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e-Learning

Basics of Low-Dropout (LDO) Regulators

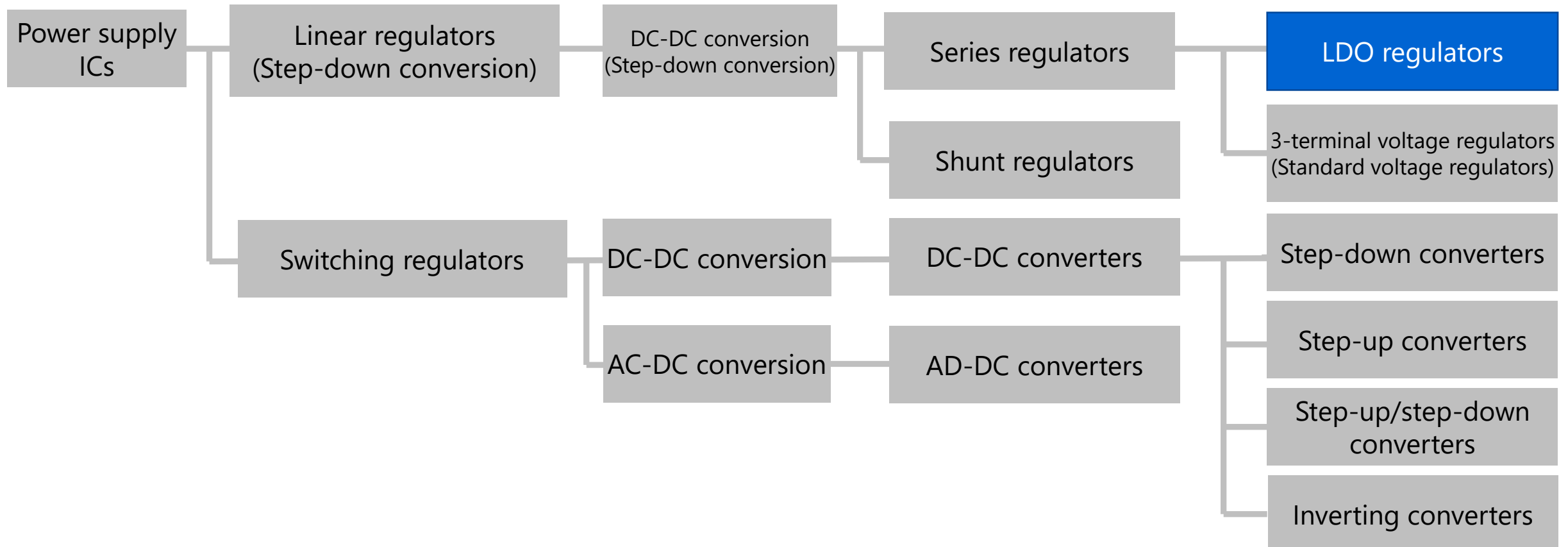
Toshiba Electronic Devices & Storage Corporation

Chapter1 Introduction to Low-Dropout (LDO) Regulators

Types of voltage regulator ICs

Voltage regulator ICs are broadly classified into ICs for converting a DC voltage into a required DC voltage and those for converting an AC voltage into a desired DC voltage.

Voltage regulator ICs for DC-DC conversion are further classified into linear regulators and switching regulators also known as DC-DC converters. Linear regulators exist in two basic forms: series regulators and shunt regulators. Low-dropout (LDO) regulators are a type of series regulators.



Advantages and disadvantages of linear regulators and switching regulators

Both linear and switching regulators have their own advantages and disadvantages as shown below.

	Linear regulators	Switching regulators
Step-down conversion	Supported	Supported
Step-up conversion	N/S	Supported
Step-up/step-down conversion	N/S	Supported
Inverting conversion	N/S	Supported
Part count	Low	High
Design complexity	Simple	Complicated
Input-output voltage differential	Small ^{*1}	Large
Output voltage ripple	Small	Large
Noise (e.g., EMI)	Small	Large
Heat generation	Large ^{*2}	Small

*1 LDO regulators have a small input-output voltage differential, depending on usage conditions.

*2 The amount of heat generated by LDO regulators might be small, depending on usage conditions.

What is an LDO regulator?

An LDO regulator is a type of semiconductor voltage regulator that is used when the required output voltage differs from the input voltage.

Suppose, for example, that the input voltage is 5 V and that the required output voltage is 3 V. In such cases, LDO regulators provide a simple and inexpensive solution for power supply regulation.

A voltage regulator with a small difference in voltage between input and output is called an LDO regulator. LDO stands for low dropout; an LDO regulator is a type of linear regulator with a low input-output voltage differential.

This article describes why electronic devices require LDO regulators for stable operation and provides an overview of them.

Need of LDO regulators for electronic systems

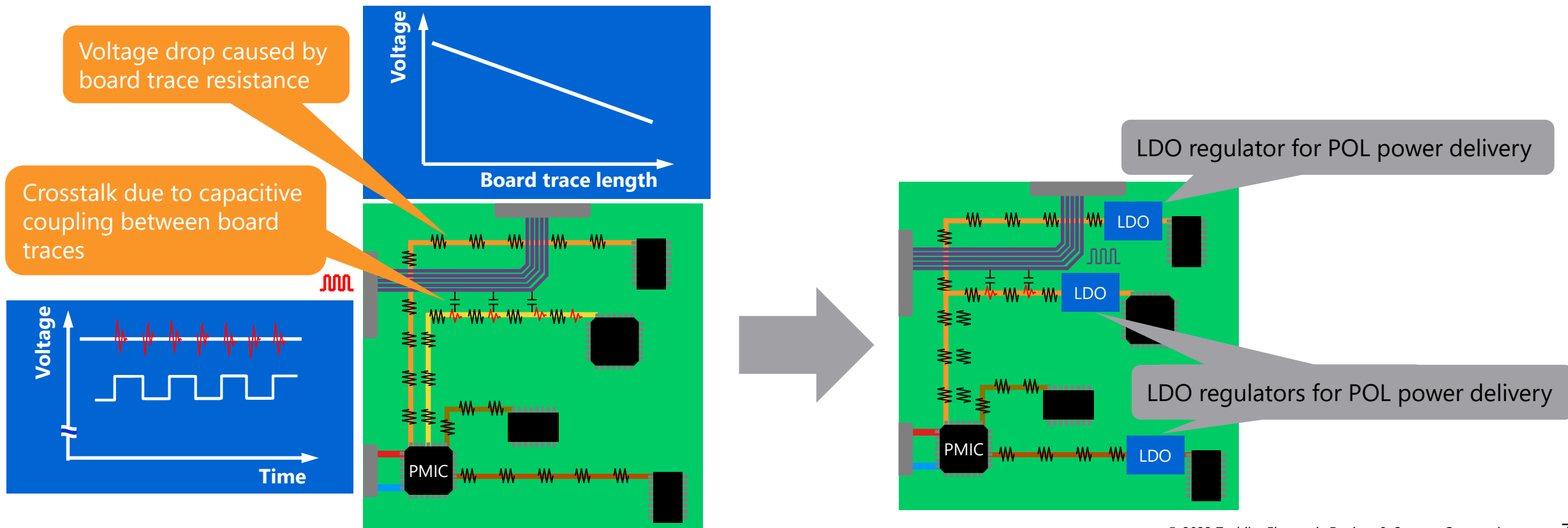
Nowadays, electronic circuits are becoming increasingly complex and power-efficient to improve the performance, reduce the size, and enhance the versatility of electronic equipment.

Under these circumstances, electronic circuits and ICs are shifting to low-voltage operation.

In addition, sensors and high-precision analog circuits require low-noise circuit design.

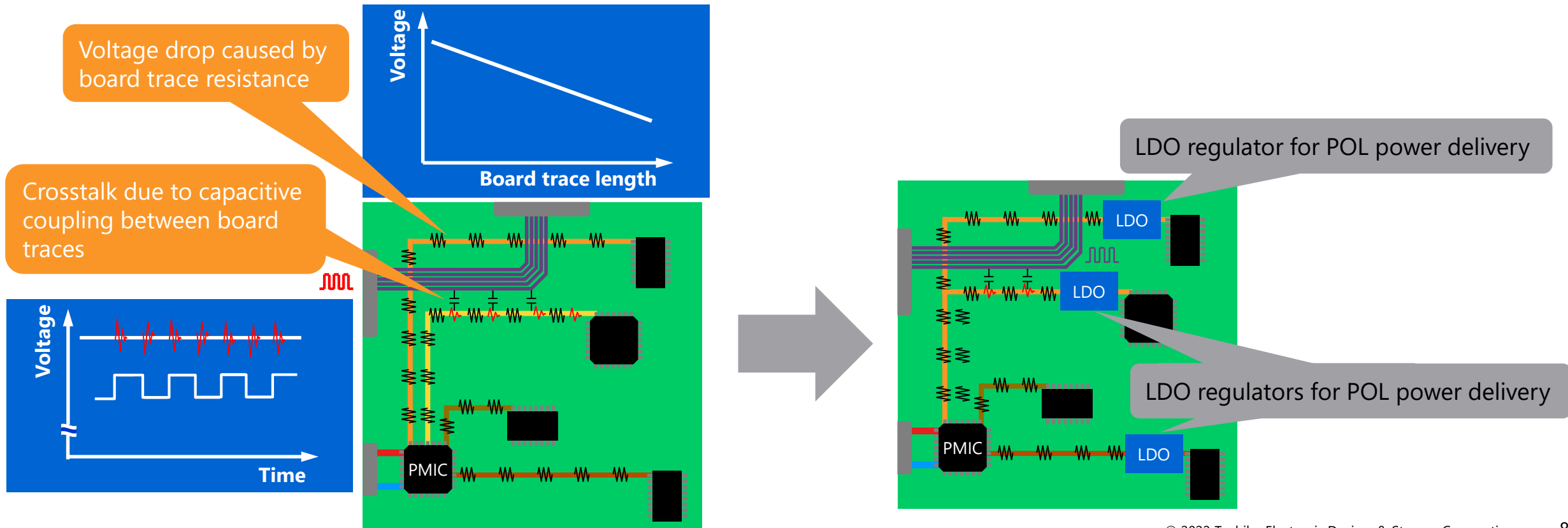
Need of LDO regulators for electronic systems

Conventionally, power supply circuits or regulator ICs (e.g., PMICs*1) have been commonly used on a board to supply the required voltage to each circuit block or IC. Then, the power supply voltage was supplied to each circuit from the power supply circuit and the regulator IC. However, the resistance of a long board trace causes a considerable voltage drop, while crosstalk between parallel board traces tends to affect the operation of noise-sensitive devices. To solve these issues, point-of-load (POL) regulator ICs are often used to locally produce the voltage required for each circuit block or IC.



Need of LDO regulators for electronic systems

Place LDO regulators and other power supply ICs close to their point of use in order to provide precisely regulated voltage with low noise for the subsequent IC or circuitry and thereby improve system stability.

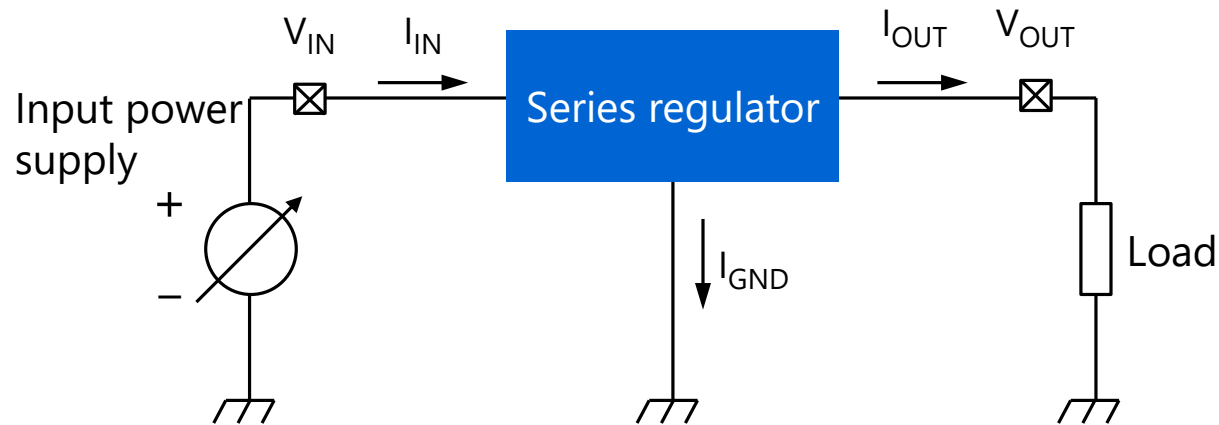


What is a linear regulator?

A linear regulator is a type of voltage regulator IC that acts as a variable resistor in response to changes in input voltage or output current in order to maintain output voltage regulation.

