimum value of input voltage V_{IN} is higher than that of the IC operating range by V_{BE} of Q_1. Increase the capacitances of input and output capacitors C_{IN} and C_{OUT} according to the conditions of the load current and the ripple voltage. The output current and R_1 can be calculated with the following equations.

$$I_{OUT} = I_{REG} + I_{Q1} \quad [A]$$

$$R_1 = \frac{V_{BE(Q1)}}{I_{REG}} \quad [\Omega]$$

R_1: Resistor for setting the maximum output current of BA178xx $[\Omega]$

$V_{BE(Q1)}$: Voltage between the base and emitter of the current boost transistor $[V]$

I_{REG}: Setting value for the maximum output current of BA178xx $[A]$

Practical example

- Output voltage 5 V

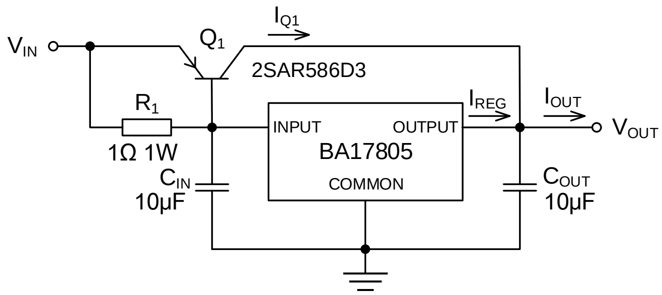


Figure 17-5-2. 5 V output, current boost regulator

$$R_1 = \frac{V_{BE(Q1)}}{I_{REG}} = \frac{0.8V}{0.8A} = 1 \quad [\Omega]$$

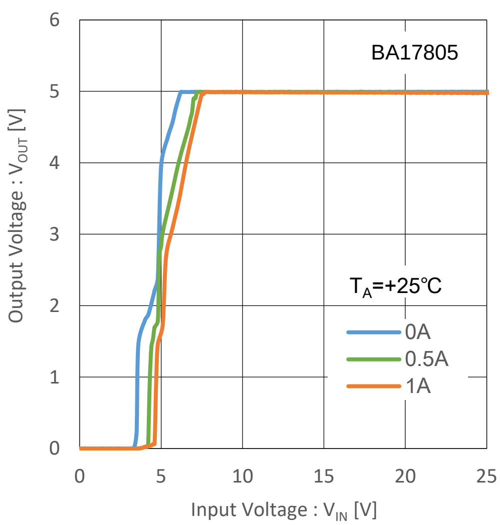


Figure 17-5-3. Input/output characteristics (output current)

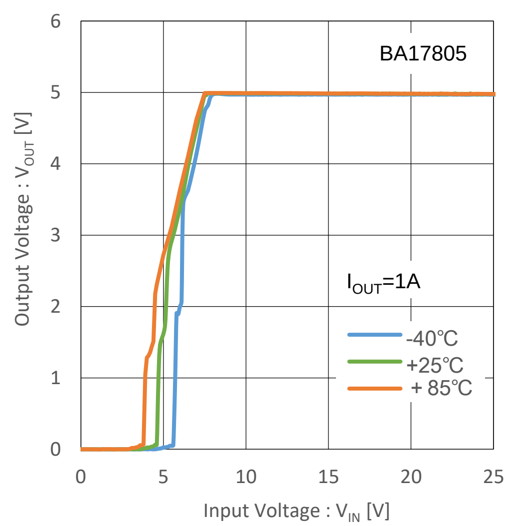


Figure 17-5-4. Input/output characteristics (temperature)

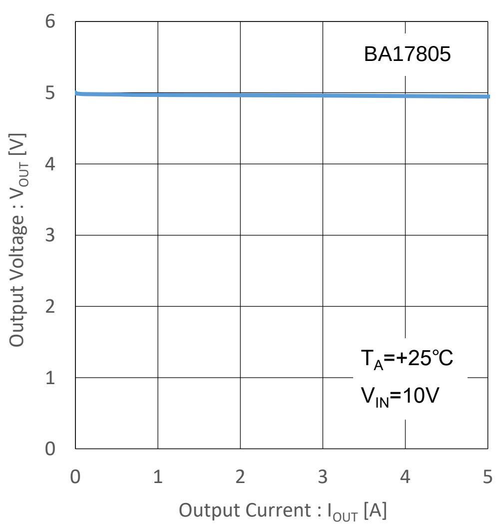


Figure 17-5-5. Output voltage vs. output current

The maximum output current is determined by whichever of the following factors that has the smallest value: the current capacity of the supply source, the current capacity of Q_1, the power dissipation of Q1, and the power dissipation of BA17805.

