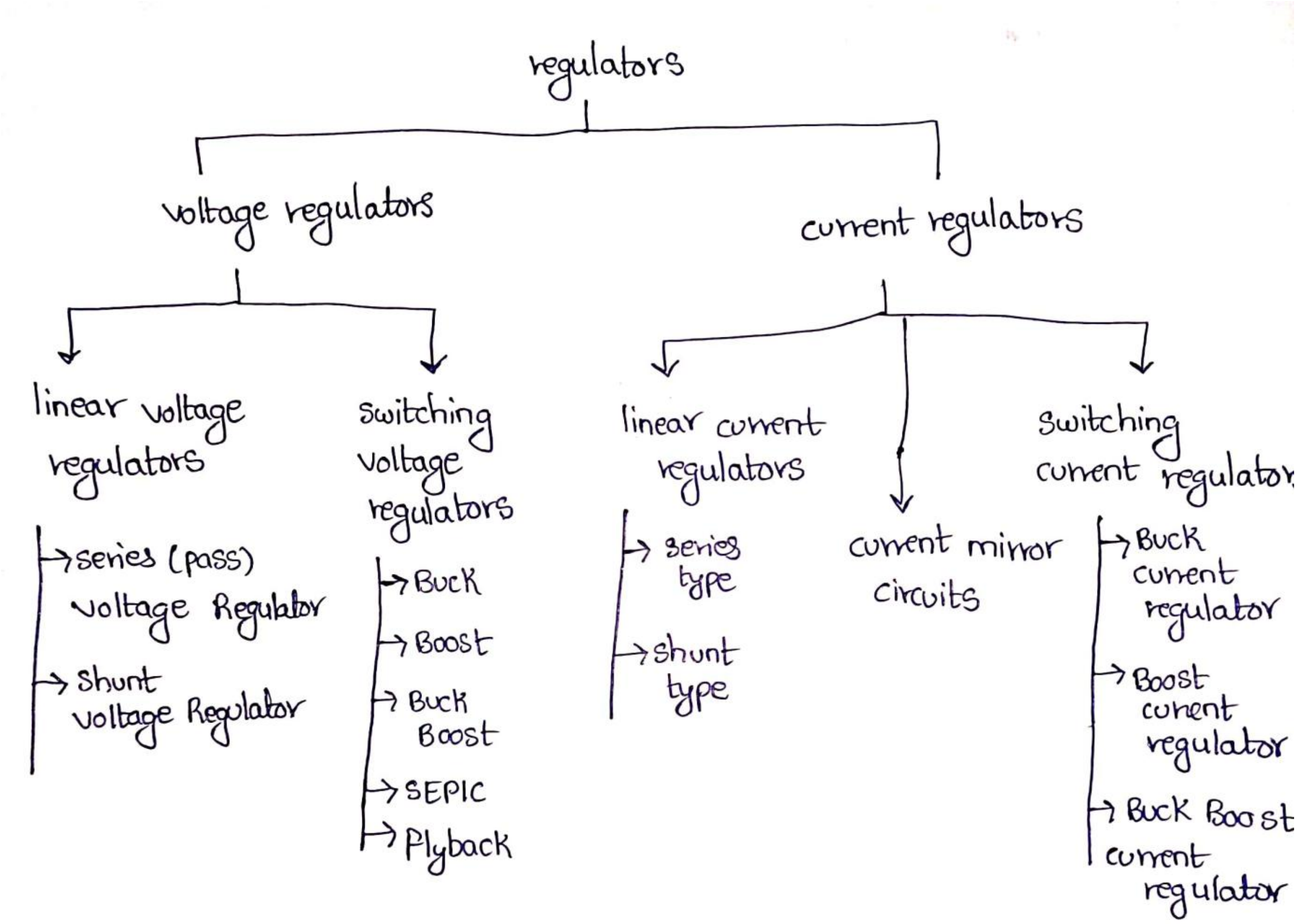
Regulators

Definition: A regulator is a device or circuit that maintains a stable output voltage or current, even when the input voltage or load current changes