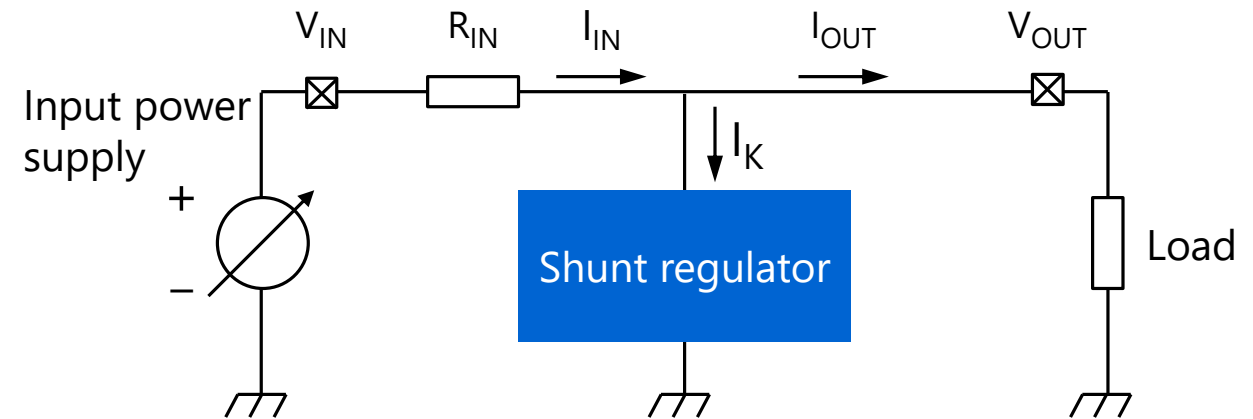
There are two types of linear regulators: series regulators and shunt regulators.

A series regulator, as the name implies, is placed in series between a power supply and a load whereas a shunt regulator is placed in parallel between a power supply and a load.



Series regulator

$$I_{IN} = I_{OUT} + I_{GND}$$



Shunt regulator

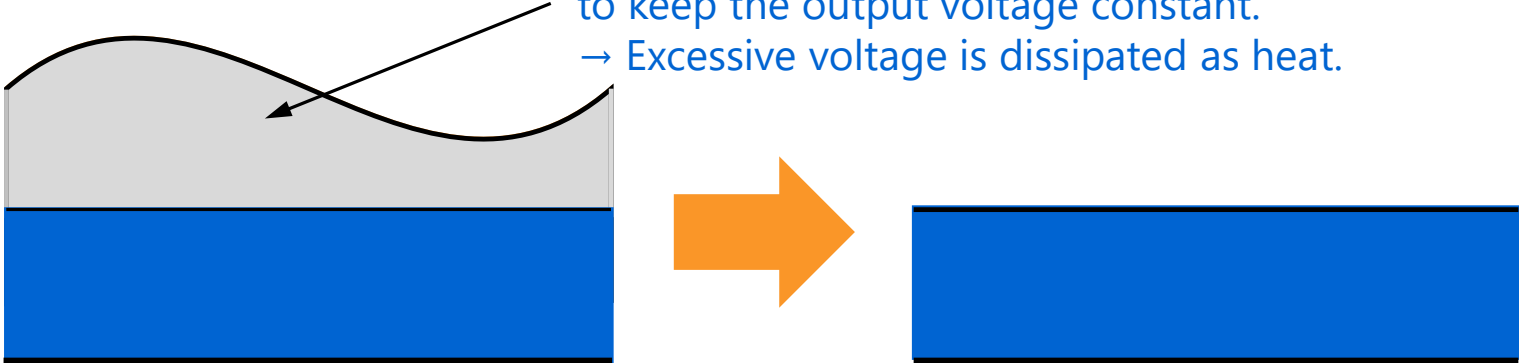
$$I_{IN} = I_{OUT} + I_K$$

Operations of linear and switching regulators

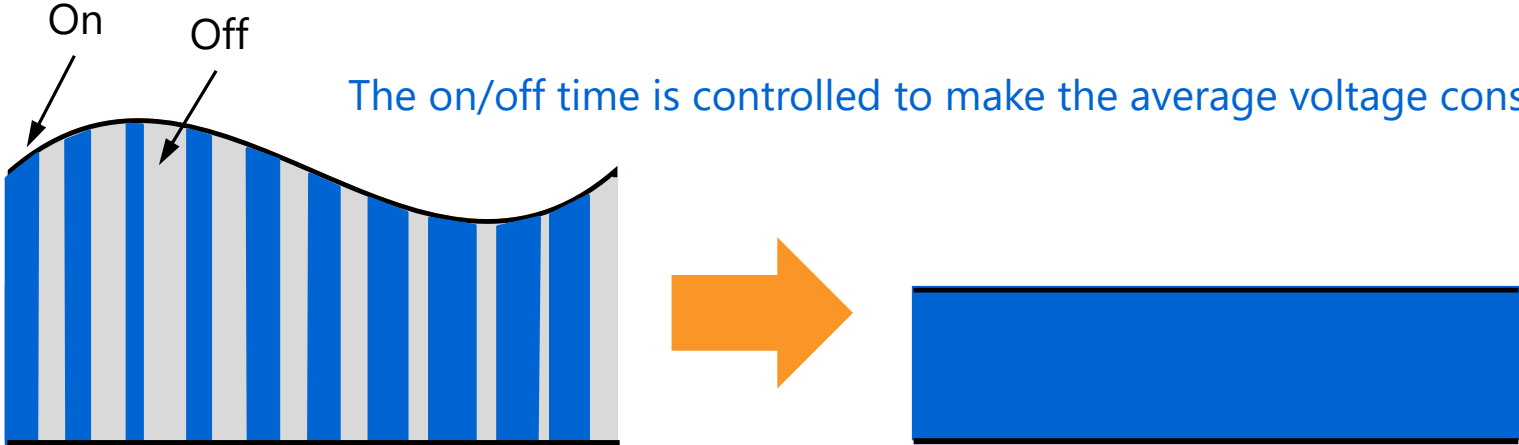
Linear regulators cut off excessive voltage to keep the output voltage constant. In contrast, switching regulators control the on/off-time to make the average value of the input voltage constant, thereby regulating the output.

Linear regulators cut off excessive voltage to keep the output voltage constant.
→ Excessive voltage is dissipated as heat.

Linear regulators



Switching regulators

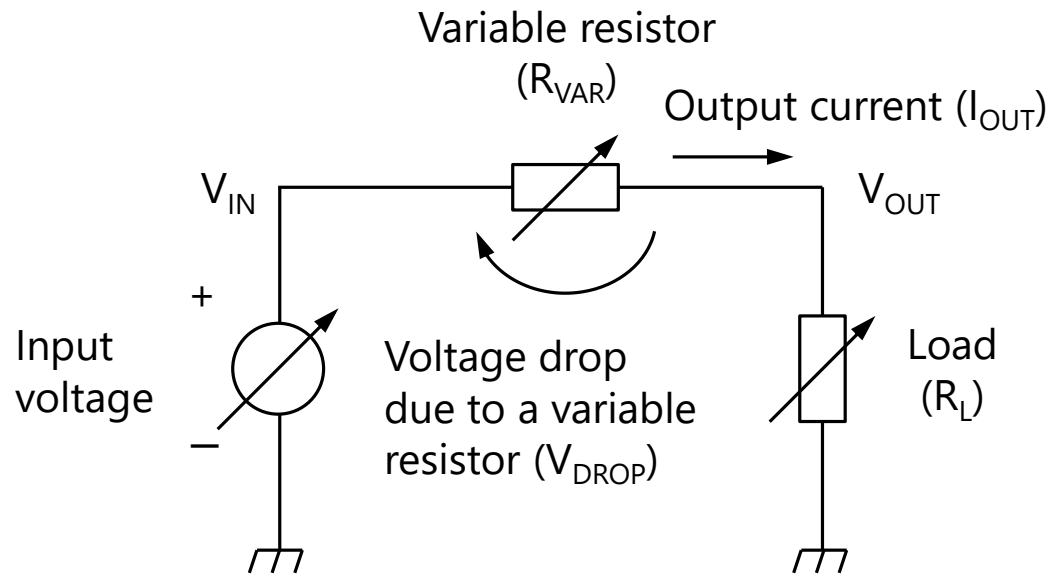


The on/off time is controlled to make the average voltage constant.

Input voltage

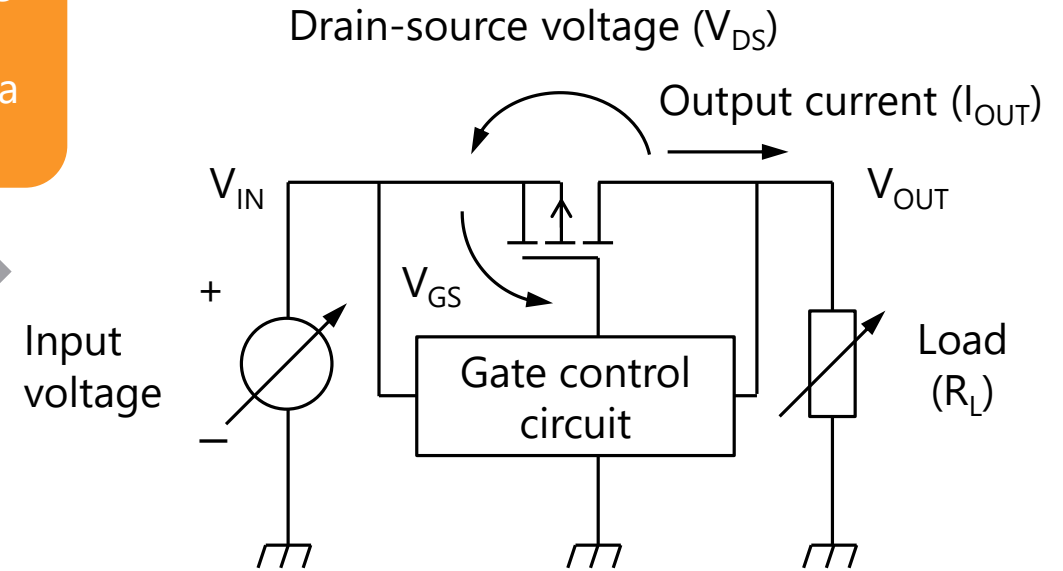
Output voltage

Principle of operation of series regulators



The value of a variable resistor is controlled according to changes in input voltage or output current to regulate the output voltage (V_{OUT}) to a load.

Replacing the variable resistor with a MOSFET

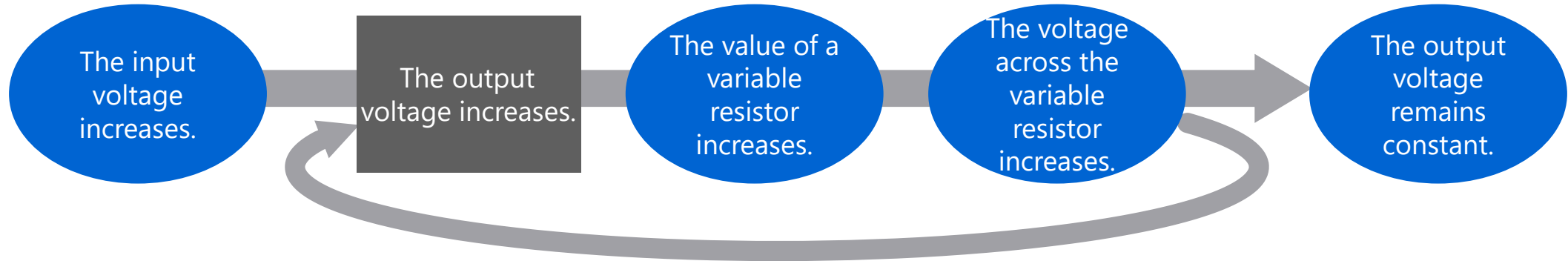


The gate-source voltage (V_{GS}) of a MOSFET is adjusted according to changes in input voltage or output current to increase or decrease the drain-source voltage (V_{DS}), thereby regulating the output voltage (V_{OUT}) to a load.

Principle of operation of series regulators

A series regulator is placed between a power supply and a load. It regulates the output voltage by adjusting the value of a variable resistor according to changes in input voltage or output current.

