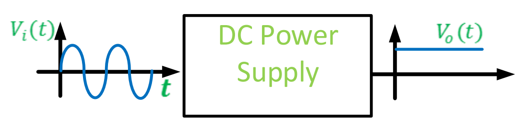
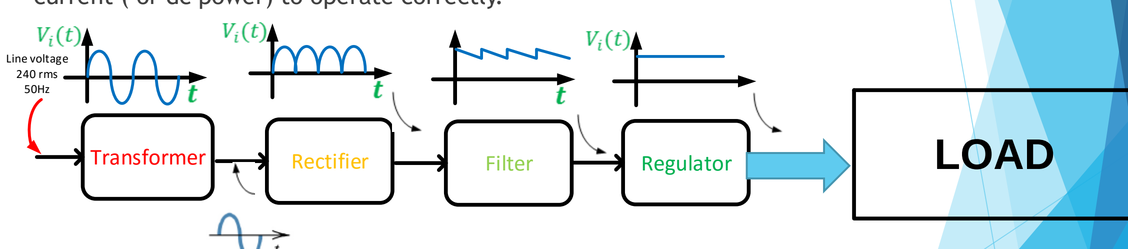
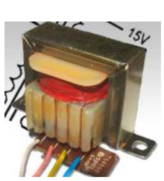
Voltage Regulator

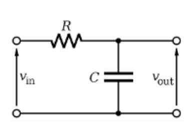
Dc Power Supply

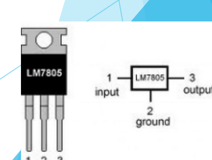


- All electronic circuits and systems require a stable source of dc voltage and current (or dc power) to operate correctly.









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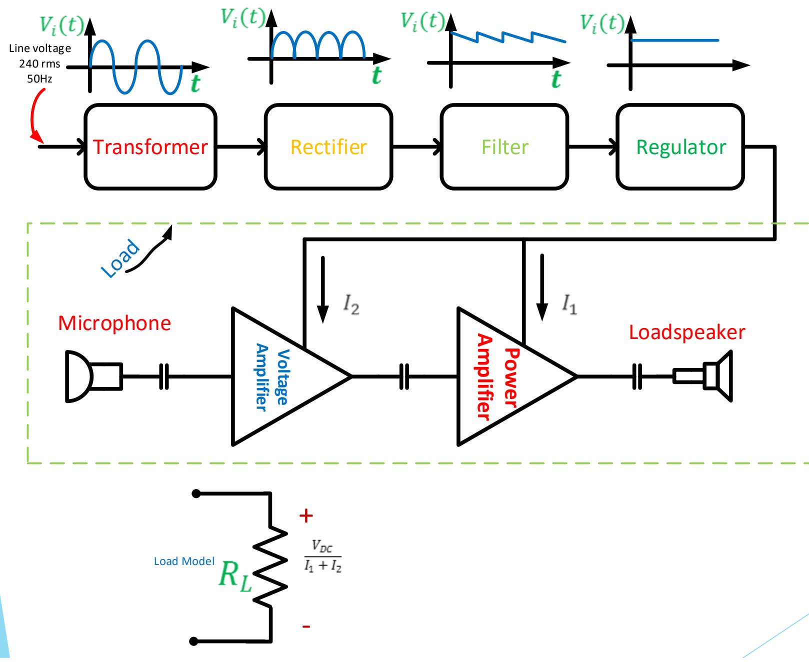


- **Transformer: Used to increase or decrease the amplitude of the ac line voltage**
- **Rectifier: used to convert the ac voltage (zero-average value) into either positive and negative pulsating dc.**

1) Have- Wave Rectifier

2) Full-Wave Rectifier

a) Center-tapped transformer full-wave Rectifier

b) Bridge full-wave rectifier

- **Filter : used to smooth out the pulsating dc roduced by the rectifier by removing its ac ripple contents and passing its dc component (average value)**

- **Regulator: used to maintain a constant DC output voltage under variations in the load current drawn from the supply and under variation in AC line voltage**

To determine the effectiveness of the voltage regulator ,we define two indicators

a) **Load regulation** = $\frac{\Delta V_O}{\Delta I_L}$

assuming V_S constant

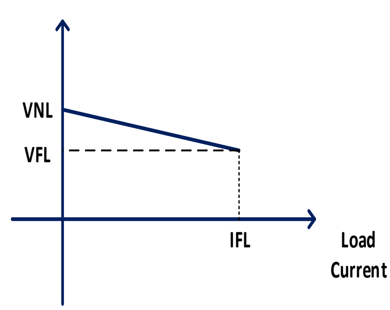
b) **Line regulation** = $\frac{\Delta V_O}{\Delta V_S}$

assuming R_L fixed

Voltage Regulator

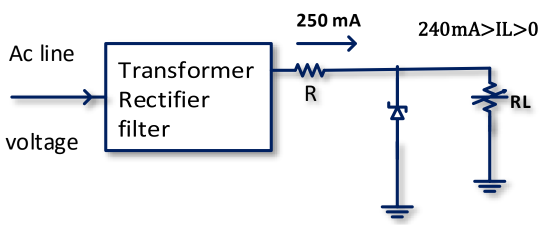
- An ideal power supply maintains a constant voltage at its output terminal , no matter what current it drawn from it .
- The output voltage of a practical power supply changes with load current.
- One measure of power supply performance is called percent voltage regulation.

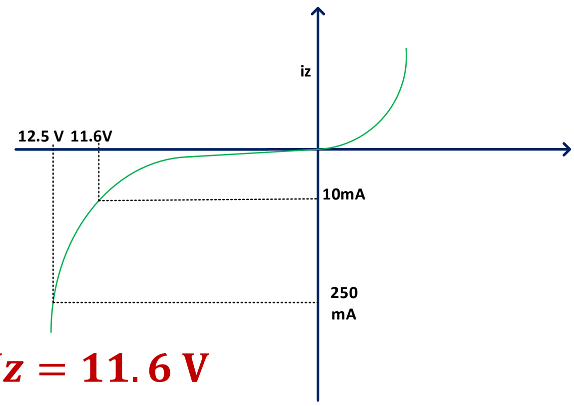
$$Vr = \frac{VNL - VFL}{VFL} \times 100\%$$



