Voltage Regulators

- All electronic devices are designated to run at predetermined power ratings, i.e. voltage and current.
- While current consumption is dynamic and depends on the device load, the voltage supply is fixed and ideally constant for the proper functioning of the device.
- A voltage regulator is responsible to maintain this ideal voltage needed for the device.
- Your laptop, wall charger, and coffee maker all have voltage regulators.

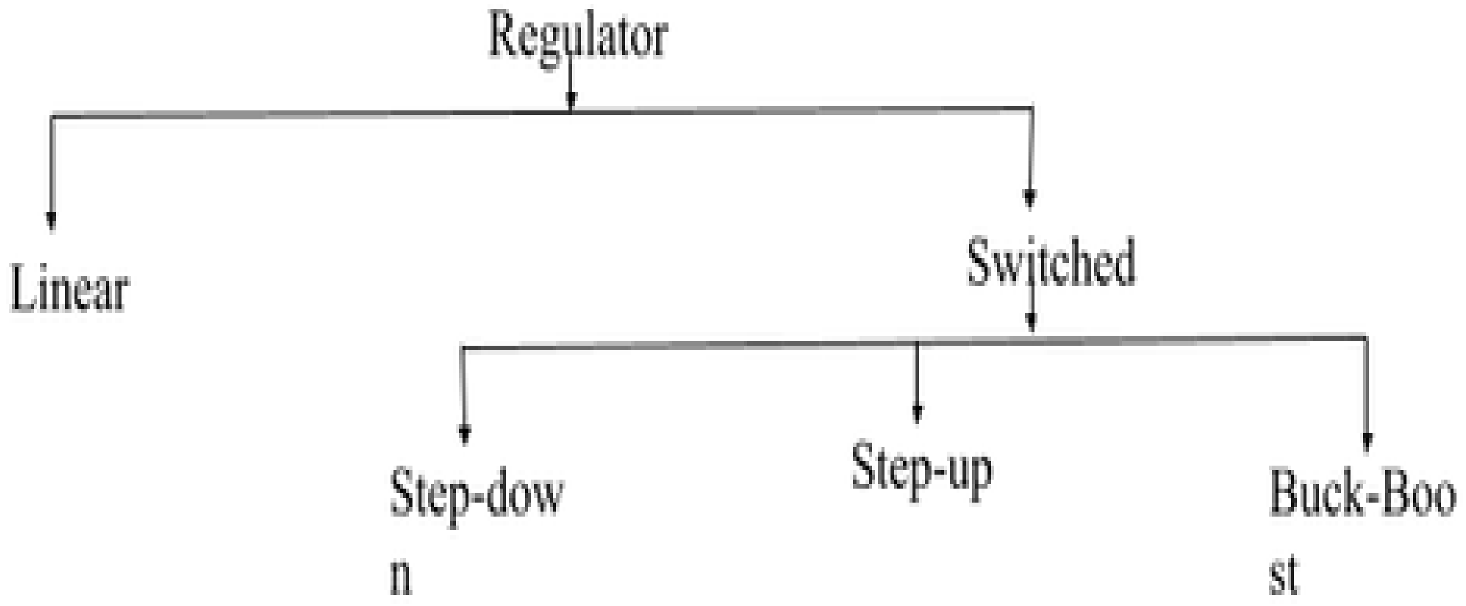
What is a voltage regulator?

- The power supply unit of an electronic device converts incoming power into the desired type (AC-DC or DC-AC) and desired voltage/current characteristics.
- A voltage regulator is a component of the power supply unit that ensures a steady constant voltage supply through all operational conditions. It regulates voltage during power fluctuations and variations in loads. It can regulate AC as well as DC voltages.
- A voltage regulator usually takes in higher input voltage and gives a lower, more stable output voltage. Their secondary use is also to protect the circuit against voltage spikes that can potentially damage the circuit/appliance.

Types

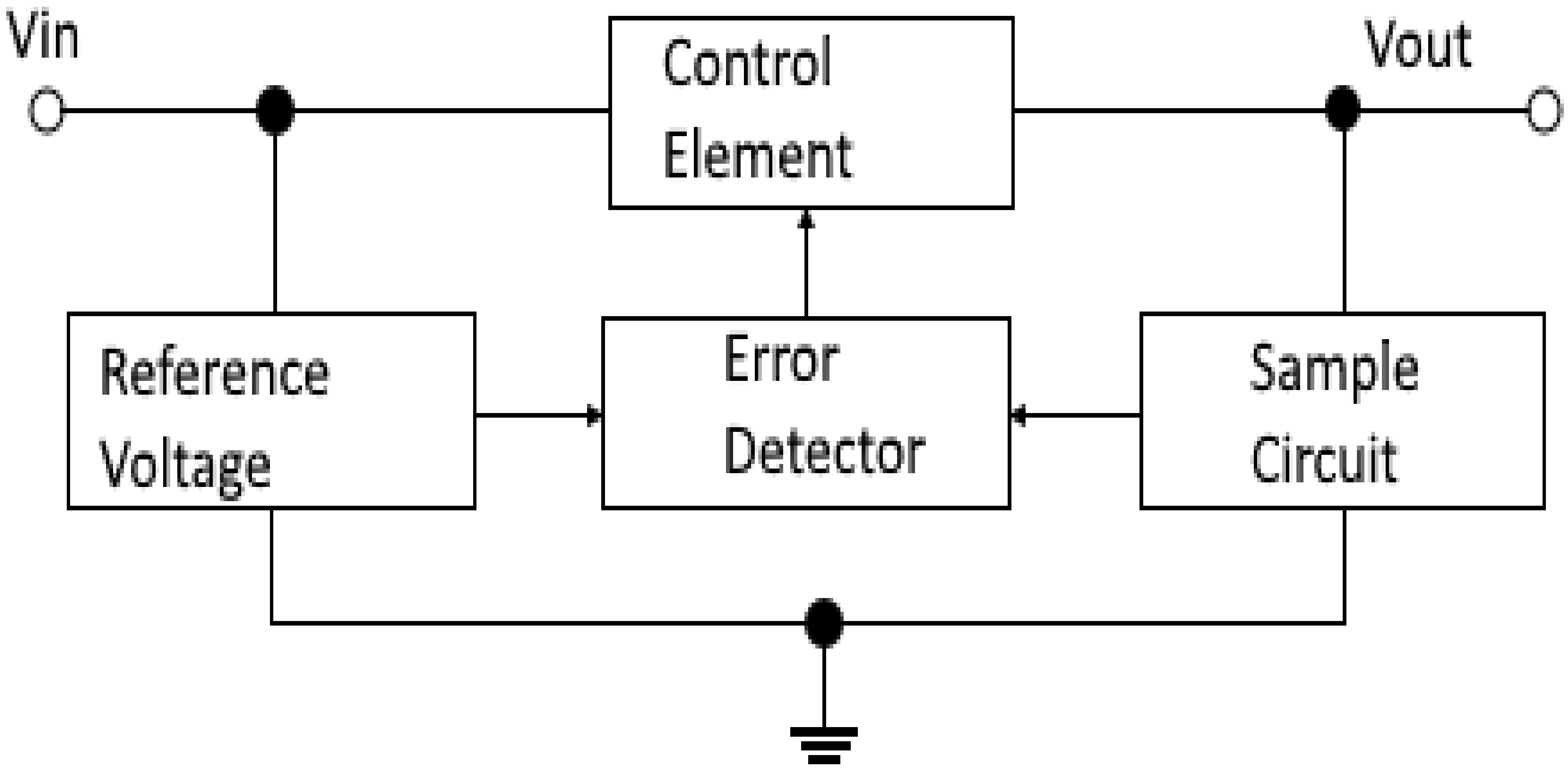
- Voltage regulators used in low-voltage electronic devices are usually integrated circuits.
- **Linear regulators** are simple transistor-based devices usually packaged as ICs. Their internal circuitry uses differential amplifiers to control output voltage against a reference voltage. Linear voltage regulators may implement fixed output or have an adjustable control. They typically need input current comparable to the output current.
- A) Series Linear Regulators
- B) Shunt Linear Regulators

- **Switching regulators** toggle a series device ON/OFF at high frequency, varying the duty cycle of voltage transferred as output.
- Their common topologies are buck, boost, and buck-boost. Buck converters are more efficient during voltage step down and are still



- Video Clip about Voltage Regulators and Types

Series DC Voltage Regulator



A) Sampling Unit:

The sampling unit takes a sample from the o/p voltage and feed to the error detector stage. In the error detector stage compare the o/p voltages with reference voltages and give the error signal to the control element, which control the o/p voltage.

