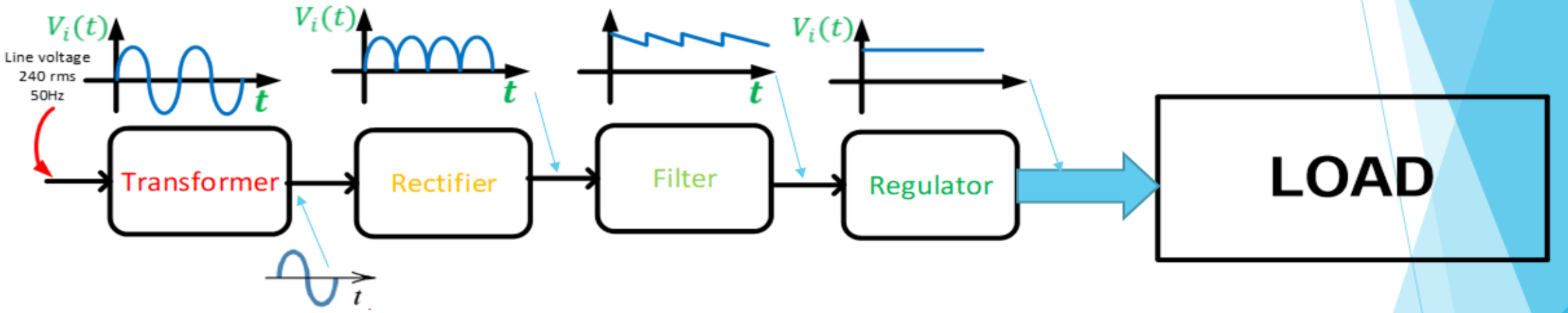
Voltage Regulator

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.



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.

Filter : used to smooth out the pulsating dc produced 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

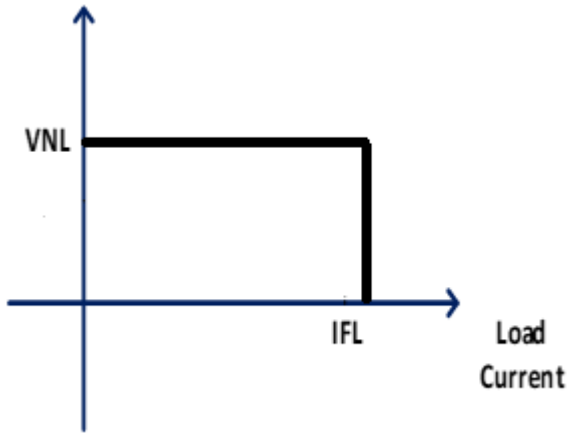
Voltage Regulator

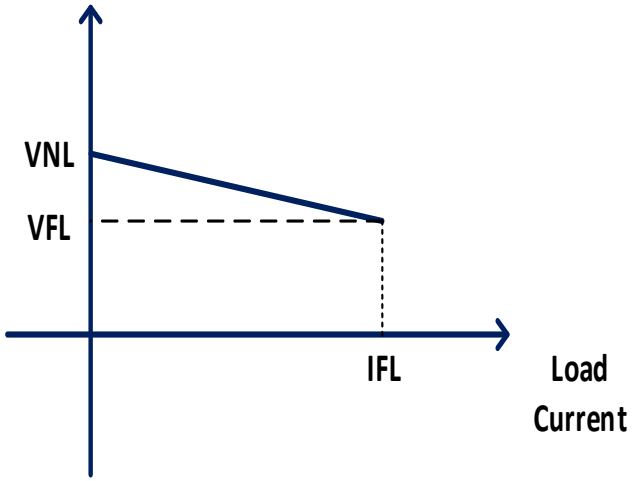
- An ideal power supply maintains a constant voltage at its output terminal , no matter what current it drawn from it .

- The output voltage of a practical power supply changes with load current.

- One measure of power supply performance is called percent voltage regulation.

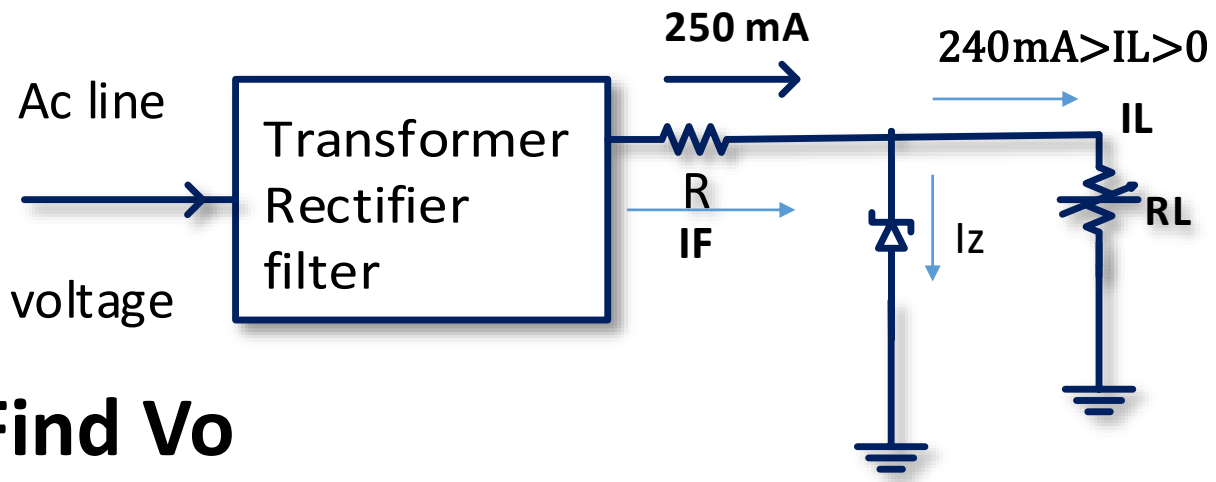
$$Vr = \frac{VNL - VFL}{VFL} \times 100\%$$

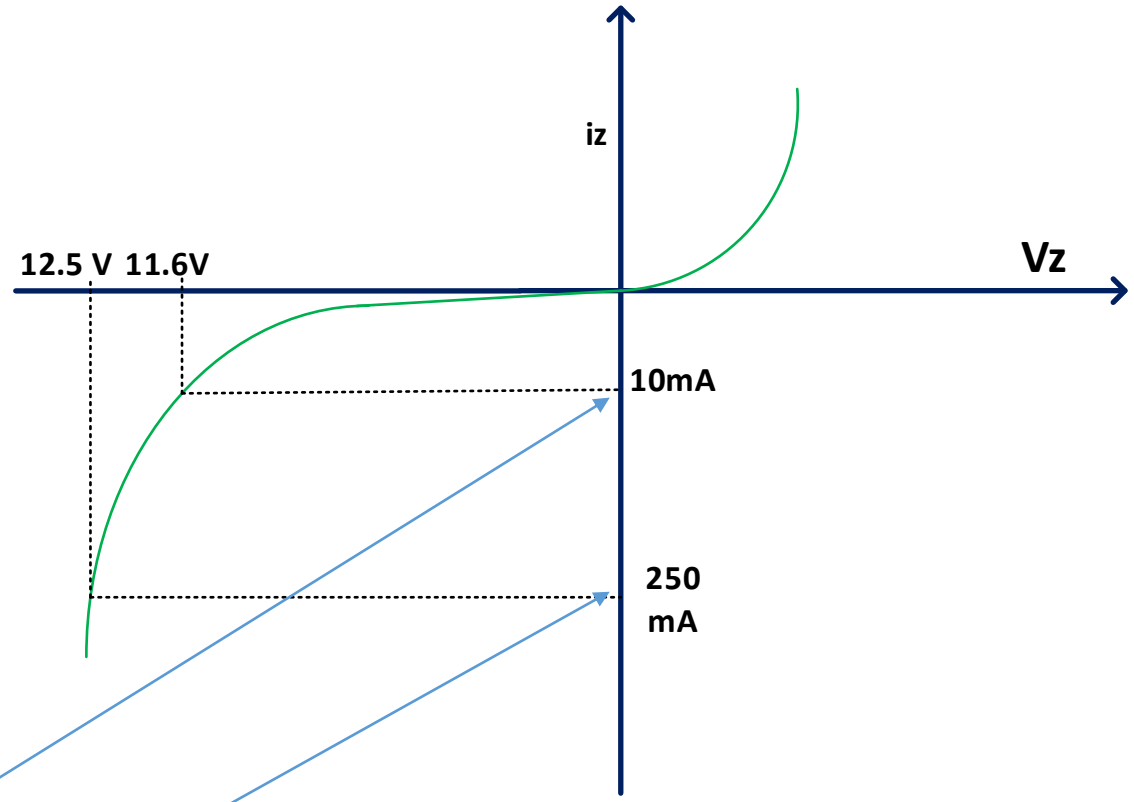




Voltage Regulator

Simple Voltage Regulator





Find Vo

Vo = Vz

$$IF = Iz + IL$$

$$Iz(min) = 250 - 240 = 10mA \Rightarrow Vz = 11.6\,V$$

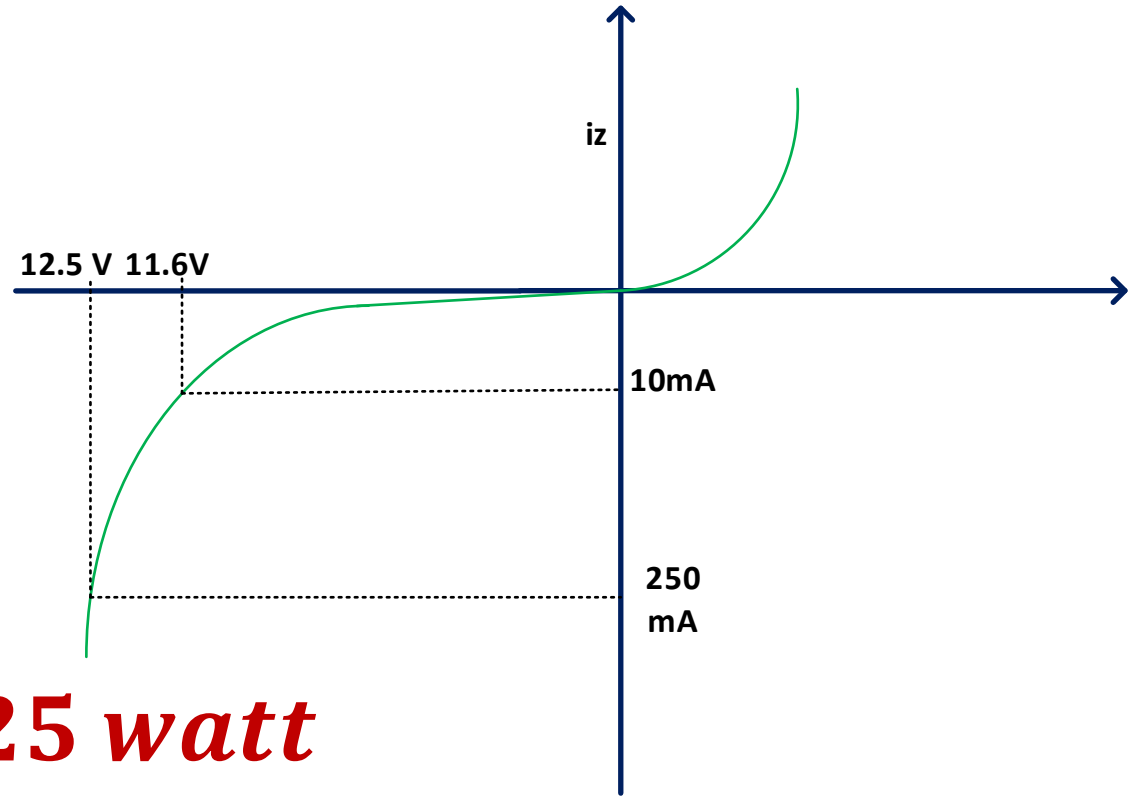
$$Iz(max) = 250 - 0 = 250mA \Rightarrow Vz = 12.5\,V$$