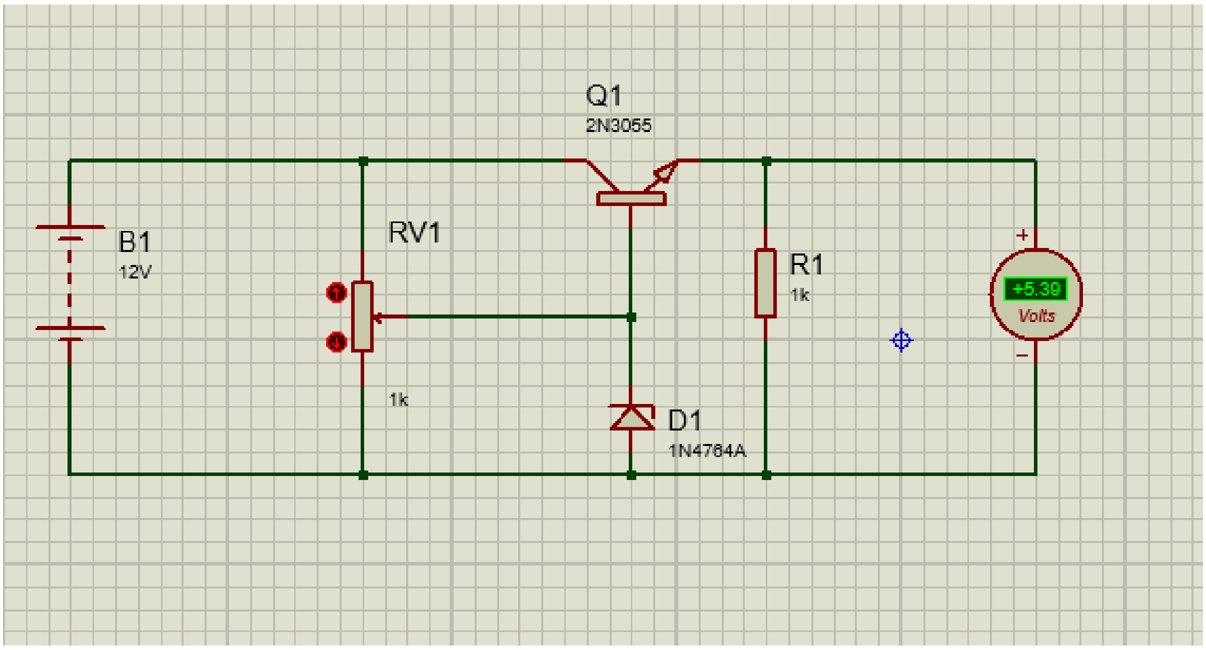
Linear Voltage Regulator:

Series Voltage Regulator:

It keeps the output Voltage constant by adjusting the resistance of a series pass element placed in series with the load

Pass element (BJT or MOSFET)

$$V_{out} = V_z - V_{be}$$

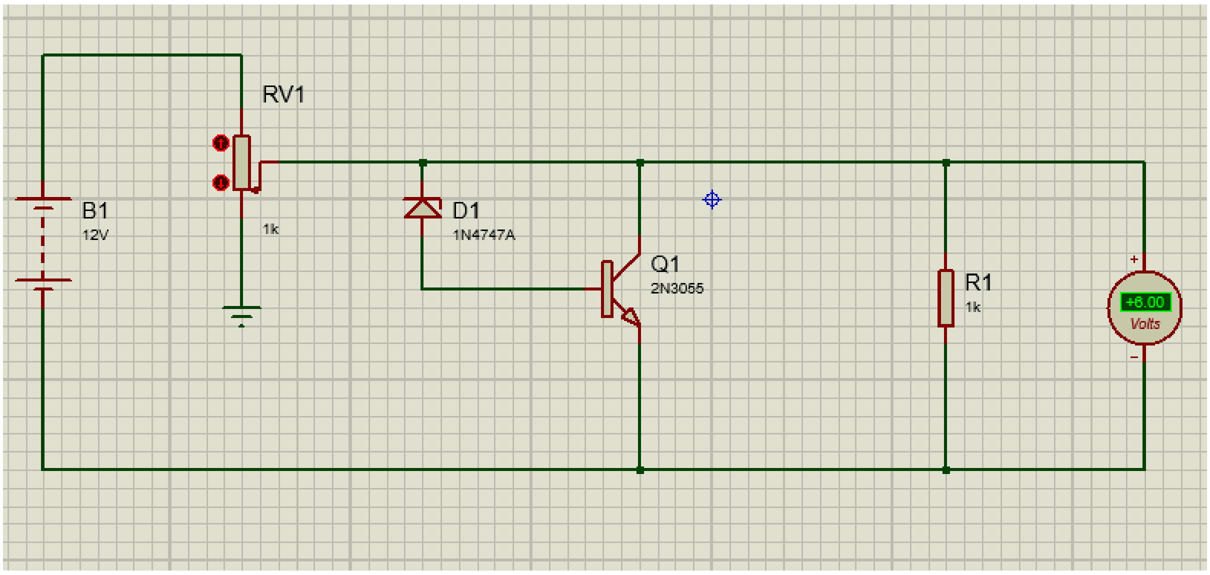


Shunt Voltage Regulator

A shunt voltage regulator is a simple type of voltage regulator that maintains a constant output voltage by diverting (shunting) excess current away from the load through a regulating element connected in parallel with the load

If **voltage increases**, the regulator shunts more current to ground to drop the voltage back to normal.