B) Reference Voltage

This stage provides reference voltages to the error detector stage for the comparison. In the reference voltage stage normally the zener diodes are used.

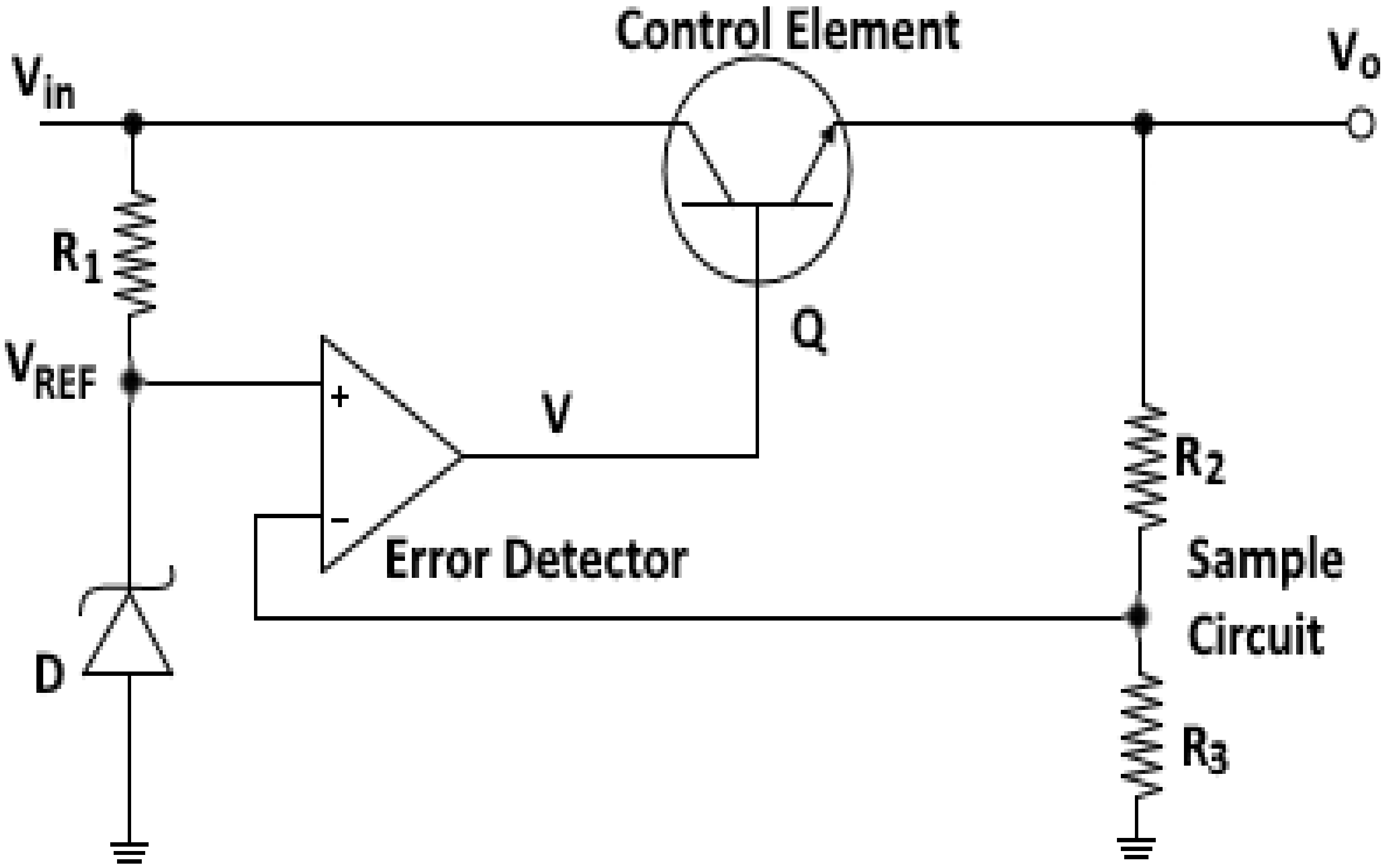
C) Control Element

The control element of the series voltage regulator is used and amplified signals to keep o/p voltage constant.

D) Error Detector

This stage gets a sample from the sampling unit, compare it with the reference voltage and give the error signal to the control element for controlling the o/p voltage.

Basic Op-Amp Series Voltage Regulator

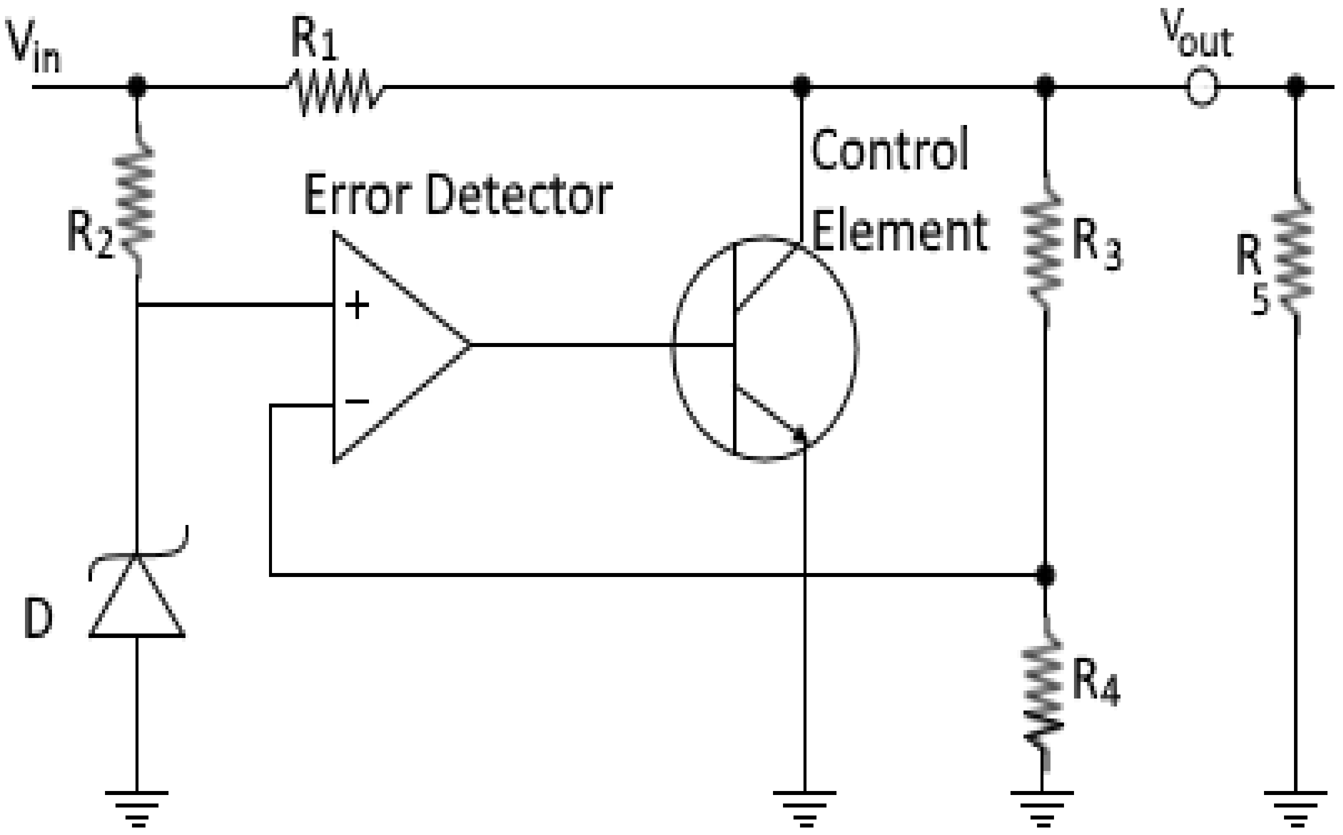


In the series voltage regulator the controlling element (Q) is connected in series

- In the figure of basic op-amplifier series voltage regulator , the op-amp is used as comparator .
- Resistor R2 and R3 is the voltage divider network which is used to sense any change at the o/p.
- The change sensed by the divider network is applied at the inverting i/p of the comparator, while the reference voltage hold by the zener diode is applied at the non-inverting i/p of the comparator is applied at the base of transistor “Q
- When the o/p voltage decreases because of the decrease in i/p voltage , the voltage drop across R1,R2 decreases and so this error voltage (-ve) is sensed by the divider network which is applied at the inverting i/p of the comparator.
- The comparator compare the reference constant voltage and the –ve error voltage and provide the difference (+ve) of the two voltages at the o/p as i/p at the base of transistor . The transistor conduct according to the forward bias voltage at the base and so, the o/p voltage remain constant.