$$\Delta Vo = \Delta Vz = 12.5 - 11.6 = 0.9\,V$$

How to select the Zener Diode

Pd = Vz Iz

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



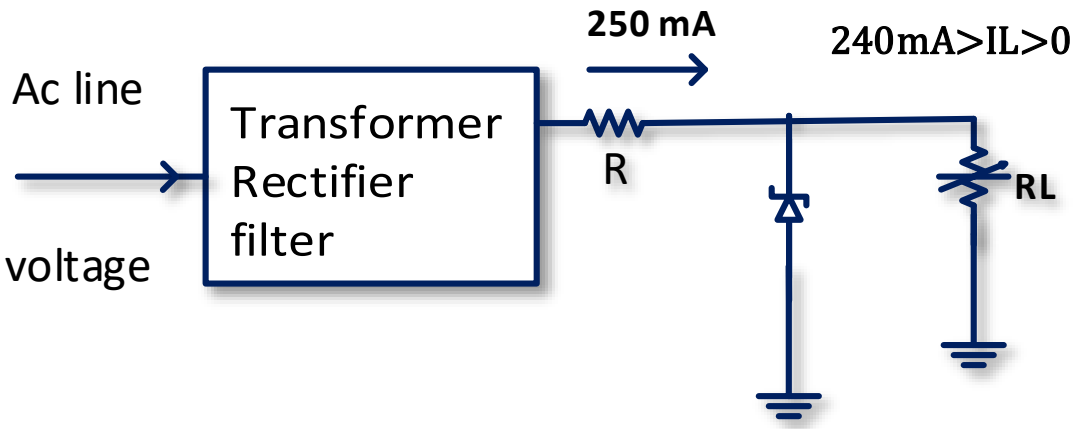
$$Pd,max = 12.5 \times 250 = 3.125\ watt$$

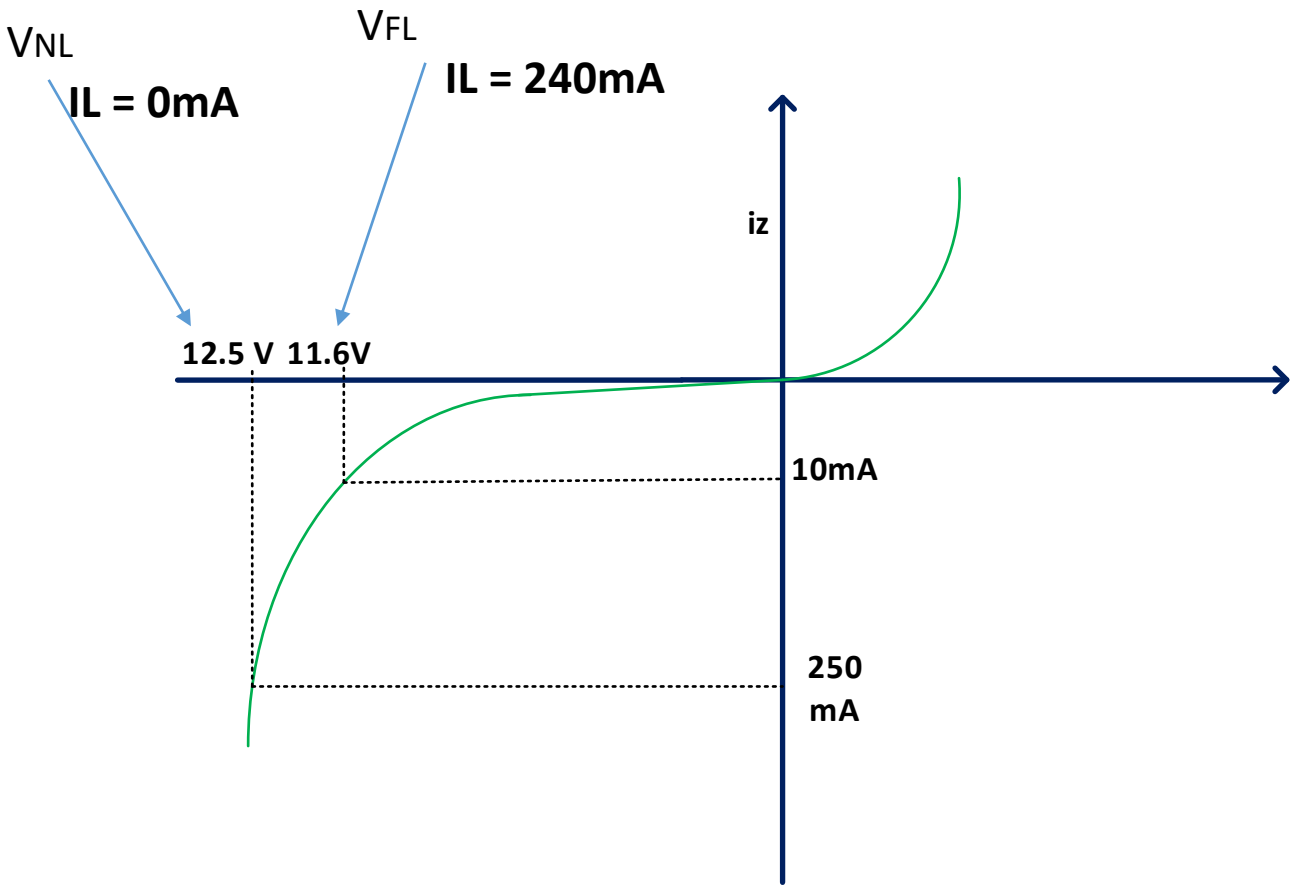
When RL = ω (OPEN CIRCUIT)

Voltage Regulator

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

Simple Voltage Regulator





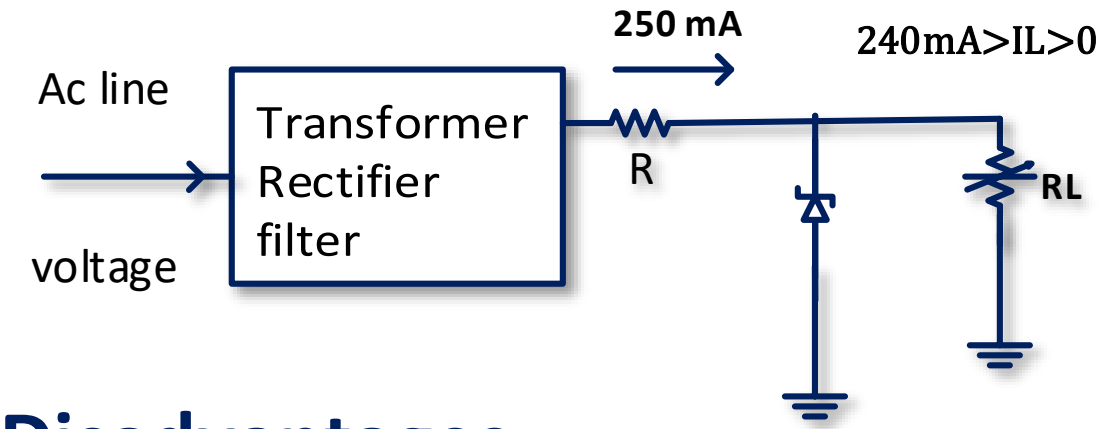
$$Vr = \frac{VNL - VFL}{VFL} \times 100\%$$

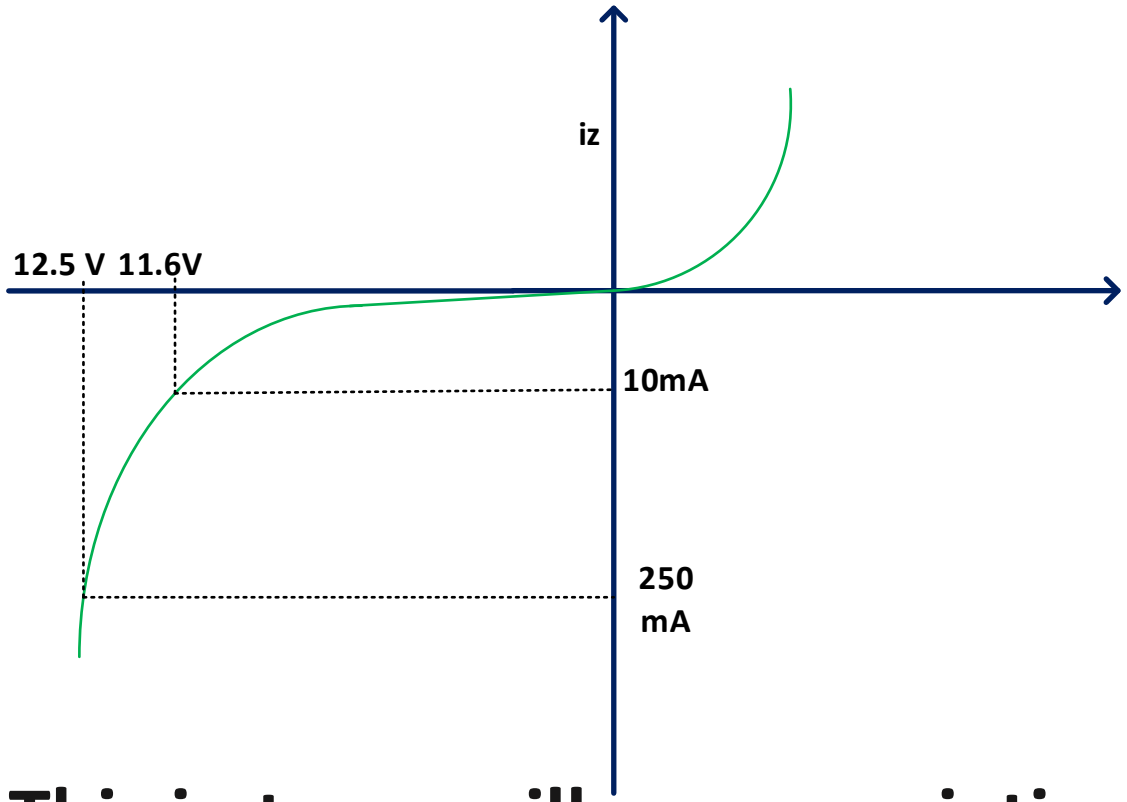
$$Vr = \frac{12.5 - 11.6}{11.6} \times 100\%$$