Voltage Regulator

Simple Voltage Regulator

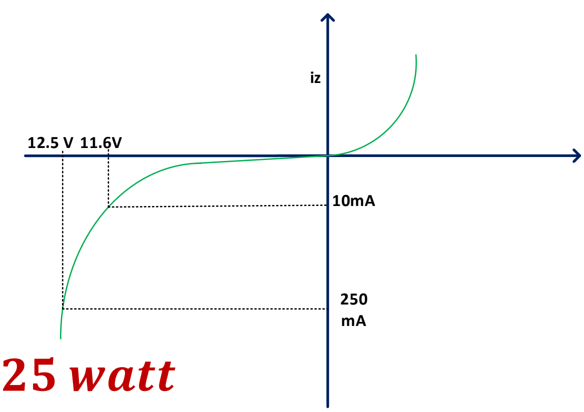




$$Iz(min) = 250 - 240 = 10mA; Vz = 11.6 \text{ V}$$

$$Iz(max) = 250 - 0 = 250mA; Vz = 12.5 \text{ V}$$

$$\Delta Vo = \Delta Vz = 12.5 - 11.6 = 0.9 \text{ V}$$



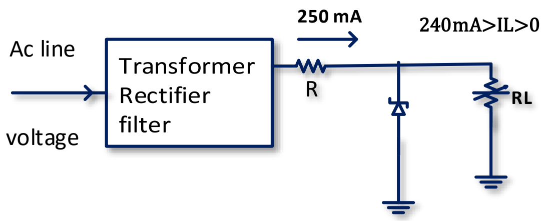
$$Pd = Vz \;\; Iz$$

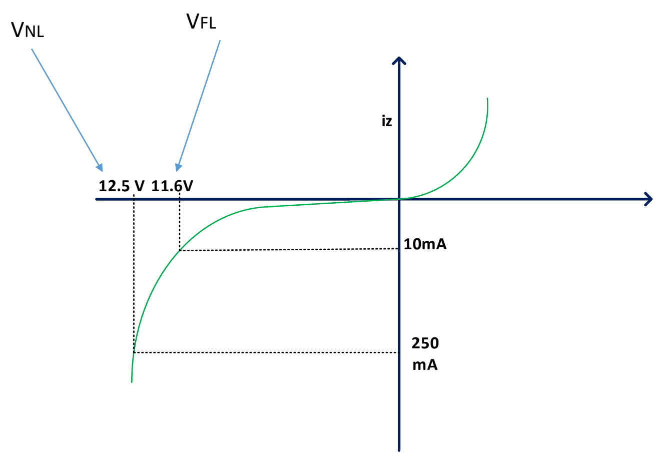
$$Pd, max = Vz(max) \;\; Iz(max)$$

$$Pd, max = 12.5 \times 250 = 3.125 \; watt$$

Voltage Regulator

Simple Voltage Regulator





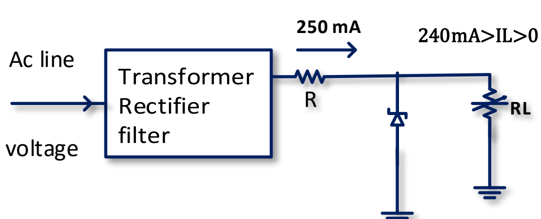
$$Vr = \frac{VNL - VFL}{VFL} \times 100\%$$

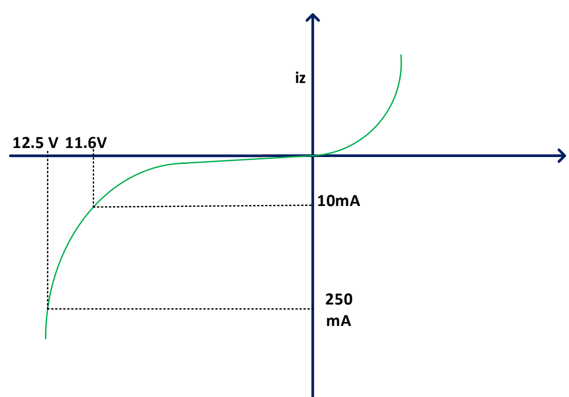
$$Vr = \frac{12.5 - 11.6}{11.6} \times 100\%$$

Vr= 7.6%

Voltage Regulator

Simple Voltage Regulator

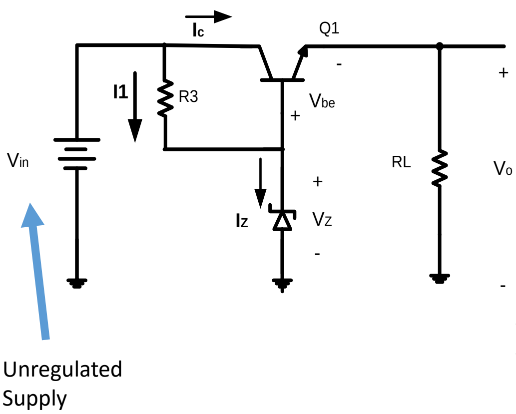




Disadvantages:

1. **Variation in IL will cause Iz to vary.This in turns will cause variation in Vz=Vo**
2. **The Zener power dissipation will increase as IL decreases.**

Transistorized Voltage regulator



$$V_o = V_Z - V_{BE}$$

$$V_{BE} = V_Z - V_o$$

$$I_C = I_S\left(e^{\frac{VBE}{\eta V_T}} - 1\right)$$

If $V_o \downarrow$, $(V_{BE} = V_Z - V_o)\uparrow$,

$I_C \uparrow, V_o \uparrow$

Example

Calculate the output voltage and Zener current for R_L=1kΩ.

Solution:

V_o=Vz-VBE=12-0.7=11.3 V

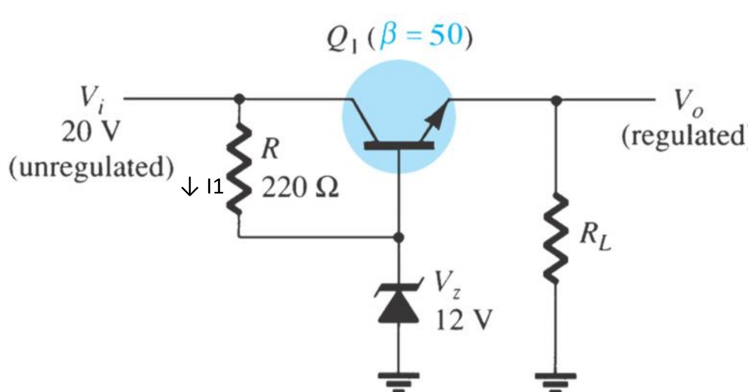
IE = 11.3/1K = 11.3 mA

Iz = I1 – IB

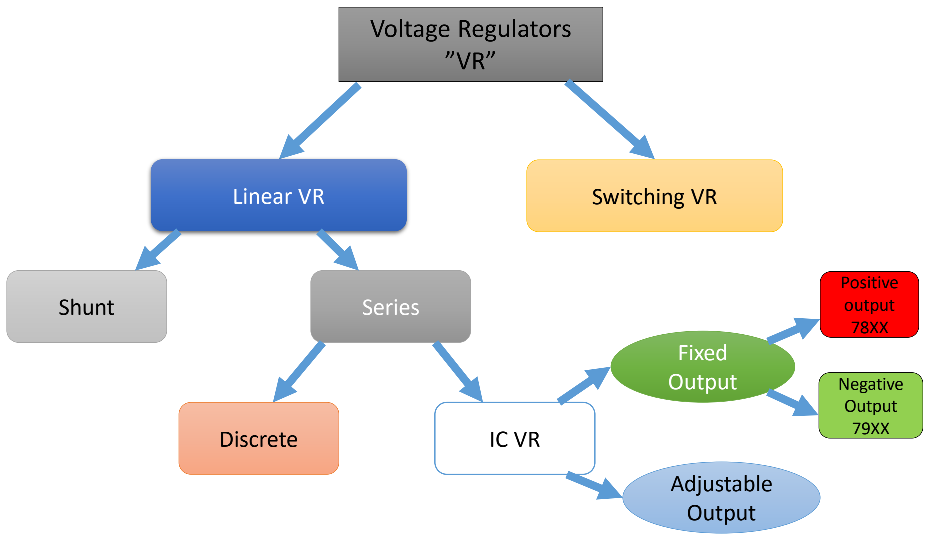
I1 = (20-12)/220= 36 mA

IB = IE/B+1

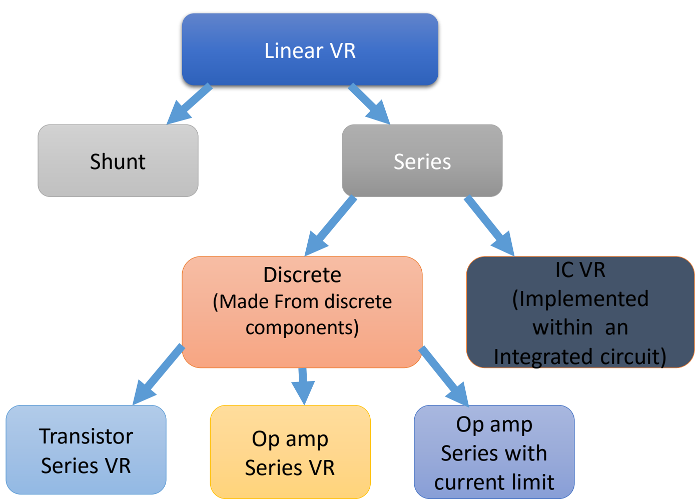
Iz = 35.78 mA



Types of Regulators

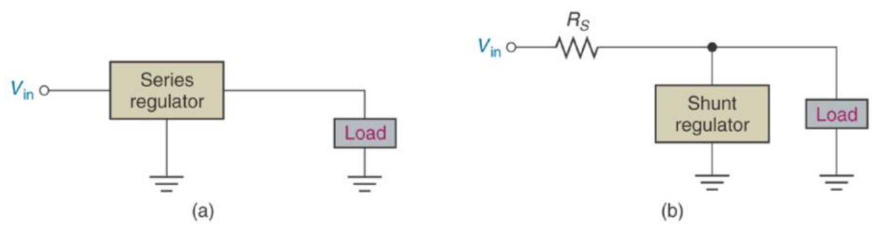


Types of Regulator



Types of Regulator

- Fundamental classes of voltage regulators are **linear regulators** and **switching regulators**.
- Two basic types of linear regulator are the **series regulator** and the **shunt regulator** .
- The series regulator is connected in **series** with the load and the shunt regulator is connected in **parallel** with the load.

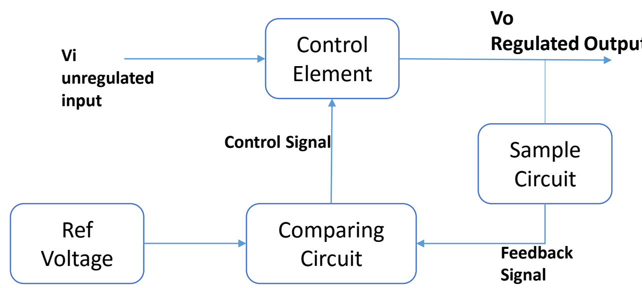


Series and shunt Regulators

- **The purpose of a regulator is to eliminate any output voltage variation that might occur because of**
- **changes in load currents,**
- **changes in ac line Voltage ,**
- **or changes in temperature.**
- **It monitors the output voltage and generates feedback signal that automatically Increases or decreases the supply voltage as necessary to compensate for any tendency of the output voltage to change.**

Voltage Regulator

Series Regulators

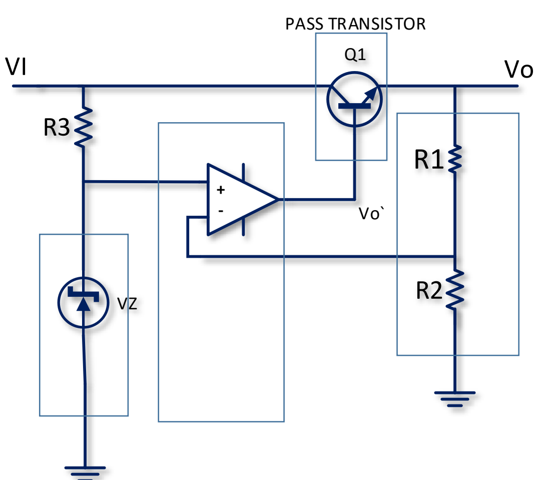


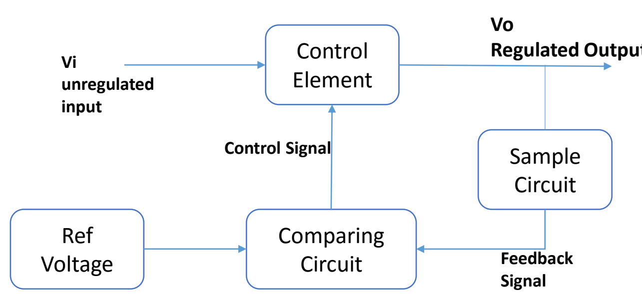
Control element: is a device whose operating state adjusts as necessary to maintain a constant Vo.

It is in series path between Vi and Vo

Voltage Regulator

Series Regulators





Voltage Regulator

Series Regulators

An Op-amp used in series voltage regulators

$$V(-) = \frac{R2}{R1+R2}Vo$$

$$V(+) = Vz$$

$$V(-) = V(+)$$

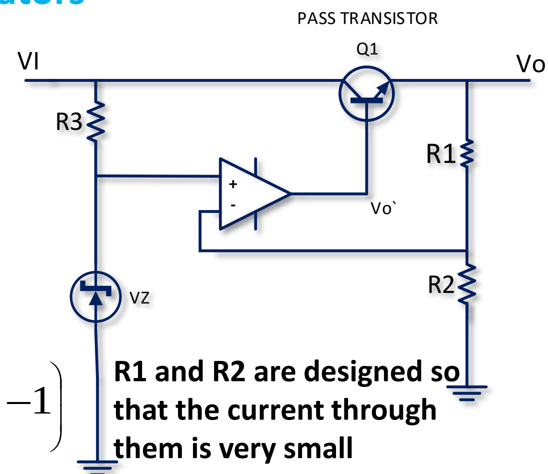
$$Vo = Vz\left(1+\frac{R1}{R2}\right)$$

Operation:

$$Vo' = AdVd$$

$$Vo' = Ad\left(Vz - \frac{R2}{R1+R2}Vo\right)$$

VBE = Vo' - Vo



$$I_C = I_S\left(e^{\frac{VBE}{\eta V_T}} - 1\right)$$

R1 and R2 are designed so that the current through them is very small

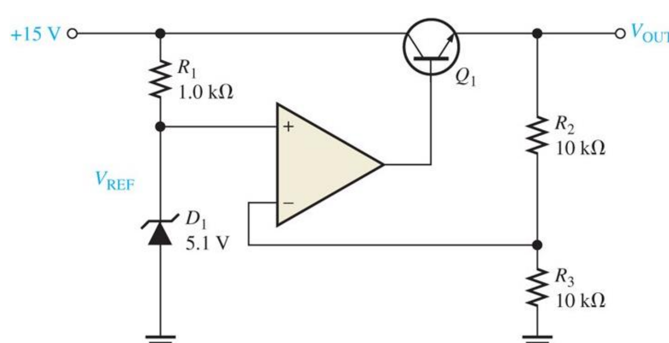
Assume Vo ↓ , Vo' ↑, VBE ↑ , IE ↑ , Vo ↑

Example

Determine the output voltage for the regulator below.

$$V_o = \left(1+\frac{R_2}{R_3}\right)V_Z$$

$$V_O = \left(1+\frac{10k}{10k}\right)5.1 = 10.2\ V$$



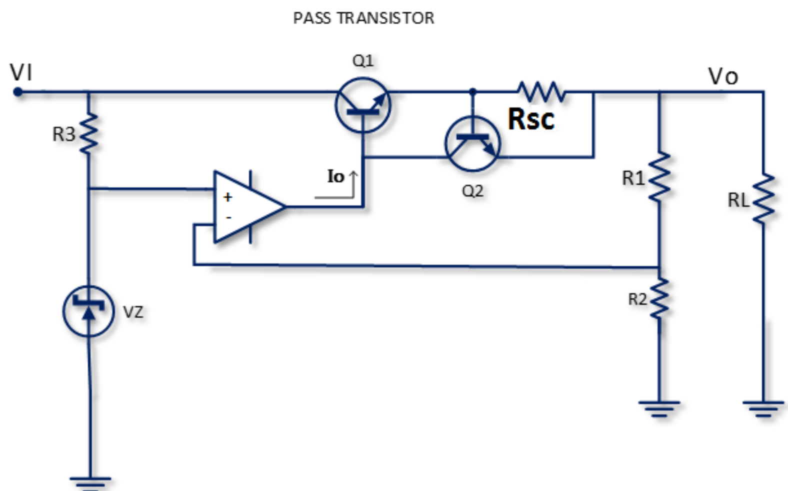
Voltage Regulator

An Op-amp used in series voltage regulators

Current Limiting:

$$Rsc = \frac{0.7}{IL(\max)}$$

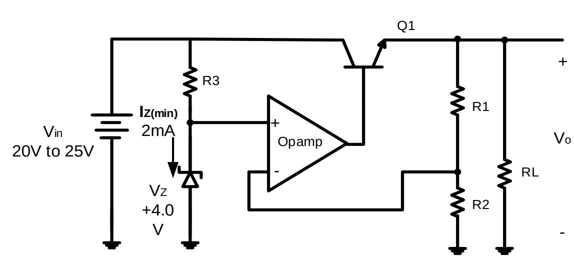
- In normal operation
Q2 is off (VBE2<0.7V)
IB1=Io; IL=IE=β.Io
-when IL=IL(max)
VBE2 = 0.7V
Q2 turns on;
Io=IB1+IC2
Q1 will conduct less current