In response to changes in input voltage



In response to changes in output current



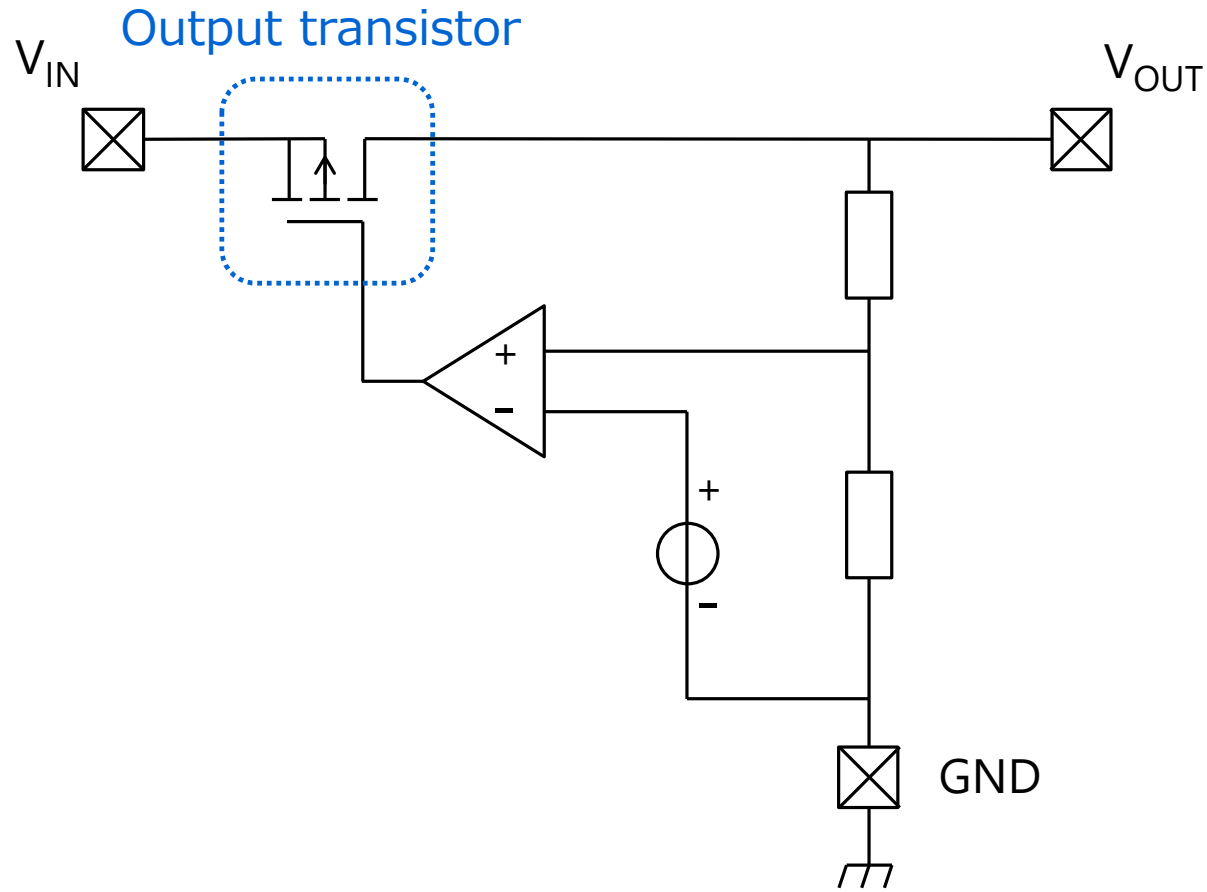
Series regulator ICs use an active device such as a MOSFET or a bipolar junction transistor instead of a variable resistor.

Circuit configuration of a series regulator

Basically, a series regulator consists of the following blocks:

Output transistor

The output transistor is placed in series between the input and output pins of a series regulator. In response to changes in input voltage or output current, its gate voltage or base current is controlled by a signal from an error amplifier. As a result, the output transistor acts as a variable resistor to maintain output voltage regulation.

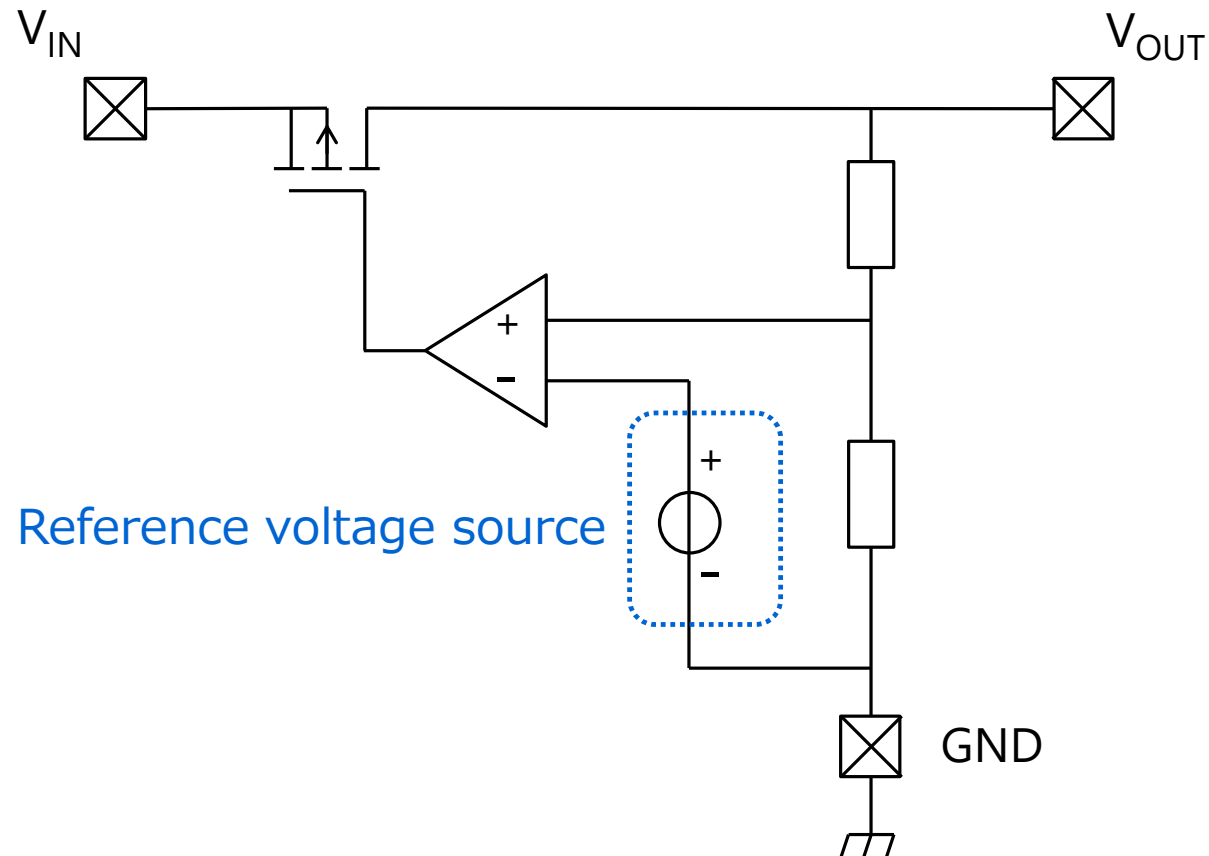


Circuit configuration of a series regulator

Basically, a series regulator consists of the following four blocks:

Reference voltage source

This is a reference voltage source for the error amplifier. The error amplifier controls the gate or base of the output transistor according to this reference voltage to maintain output voltage regulation.

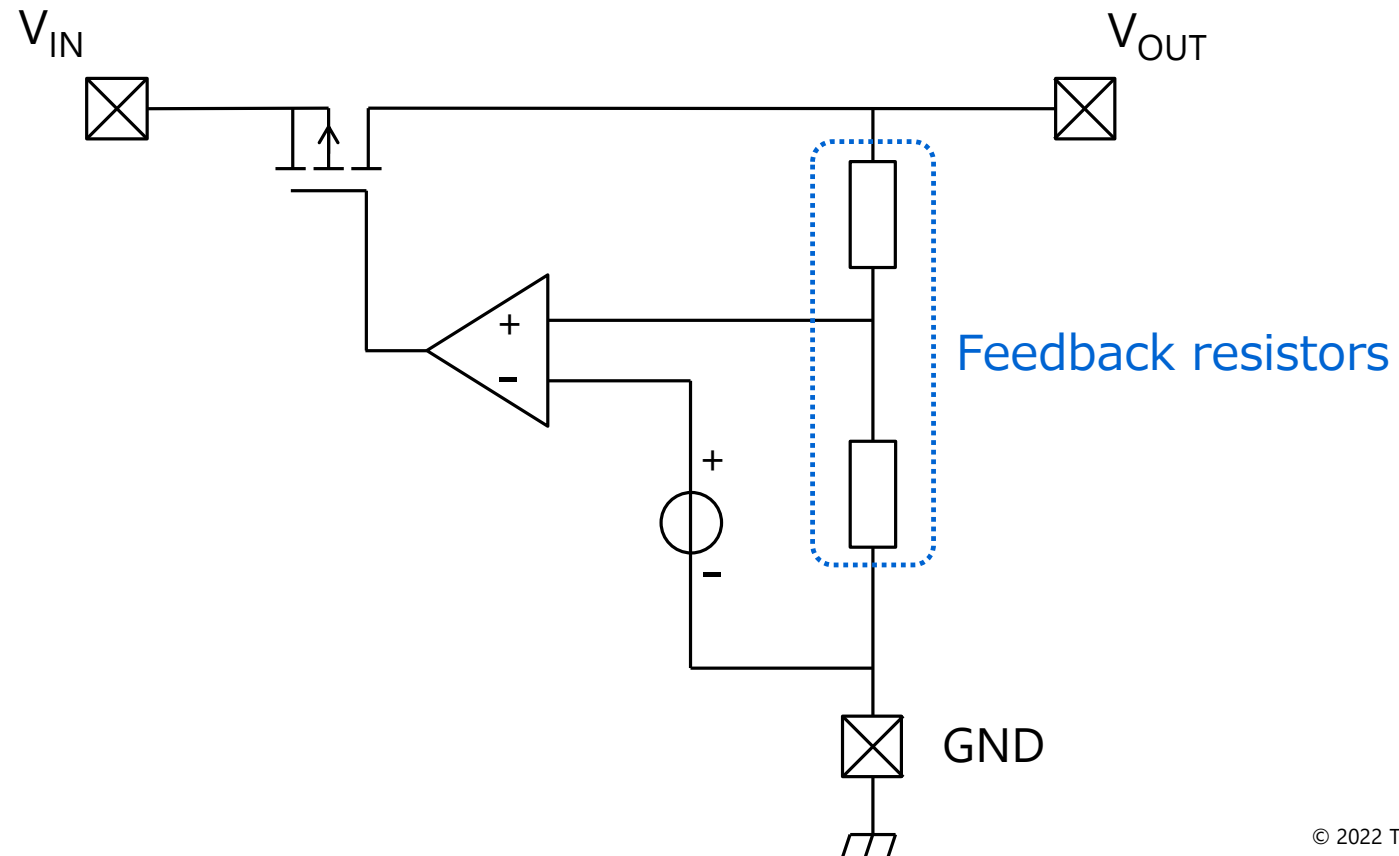


Circuit configuration of a series regulator

Basically, a series regulator consists of the following four blocks:

Feedback resistors

The feedback resistors divide the output voltage to generate a feedback voltage. The error amplifier compares the feedback voltage to the reference voltage to control the output voltage. Two feedback resistors are connected in series between the V_{OUT} and GND pins. The midpoint voltage between these resistors is applied to the error amplifier.



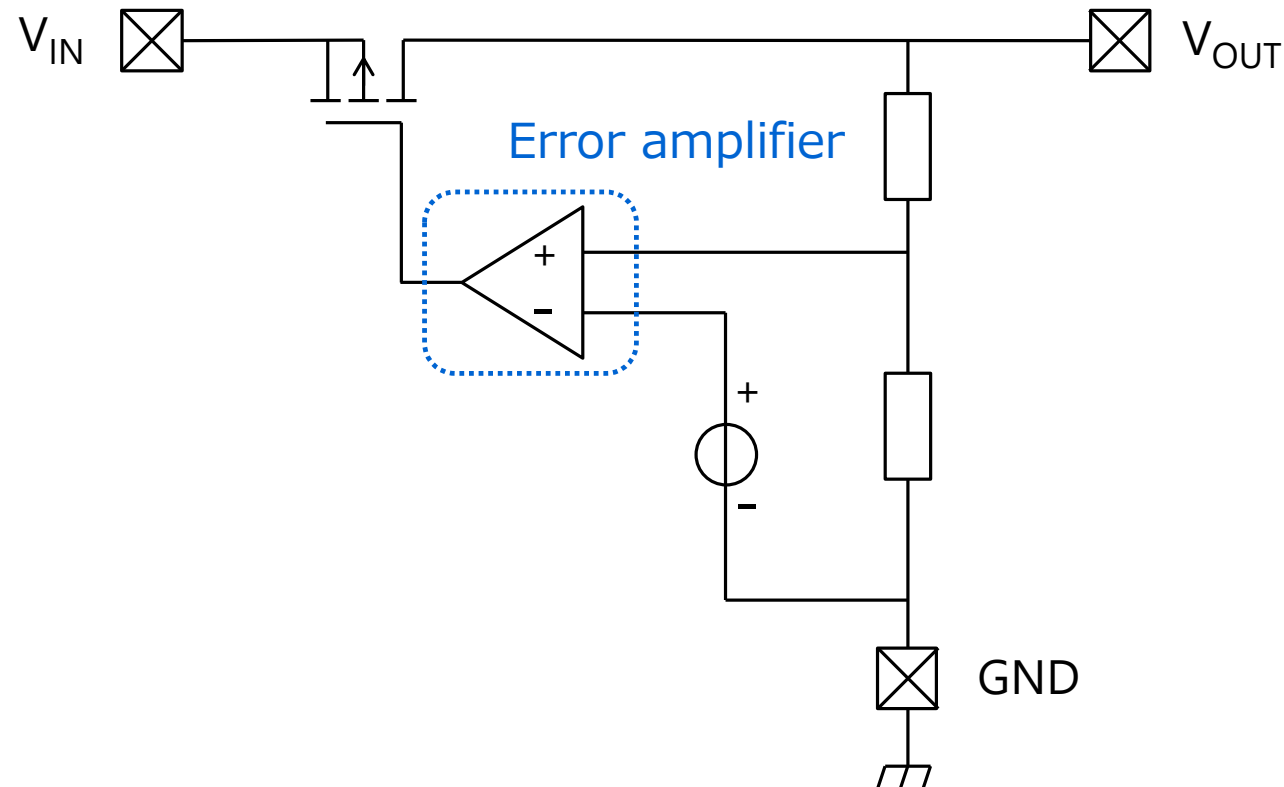
Circuit configuration of a series regulator

Basically, a series regulator consists of the following four blocks:

Error amplifier

The error amplifier compares the feedback voltage (i.e., the midpoint voltage of the two feedback resistors) to the reference voltage. When the feedback voltage is lower than the reference voltage, the error amplifier increases the drive capability of the MOSFET to reduce its drain-source voltage and thereby increase the output voltage.