Vr= 7.6%

Voltage Regulator

Simple Voltage Regulator



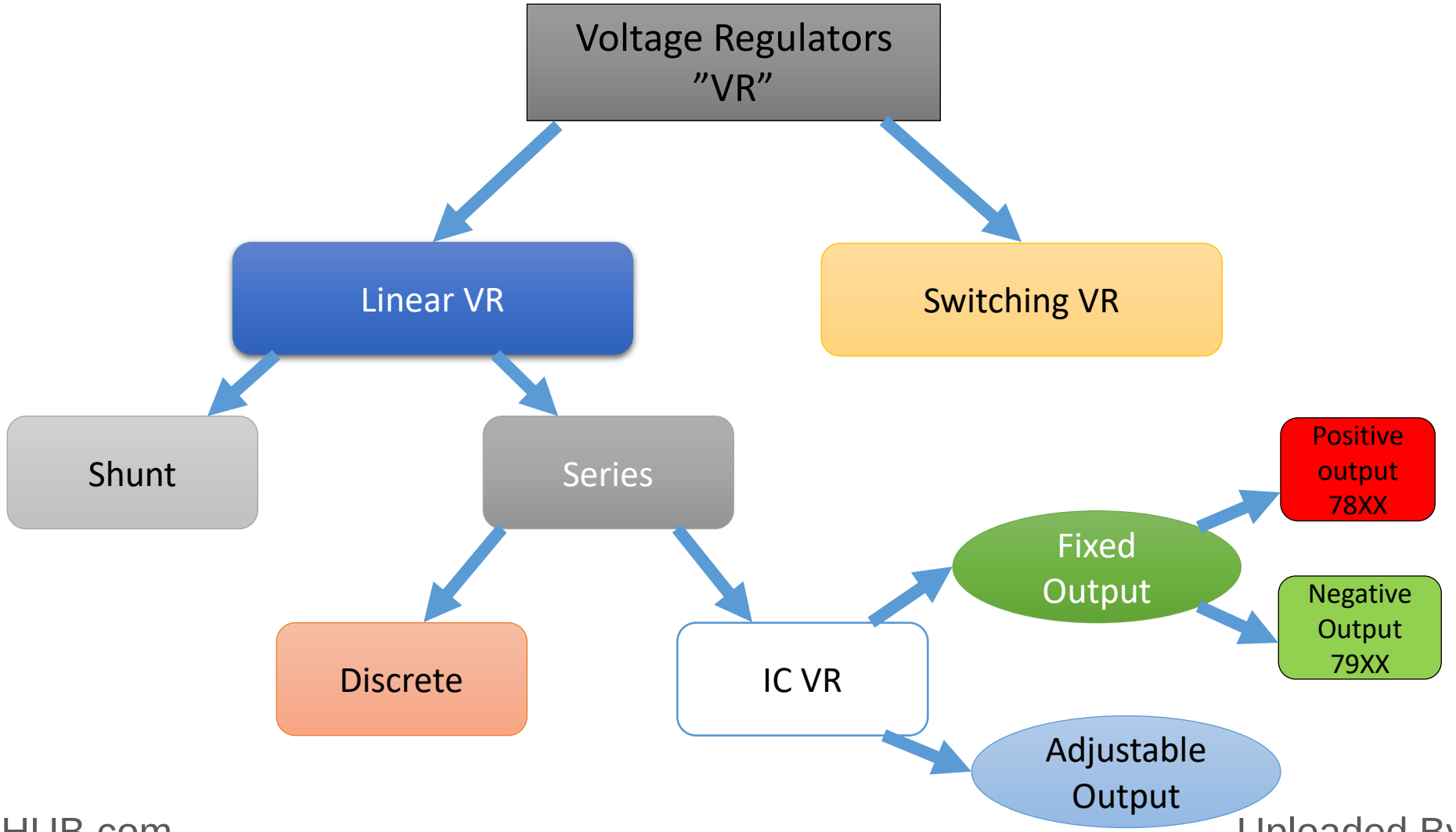


Disadvantages:

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.