17-6. Current boost regulator with short circuit protection

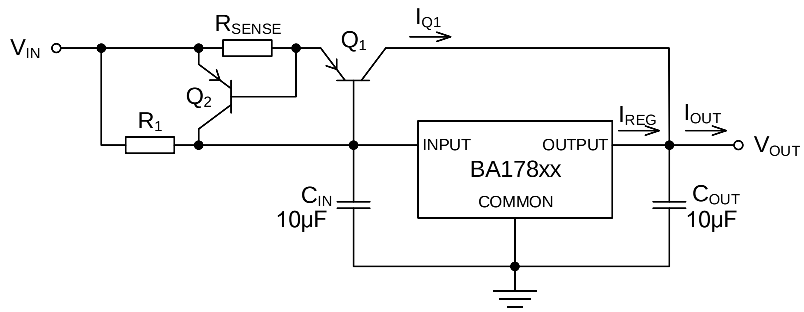


Figure 17-6-1. Current boost regulator with short circuit protection

Figure 17-6-1 shows a circuit in which the short circuit protection function is added to the regulator in Figure 17-5-1. R_{SENSE} is a resistor for the current detection, which is placed in series to the load. When the load current increases, the voltage generated in R_{SENSE} increases as well. Q_2 is turned ON when this voltage reaches V_{BE} of Q_2, and short circuits between the base and emitter of Q_1. As a result, the output current of Q_1 is limited and the short circuit protection function is enabled. Since the collector current of Q_2 flows up to the peak output current value of BA178xx (see 12. Over current protection), select a transistor that can handle this current. Increase the capacitances of input and output capacitors C_{IN} and C_{OUT} according to the conditions of the load current and the ripple voltage. The value of R_{SENSE} can be calculated with the following equation. Refer to the previous section (17-5. Current boost regulator) for the explanation of current boost.

$$R_{SENSE} = \frac{V_{BE(Q2)}}{I_{SC} - I_{SC(BA178xx)}} \quad [\Omega]$$

$V_{BE(Q2)}$: Voltage between the base and emitter of $Q2_2$ $[V]$

I_{SC}: Short circuit current $[A]$

$I_{SC(BA178xx)}$: Short circuit current of BA178xx (Figure 12-1) $[A]$

Practical example

- Output voltage 5 V

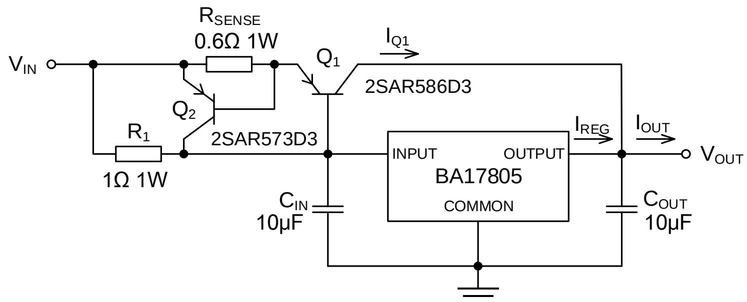


Figure 17-6-2. 5 V output, current boost regulator with short circuit protection

$$R_1 = \frac{V_{BE(Q1)}}{I_{REG}} = \frac{0.8V}{0.8A} = 1 \quad [\Omega]$$

$$R_{SENSE} = \frac{V_{BE(Q2)}}{I_{SC} - I_{SC(BA178xx)}} = \frac{0.8V}{2.8A - 1.6A} = 0.67 \quad [\Omega]$$

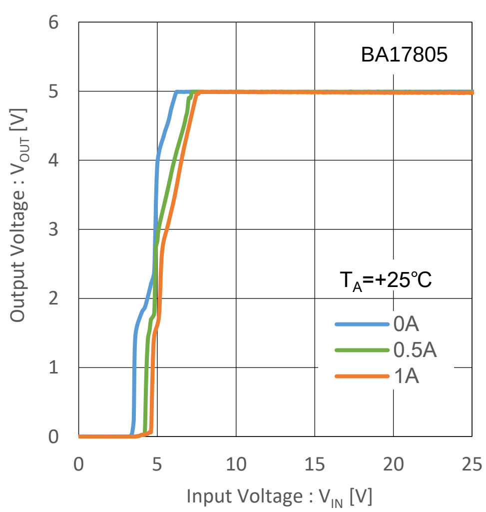


Figure 17-6-3. Input/output characteristics (output current)