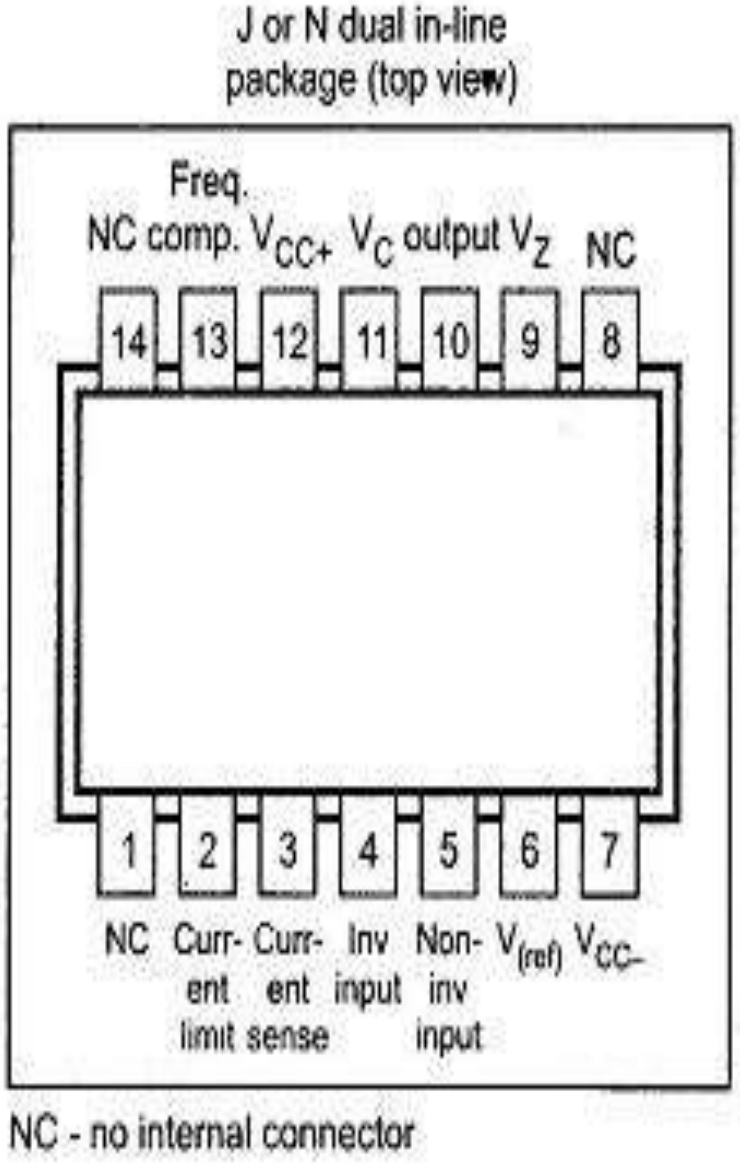
- When the o/p voltage tries to increase, the voltage sensed by the divider network is increased . This is applied at the inverting i/p of the comparator. The comparator provide the difference (-ve) of the two voltage at the i/p of Q1 and so, the conduction of transistor decreases to the constant (required) voltage level.”.

OP-amp Series Shunt VR

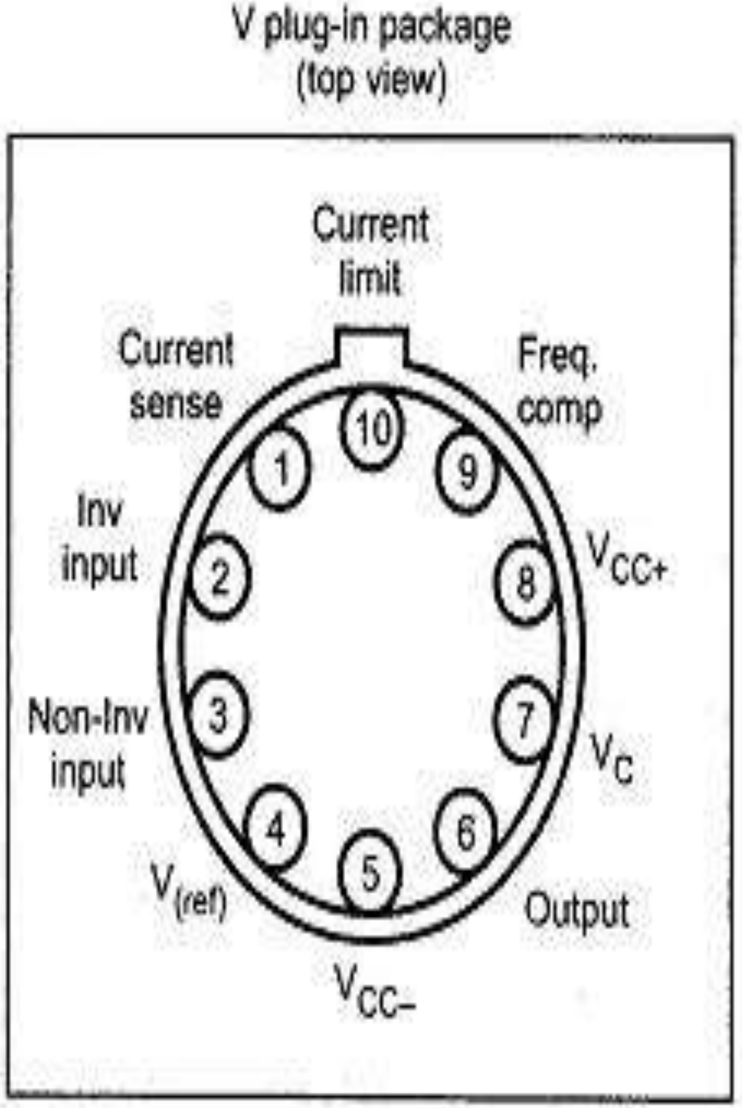


IC 723

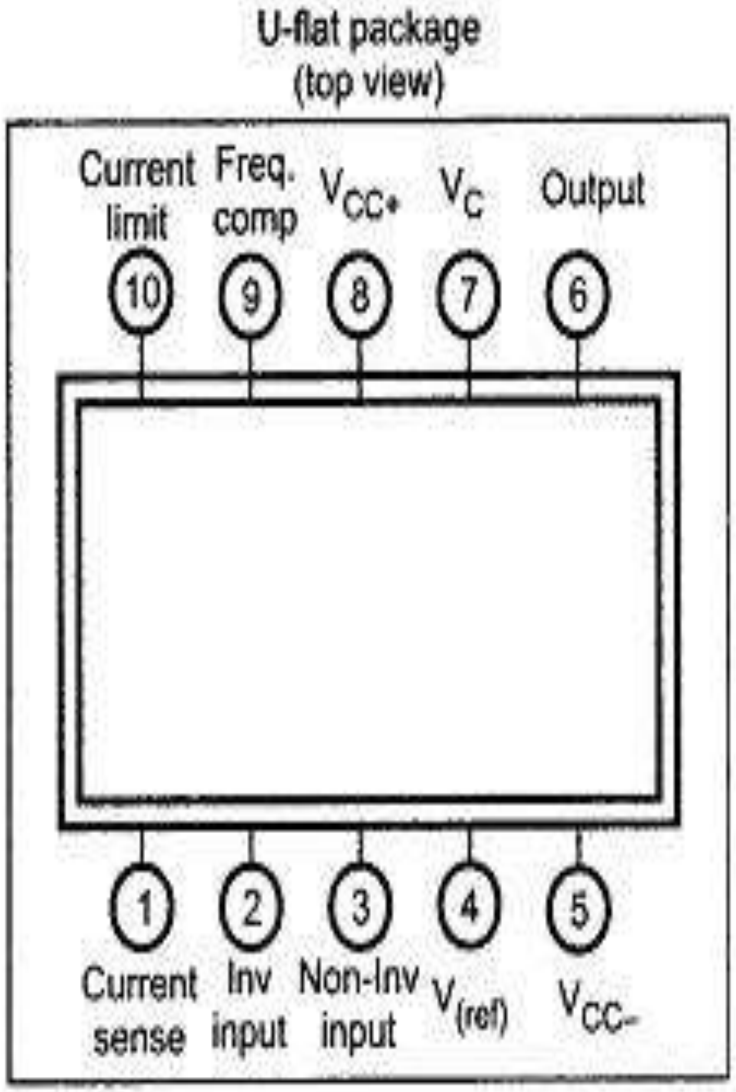
- It is one of the popular general purpose precision regulator.
- It is a monolithic linear integrated circuit in different physical packages.
- The pin diagram of IC 723 Voltage Regulator along with the various packages is shown in the Fig.