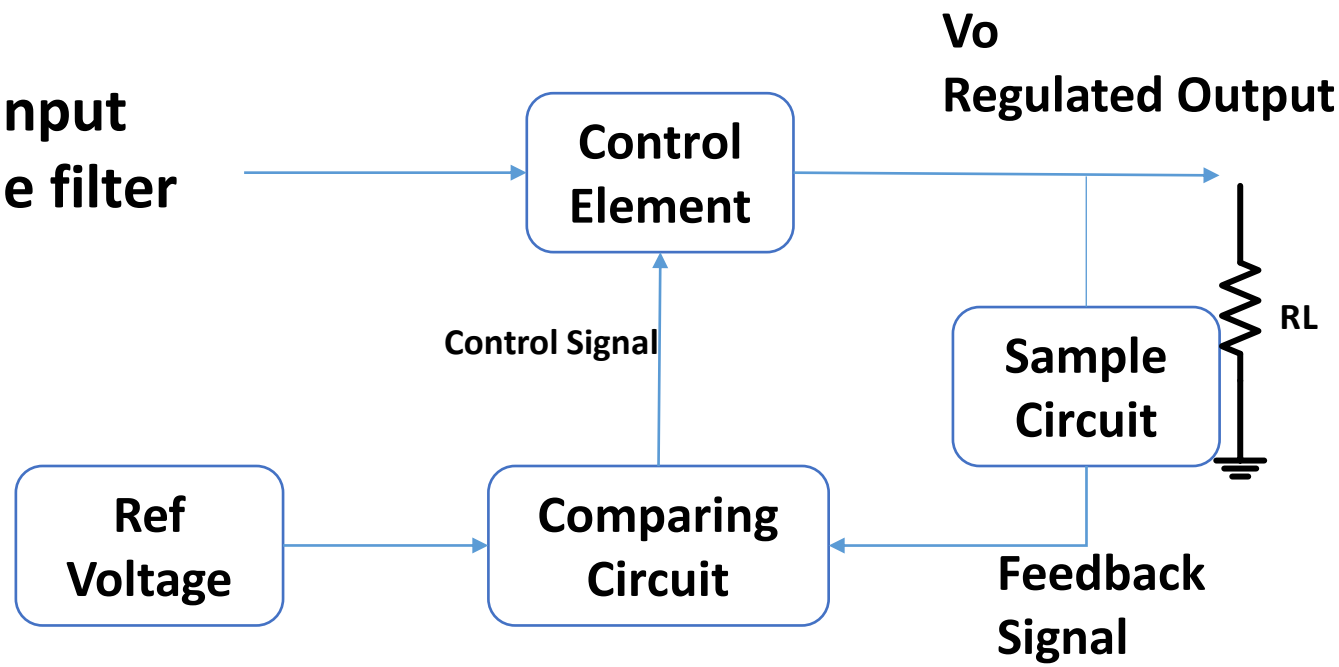
Types of Regulators



Voltage Regulator

Series Regulators

Vi unregulated input
The output of the filter



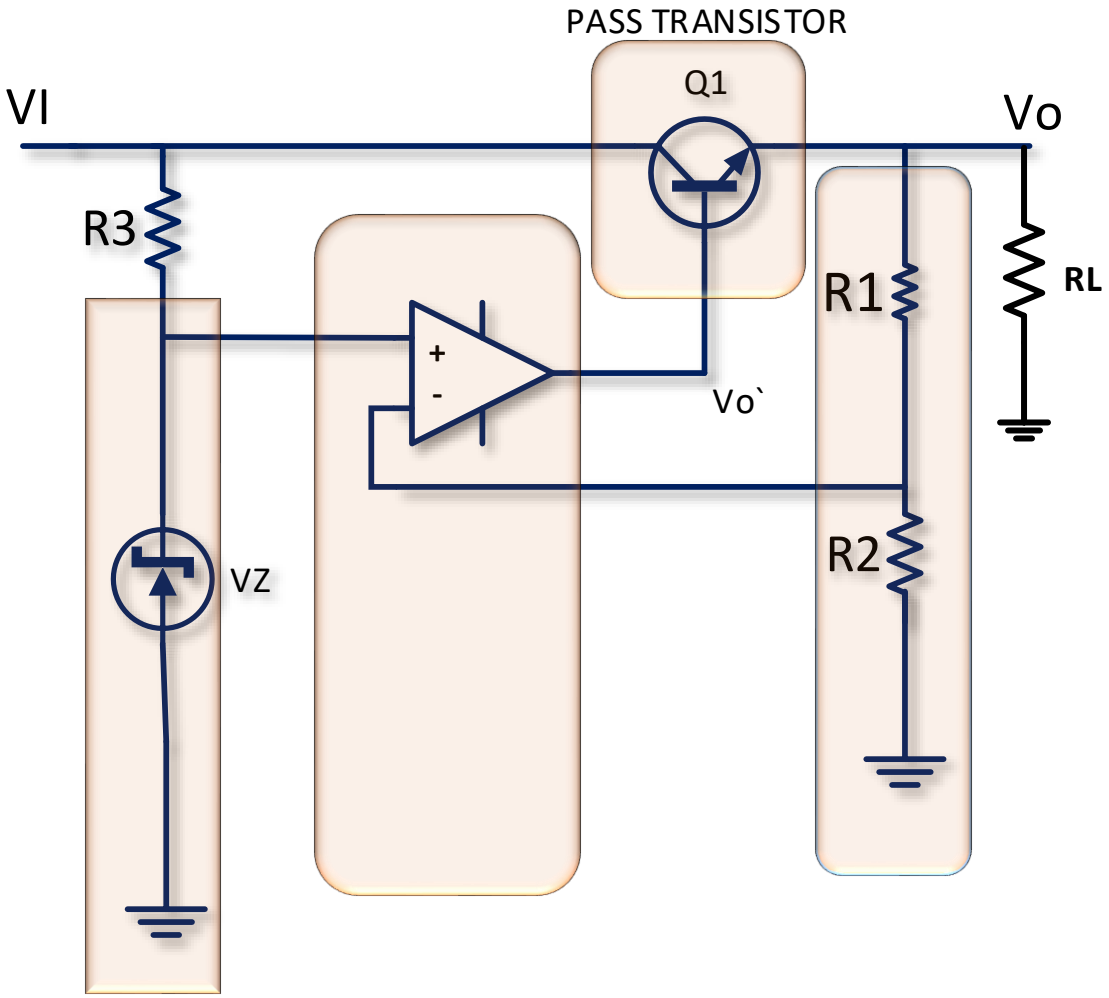
Blog Diagram of the series regulator

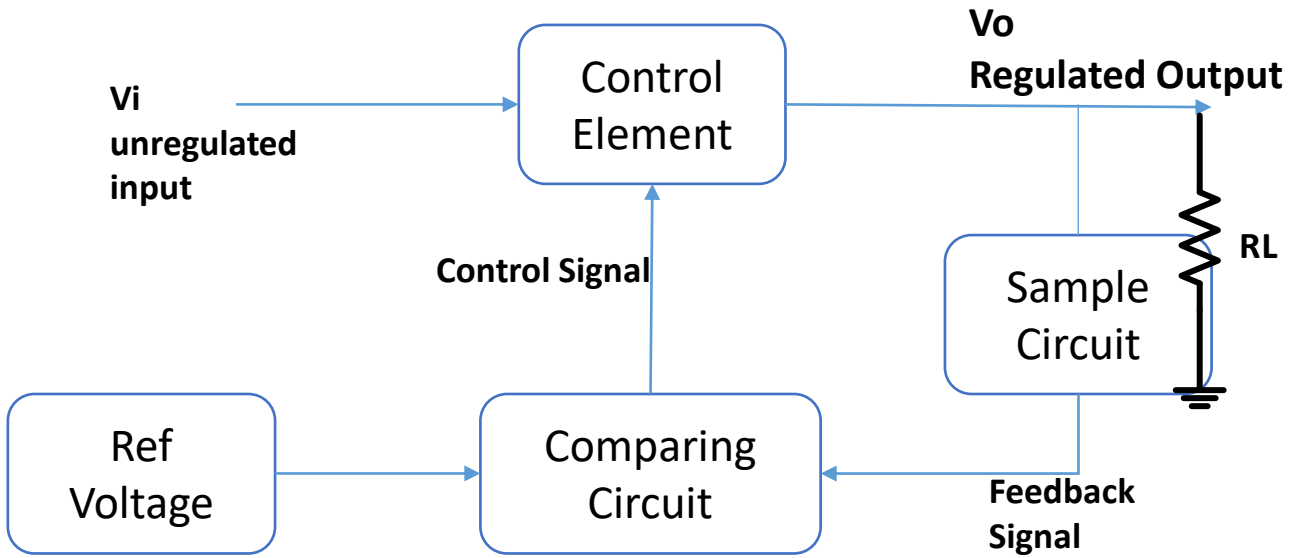
Control element: is a device whose operating state adjusts as necessary to maintain a constant Vo.

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

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

$$V(+) = Vz$$

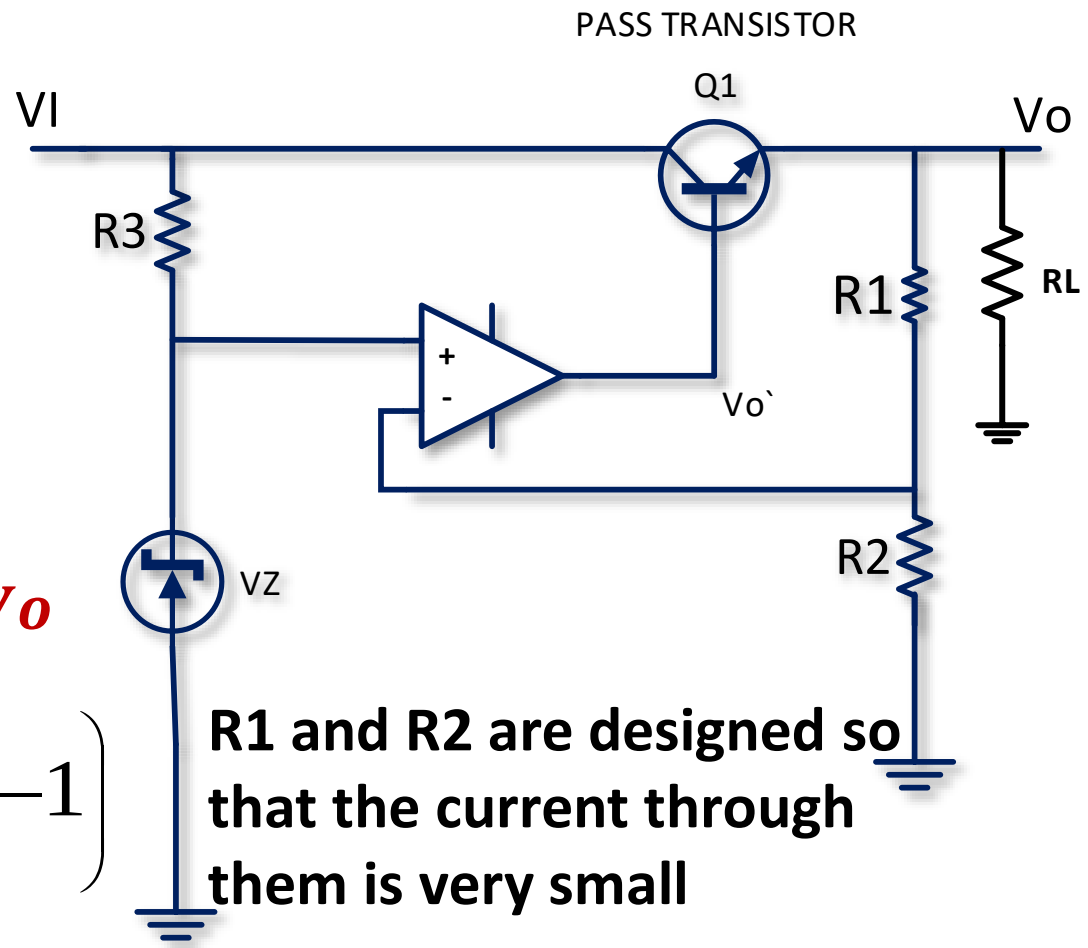
$$V(-) = V(+)$$

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

Operation:

$$Vo' = AdVd$$

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



VBE = $Vo' - Vo$

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

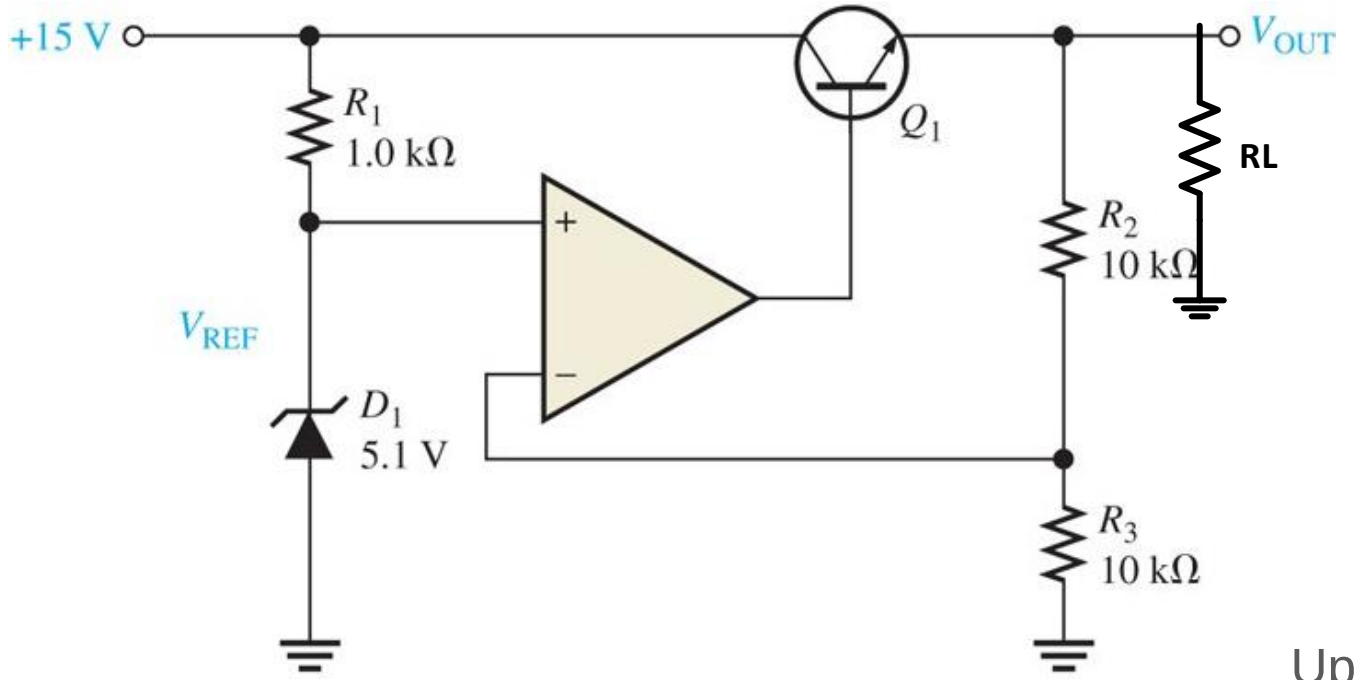
R1 and R2 are designed so that the current through them is very small

Assume Vo ↓ Vo' ↑ **VBE ↑** **IE ↑** **Vo ↑**

Example

Determine the output voltage for the regulator below.

$$V_o = \left(1 + \frac{R_2}{R_3}\right) V_Z \quad \Rightarrow \quad V_O = \left(1 + \frac{10\text{k}}{10\text{k}}\right) 5.1 = 10.2\ \text{V}$$