When the feedback voltage is higher than the reference voltage, the error amplifier decreases the drive capability of the MOSFET to increase the drain-source voltage and thereby reduce the output voltage.

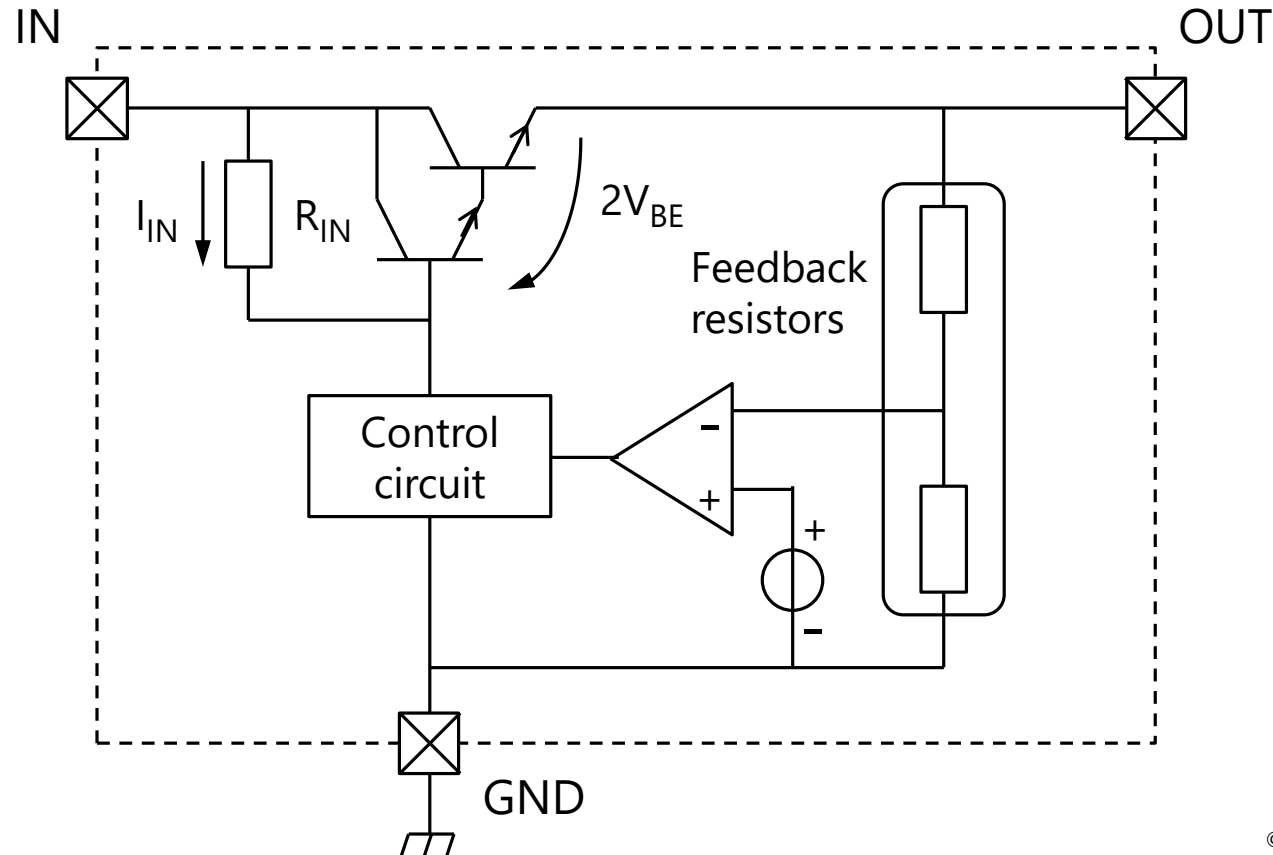


Differences between a three-terminal voltage regulator and an LDO regulator

Three-terminal voltage regulator

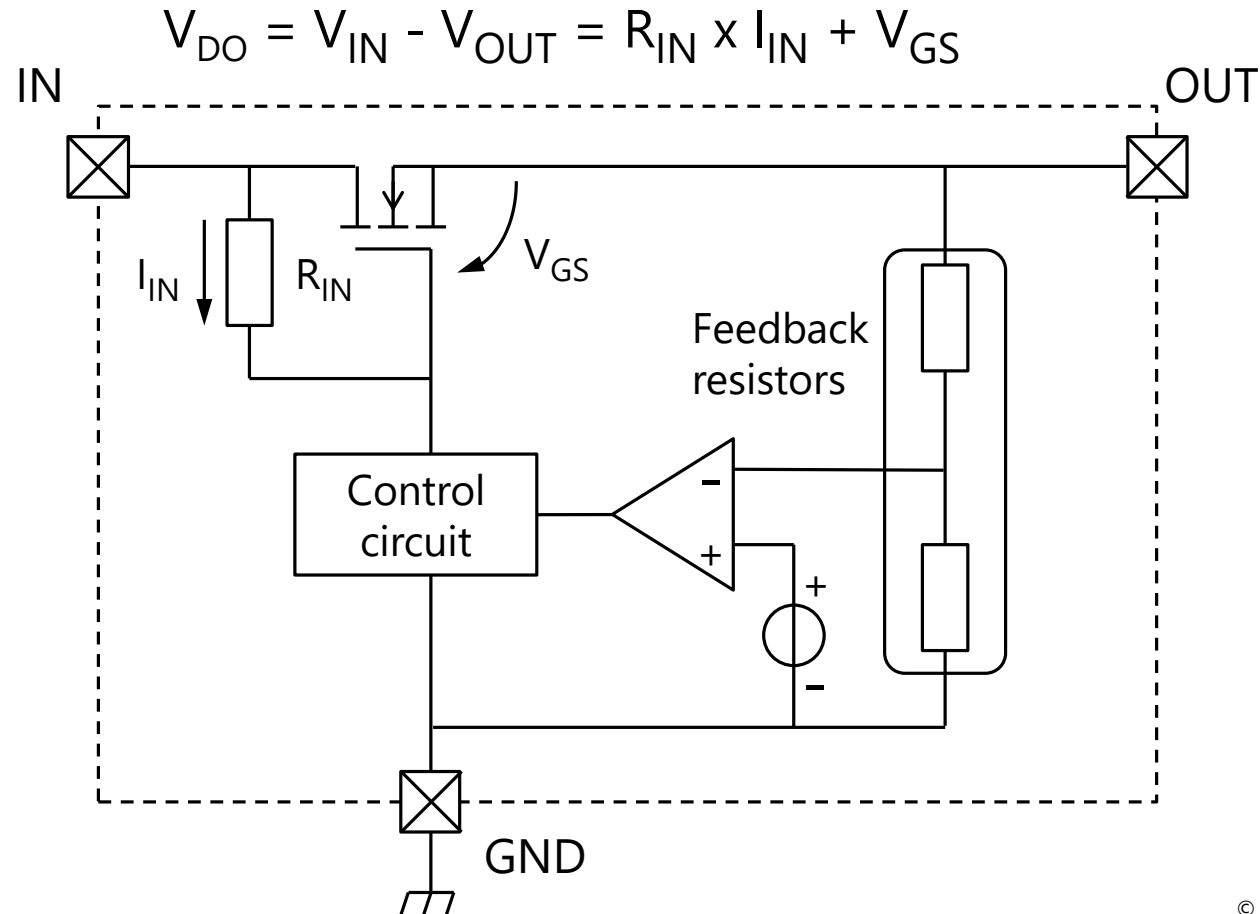
Classic three-terminal voltage regulators (also known as standard voltage regulators) use an NPN-type transistor or an N-channel MOSFET as an output transistor.

For these regulators to work, an input-output voltage differential called a dropout voltage (V_{DO}) is necessary as shown below. In the case of NPN-type voltage regulators, the minimum value of V_{DO} must satisfy $V_{IN} - V_{OUT} > R_{IN} \times I_{IN} + 2 \times V_{BE}$.



Differences between a three-terminal voltage regulator and an LDO regulator

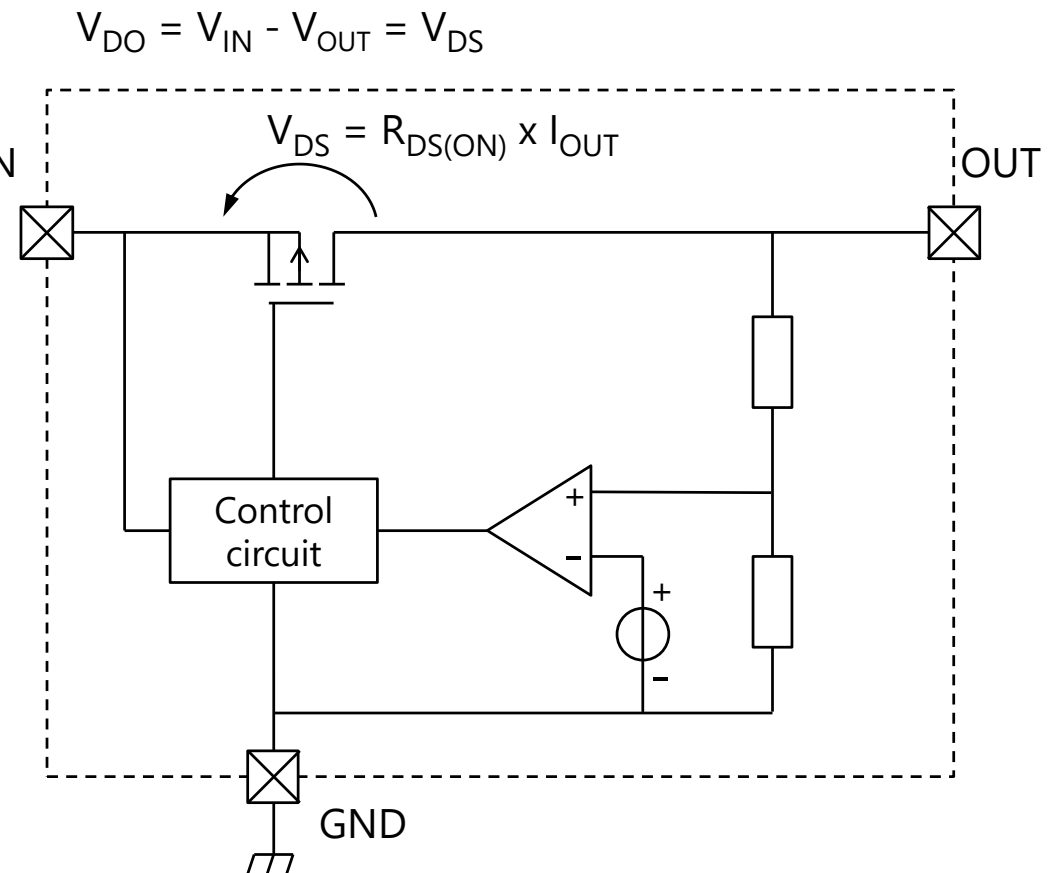
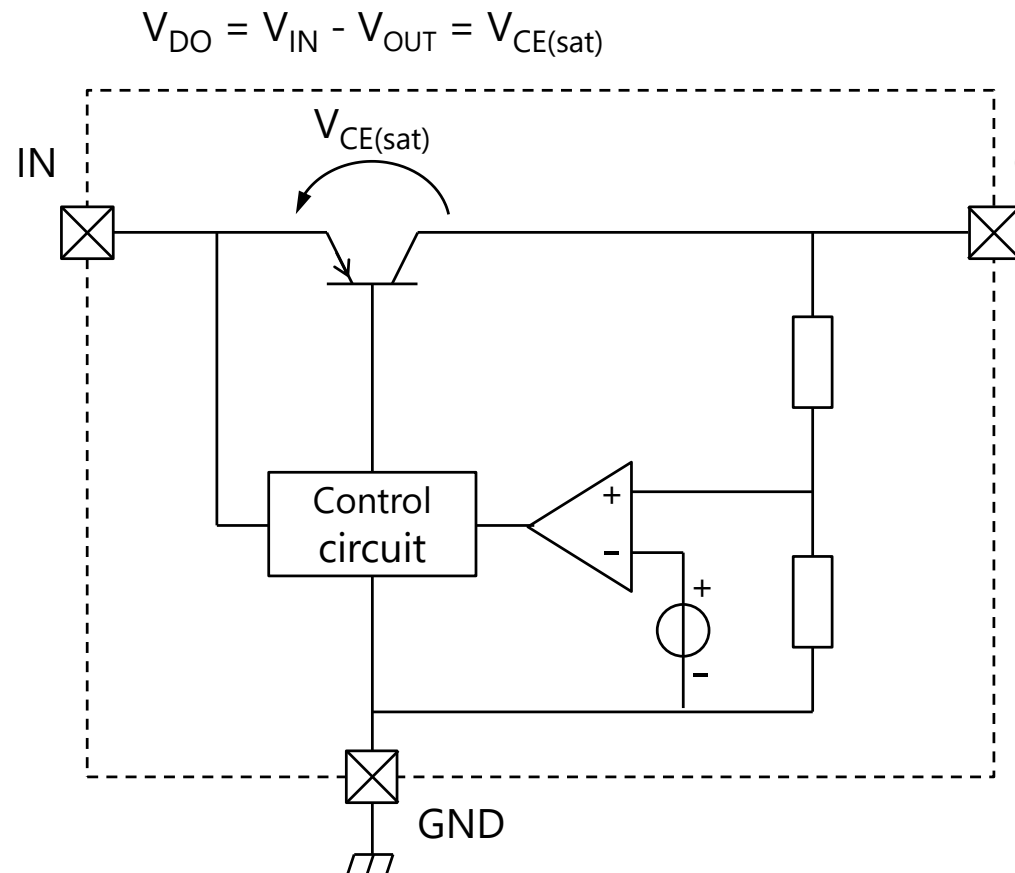
In the case of MOSFET-based voltage regulators, the minimum value of V_{DO} must satisfy $V_{IN} - V_{OUT} > R_{IN} \times I_{IN} + V_{GS}$. Suppose $R_{IN} = 1 \text{ k}\Omega$, $I_{IN} = 1 \text{ mA}$, $V_{BE} = 0.7 \text{ V}$, and $V_{GS} = 1 \text{ V}$. Then, the minimum input voltage required to generate a 5-V output is calculated to be 7.4 V in the case of NPN-type voltage regulators and 7 V in the case of MOSFET-based voltage regulators.