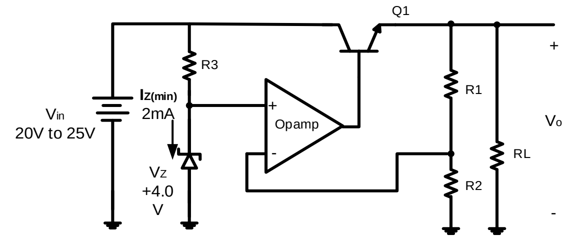
Voltage Regulators example

- Given the following series voltage regulator
- 1) Complete the design of the following voltage regulator (Find of R1, R2 and R3) assuming that the voltage across the load resistor R_L is equal to 12V. Assume Iz(min) = 2mA.
- 2)Show how to modify the circuit to limit the load current to 1A.
- 3)Find the output voltage for the modified circuit of part 2) when the load resistor $R_L = 100\Omega$ and when $R_L = 8\Omega$.
- 4) Choose a transistor with suitable power

  rating



1) Complete the design of the following voltage regulator (Find of R1, R2 and R3) assuming that the voltage across the load resistor R_L is equal to 12V. Assume Iz(min) = 2mA.



$$V_o = \left(1 + \frac{R_1}{R_2}\right) V_Z = 12\text{ V}$$

$$\therefore \frac{R1}{R2} = \frac{V_O}{V_Z} - 1 = \frac{12}{4} - 1 = 2$$

choose $R_1 = 20\text{ k}\Omega$

$\therefore R_2 = 10\text{ k}\Omega$

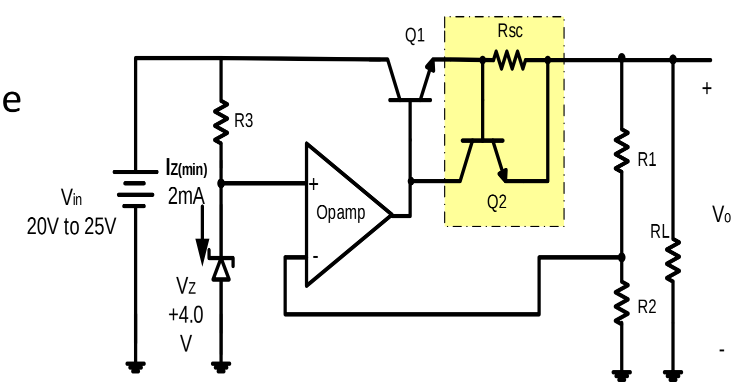
$$I_Z > I_{Z(Min)} = \frac{V_{IN(Min)} - V_Z}{R_3}$$

$$R_3 \le \frac{V_{IN(Min)} - V_Z}{I_{Z(Min)}}$$

$$R_3 \le \frac{20 - 4}{2\text{ mA}} = 8\text{ k}\Omega$$

Voltage Regulators

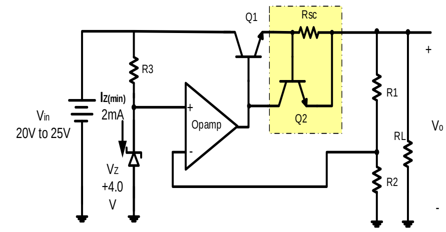
2)Show how to modify the circuit to limit the load current to 1A.



The change for current limit is done by adding Q2 and Rsc as shown

$$\& \ R_{SC} = \frac{V_{BE}}{I_{L(Max)}} = \frac{0.7\text{ V}}{1\text{A}} = 0.7\Omega$$

3)Find the output voltage for the modified circuit of part 2) when the load resistor R_L =100Ω and when R_L =8Ω.



$$\text{For } R_L = 100 \text{ ohm}, \text{ Vo} = 12\text{V}, \text{ then } I_L = \frac{12\text{V}}{100\Omega} = 0.12\text{A}$$

which is smaller than $I_{L(max)}$,

$$\therefore V_O = 12 \text{ V and is not affected by the current limit circuit}$$

$$\text{For } R_L = 8 \text{ ohm}, \text{ Vo} = 12\text{V}, \text{ then } I_L = \frac{12\text{V}}{8\,\Omega} = 1.5\text{A}$$

which is bigger than $I_{L(max)}$, and the current limit circuit limits the current to the maximum allowable value which is 1 A