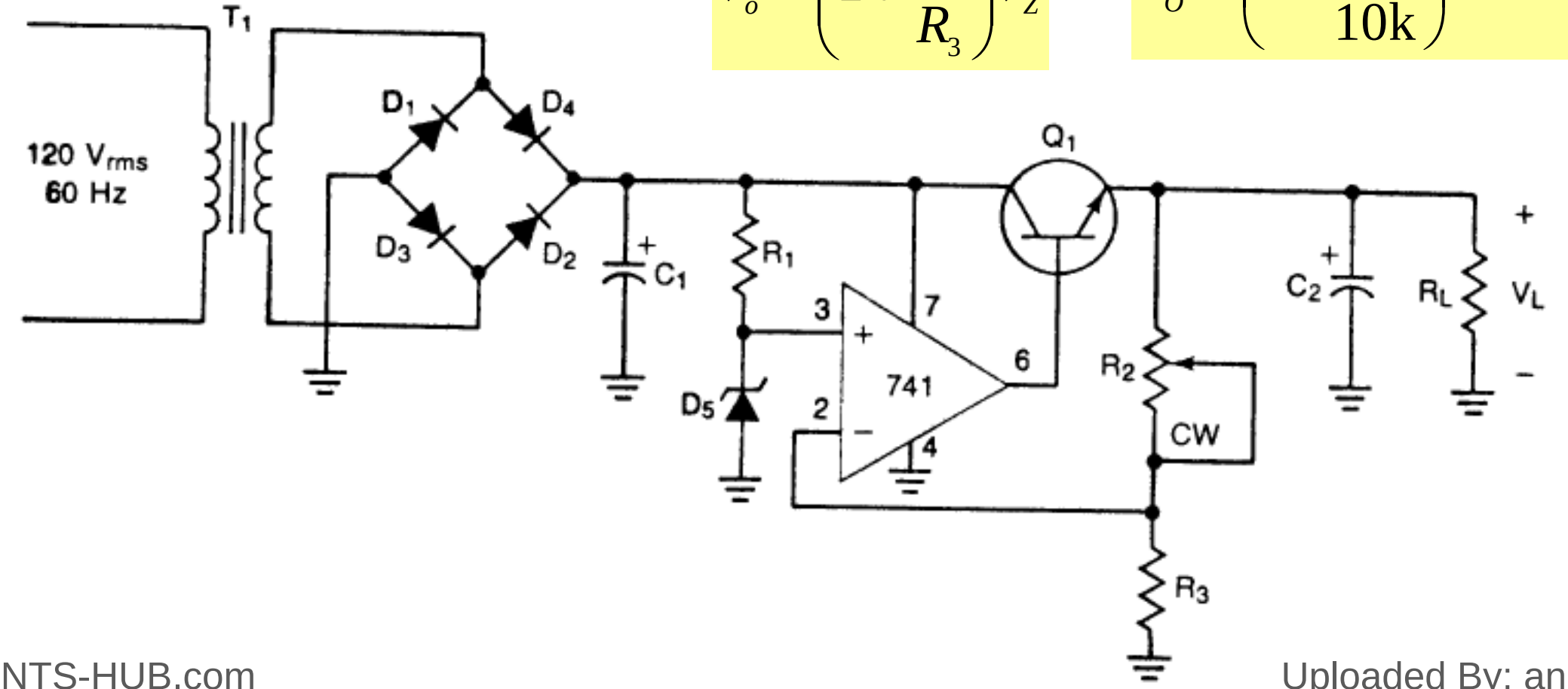


Practical DC Power supply

Determine the output voltage for the regulator below if R3 = R2 = 10K and Vz = 5.1V

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

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



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+1).Io

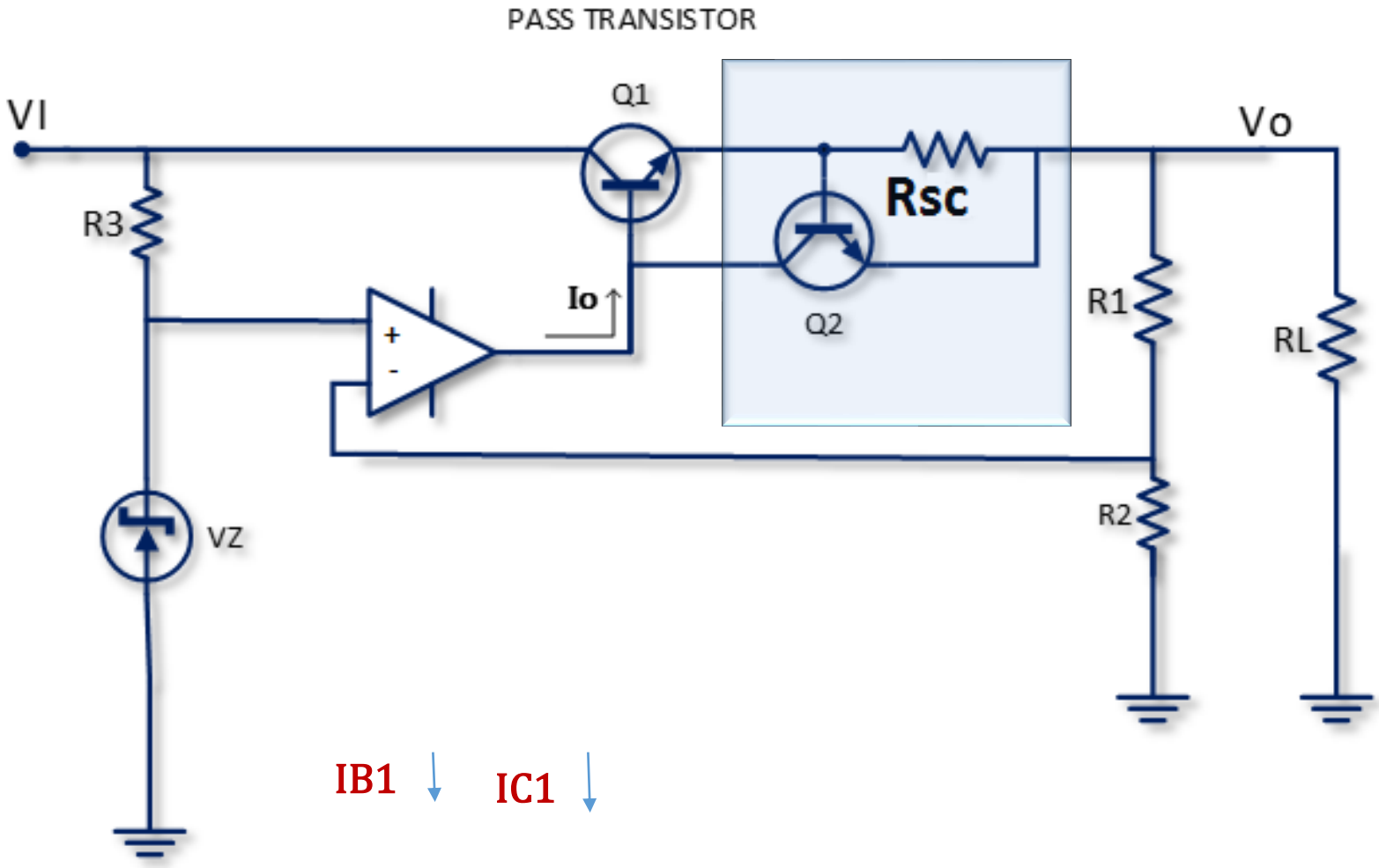
-when IL=IL(max)

VBE2 = 0.7V

Q2 turns on;

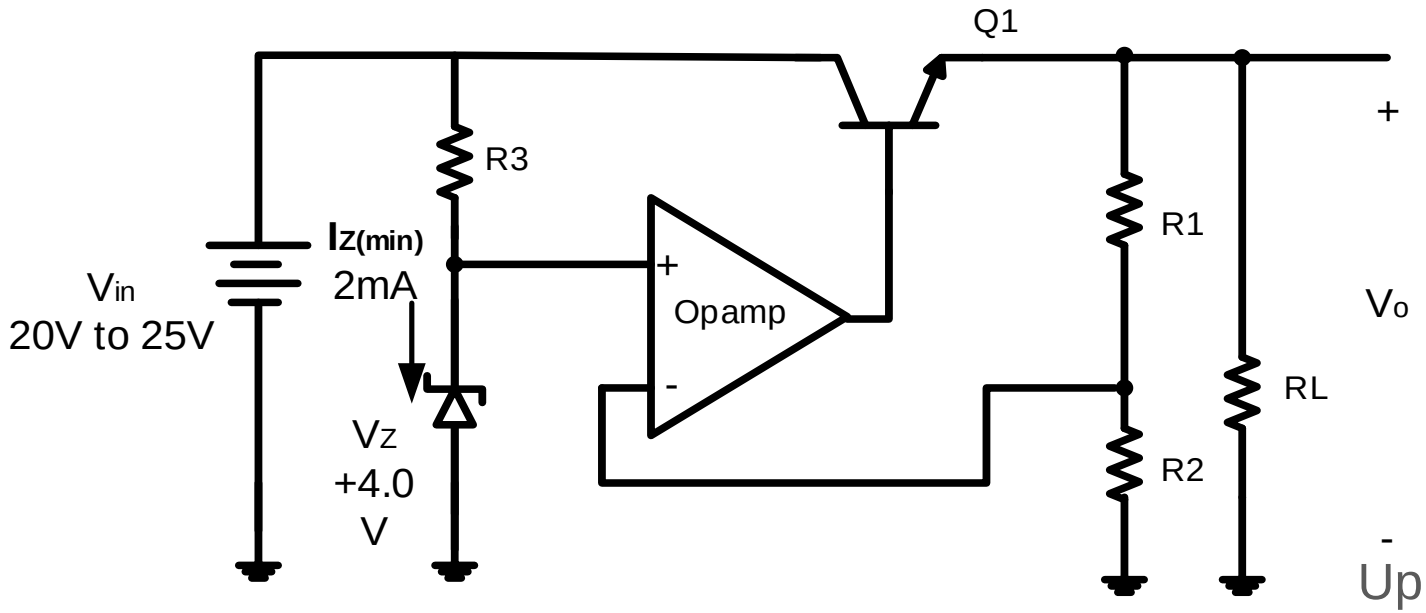
Io=IB1+IC2

Q1 will conduct less current

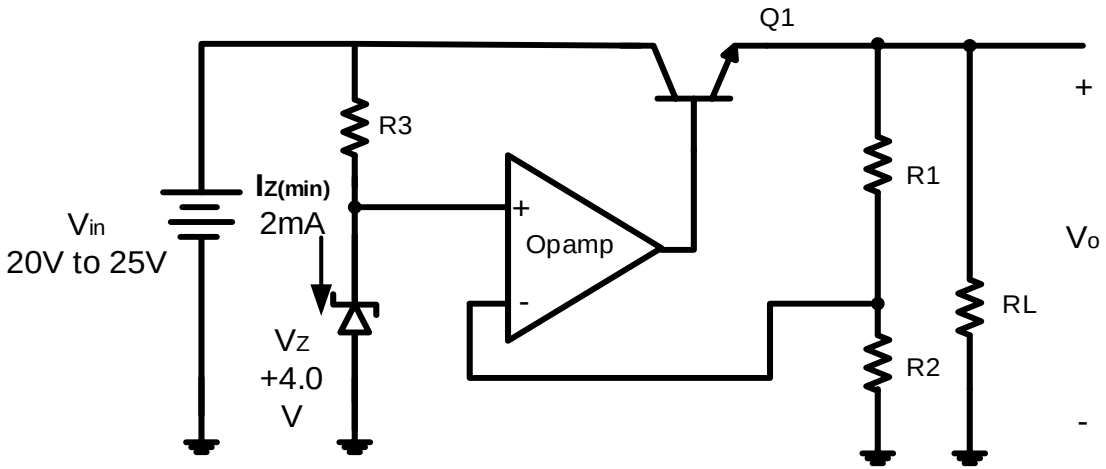


Voltage Regulators example

- Given the following series voltage regulator
- 1) Complete the design of the following voltage regulator (Find the values 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 =100Ω and when R_L =8Ω



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.