Differences between a three-terminal voltage regulator and an LDO regulator

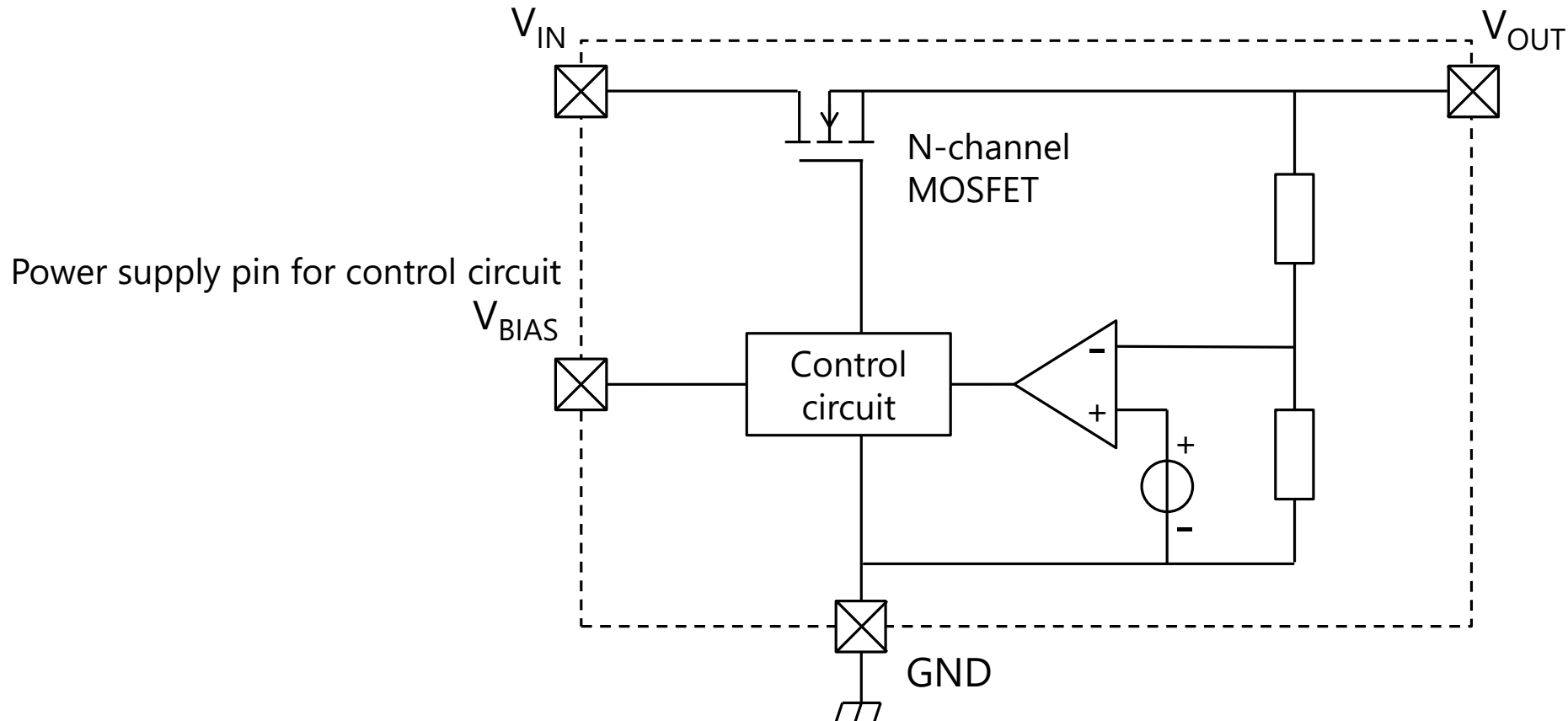
LDO regulator

In contrast to these regulators, LDO regulators mainly use a PNP transistor or a P-channel MOSFET as an output transistor. The minimum dropout voltage of such LDO regulators is determined by the collector-emitter voltage ($V_{CE(sat)}$) and the drain-source voltage ($V_{DS} = R_{DS(ON)} \times I_D$). Therefore, LDO regulators can operate with a smaller dropout voltage than three-terminal voltage regulators.



Differences between a three-terminal voltage regulator and an LDO regulator

There is also a new type of LDO regulator that provides an even smaller dropout voltage, which uses an N-channel MOSFET with a smaller on-resistance than a P-channel MOSFET as an output transistor and has a power supply pin dedicated to the control circuit (including the MOSFET drive circuit).



Chapter2 Convenient functions of LDO

Useful functions available with LDO regulators

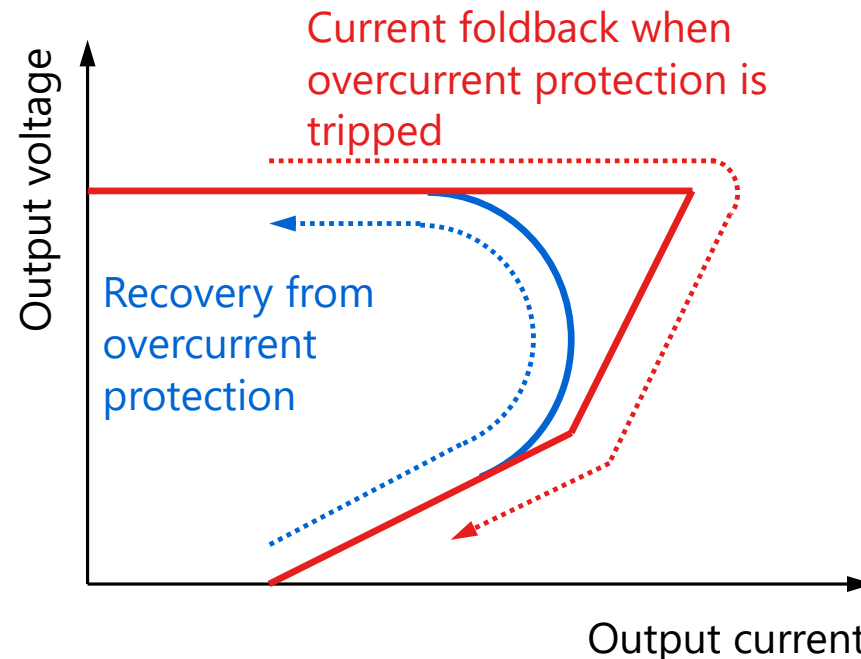
LDO regulators provide various functions to ensure stable system operation.

Function	Description
Overcurrent protection	This function limits the output current to protect a system in the event of an excessive current flowing in an LDO regulator, for example, because of a short-circuit between a load on the V_{OUT} side and GND.
Thermal shutdown	This function turns off the LDO regulator to protect the system when the heat generated by the LDO regulator exceeds its heat dissipation capacity.
Inrush current reduction (slew rate control, soft start)	This function helps ensure stable system operation by slowly increasing the output voltage during the turn-on of an LDO regulator. Inrush current reduction is also called slew rate control or soft start.
Auto discharge	This function facilitates system power sequencing by quickly discharging the smoothing capacitor connected to the V_{OUT} pin when an LDO regulator is turned off.
Undervoltage lockout (UVLO)	This function turns off the output of an LDO regulator when its input voltage drops below a predefined threshold so that the system operation will not become unstable.

The subsequent sections describe each of these functions.

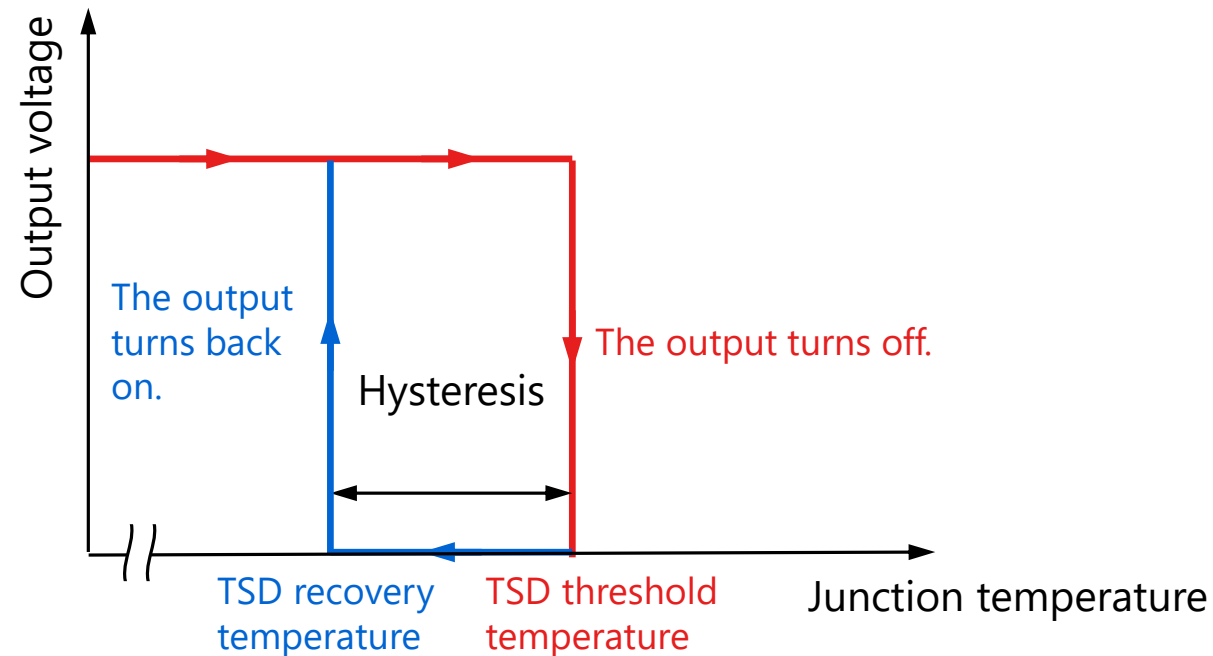
Overcurrent protection operation of LDO regulators

When a short-circuit between a load on the V_{OUT} side and GND or other system failure occurs, this function limits the output current of an LDO regulator to protect itself and the system in which it is used. Toshiba's LDO regulators provide overcurrent protection called foldback. In the event of excessive current higher than the internal threshold, foldback reduces the output current (I_{OUT}) as the output voltage (V_{OUT}) decreases. Even when the output voltage has reached 0 V, the output current continues flowing at the internally set level. The term "foldback" is derived from the shape of the I_{OUT} -vs- V_{OUT} curve that folds back as shown below during protection operation. When a faulty condition causing an overcurrent condition disappears, an LDO regulator automatically recovers from overcurrent protection, returning the output voltage to the normal level.



Thermal shutdown (TSD) operation of LDO regulators

In the event of excessive power dissipation or the junction temperature exceeding a threshold due to an excessive increase in ambient temperature, the thermal shutdown (TSD) function turns off an LDO regulator to protect itself and the system in which it is used.