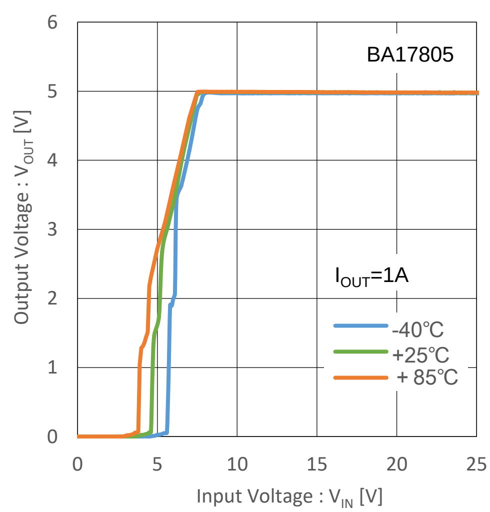


Figure 17-6-4. Input/output characteristics (temperature)

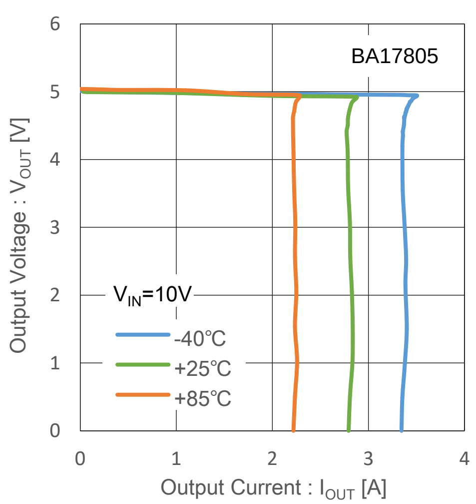


Figure 17-6-5. Output voltage vs. output current

17-7. Negative output voltage circuit

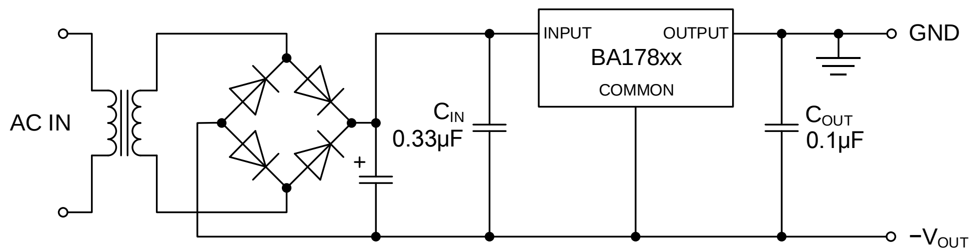


Figure 17-7-1. Negative output voltage circuit

Figure 17-7-1 shows a circuit that outputs a negative voltage. If a linear regulator is used to obtain a negative voltage from a positive voltage, it is necessary to supply the IC input with a power supply floated from the ground using a transformer. Treat the OUTPUT pin of IC as the system ground (GND), and the COMMON pin as the negative output ($-V_{OUT}$). Increase the capacitances of input and output capacitors C_{IN} and C_{OUT} according to the conditions of the load current and the ripple voltage.