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

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

$$\Rightarrow \quad \text{choose } \text{R}_1 = 20\ \text{k}\Omega$$

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

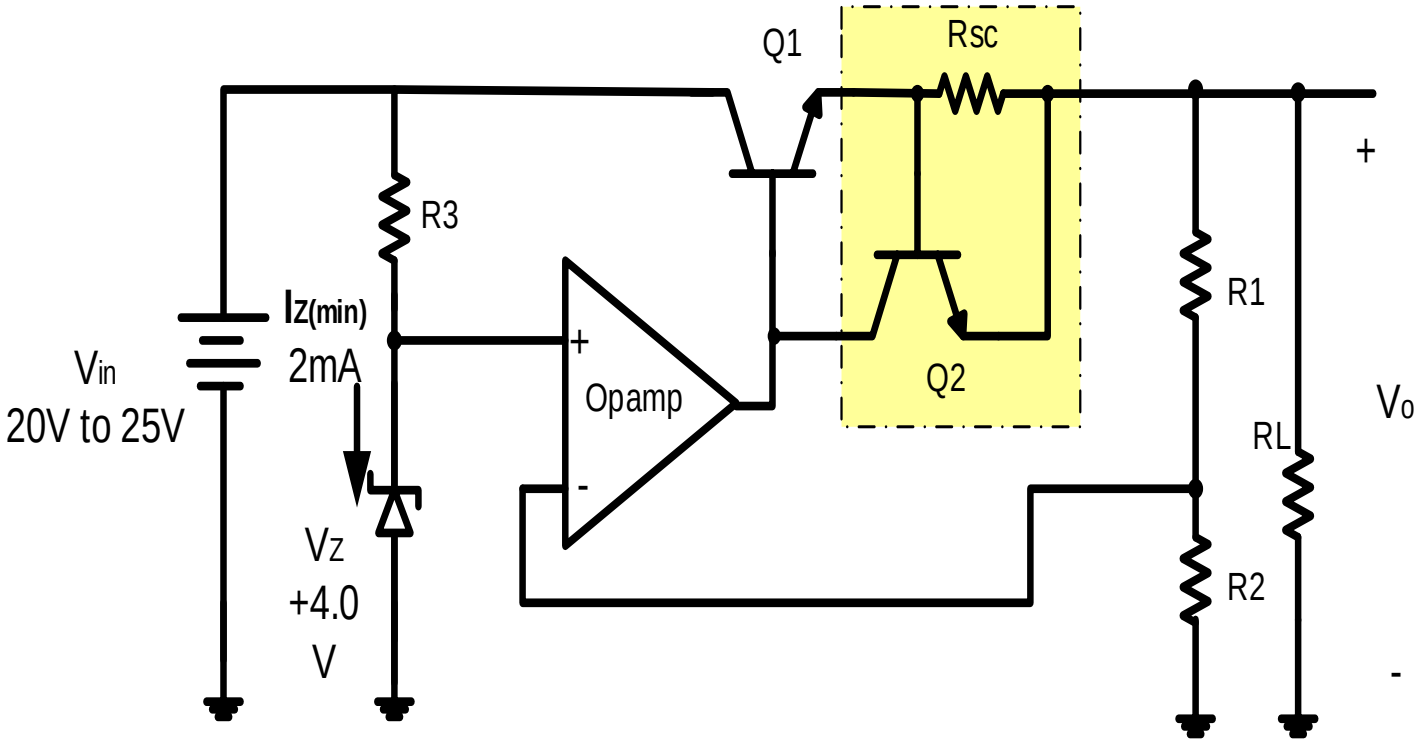
$$\text{I}_\text{Z} > \text{I}_{\text{Z(Min)}} = \frac{\text{V}_{\text{IN(Min)}} - \text{V}_\text{Z}}{\text{R}_3} \quad \Rightarrow$$

$$\text{R}_3 \leq \frac{\text{V}_{\text{IN(Min)}} - \text{V}_\text{Z}}{\text{I}_{\text{Z(Min)}}}$$

$$\text{R}_3 \leq \frac{20 - 4}{2\ \text{mA}} = 8\ \text{k}\Omega$$

Voltage Regulators

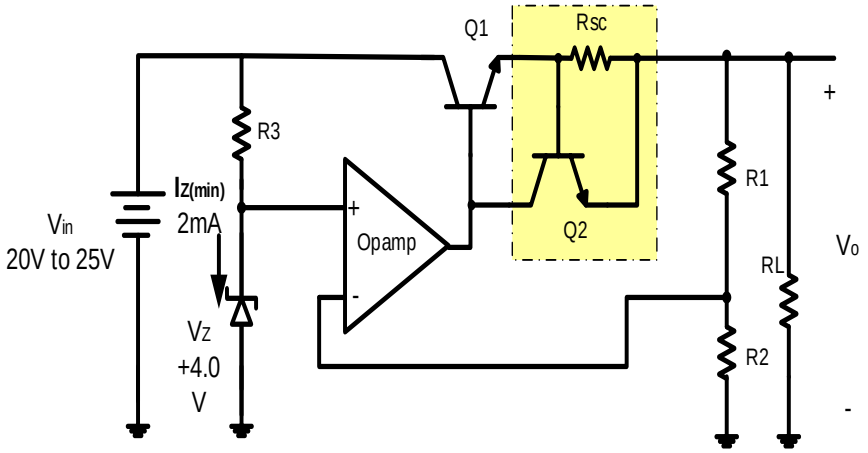
2)Show how to modify the circuit to limit the load current to 1A.



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

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

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



For $R_L = 100\ \text{ohm}$, Assume $Vo = 12V$, then $I_L = \dfrac{12V}{100\Omega} = 0.12A$ $\qquad I_{L(Max)} = 1A$

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

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

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

which is bigger than $I_{L(max)}$, and the current limit circuit

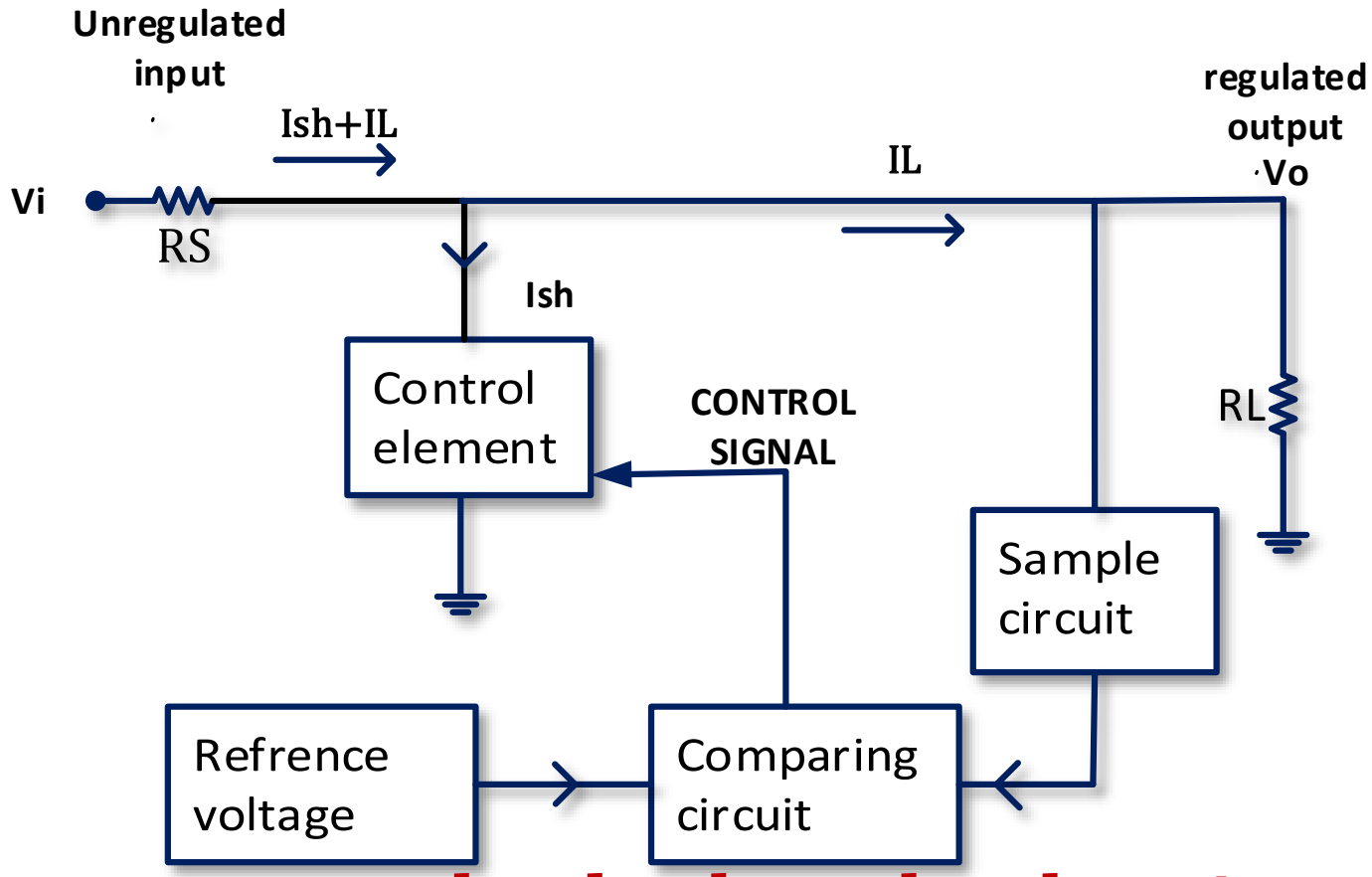
limits the current to the maximum allowable value which is 1 A