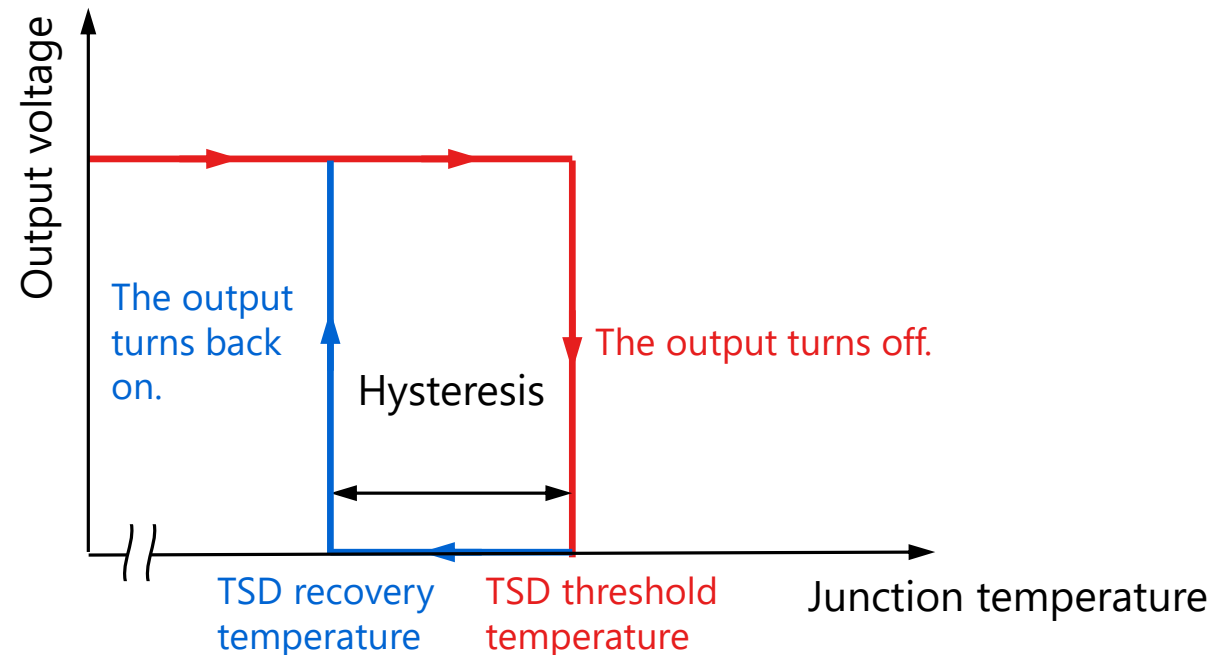


Thermal shutdown (TSD) operation of LDO regulators

LDO regulators have a thermal shutdown temperature and a recovery temperature.

The thermal shutdown temperature is the temperature at which TSD is tripped in the event of an increase in junction temperature in order to turn off an LDO regulator. Once the LDO regulator is turned off, it dissipates no power; so the junction temperature begins to fall. When the junction temperature reaches the recovery temperature, the LDO regulator turns back on automatically and supplies the regulated voltage to the subsequent IC and circuitry.

The recovery temperature is the temperature at which the LDO regulator turns back on after TSD forces it off. In the datasheets of LDO regulators, a difference between the shutdown and recovery temperatures is specified as thermal shutdown hysteresis.

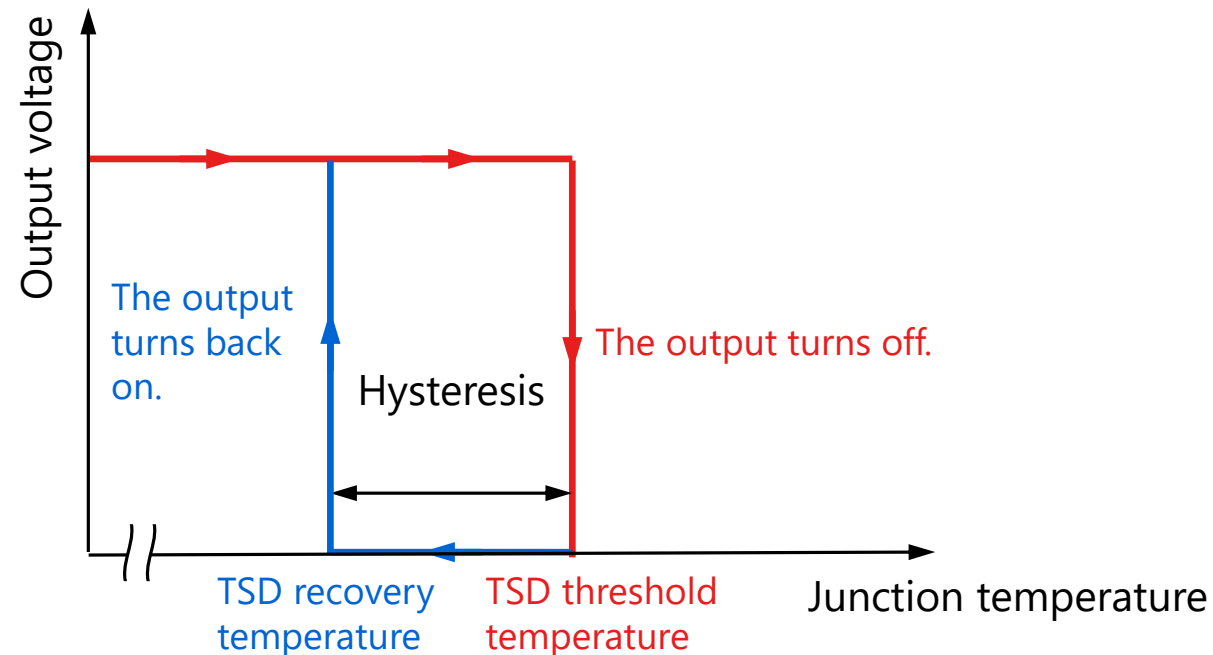


Thermal shutdown (TSD) operation of LDO regulators

Once thermal shutdown is tripped, its cause must be removed to set the CONTROL pin Low. If the CONTROL pin is left High, the junction temperature increases again.

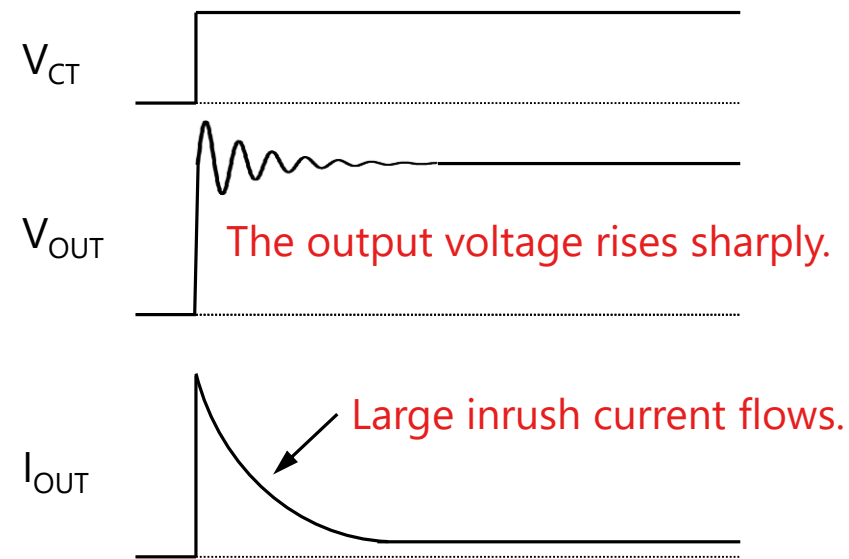
This causes an LDO regulator to enter the following loop: a turn-off of an LDO regulator → a decrease in junction temperature → a turn-on of the LDO regulator → an increase in junction temperature.

The LDO regulator should not be left at an excessive temperature for an extended period because doing so might affect the system stability or degrade the reliability of the LDO regulator. Be sure to provide a fail-safe mechanism for a system in case of thermal shutdown.



Inrush current reduction function of LDO regulators

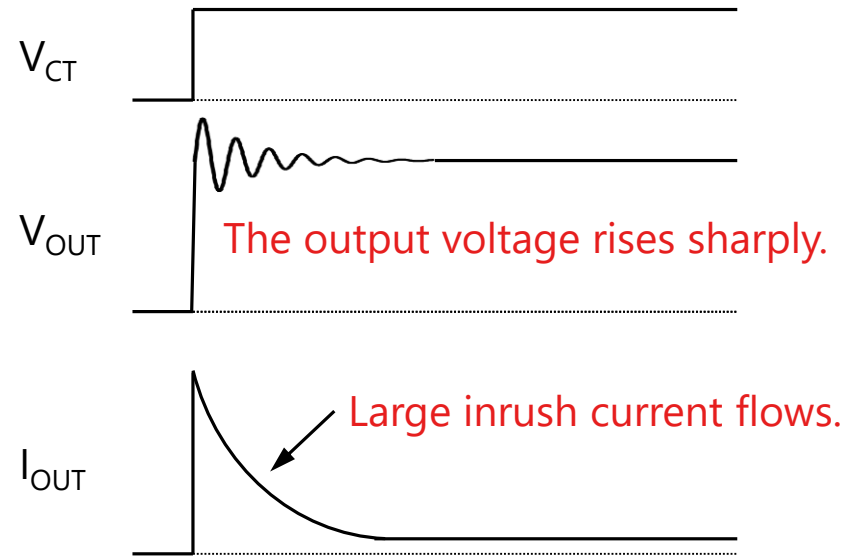
When the input voltage rises from 0 V and reaches the minimum operating voltage, an LDO regulator turns on to supply a regulated output voltage. At this time, the internal error amplifier drives the output transistor between the V_{IN} and V_{OUT} pins with the maximum drive capability to raise the output voltage to the programmed level. Once the output voltage reaches the programmed level, the LDO regulator tries to maintain it at that level. However, the internal circuit delay, for example, might cause the output voltage to overshoot, exceeding the rated voltage of the load IC or circuit.



V_{OUT} and I_{OUT} waveforms without inrush current limiting

Inrush current reduction function of LDO regulators

In addition, a large inrush current flows into the LDO regulator to charge the output smoothing capacitor connected to the V_{OUT} pin. Inrush current occurs during the period from the time when the LDO regulator turns on to the time when the output voltage stabilizes. If the V_{IN} pin is connected with a board trace with large impedance, the input voltage might sag because of a voltage drop that occurs across the board trace impedance due to inrush current. Consequently, the LDO regulator is unable to produce an output voltage at a normal level. The inrush current limiting function prevents these conditions.

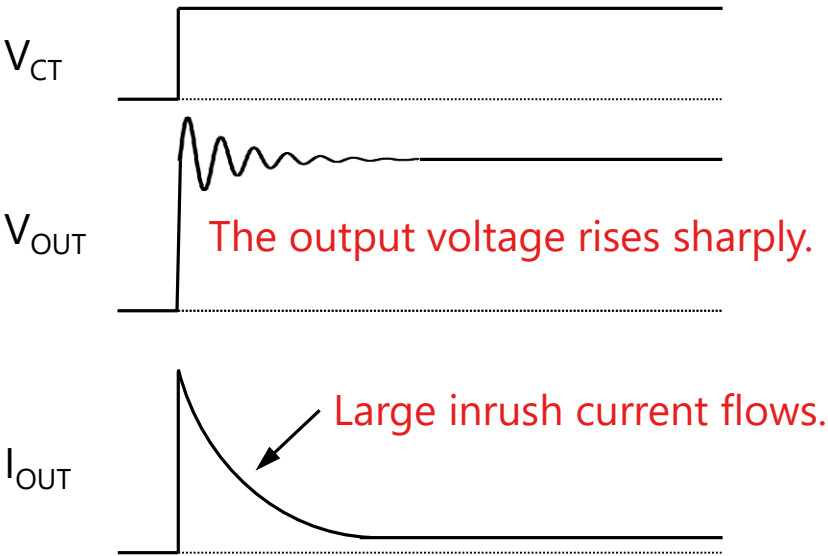


V_{OUT} and I_{OUT} waveforms without inrush current limiting

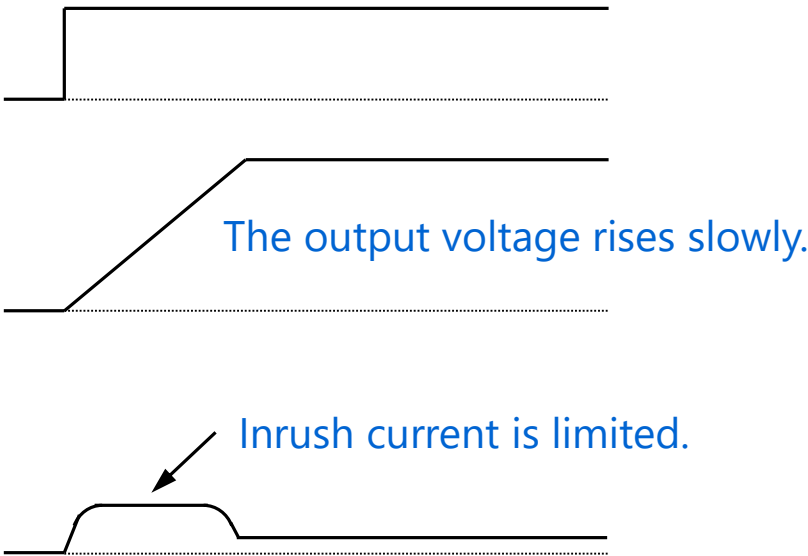
Inrush current reduction function of LDO regulators

After the LDO regulator turns on, it raises the output current slowly while limiting inrush current, thereby suppressing the output voltage overshoot and the input voltage drop. Therefore, inrush current limiting helps improve system stability.

Inrush current limiting is also called slew rate control or soft start.