17-8. Positive-negative power supply

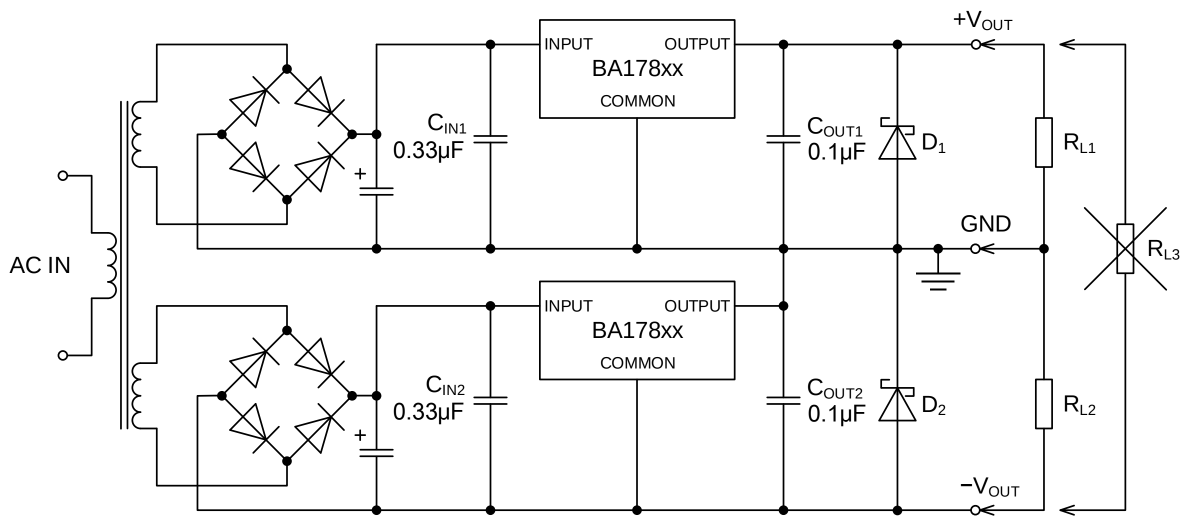


Figure 17-8-1. Positive-negative power supply

Figure 17-8-1 shows a positive-negative power supply circuit that uses positive voltage output type linear regulators. On the negative voltage side, since the positive voltage output type is used, it is necessary to supply the IC input with a power supply floated from the ground using a transformer. Treat the OUTPUT pin of IC as the system ground (GND), and the COMMON pin as the negative output ($-V_{OUT}$). This configuration of the power supplies is limited by the current path of the load. There is no problem if load R_{L1} of the positive power supply and load R_{L2} of the negative power supply are connected with the respective power supplies against the system ground. However, if there is load R_{L3} between the positive and negative power supplies, the negative voltage rises because the negative power supply side is incapable of drawing a current. Therefore, this configuration of power supplies cannot be used if there is load R_{L3}. If there is load R_{L3}, use linear regulators of the negative voltage output type. D_1 and D_2 are Schottky barrier diodes for preventing either of the power supplies from failing to rise because of the latch down due to the difference in the rise time of each power supply. Increase the capacitances of input and output capacitors C_{IN} and C_{OUT} according to the conditions of the load current and the ripple voltage.

17-9. High input voltage circuit

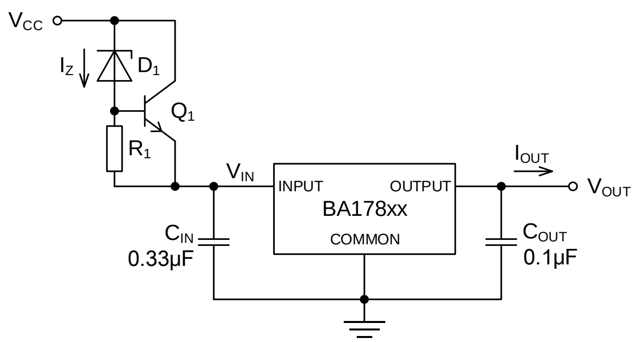


Figure 17-9-1. High input voltage circuit 1

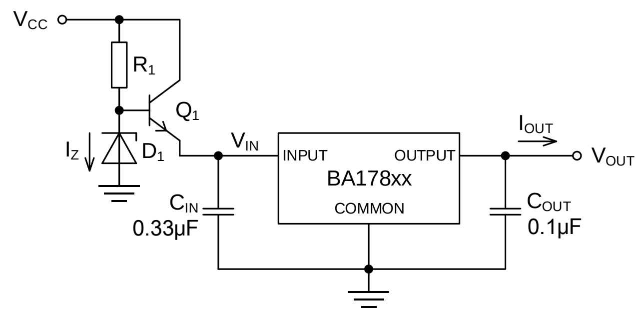


Figure 17-9-2. High input voltage circuit 2

Figures 17-9-1 and 17-9-2 show circuits for enabling input of the power supply voltage higher than the IC rating. Add a buck circuit of the emitter follower type to the previous stage so that V_{IN} enters within the IC operating range. In Figure 17-9-1, the V_{IN} voltage is determined with reference to V_{CC}. In Figure 17-9-2, the V_{IN} voltage is determined with reference to the ground. Since the collector current of Q_1 flows up to the peak output current value of BA178xx (see 12. Over current protection), select a transistor that can handle this current. Increase the capacitances of input and output capacitors C_{IN} and C_{OUT} according to the conditions of the load current and the ripple voltage. The power loss of V_{IN}, R_1, and each element can be calculated with the following equations.