If **voltage decreases**, the regulator shunts less current, allowing more to go to the load.

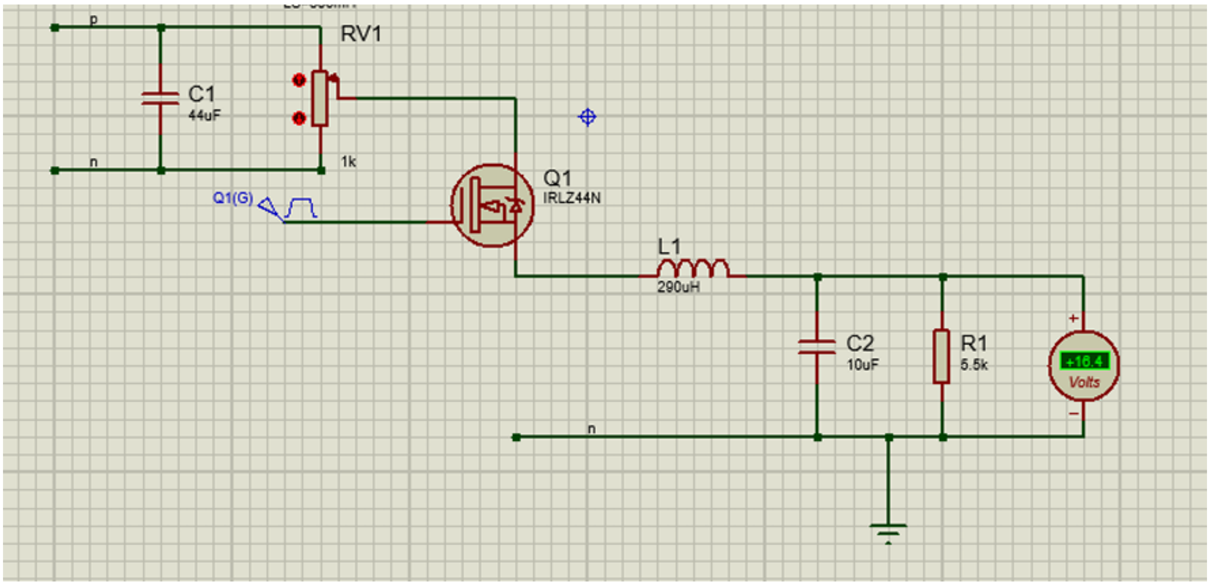


Switching Voltage Regulator

Switching regulators are voltage regulators that maintain a constant output voltage by rapidly switching an energy storage element (inductor, capacitor, or transformer) on and off, and then smoothing the output.

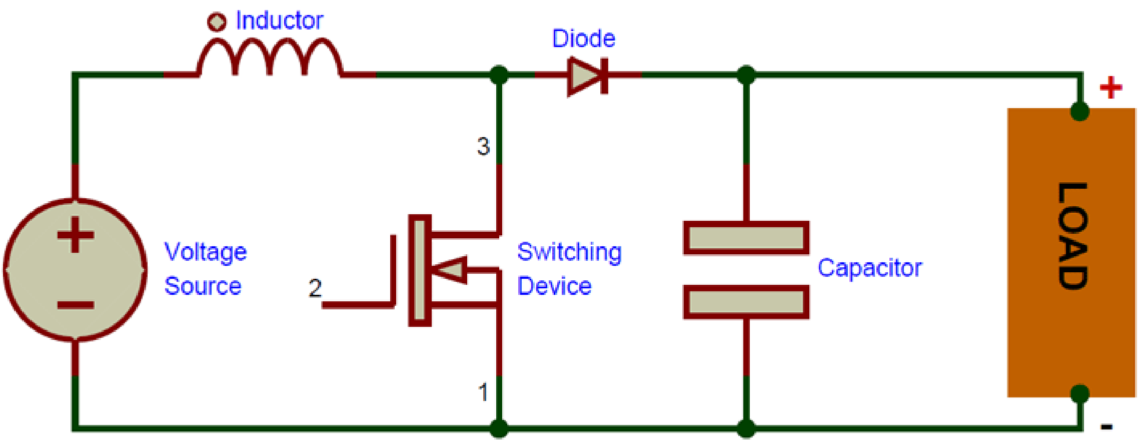
Buck Converter:

A buck converter works by rapidly switching a transistor on and off, using an inductor and capacitor to smooth the output.