J or N dual in-line package (top view)
Freq. comp.
NC
VCC+
VC
output
VZ
NC
14 13 12 11 10 9 8
1 2 3 4 5 6 7
NC
Curr-ent limit
Curr-ent sense
Inv input
Non-inv input
V(ref)
VCC–
NC - no internal connector

(a)


V plug-in package (top view)
Current limit
Current sense
Freq. comp
Inv input
VCC+
Non-Inv input
VC
V(ref)
Output
VCC–
1 2 3 4 5 6 7 8 9 10

(b)

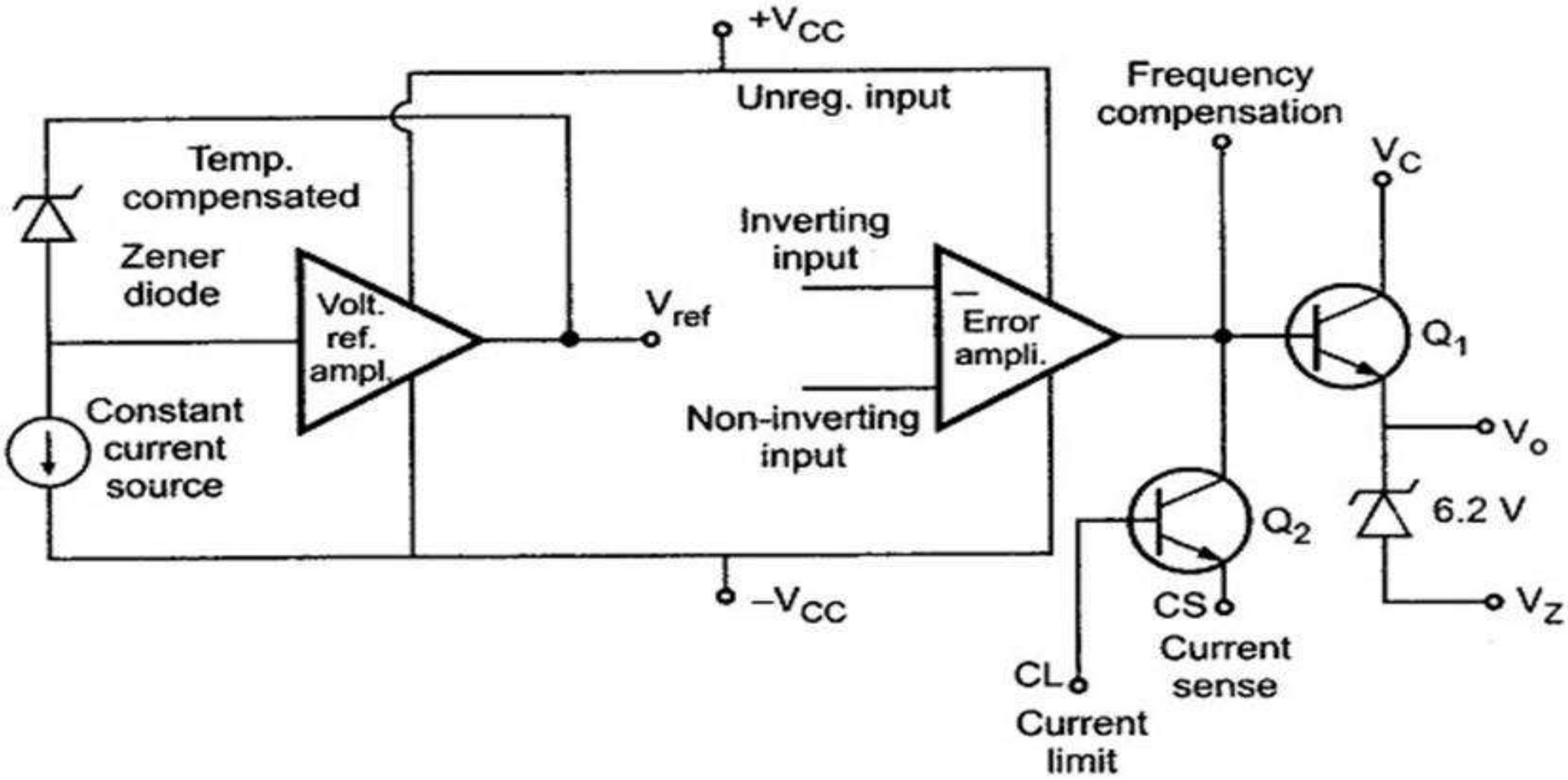

U-flat package (top view)
Current limit
Freq. comp
VCC+
VC
Output
10 9 8 7 6
1 2 3 4 5
Current sense
Inv input
Non-Inv input
V(ref)
VCC–

(c)

Features of IC723

- It is a variable voltage Regulator (unlike 7805 a fixed 5v regulator)
- It works as voltage regulator at output voltage ranging from 2 to 37 volts at currents upto 150 mA.
- It can be used at load currents greater than 150 mA with use of suitable NPN or PNP external pass transistors.
- Input and output short-circuit protection is provided.
- It has good line and load regulation (0.03%).
- Wide variety of applications of series, shunt, switching and floating regulator.
- Low temperature drift and high ripple rejection.
- Low standby current drain.
- Small size, lower cost.
- Relative ease with which power supply can be designed.
- It provides a choice of supply voltage.

Functional Block Diagram



The functional block diagram of IC 723 Voltage Regulator can be divided into four major blocks:

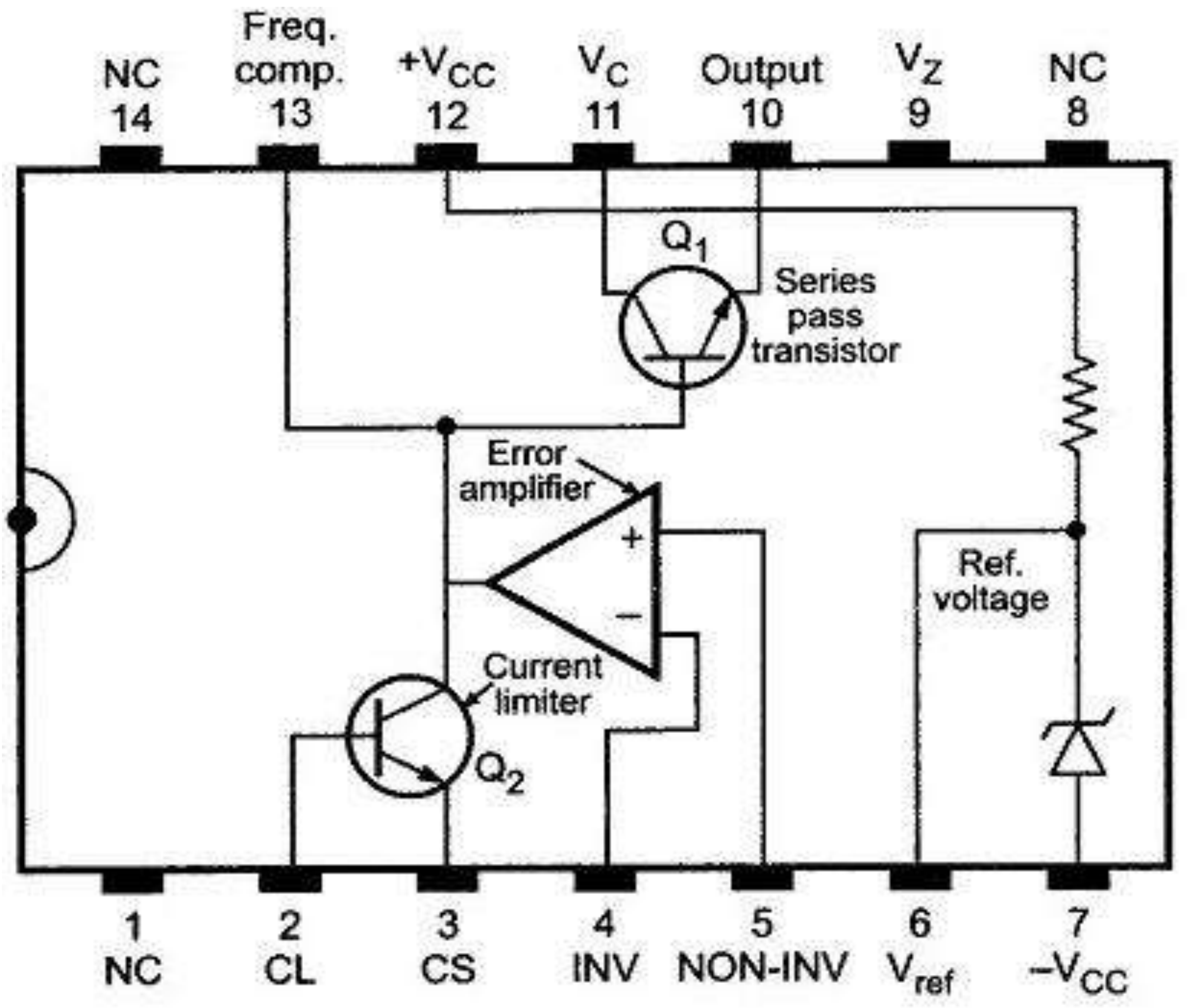
1. 1. Temperature compensated voltage reference source, which is zener diode.
2. An op-amp circuit used as an error amplifier.
3. A series pass transistor capable of a 150 mA output current.
4. Transistor used to limit output current.