Figure 17-9-1

$$V_{IN} = V_{CC} - V_{Z(D1)} - V_{BE(Q1)} \quad [V]$$

$$I_Z = \frac{V_{BE(Q1)}}{R_1} + \frac{I_{OUT}}{\beta_{Q1}} \quad [A]$$

$$R_1 = \frac{V_{BE(Q1)}}{I_Z - \frac{I_{OUT}}{\beta_{Q1}}} \quad [\Omega]$$

Power loss in *D1*

$$P_{D(D1)} = V_{Z(D1)} \times I_Z \quad [W]$$

Power loss in *Q1*

$$P_{D(Q1)} = (V_{CC} - V_{IN}) \times I_{OUT} \quad [W]$$

Power loss in *R1*

$$P_{D(R1)} = \frac{V_{BE(Q1)}^2}{R_1} \quad [W]$$

Figure 17-9-2

$$V_{IN} = V_{Z(D1)} - V_{BE(Q1)} \quad [V]$$

$$I_Z = \frac{V_{CC} - V_Z}{R_1} + \frac{I_{OUT}}{\beta_{Q1}} \quad [A]$$

$$R_1 = \frac{V_{CC} - V_Z}{I_Z + \frac{I_{OUT}}{\beta_{Q1}}} \quad [\Omega]$$

Power loss in *D1*

$$P_{D(D1)} = V_{Z(D1)} \times I_Z \quad [W]$$

Power loss in *Q1*

$$P_{D(Q1)} = (V_{CC} - V_{IN}) \times I_{OUT} \quad [W]$$

Power loss in *R1*

$$P_{D(R1)} = \left(\frac{V_{CC} - V_Z}{R_1} + \frac{I_{OUT}}{\beta_{Q1}}\right)^2 \times R_1 \quad [W]$$

$V_{Z(D1)}$: Voltage of the Zener diode $[V]$
$V_{BE(Q1)}$: Voltage between the base and emitter of Q_1 $[V]$
I_Z: Current of the Zener diode $[A]$
I_{OUT}: Output current $[A]$
R_1: Resistor for setting the current of the Zener diode $[\Omega]$
β_{Q1}: h_{fe} of Q_1

17-10. Dispersing the power loss using a resistor

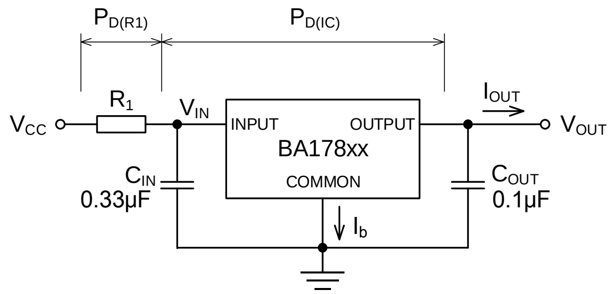


Figure 17-10-1. Dispersing the power loss using a resistor

Figure 17-10-1 shows a circuit for dispersing the power loss to a resistor when the power dissipation of IC is insufficient. Total power loss P_D of this circuit can be calculated with the following equation.

$$P_D = (V_{CC} - V_{OUT}) \times I_{OUT} \quad [W]$$

When the power loss to be generated in the IC is $P_{D(IC)}$, power loss $P_{D(R1)}$ generated in the resistor can be calculated with the following equations.

$$P_D = P_{D(IC)} + P_{D(IC)} \quad [W]$$
$$P_{D(R1)} = P_D - P_{D(IC)} \quad [W]$$

The resistance value required for generating power loss $P_{D(R1)}$ in the resistor can be calculated with the following equation.

$$R_1 = \frac{P_{D(R1)}}{{I_{OUT}}^2} \quad [\Omega]$$

Since the voltage drop occurs due to the resistor, calculate input pin voltage V_{IN} at the maximum output current with the following equation.

$$V_{IN} = V_{CC} - I_{OUT(MAX)} \times R_1 \quad [V]$$

Confirm that the difference between the input and output voltages of IC that can be calculated with $V_{IN} - V_{OUT}$ satisfies the specification. If the voltage is insufficient, reduce the resistance value (reduce the power loss generated in the resistor) and perform the calculation again. Increase the capacitances of input and output capacitors C_{IN} and C_{OUT} according to the conditions of the load current and the ripple voltage.