$$\therefore V_O = I_{L(Max)} * R_L = 1A * 8\Omega = 8 \text{ V}$$

4) Choose a transistor with suitable power rating

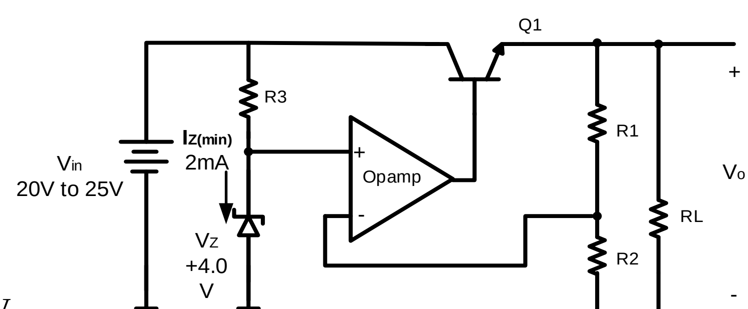
$$I_C \approx I_E$$

$$P_{C,MAX} = V_{CE(MAX)} * I_{C(MAX)}$$

$$V_{CE(MAX)} = V_{IN(MAX)} - V_{O(MIN)} = 25 - 8 = 17 \text{ V}$$

$$I_{E(MAX)} = I_{R1} + I_{L(MAX)} = \frac{V_Z}{R_2} + I_{L(MAX)}$$

$$= \frac{4 \text{ V}}{10 \text{ k}\Omega} + 1 \text{ A} = 1.0004 \text{ A}$$

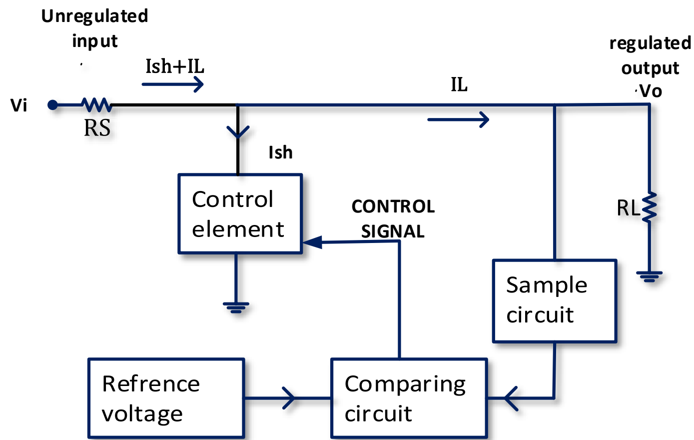


$$P_{C,MAX} = 17 \text{ V} * 1.0004\text{A} = 17.0068 \text{ W}$$

Voltage Regulator

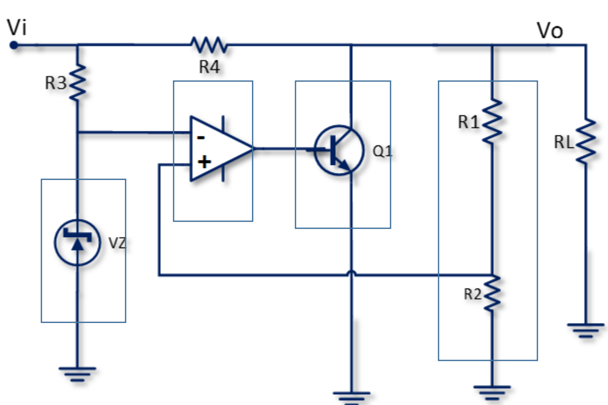
Shunt Regulators

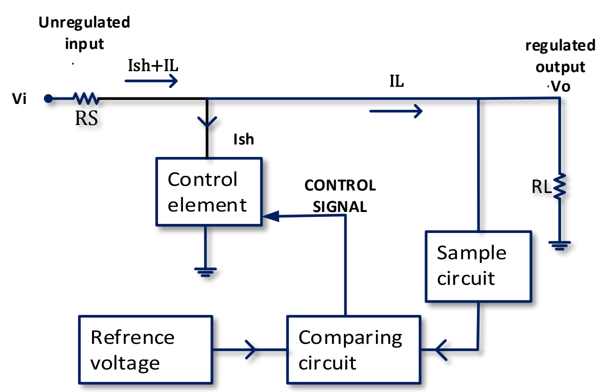
- The Control element is in parallel with the load



- The control element maintains a constant load voltage by shunting more or less current from the load
- When the load voltage decrease, the control element shunt less current

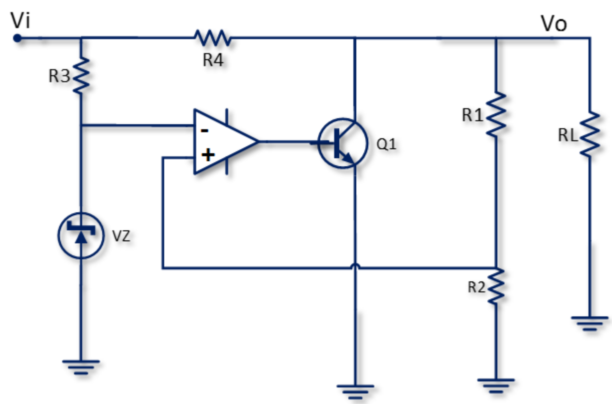
Shunt Regulators





An Op-amp used in Shunt voltage regulators

$$Vo = Vz\left(1 + \frac{R1}{R2}\right)$$



Operation:

$$Vop = AdVd$$

$$Vop = Ad\left(\frac{R2}{R1 + R2}Vo - Vz\right)$$

IF VO ↓, V(+) ↓, Vop ↓, VBE ↓

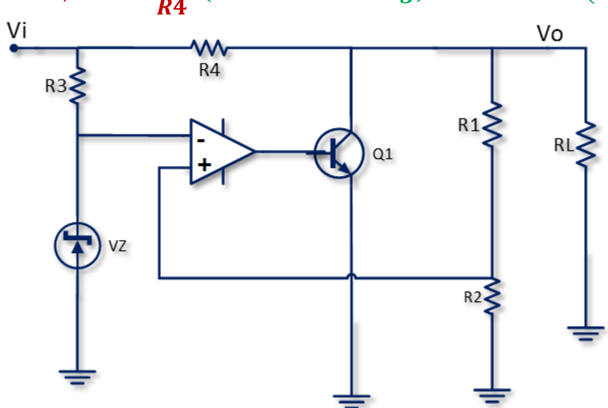
VBE = Vop

$$\therefore \textit{The transistor conduct Less}, Ic \downarrow, IL \uparrow Vo \uparrow$$

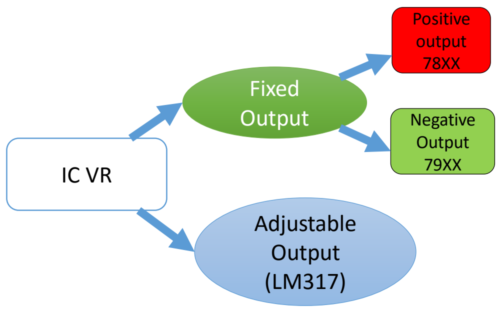
$$I_C = I_S\left(e^{\frac{VBE}{\eta V_T}} - 1\right)$$

Current Limiting

$$IL, \max = \frac{Vi}{R4} \quad (\textit{Current Limiting})\ \textit{When } RL = 0\ (\textit{SHORTED})$$

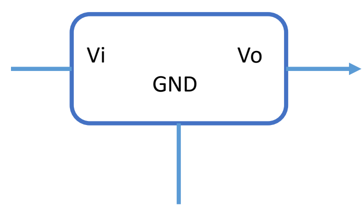


IC Voltage Regulator



Voltage Regulator

Three Terminal Circuit Regulators



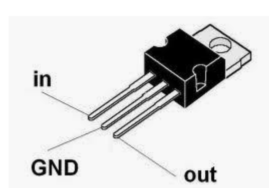
1- Fixed voltage regulator

a-78xx

7805…………………5 V
7812…………………12 V
7815…………………15V

b- 79xx

7905………….. -5 V
7912………….. -12 V
7915………….. -15V



Fixed Voltage Regulator

Positive-Voltage Regulators in the 78XX Series

IC Part	Output Voltage (V)	Minimum V_i (V)
7805	+5	+7.3
7806	+6	+8.3
7808	+8	+10.5
7810	+10	+12.5
7812	+12	+14.5
7815	+15	+17.7
7818	+18	+21.0
7824	+24	+27.1

Vin must be higher than Vo by at least 2V for proper operation of the voltage regulator

Fixed Voltage Regulator

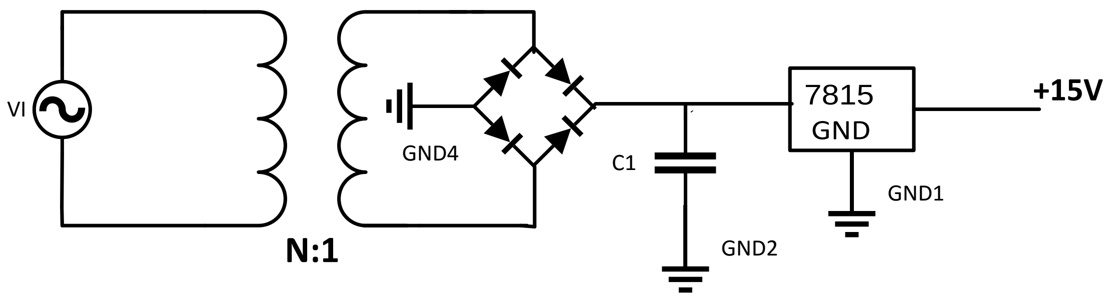
Negative-Voltage Regulators in the 79XX Series

IC Part	Output Voltage (V)	Minimum V_i (V)
7905	-5	-7.3
7906	-6	-8.4
7908	-8	-10.5
7909	-9	-11.5
7912	-12	-14.6
7915	-15	-17.7
7918	-18	-20.8
7924	-24	-27.1