Explanation

- Temperature compensated zener diode, constant current source and reference amplifier constitutes the reference element. In order to get a fixed voltage from zener diode, the constant current source forces the zener to operate at a fixed point.
- Output voltage is compared with this temperature compensated reference potential of the order of 7 volts. For this V_{ref} is connected to the non-inverting input of the error amplifier.
- This error amplifier is high gain differential amplifier. It's inverting input is connected to the either whole regulated output voltage or part of that from outside. For later case a potential divider of two scaling resistors is used. Scaling resistors help in getting multiplied reference voltage or scaled up reference voltage

- Error amplifier controls the series pass transistor Q_1, which acts as variable resistor. The series pass transistor is a small power transistor having about 800 mW dissipation. The unregulated power supply source (< 36V d.c.) is connected to collector of series pass transistor.
- Transistor Q_2 acts as current limiter in case of short circuit condition. It senses drop across R_{sc} placed in series with regulated output voltage externally.
- The frequency compensation terminal controls the frequency response of the error amplifier. The required roll-off is obtained by connecting a small capacitor of 100 pF between frequency compensation and inverting input terminals.
- The internal structure can be represented in more simplified form as shown in the Fig.
-

Simplified Internal Structure of IC723



Both noninverting and inverting terminals of the error amplifier are available on outside pins of IC 723.

Due to this, device becomes versatile and flexible to use.

Only restriction is that internal reference voltage is 7 volts and therefore we have to use two different circuits for getting regulated outputs of below 7 volts and above 7 volts.

- Basic Low-voltage Regulator (V_o = 2 to 7 volts)
- Low Voltage High Current Regulator
- Basic Positive High Voltage Regulator
- Positive High Voltage High Current Regulator
- Negative Voltage Regulator

Applications

- Basic Low-voltage Regulator (V_o = 2 to 7 volts)
- Low Voltage High Current Regulator
- Basic Positive High Voltage Regulator
- Positive High Voltage High Current Regulator
- Negative Voltage Regulator

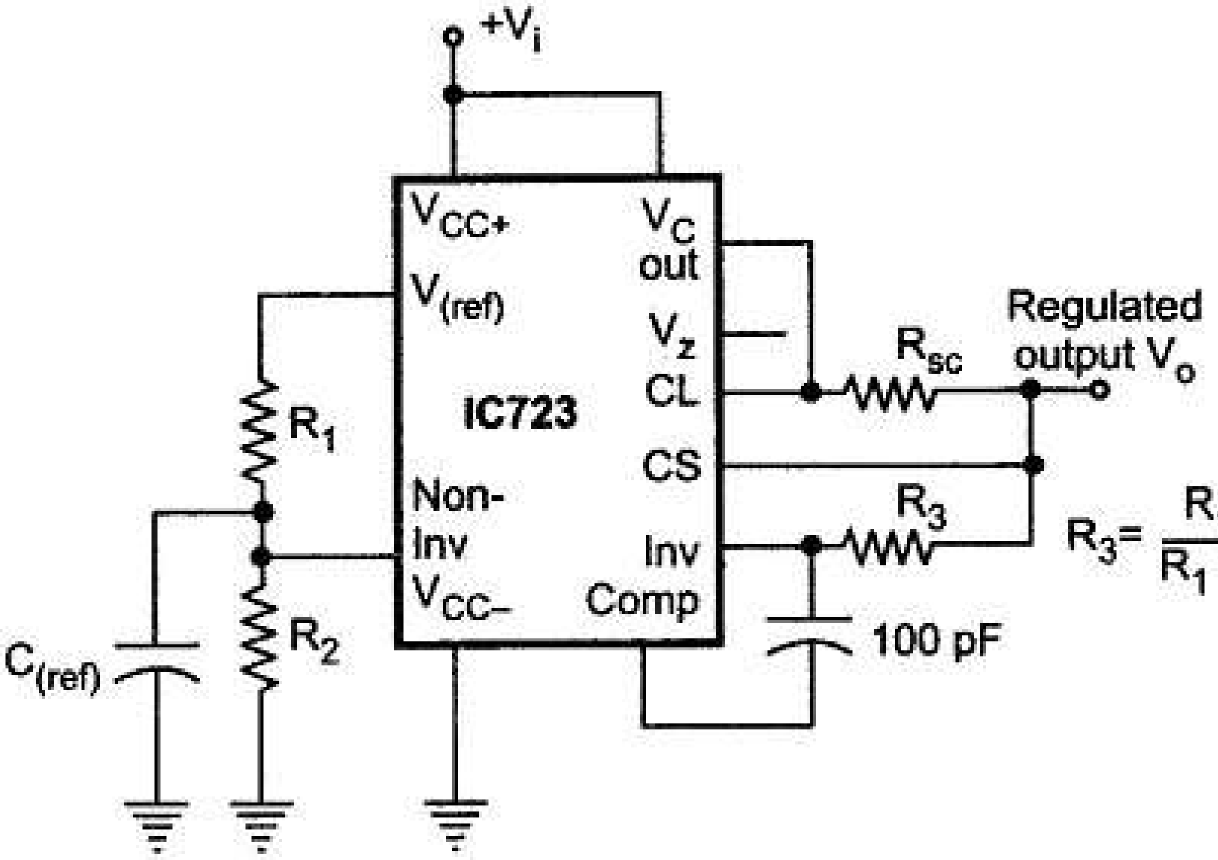
PIN Description

- Pin1 (NC): Not connected
- Pin2 (Current Limit): This pin is used to limit the current
- Pin3 (Current Sense): This pin is used in foldback application as well as to limit the current
- Pin4 (Inverting Input): This pin provides stable o/p voltage
- Pin5 (Non-inverting Input): This pin is used to supply a reference voltage to the inside of the operational amplifier.
- Pin6 (Vref): This pin provides an almost 7v reference voltage
- Pin7 (-Vcc): GND (Ground) Pin
- Pin8 (NC): Not connected
- Pin9 (Vz): This pin is generally used to make negative regulators
- Pin10 (Vout): This is the o/p pin
- Pin11 (Vc): This is the series pass transistor’s collector input. Generally, it is connected directly to the +ve voltage supply if an exterior transistor is not used.
- Pin 12 (V+): This is the input of the positive supply
- Pin13 (Frequency Compensation): This pin assists in decreasing noise with a 100pf capacitor
- Pin 14 (NC): Not connected.

LM723 Features

- The features of the LM723 include the following.
- The unnecessary o/p current will be 150mA without using an exterior pass transistor.
- The maximum input supply voltage will be 40V.
- It offers modifiable o/p from 3volts to 37volts.
- These ICs are used to make switching & linear regulator.
- It supplies 10A o/p current with the help of an external pass transistor.
- These ICs are used for different operations such as positive, negative, series, floating, and shunt.