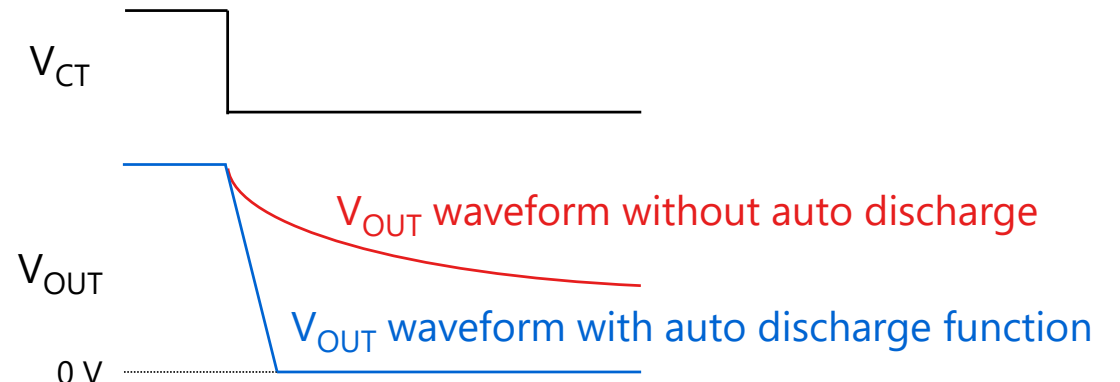
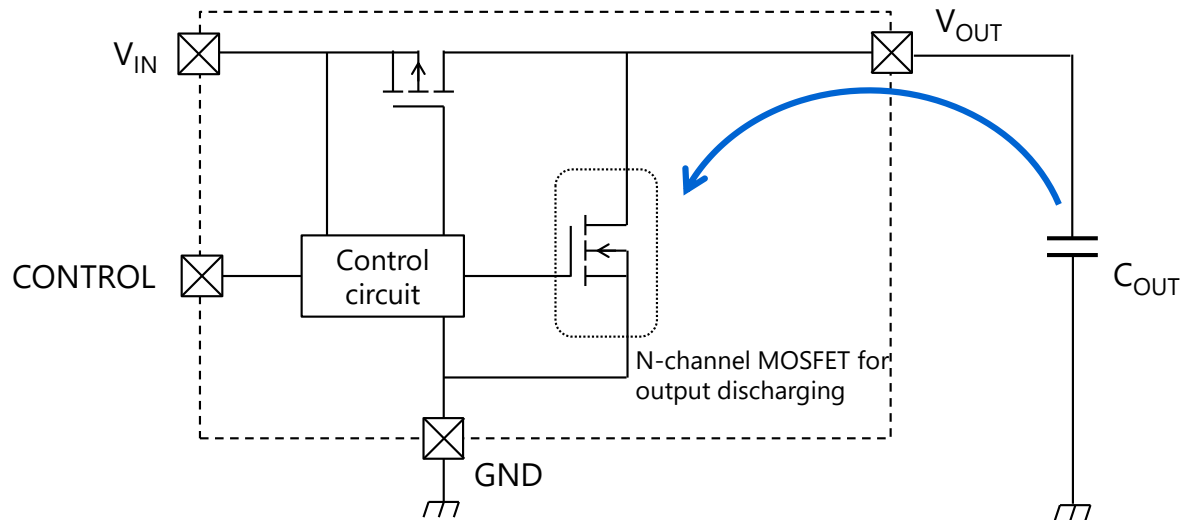
V_{OUT} and I_{OUT} waveforms without inrush current limiting



V_{OUT} and I_{OUT} waveforms with inrush current limiting

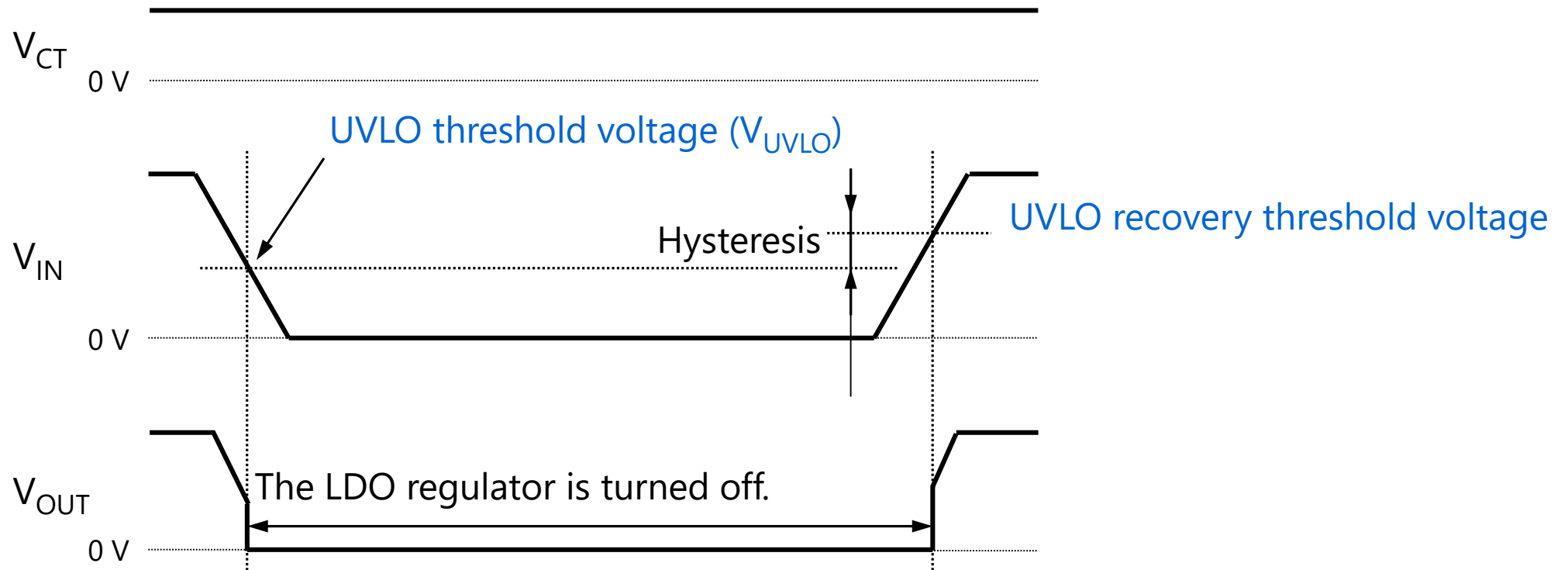
Auto discharge function of LDO regulators

An electronic system consists of multiple ICs and circuits. For the system to work properly, it is necessary to set a power supply sequence, i.e., the order in which to supply power to the constituent ICs and circuits. A relatively large capacitor is connected to the V_{OUT} pin of an LDO regulator in order to smooth the output voltage. After the LDO regulator is turned off, this smoothing capacitor remains charged for a while, depending on the supply current of the subsequent IC or circuit. This makes it difficult to set the required power supply sequence. When an LDO regulator turns off, the auto discharge function discharges the smoothing capacitor quickly via the internal N-channel MOSFET connected between the V_{OUT} and GND pins, thereby simplifying power supply sequencing.



Undervoltage lockout (UVLO) function of LDO regulators

System operation might become unstable if the voltage supplied to a constituent IC or circuit drops. To ensure system stability, the undervoltage lockout (UVLO) function of an LDO regulator turns off its output when the input voltage drops below the internal threshold. UVLO has hysteresis. The output automatically turns back on when the input voltage rises back above the recovery threshold with the high-level CONTROL voltage being applied.



Chapter3 Glossary of terms used in the datasheets for LDO regulators

Glossary of terms used in the datasheets for LDO regulators

The following table provides the definitions of major electrical characteristics shown in the datasheets of LDO regulators.

Characteristic	Symbol	Description
Input voltage	V_{IN}	V_{IN} is the input voltage range in which an LDO regulator can operate properly.
Bias voltage	V_{BIAS} V_{BAT}	V_{BIAS} and V_{BAT} are the bias voltage range in which an LDO regulator can operate properly. The bias voltage is used as a power supply for the internal control circuit.
Output voltage accuracy Output voltage	V_{OUT}	V_{OUT} is the accuracy of the minimum and maximum output voltage regulation relative to the typical value under the test conditions specified in a datasheet.
Adjustable voltage	V_{ADJ}	V_{ADJ} is the reference voltage for the internal error amplifier. V_{ADJ} is specified for LDO regulators whose output voltage can be adjusted arbitrarily with external resistors.
Quiescent current	I_B $I_{B(ON)}$	I_B and $I_{B(ON)}$ are the quiescent current of the internal circuitry minus the pull-down current of the CONTROL pin flowing out of the GND pin when an LDO regulator is operating under the test conditions specified in a datasheet.
Quiescent current	$I_{IN(ON)}$	$I_{IN(ON)}$ is the quiescent current flowing into the V_{IN} pin when an LDO regulator is operating under the test conditions specified in a datasheet.
Quiescent current	$I_{BIAS(ON)}$	$I_{BIAS(ON)}$ is the quiescent current flowing into the V_{BIAS} pin when an LDO regulator is operating under the test conditions specified in a datasheet.

Glossary of terms used in the datasheets for LDO regulators

Characteristic	Symbol	Description
Standby current	$I_{B(OFF)}$ $I_{IN(OFF)}$ $I_{BIAS(ON)}$	$I_{B(OFF)}$, $I_{IN(OFF)}$, and $I_{BIAS(ON)}$ are the current flowing through the V_{IN} and V_{BIAS} pins when an LDO regulator is in standby mode with $V_{CT} = 0$ V.
ADJ pin current	I_{ADJ}	I_{ADJ} is the input current to an error amplifier connected to the V_{ADJ} pin. I_{ADJ} is specified for LDO regulators whose output voltage can be adjusted arbitrarily with external resistors.
Control voltage (ON)	$V_{CT(ON)}$	$V_{CT(ON)}$ is the voltage required at the CONTROL pin to turn on an LDO regulator. When a voltage in the range specified in a datasheet is applied to the CONTROL pin, output voltage appears at the V_{OUT} pin.
Control voltage (OFF)	$V_{CT(OFF)}$	$V_{CT(OFF)}$ is the voltage required at the CONTROL pin to turn off an LDO regulator. When a voltage in the range specified in a datasheet is applied to the CONTROL pin, an LDO regulator shuts down.
Control pulldown current	I_{CT}	I_{CT} is the current that flows through a pull-down device connected between the CONTROL and GND pins of an LDO regulator.

Glossary of terms used in the datasheets for LDO regulators

Characteristic	Symbol	Description
Line regulation	Reg·line	Line regulation (Reg·line) is an amount of change of the output voltage (V_{OUT}) with respect to the input voltage (V_{IN}). LDO regulators with a smaller Reg·line value have a higher ability to maintain V_{OUT} regulation despite changes to V_{IN} .
Load regulation	Reg·load	Load regulation (Reg·load) is an amount of change of the output voltage (V_{OUT}) with respect to the output current (I_{OUT}). LDO regulators with a smaller Reg·load value have a higher ability to maintain V_{OUT} regulation despite changes to I_{OUT} .
Dropout voltage	V_{DO}	Also called the input-output voltage differential, the dropout voltage (V_{DO}) is a difference between input and output voltages necessary to maintain output voltage regulation.
Current limit	I_{CL}	I_{CL} is the specified current value at which an LDO regulator begins limiting excessive output current in the event of overcurrent protection being tripped.
Undervoltage lockout threshold voltage	V_{UVLO}	V_{UVLO} is the input voltage of an LDO regulator at which its undervoltage lockout (UVLO) function is tripped.
Temperature coefficient	T_{CVO}	T_{CVO} is a rate of change of the output voltage with respect to a change of 1° C in ambient temperature under the test conditions specified in a datasheet. LDO regulators with a smaller temperature coefficient value have a higher ability to maintain output voltage regulation despite changes in temperature.

Glossary of terms used in the datasheets for LDO regulators

Characteristic	Symbol	Description
Output noise voltage	V_{NO}	V_{NO} is the magnitude of noise that occurs at the output of an LDO regulator.
Ripple rejection ratio	R.R. (V_{IN}) R.R. (V_{BIAS})	The ripple rejection ratio is the ability of an LDO regulator to suppress ripple in the input or bias voltage. It is expressed in dB. LDO regulators with a higher R.R. value have a higher ability to suppress ripple. Use R.R. as a guide when selecting LDO regulators for power supplies for sensor, analog, and other highly noise-sensitive circuits. The ripple rejection ratio is also called the power supply rejection ratio (PSRR) or the supply voltage rejection ratio (SVRR).
Load transient response	ΔV_{OUT}	The load transient response (ΔV_{OUT}) is an amount of change in the undershoot and overshoot of the output voltage for a load current step change. LDO regulators with a large ΔV_{OUT} value might affect the correct operation of a system.
Output discharge on-resistance	R_{SD}	R_{SD} is the on-resistance of the internal N-channel MOSFET connected between the V_{OUT} and GND pins of an LDO regulator.
Thermal shutdown temperature	T_{SD}	T_{SD} is the junction temperature at which thermal shutdown is tripped in the event of excessive power dissipation or an excessive increase in ambient temperature.
Thermal shutdown temperature hysteresis	T_{SDH}	T_{SDH} is a difference between the temperature at which the LDO regulator trips thermal shutdown and the temperature at which it recovers from thermal shutdown.