Voltage Regulator

Three Terminal Circuit Regulators

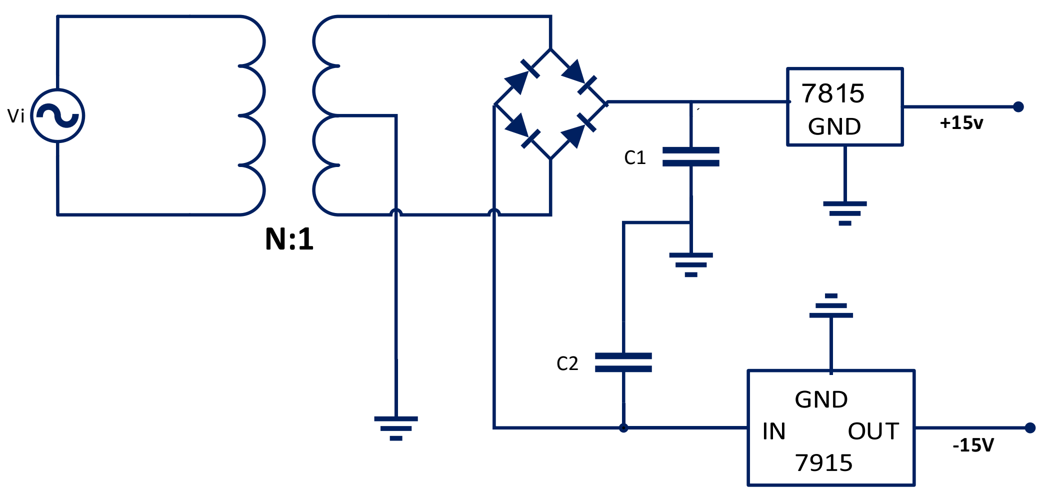
Dc Power Supply



Voltage Regulator

Three Terminal Circuit Regulators

Dual Polarity Dc Power Supply



Voltage Regulator

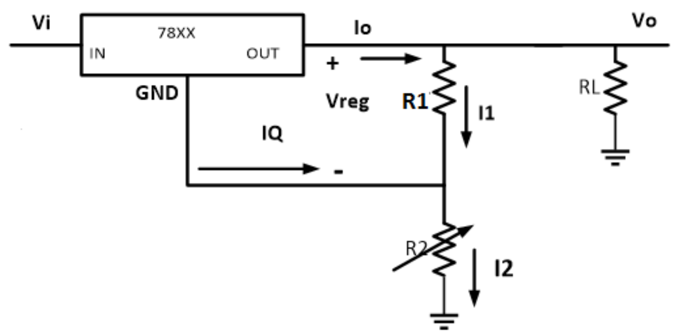
Changing the fixed Voltage Regulator to adjustable

$$Vo = V_{REG} + R_2 I_2$$

$$Vo = V_{REG} + R_2(I_1 \ \ +I_Q)$$

$$I_1 = \frac{V_{REG}}{R_1}$$

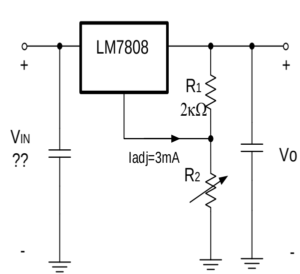
$$\therefore Vo = V_{REG}\,(1+\frac{R_2}{R_1})+R_2 I_Q$$



I_Q *is in milliampere and change with temperature*

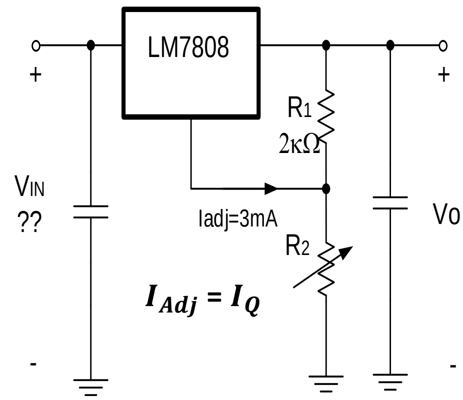
Example

- **Find the minimum and maximum output voltage (Vo) for the following IC voltage regulator. Note that R2 is a variable resistor that can be varied from 0 to 3kΩ**
- **What is the range of values of V_{IN} required for proper operation of the circuit**
- **What is the power dissipation of the LM7808 when Vo=Vo(min) and Vin=Vin(max) and load current =0.25A**



Find the minimum and maximum output voltage (Vo) for the following IC voltage regulator. Note that R2 is a variable resistor that can be varied from 0 to 3kΩ

$$\therefore Vo = V_{REG}\,(1+\frac{R_2}{R_1})+R_2 I_Q$$



$$V_{O(MIN)} = V_{REG} = 8\text{ V} \quad (\text{when } R_2 = 0\,\Omega)$$

$$V_{O(MAX)} = \frac{V_{REG}}{R_1}(R_1 + R_2) + I_Q(R_2)$$

$$= \frac{8V}{2k\Omega}(2k\Omega + 3k\Omega) + 3mA.(3k\Omega)$$

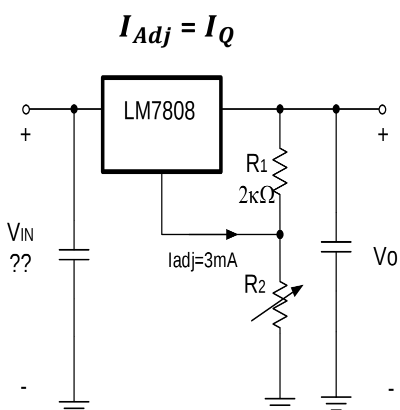
$$= (4mA).(5k\Omega) + 9V = 29V \text{ (when } R_2 = 3k\Omega k)$$

What is the range of values of VIN required for proper operation of the circuit ?

Vin must be higher than Vo by at least 2V

$$\text{when } Vo = 8V \quad , V_{IN(MIN)} = 8 + 2 = 10\text{ V}$$

$$\text{when } Vo = 29V \quad , V_{IN(MAX)} = 29 + 2 = 31\text{ V}$$



What is the power dissipation of the LM7808 when Vo=Vo(min) and Vin=Vin(max) and load current =0.25A ?

Io = IL +I1 = 0.25A+4mA = 0.254A

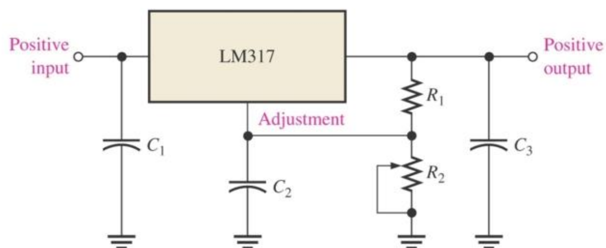
Power Dissipation of LM7808:

$$P_{(LM7808)} = (V_{IN} - V_O) * I_O = (31-8) * 0.254 = 5.842\text{ W}$$

Adjustable-Voltage Regulator

Adjustable-Voltage Regulator

- Voltage regulators are also available in circuit configurations that allow to set the output voltage to a desired regulated value.
- The LM317 is an example of an adjustable-voltage regulator, can be operated over the range of voltage from 1.25 to 35 V.