17-11. Constant current regulator

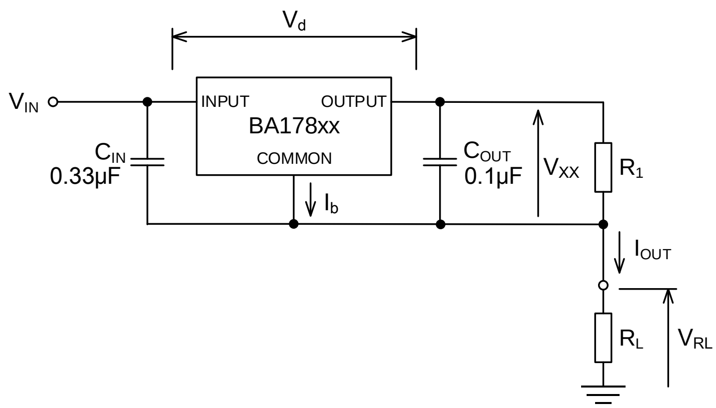


Figure 17-11-1. Constant current regulator

Figure 17-11-1 shows a constant current regulator circuit. The value of the output current is the sum of IC bias current I_b and the quotient of the voltage between the OUTPUT and COMMON pins divided by the resistance of R_1. This relation can be expressed with the following equation. Although the maximum output current is 1 A, it is required that the power dissipation of IC and the junction temperature do not exceed 150°C.

$$I_{OUT} = \frac{V_{XX}}{R_1} + I_b \quad [A]$$

V_{XX}: Voltage indicated in the “xx” section of the product name $[V]$
I_b: IC bias current $[A]$

The minimum input voltage at the V_{IN} terminal of this circuit can be calculated with the following equation. The maximum input voltage is the maximum value of the operating range described in the data sheet of IC.

$$V_{IN(MIN)} = V_{RL} + V_{XX} + V_d \quad [V]$$

V_{RL}: Voltage generated in the load $[V]$
V_{XX}: Voltage indicated in the “xx” section of the product name $[V]$
V_d: Minimum input/output voltage difference of IC $[V]$

Practical example

- Output current 50 mA

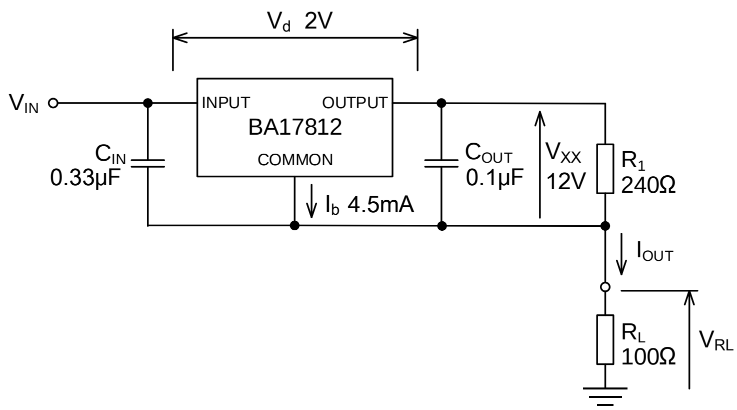


Figure 17-11-2. 50 mA constant current regulator

$$I_{OUT} = \frac{V_{XX}}{R_1} + I_b = \frac{12V}{240\Omega} + 4.5mA = 54.5 \quad [mA]$$

$$V_{IN(MIN)} = V_{RL} + V_{XX} + V_d = (50mA \times 100\Omega) + 12V + 2V = 19V \;\; [V]$$

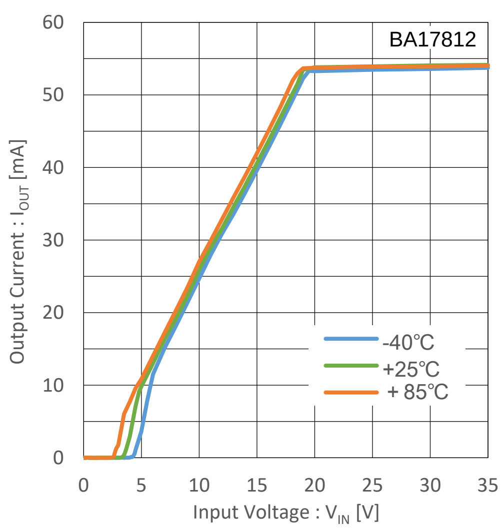


Figure 17-11-3. Output current vs. input voltage