Chapter4 Efficiency and power loss calculation for LDO

Efficiency of LDO regulators

The efficiency of an LDO regulator can be calculated as follows:

$$\eta = \frac{P_{OUT}}{P_{IN}} \quad \dots (1)$$

Input power (P_{IN}) and output power (P_{OUT}) can be calculated using Equation 2 and Equation 3, respectively:

$$P_{IN} = V_{IN} \times (I_{IN} + I_B) \quad \dots (2)$$

$$P_{OUT} = V_{OUT} \times I_{OUT} \quad \dots (3)$$

When the quiescent current (I_B) of an LDO regulator is negligibly smaller than the input current (I_{IN}), Equation 2 can be approximated as follows:

$$P_{IN} = V_{IN} \times I_{IN} \quad \dots (4)$$

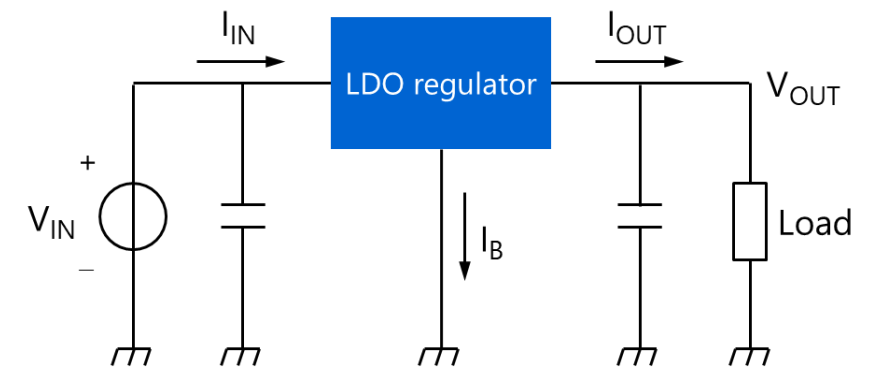
Substituting Equations 3 and 4 into Equation 1, we obtain:

$$\eta = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{IN}}$$

In the case of series regulators, $I_{IN} = I_{OUT}$. Hence,

$$\eta = \frac{V_{OUT}}{V_{IN}}$$

So, the efficiency of an LDO regulator can be calculated as the ratio of input voltage (V_{IN}) to output voltage (V_{OUT}). Therefore, an LDO regulator can be used to compose a high-efficiency power supply, depending on the input and output voltage conditions.



Calculating the power dissipation and junction temperature of an LDO regulator

The power dissipation (P) of an LDO regulator can be calculated as follows:

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} + V_{IN} \times I_B \cdots (1)$$

When the term $V_{IN} \times I_B$ is negligibly small, Equation 1 can be approximated as follows:

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} \cdots (2)$$

The junction temperature T_j of the LDO regulator can be calculated as follows:

$$T_j = P \times R_{th(j-a)} + T_a \cdots (3)$$

where $R_{th(j-a)}$ is the thermal resistance of the LDO regulator when it is mounted on a board. If $R_{th(j-a)}$ is not shown in the datasheet, you can calculate it from the power dissipation (P_D) value:

$$R_{th(j-a)} = \frac{T_{j(max)} - 25}{P_D} \cdots (4)$$

Substituting Equation 4 into Equation 3, we obtain:

$$T_j = P \times \frac{T_{j(max)} - 25}{P_D} + T_a \cdots (5)$$

Suppose that $T_{j(max)} = 150^\circ\text{C}$, $P_D = 600 \text{ mW}$, $V_{IN} = 3.6 \text{ V}$, $V_{OUT} = 1.8 \text{ V}$, $I_{OUT} = 100 \text{ mA}$, $T_a = 40^\circ\text{C}$. Then, T_j is calculated as follows:

$$T_j = (3.6 - 1.8) \times 0.1 \times \frac{150 - 25}{0.6} + 40 = 77.5 \text{ }^\circ\text{C}$$

Note that the power dissipation and thermal resistance values in the datasheet are the values under the specified board conditions. It is therefore necessary to evaluate LDO regulators carefully to ensure that they work properly under actual usage conditions.

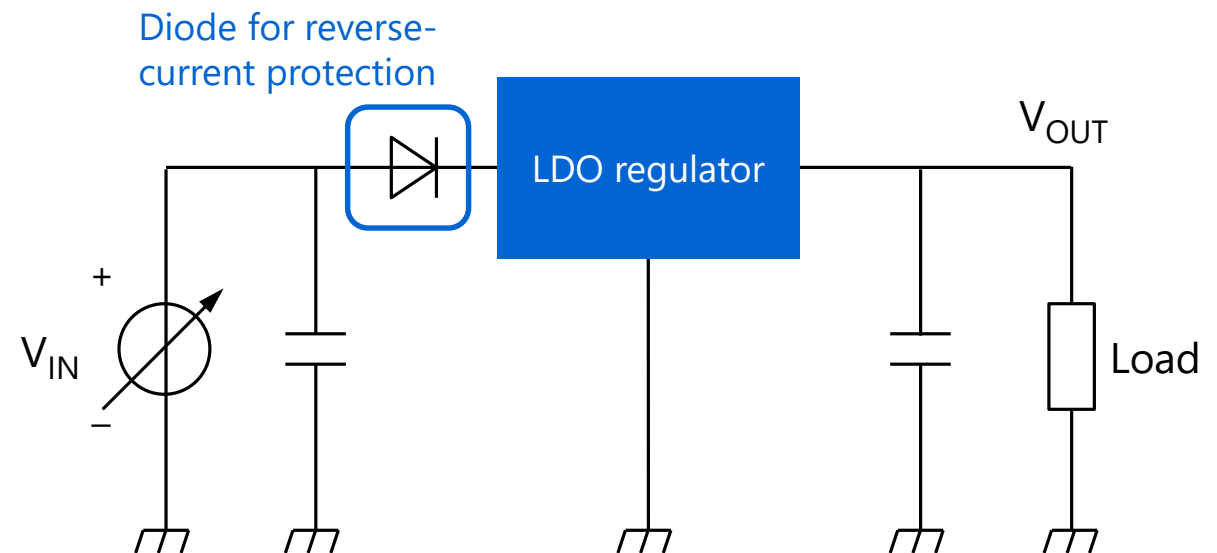
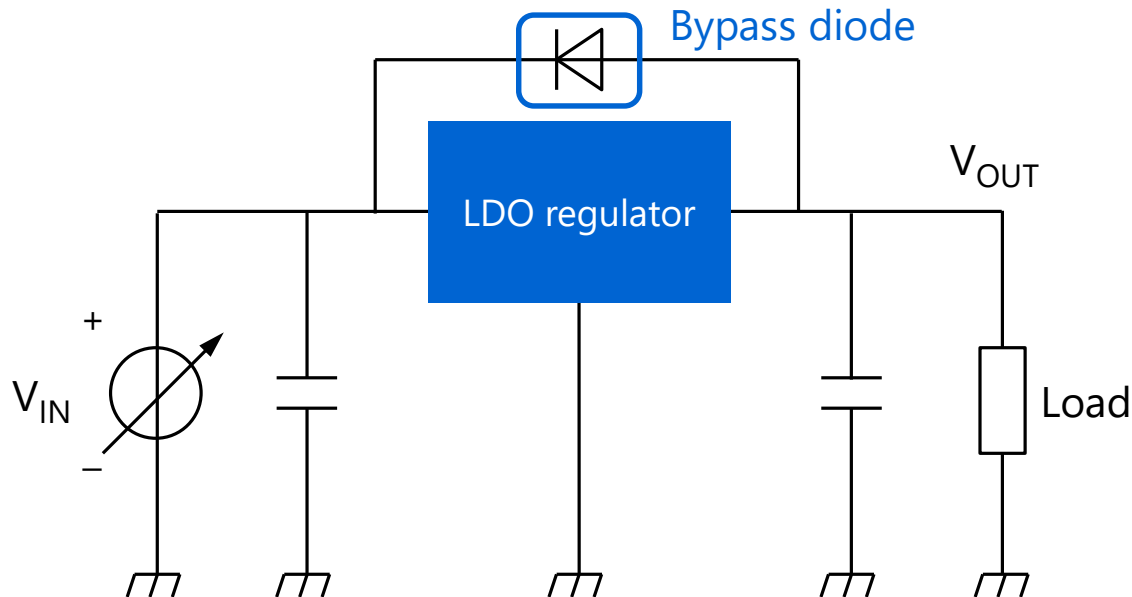
Chapter5 Precautions for use

Usage considerations for LDO regulators

Reverse biasing condition of an LDO regulator (i.e., output voltage higher than input voltage)

If the output voltage of an LDO regulator becomes higher than the input voltage, current flows in the reverse direction from the output pin to the input pin. This reverse biasing condition could degrade or destroy the LDO regulator. If this could occur, connect a bypass diode between the V_{IN} and V_{OUT} pins as shown in Figure 1 or add a reverse-current blocking diode between a power supply and the V_{IN} pin as shown in Figure 2.

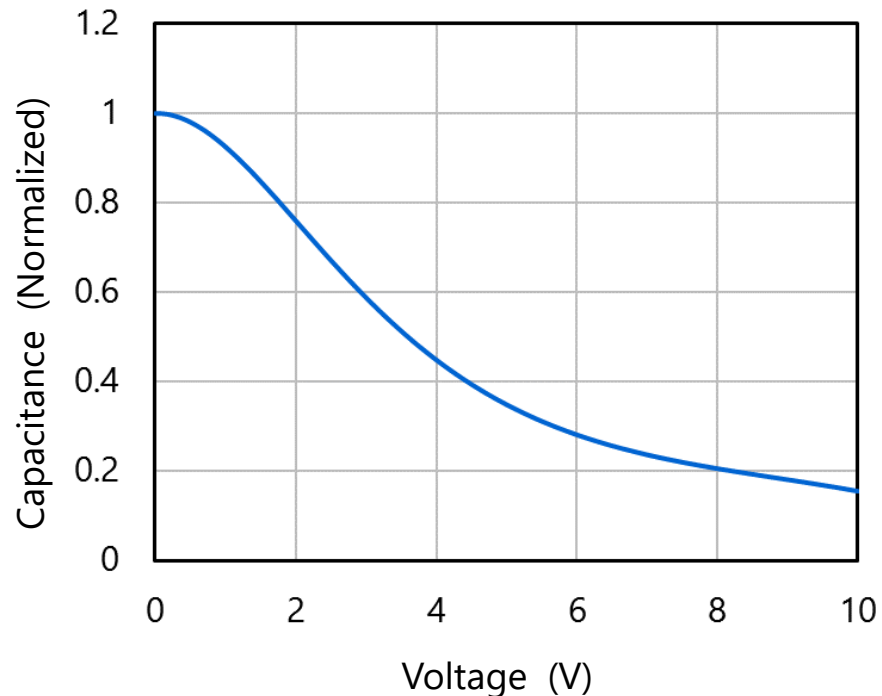
When you use a reverse-current blocking diode, exercise care as to a voltage drop due to the diode's forward voltage (V_F) in order to ensure that the LDO regulator operates properly over the input voltage range. A diode with low forward voltage (V_F) and leakage current (I_R) should be selected, taking the derating of reverse-bias voltage (V_R) and forward current (I_F) into consideration.



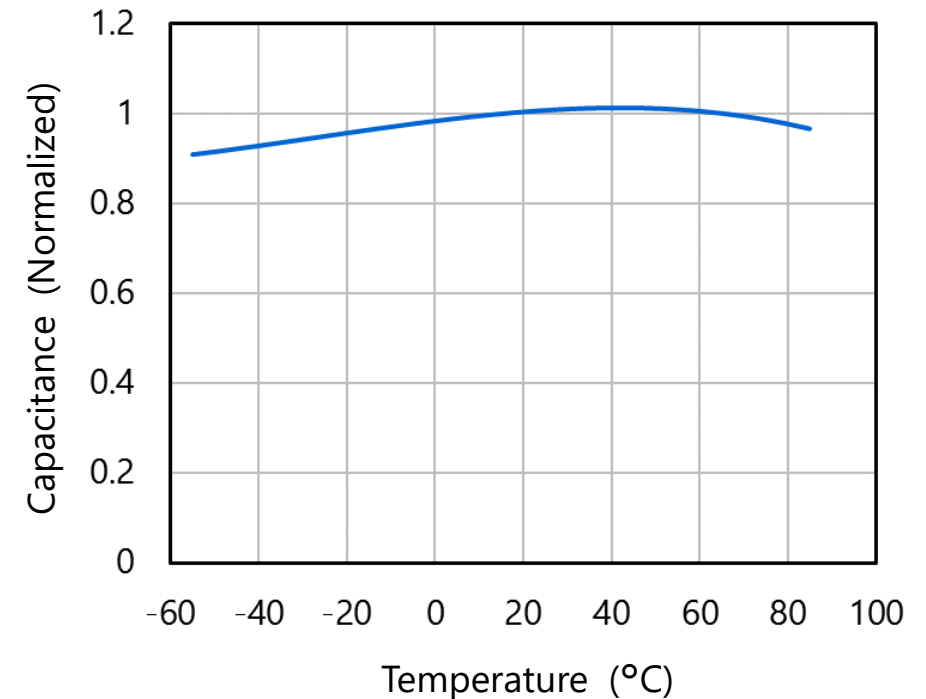
Usage considerations for LDO regulators

Using a ceramic capacitor to smooth the output voltage

Ceramic capacitors are ideal for use with LDO regulators since small ceramic capacitors are becoming available with large capacitance and small equivalent series resistance (ESR). However, the values of ceramic capacitors depend on voltage and temperature as shown below. In particular, the value of the output capacitor greatly affects the negative feedback operation of an LDO regulator. Be sure to fully evaluate a system, taking voltage and temperature into consideration.



Example of a capacitance-vs-voltage curve of a ceramic capacitor



Example of a capacitance-vs-temperature curve of a ceramic capacitor

TOSHIBA