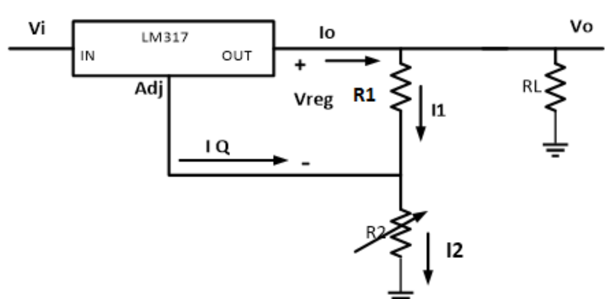
Voltage Regulator

2- Adjustable Voltage regulator

$IQ = 50uA \rightarrow 100uA$ $\quad I_{Adj} = I_Q$

Io,max =1.5 A

$V_{REG} = 1.25$ V



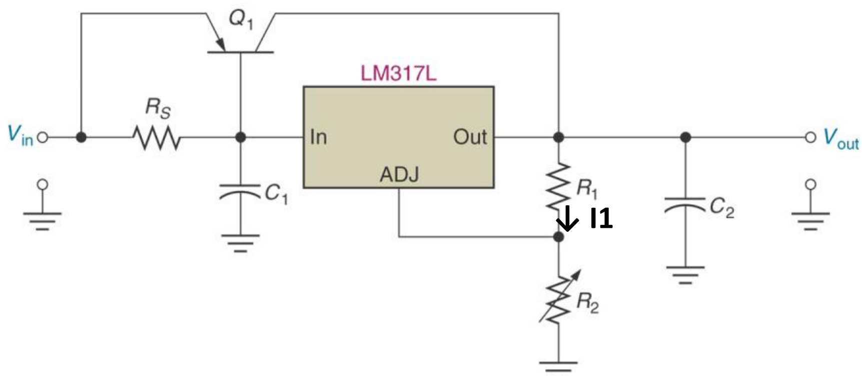
$$Vo = V_{REG} + R_2 I_2$$

$$Vo = V_{REG} + R_2(I_1 + I_Q)$$

$$I_1 = \frac{V_{REG}}{R_1}$$

$$\therefore Vo = V_{REG}\,(1+\frac{R_2}{R_1}) + R_2 I_Q$$

IC REGULATOR WITH BOOSTER CURRENT



IC regulators are limited to a maximum allowable current before shutting down. The circuit shown uses an external pass transistor to increase the maximum available load current

When I_O is less than I_O,max , VEB1 < 0.7 V So that the Q1 is OFF

When I_O is equal to I_O,max , VEB1 = 0.7 V So that the Q1 is on and I_L = I_O,max +I_{C1} - I_1

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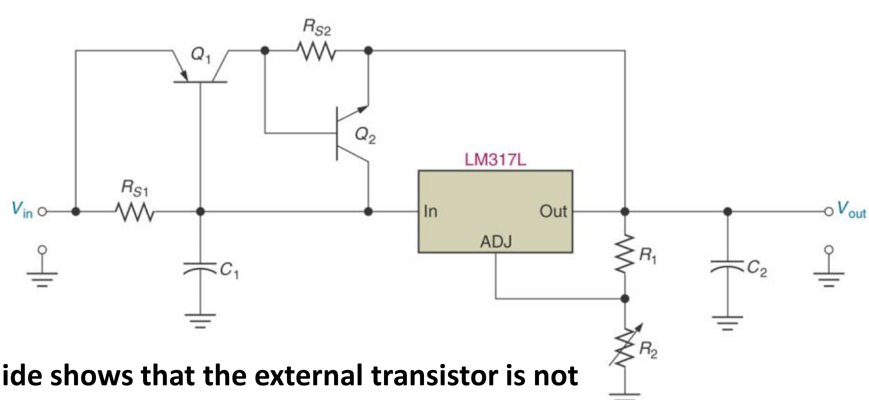


Previous slide shows that the external transistor is not protected from excessive current, such as would result from shorted output. An additional current-limiting circuit (Q2 and Rs2) can be added to protect Q1 from excessive current and possible burn out.

When I_{C1} is equal to I_{C1},max , VBE2 = 0.7V So that the Q2 is on and I_L = I_{C1},max +I_{O1},max +I_{E2} - I_1

2

Types of Voltage Regulators

- Linear Power Supply.
  - Used power devices that operated at linear/active region.
  - Dissipates more power.

- Non-Linear Power Supply.
  - Used power devices that operated at saturation and cutoff alternately.
  - Dissipates less power.
  - Also named as switching power supply or switching regulator.

Voltage Regulator

Switching Mode regulator

The Switching mode regulator components

Q1: control element;switch

L & C: form a low-pass filter

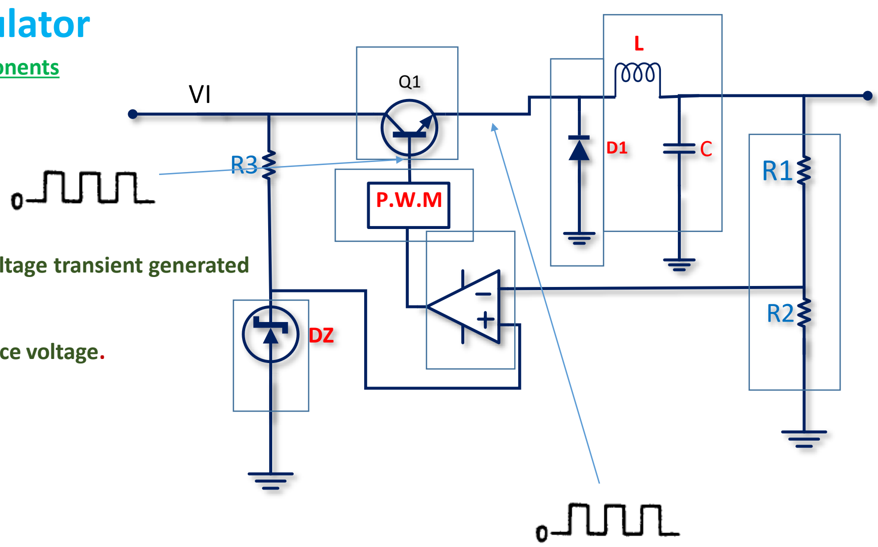
D1: used to suppress the negative voltage transient generated by the inductor when Q2 turns off

DZ : Zener diode to provide a reference voltage.