Basic Low Voltage Regulator



$$R_3 = \frac{R_1 R_2}{R_1 + R_2}$$

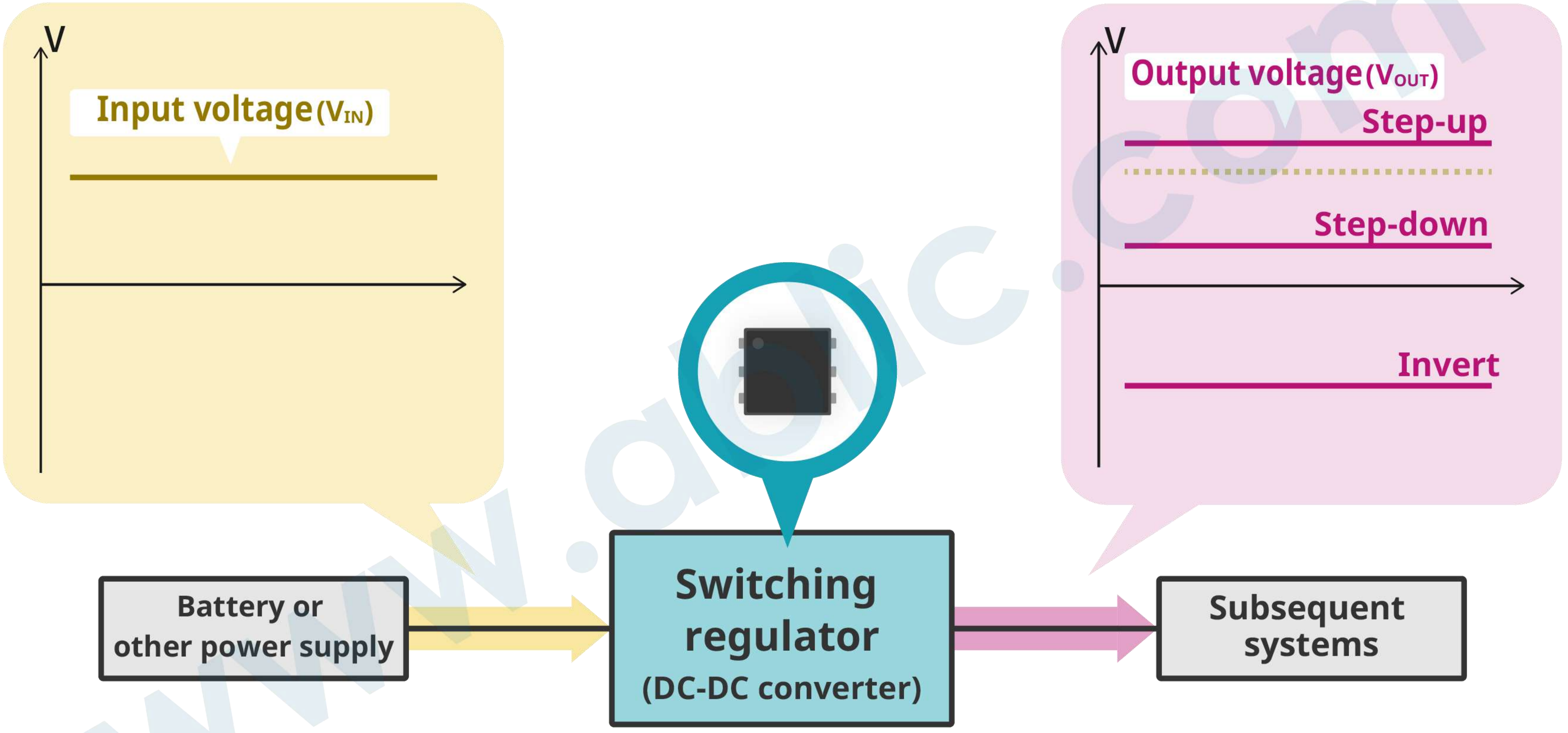
Switching Regulator

- A switching regulator (DC-DC converter) is a regulator (stabilized power supply).

- A switching regulator can convert input direct current (DC) voltage to the desired direct current (DC) voltage.
-

  In an electronic or other device, a switching regulator takes the role of converting the voltage from a battery or other power source to the voltages required by subsequent systems.

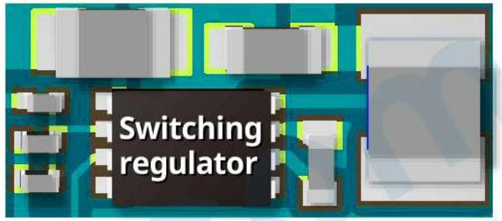
- As the illustration below shows, a switching regulator can create an output voltage (V_{OUT}) that is higher (step-up, boost), lower (step-down, buck) or has a polarity different than that of the input voltage (V_{IN}).

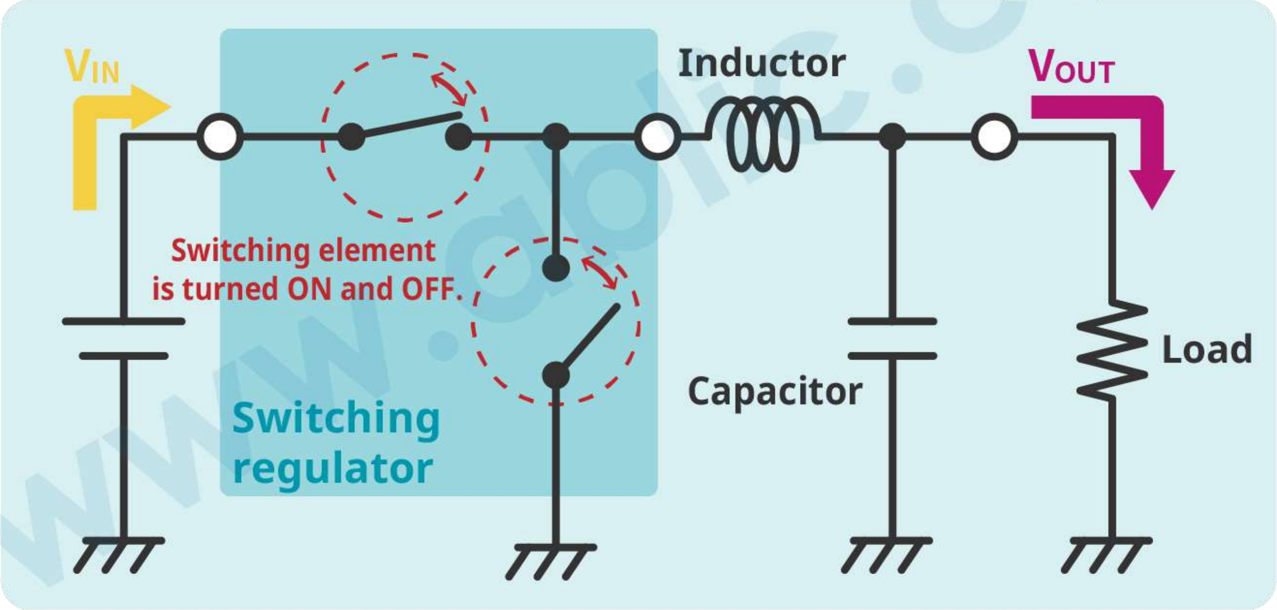


- By turning a switching element ON and OFF, a switching regulator enables high-efficiency electricity conversion as it supplies the required amount of electricity only when needed.

- A linear regulator is another type of regulator (stabilized power supply), but because it dissipates any surplus as heat in the voltage conversion process between V_{IN} and V_{OUT}, it is not nearly as efficient as a switching regulator.