Boost Converter:

The boost converter works by storing energy in an inductor when the switch is on, and then releasing it to the load at a higher voltage when the switch is off.



why switching regulators are generally more efficient than linear regulators.

Switching regulators are generally more efficient than linear regulators because of how they handle excess energy.

- A linear regulator works like a variable resistor in series with the load.
- It drops the excess voltage as heat.
- A switching regulator rapidly turns a transistor fully ON (low resistance) or fully OFF (no current).
- When fully ON, voltage drop across the transistor is very small → low power loss.
- When fully OFF, no current flows → almost no power loss.
- Energy is stored in an inductor or capacitor and then transferred to the load, instead of being burned as heat.

lets

$V_{in} = 12V$, $V_{out} = 5.0V$, $I_{load} = 1A$

<u>Linear regulator (series)</u>

output power $= P_{out} = V_{out} \times I_{load}$

$= 5V \times 1A = 5W$

input power $= P_{in} = V_{in} \times I_{load}$

$= 12V \times 1A = 12W$

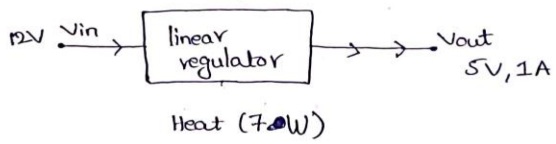
Power loss (dissipated as heat)

$P_{loss} = P_{in} - P_{out}$

$= 12W - 5W = 7W$

efficiency $(\eta) = \frac{P_{out}}{P_{in}} \times 100\%$

$\eta = \frac{5}{12} \times 100\% = 41.66\% \approx \underline{41.7\%}$



Switching regulator (buck)

$V_{in} = 12V$, $V_{out} = 5V$, $I_{Load} = 1A$

$$\text{Duty cycle} = \frac{V_{out}}{V_{in}} = \frac{5}{12} \approx 0.416$$

R_{DS_on} (high side Mosfet) $= 20.m\Omega = 0.02\,\Omega$

$R_{DS\text{-}off}$ (low side Mosfet) $= 10m\Omega = 0.01\,\Omega$

(a typical small power mosfet in TO-220/TO-252 package might have R_{DS} (on) in the 10-50 mΩ range, and R_{DS} (off) I taken 10.mΩ is a lower value)

Inductor DCR = 50mΩ = 0.05Ω

Switching frequency (f_{sw}) = 200KHZ

Mosfet turn transition time $t_r + t_f$ = 50ns

$I = 1A$

Conduction loss in high side Mosfet

$$P_{cond,hs} = I^2 \times R_{ds\_on} \times D$$
$$= 1^2 \times 0.02 \times 0.416$$
$$= 0.0083W$$

conduction loss in Low side mosfet

$$P_{cond,LS} = I^2 \times R_{ds\_off} \times (1-D)$$
$$= 1^2 \times 0.01 \times (1-0.416)$$
$$= 0.0058W$$

inductor copper (DCR) Loss :

$$P_L = I^2 \times R_{DCR} = 1^2 \times 0.05 = 0.05W$$

Switching Loss :-

$$P_{sw} \approx 0.5 \times V_{ds} \times I \times f_{sw} \times (t_r + t_f)$$

$$V_{ds} \approx V_{in} = 12V$$

$$P_{sw} = 0.5 \times 12 \times 1 \times 200\,KHZ \times (50ns)$$

$$= 0.06W$$

Diode and other losses :-

$$P_{other} = 0.02W$$

switching regulator

Total losses $P_{TSr} = 0.0083 + 0.0058 + 0.05 + 0.06 + 0.02$

$$P_{TSr} = 0.144\,W$$

input power $= P_{out} + P_{TSr}$

$$\underline{P_{in,sw}} = 5 + 0.144 = 5.1441 \; \} \rightarrow \text{input power to switching regulartor}$$

$$I_{in,sw} = \frac{P_{in,sw}}{V_{in}} = \frac{5.1441}{12} = 0.42A$$

$$\eta_{sw} = \frac{P_{out}}{P_{in,sw}} \times 100\% = \frac{5}{5.1441} \times 100\% \approx \underline{97.20\%}$$

The Switching regulators are very efficient than Linear regulator