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

Voltage Regulator

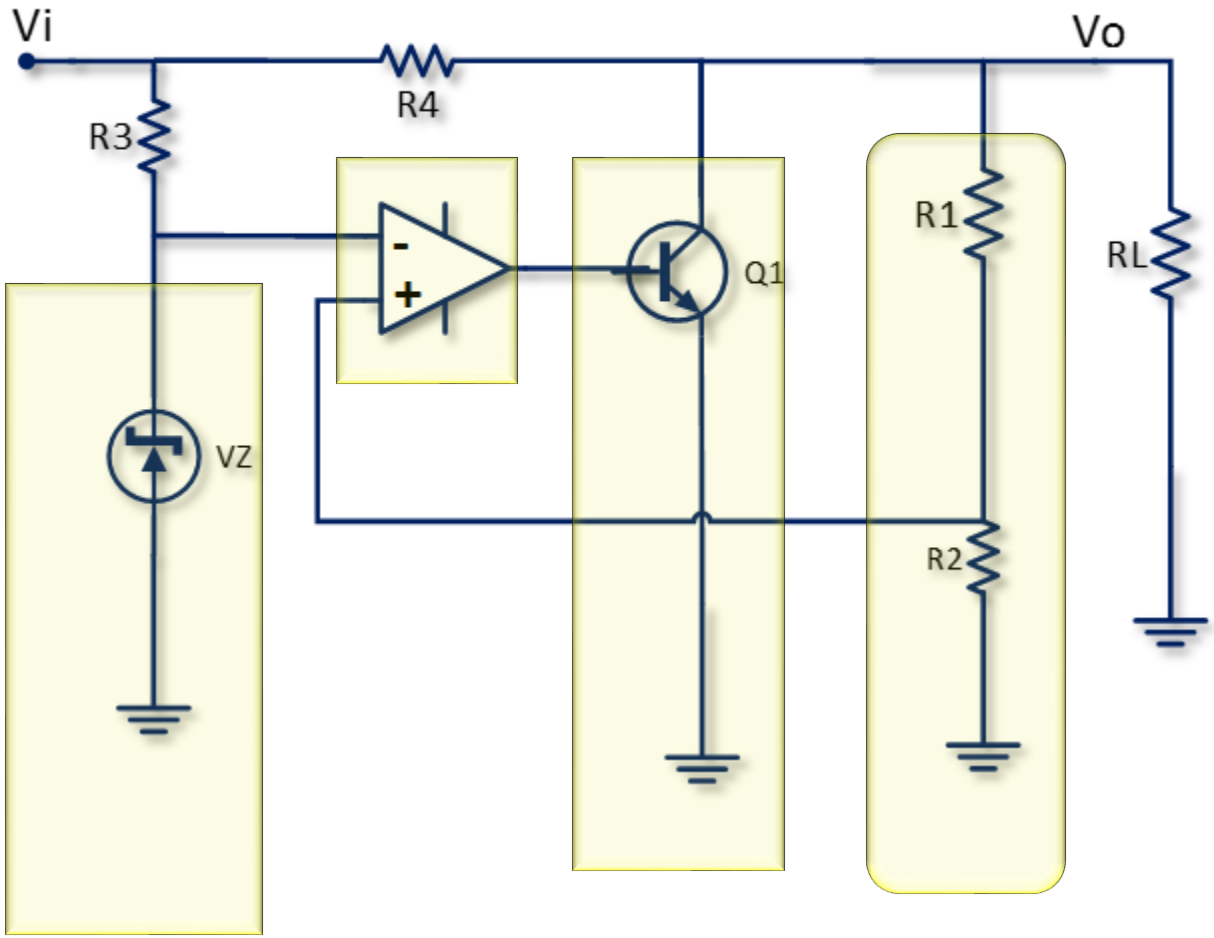
Shunt Regulators

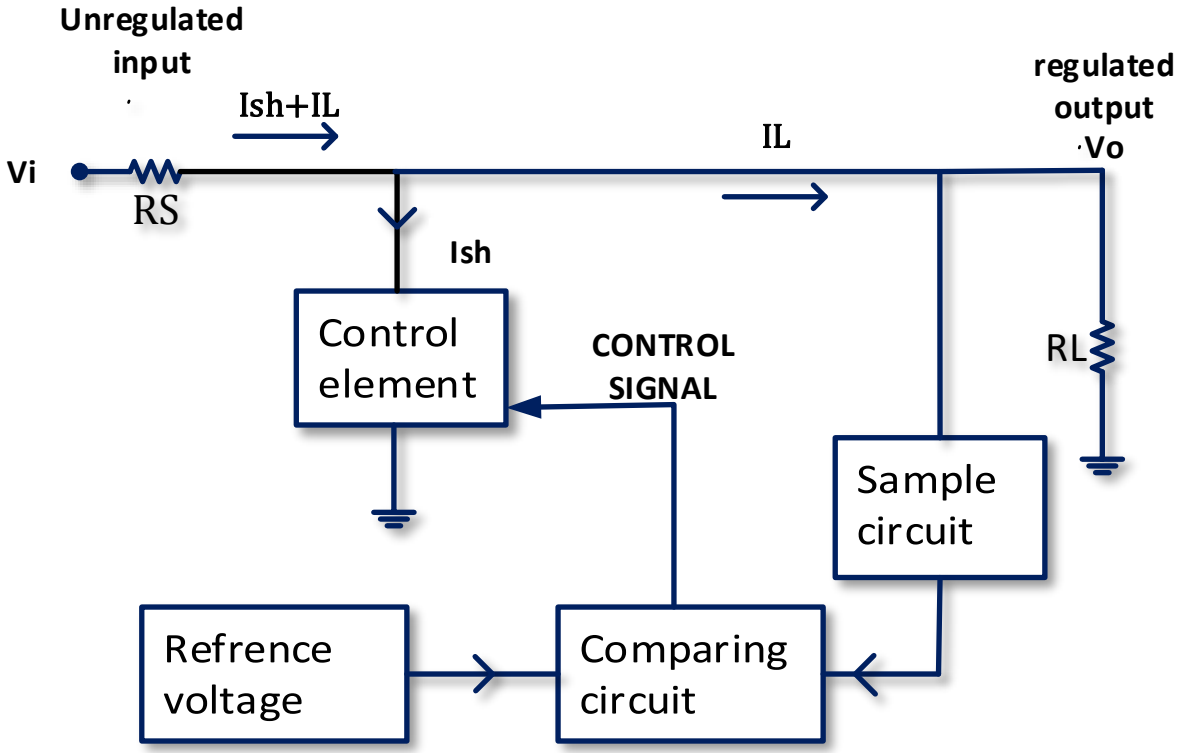
- The Control element is in parallel with the load