Schematic drawing of a switching regulator *

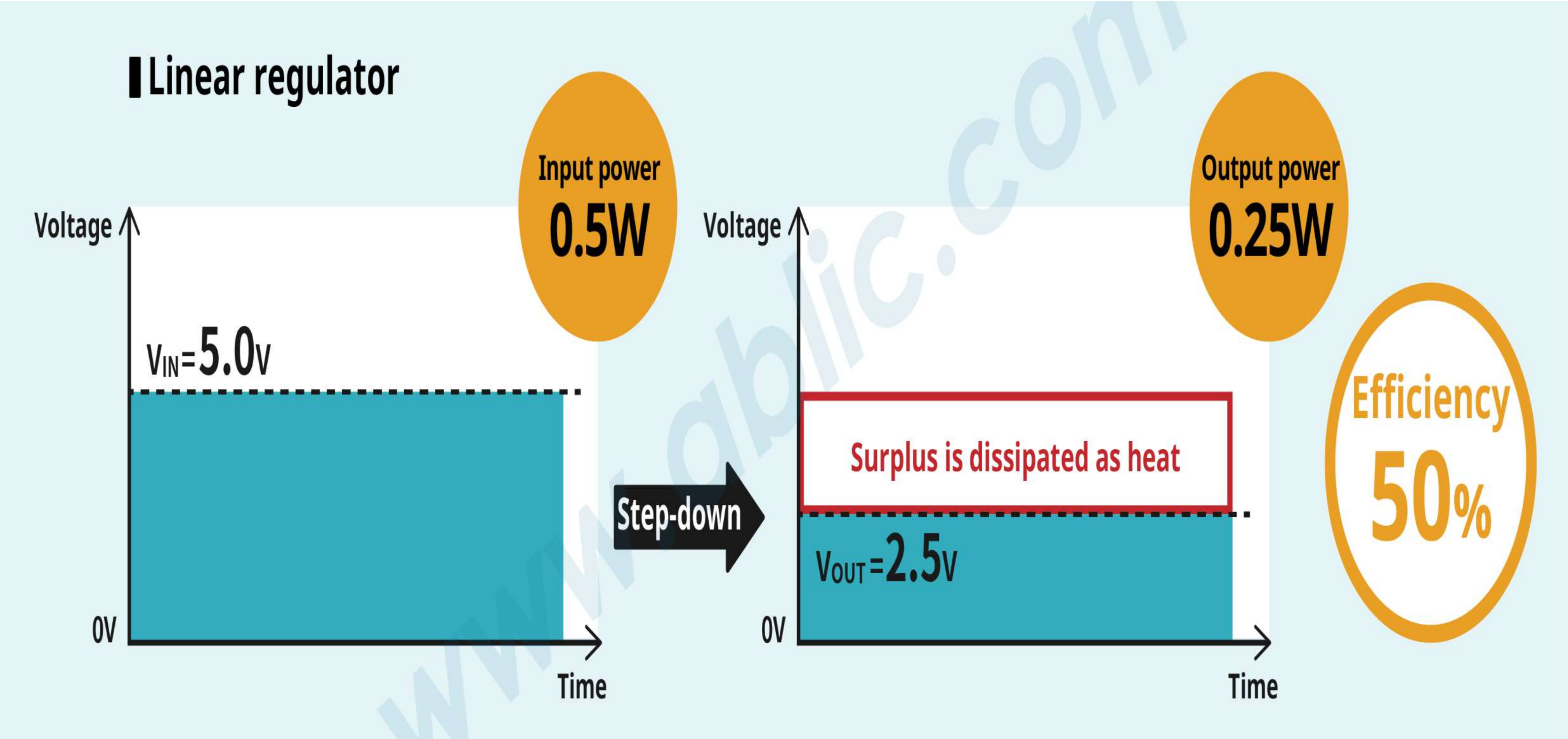




*A type of switching regulator that requires an external coil

- For example, if the input voltage (V_{IN}) is 5.0V, output voltage (V_{OUT}) is 2.5V and load current (I_{OUT}) is 0.1A,
- In a linear regulator
  Input power = Input voltage × Load current
  = 5.0V × 0.1A
  = 0.5W
  Output power = Output voltage × Load current
  = 2.5V × 0.1A
  = 0.25W
  Since efficiency = Output power ÷ Input power,

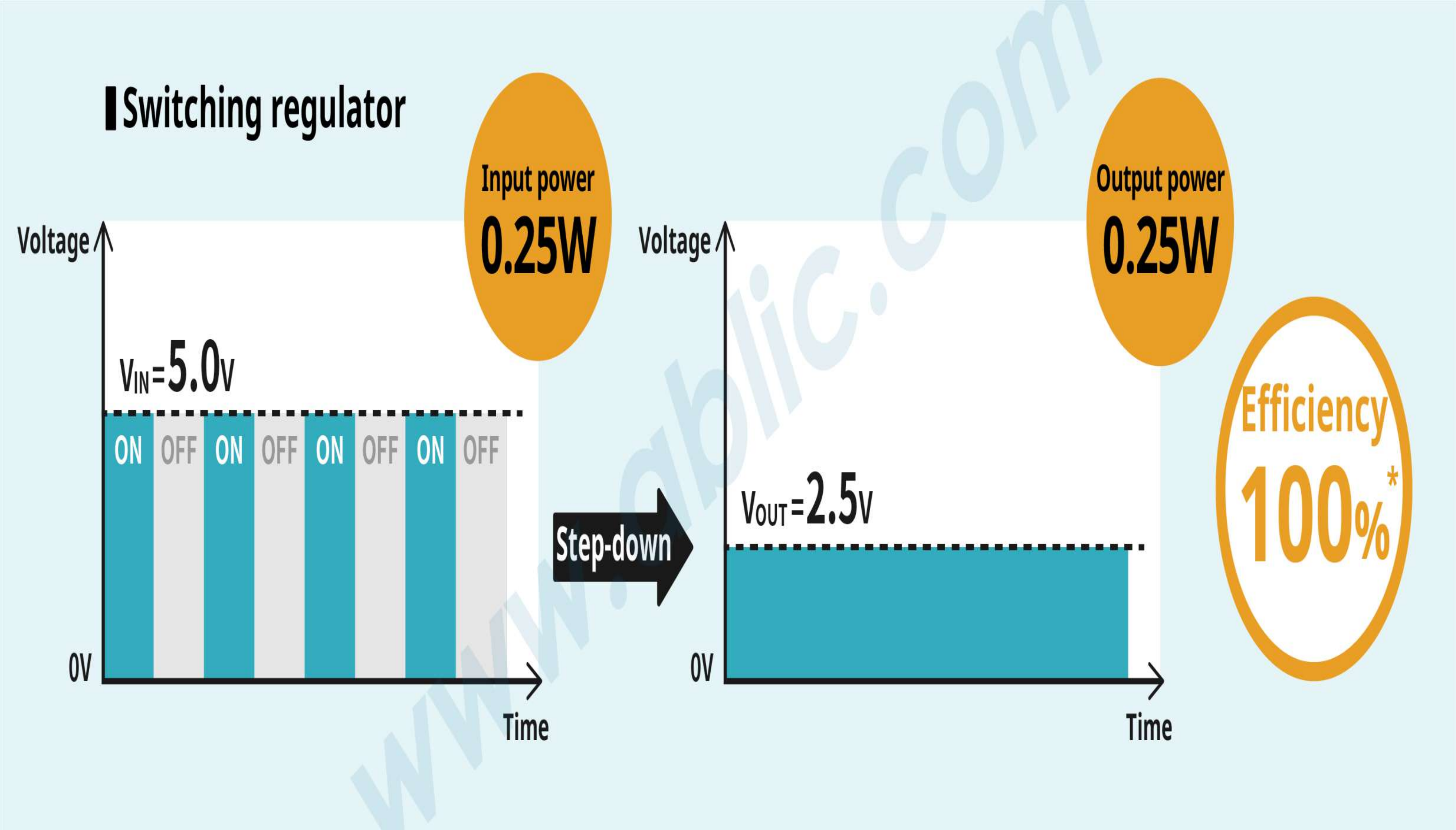
the efficiency of a linear regulator is 50%.


Linear regulator
Input power
0.5W
Voltage
V_{IN}=5.0V
0V
Time
Step-down
Voltage
Output power
0.25W
Surplus is dissipated as heat
V_{OUT}=2.5V
0V
Time
Efficiency
50%

- A switching regulator, however, controls the period when the input voltage is supplied by turning the switching element ON and OFF so that V_{OUT} becomes 2.5V. This time period when input voltage is supplied is
- $V_{OUT} / V_{IN} = 2.5V / 5.0V = 1/2$
- From this we can see that voltage is supplied for half a period. Similarly, if you try to obtain efficiency from the input and output power, we get the following:
- Input power = Input voltage × Load current × 12
  = 5.0V × 0.1A × 12
  = 0.25W

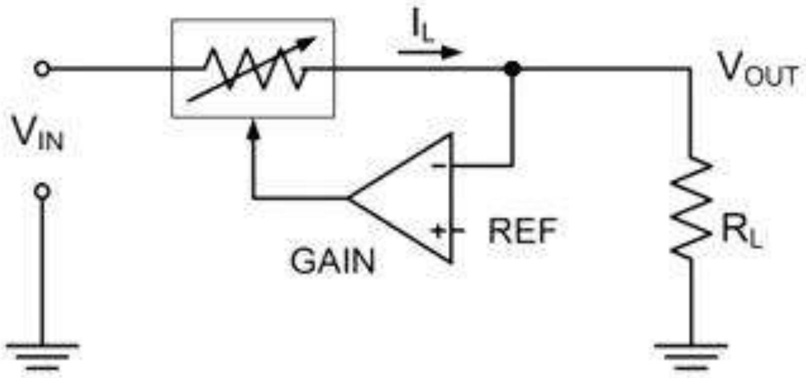
Efficiency = Output power ÷ Input power,

we obtain a value of 100%. This is why a switching regulator provides high efficiency.