R1 & R2 : sample circuit

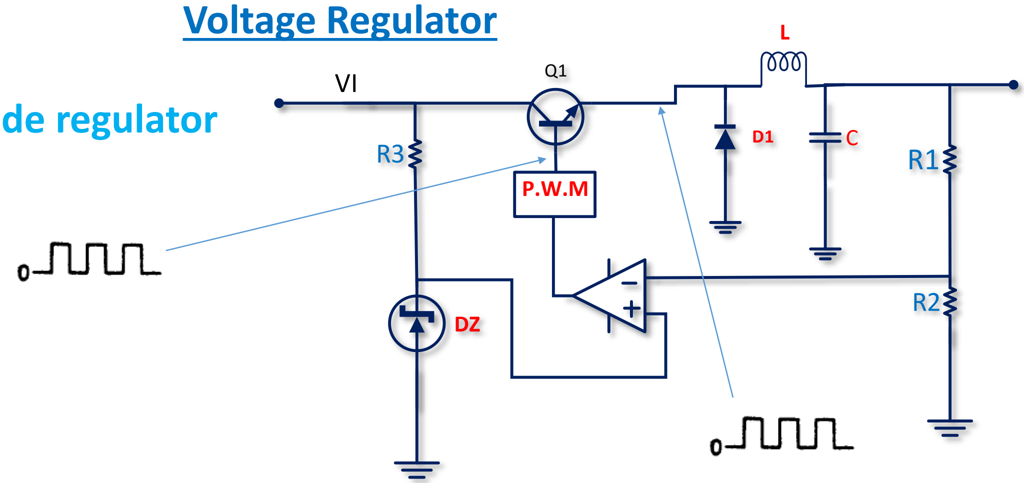
Op Amp : Comparing circuit

P.W.M : pulse width modulator



Voltage Regulator

Switching Mode regulator

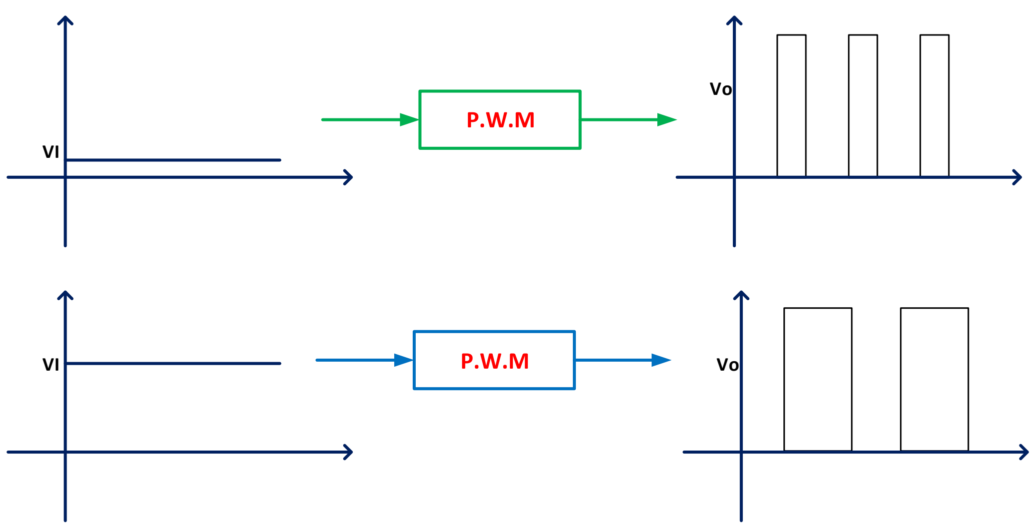


The fundamental component of a switching regulator is a pulse width modulator: P.W.M

P.W.M produces a train of rectangular pulses having width that are proportional to the Device's input.

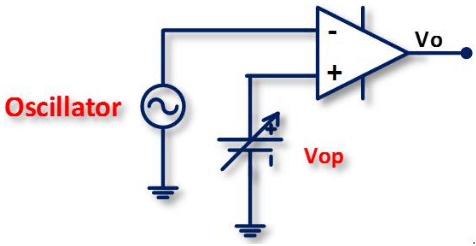
Voltage Regulator

Switching Mode regulator

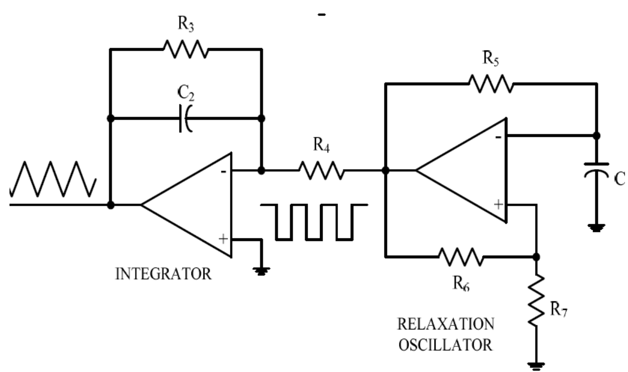


Voltage Regulator

Pulse width Modulator Circuit (P.W.M)

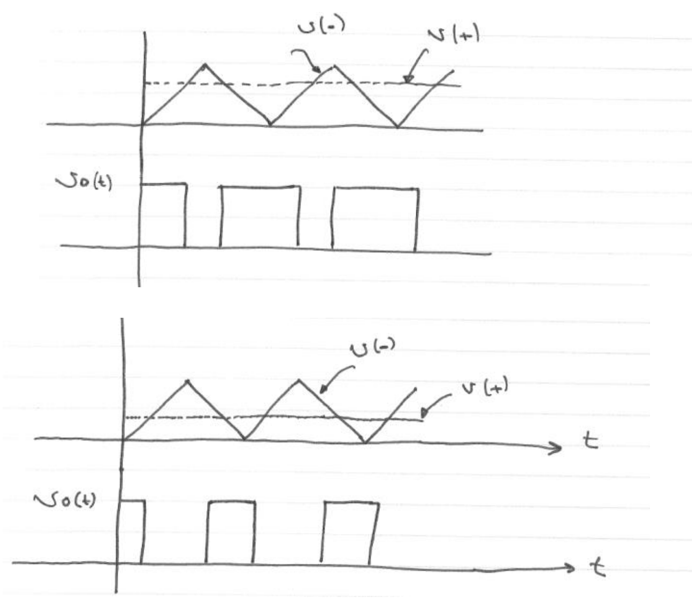


Oscillator



When V(+) > V(-) ;Vo(t) = Vsat =V

When V(+) < V(-) ;Vo(t) = -Vsat = 0



When V(+) > V(-) ;Vo(t) = Vsat =V

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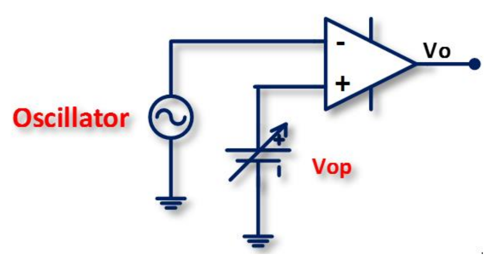


Voltage Regulator

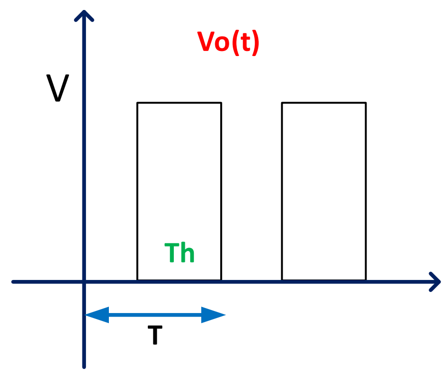
Pulse width Modulator Circuit (P.W.M)

$$Vo,dc = \frac{1}{T}\int_0^T Vo(t)dt$$

$$Vo,dc = \frac{1}{T}(V.Th)$$

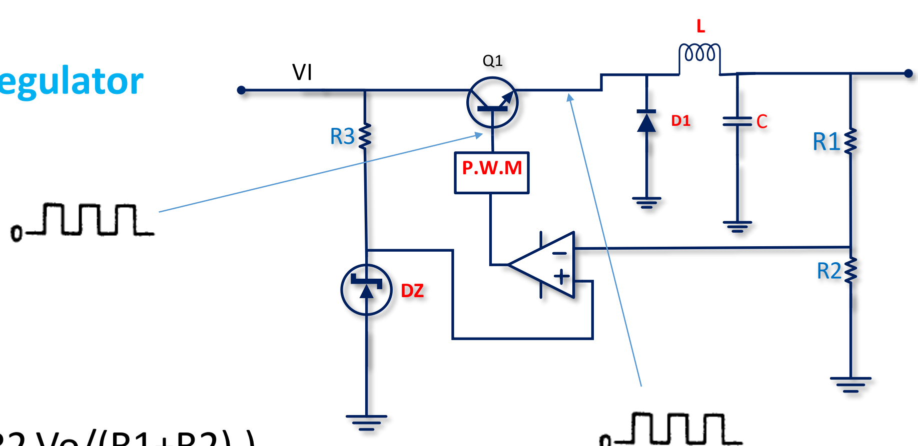
$$Vo,dc = \frac{Th}{T}.V$$

$$Vo,dc = \ D.V$$



∴ **The dc value of a pulse train is directly proportional to its duty cycle**

Switching Mode regulator



Operation :

Vop = Ad vd

Vop = Ad (Vz – R2.Vo/(R1+R2))

Vo ↓ , Vop ↑ , Duty cycle ↑ , Vo ↑

Voltage Regulator

Pulse width Modulator Circuit (P.W.M)

- A switching mode regulator uses a pulse width modulator to produce a pulse train whose duty cycle is automatically adjusted as necessary to increase or decrease the dc values of the train

- **If the load voltage Vo tends to fall, then the output of the Op Amp increases and a larger voltage is applied to the pulse width modulator**
- **It therefore produces a pulse train having a larger duty cycle.**
- **The pulse train switches Q1 on and off with a greater duty cycle , so the dc values of the load voltage raise.**