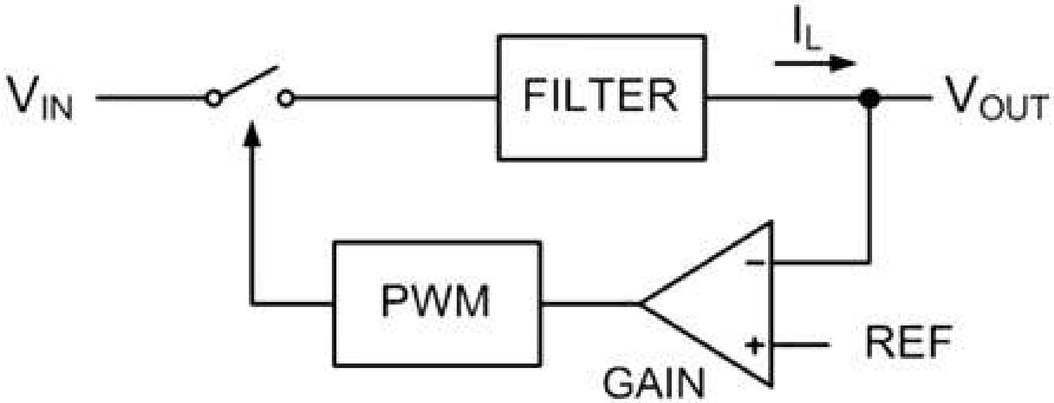
Switching regulator
Input power
0.25W
Voltage
V_{IN}=5.0V
ON
OFF
ON
OFF
ON
OFF
ON
OFF
0V
Time
Step-down
Output power
0.25W
Voltage
V_{OUT}=2.5V
0V
Time
Efficiency
100%*

The Linear Voltage Regulator



- $Power\ Loss = (V_{IN} - V_{OUT}) * I_L$
- $Efficiency = \frac{V_{OUT} * I_L}{V_{IN} * I_L} = \frac{V_{OUT}}{V_{IN}}$

The Switching Regulator

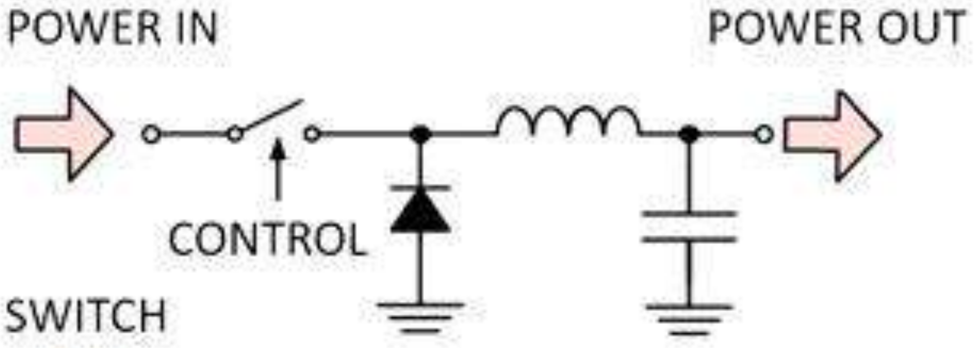


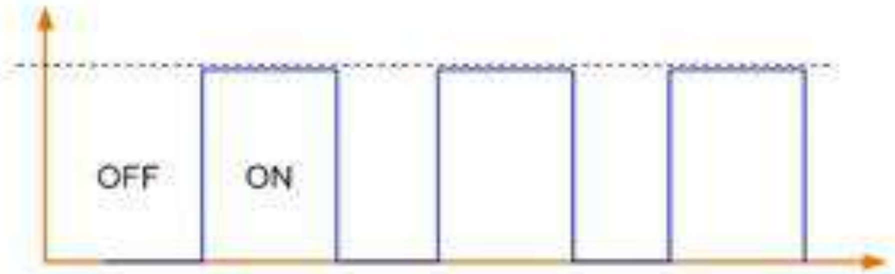
$$Power\ Loss \neq (V_{IN} - V_{OUT}) * I_L$$

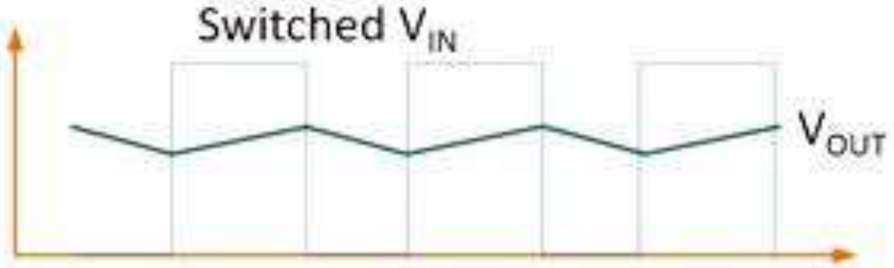
$$\begin{aligned} Power\ Loss &= P_{SW(open)} + P_{SW(closed)} \\ &= (V_{IN} * 0) + (0 * I_L) \\ &\approx Zero \end{aligned}$$

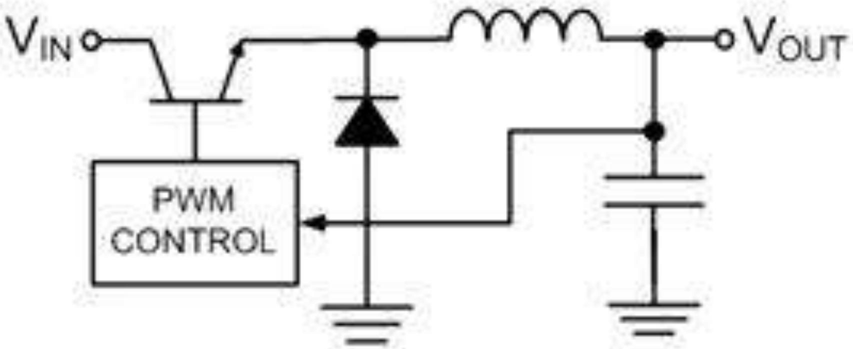
Switching Regulator Theory: Buck Regulator

- $V_{OUT} = V_{IN} * D$
- D is switch duty cycle
- Switch duty cycle is controlled by Pulse Width Modulation (PWM)
- With lossless elements, efficiency is 100%
- i.e., Ideal diode, switch, and filter





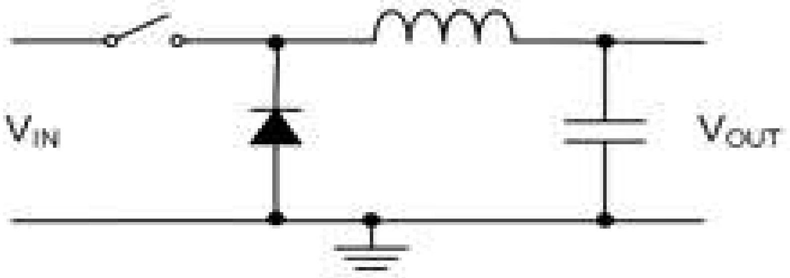




Basic Switching Topologies

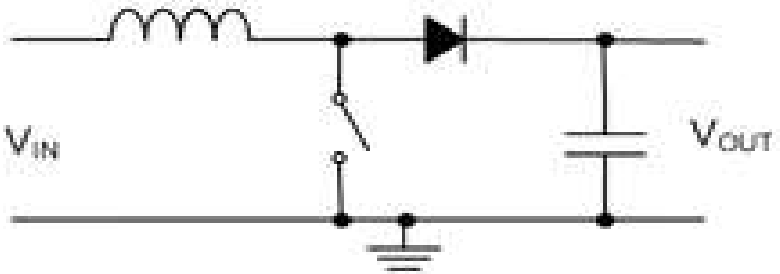
Buck

$V_{OUT} < V_{IN} \quad V_{OUT} = D * V_{IN}$



Boost

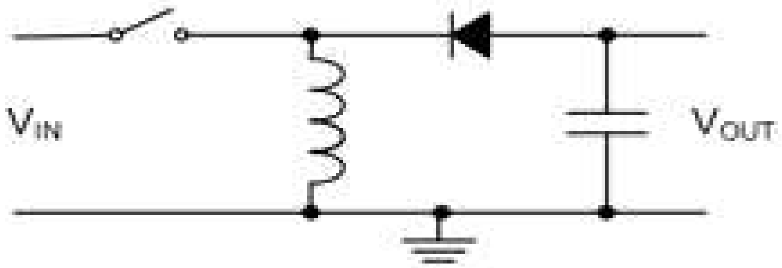
$V_{OUT} > V_{IN} \quad V_{OUT} = \frac{V_{IN}}{1 - D}$



Flyback

$V_{OUT} < \text{ or } > V_{IN}$

$V_{OUT} = -\frac{D * V_{IN}}{1 - D}$



- Anim2 URL: https://www.youtube.com/watch?v=5R2wP66RrVY