- 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

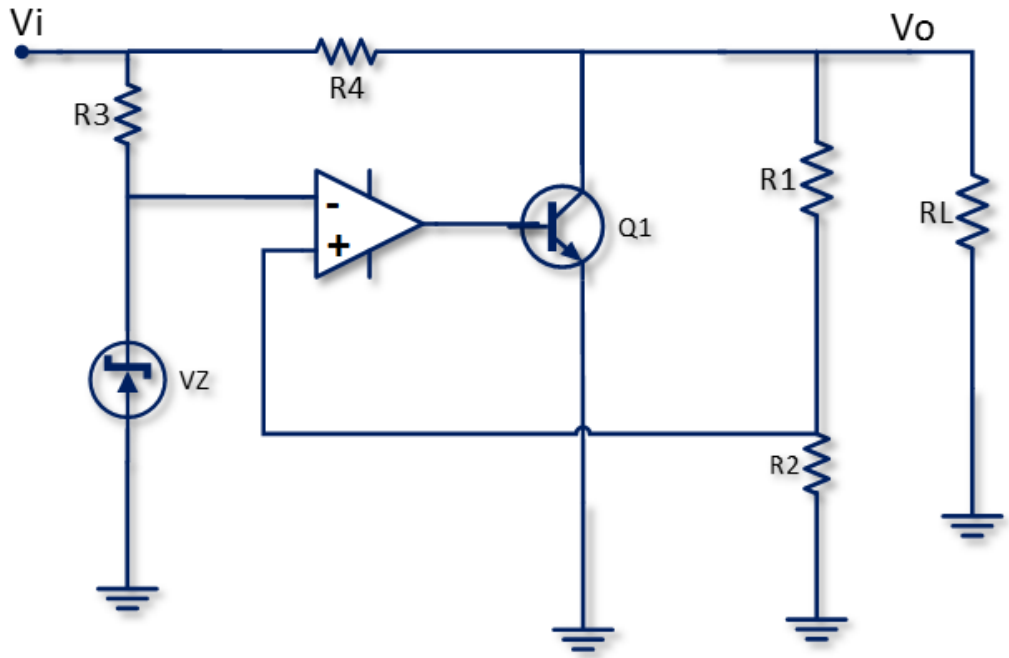
Shunt Regulators





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 ↓

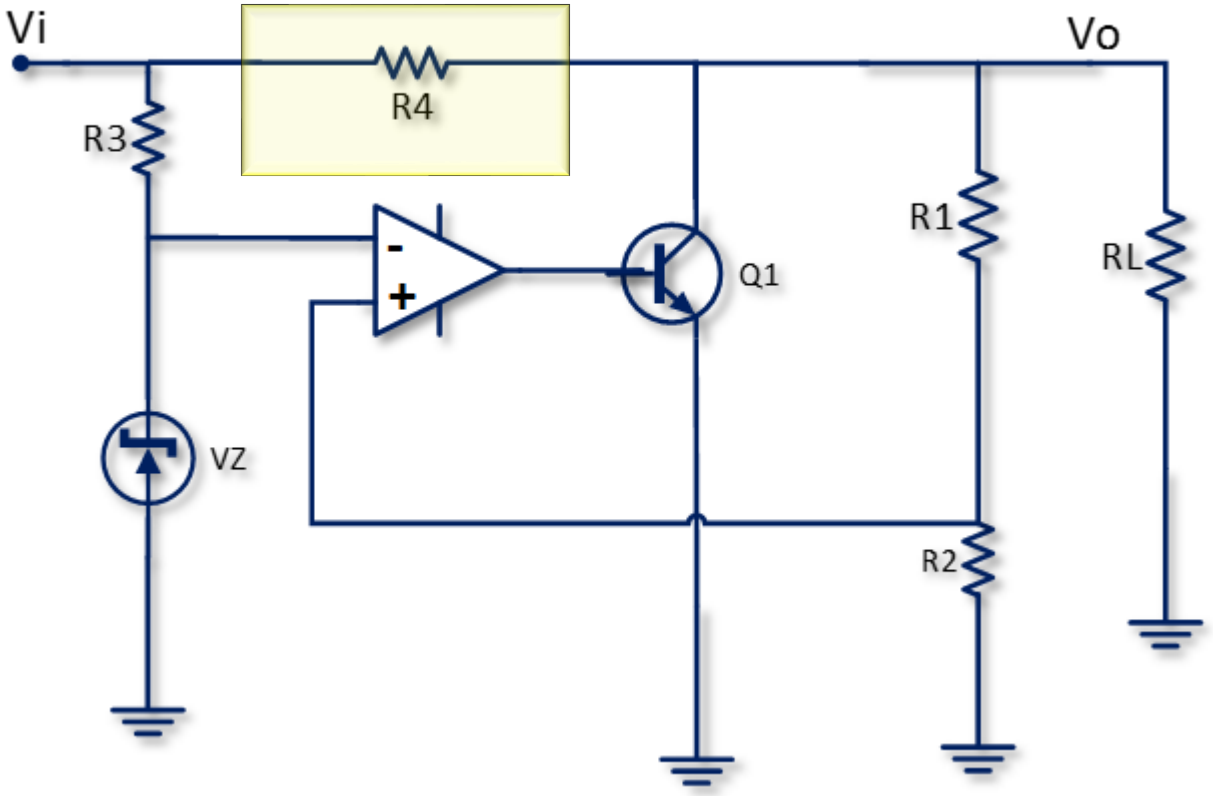
VBE = Vop

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

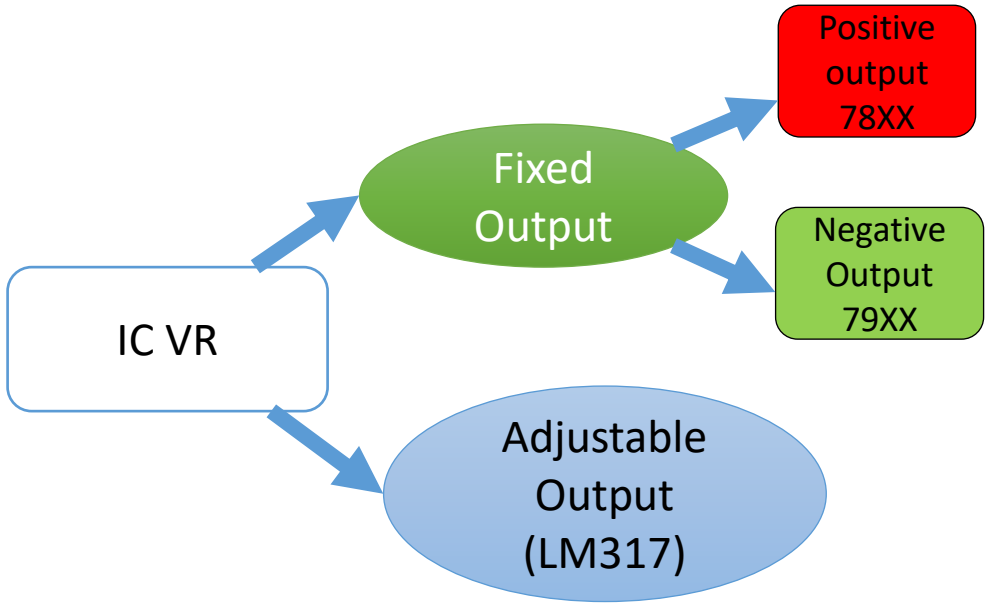
$\therefore$ ***The transistor conduct Less, Ic ↓, IL ↑ Vo ↑***

Current Limiting

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

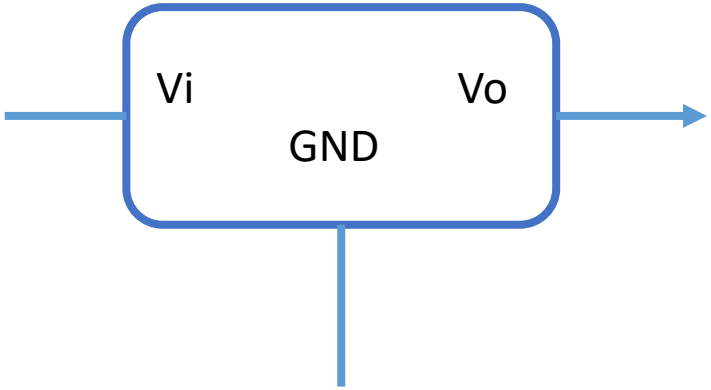


IC Voltage Regulator



Voltage Regulator

Three Terminal Circuit Regulators



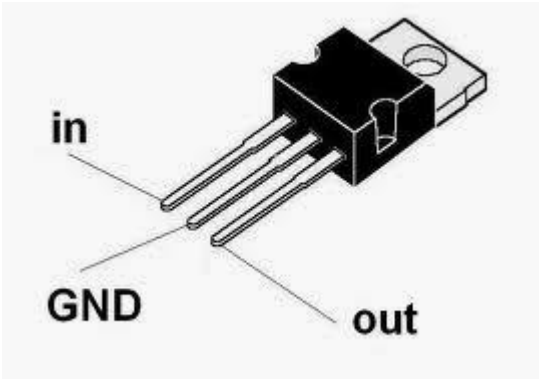
1- Fixed voltage regulator

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

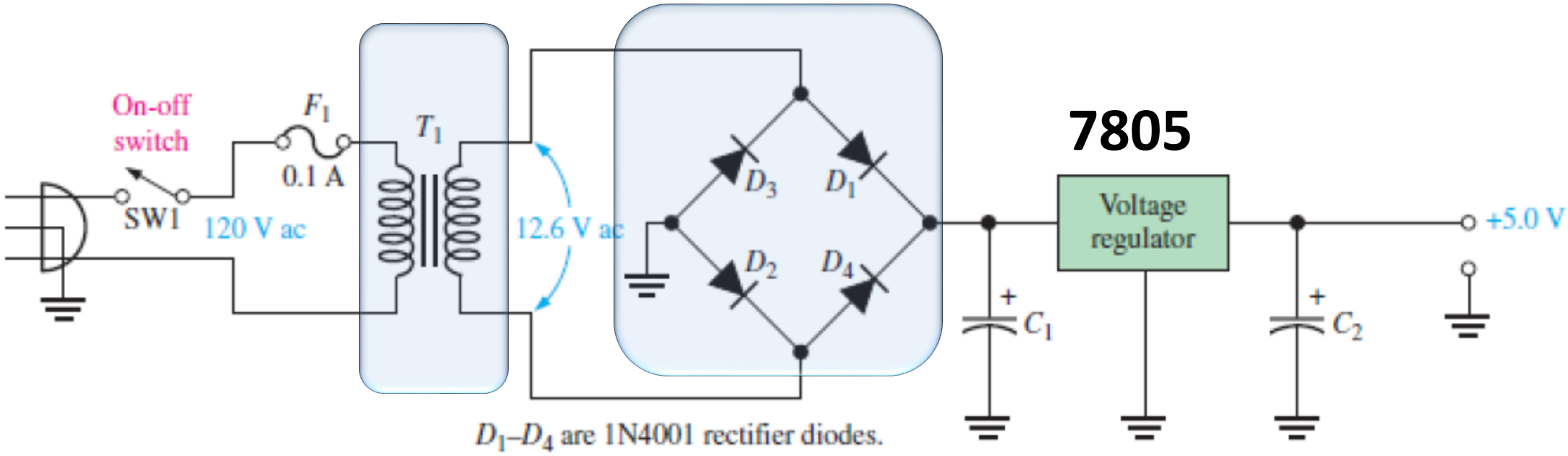
IC Part	Output Voltage (V)	Minimum V_i (V)
7805	+5	+7.3
7806	+6	+8.3
7808	+8	+10.5
7810	+10	+12.5
7812	+12	+14.5
7815	+15	+17.7
7818	+18	+21.0
7824	+24	+27.1

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

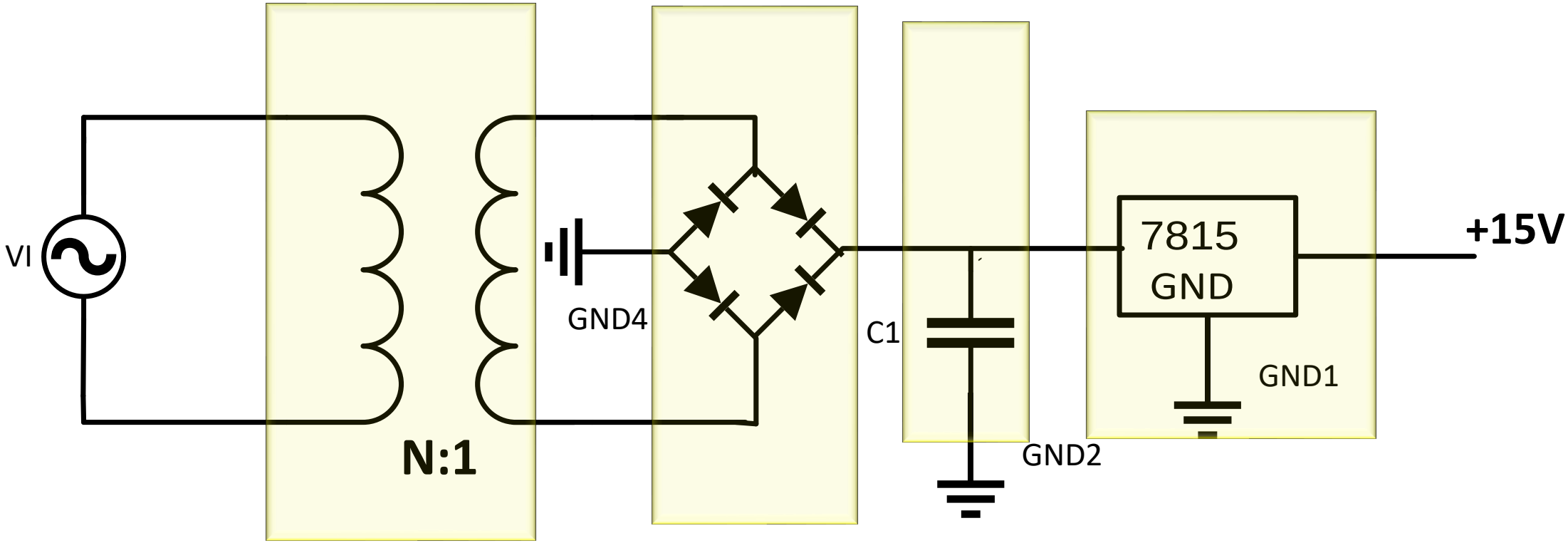
IC Part	Output Voltage (V)	Minimum V_i (V)
7905	-5	-7.3
7906	-6	-8.4
7908	-8	-10.5
7909	-9	-11.5
7912	-12	-14.6
7915	-15	-17.7
7918	-18	-20.8
7924	-24	-27.1



Voltage Regulator

Three Terminal Circuit Regulators

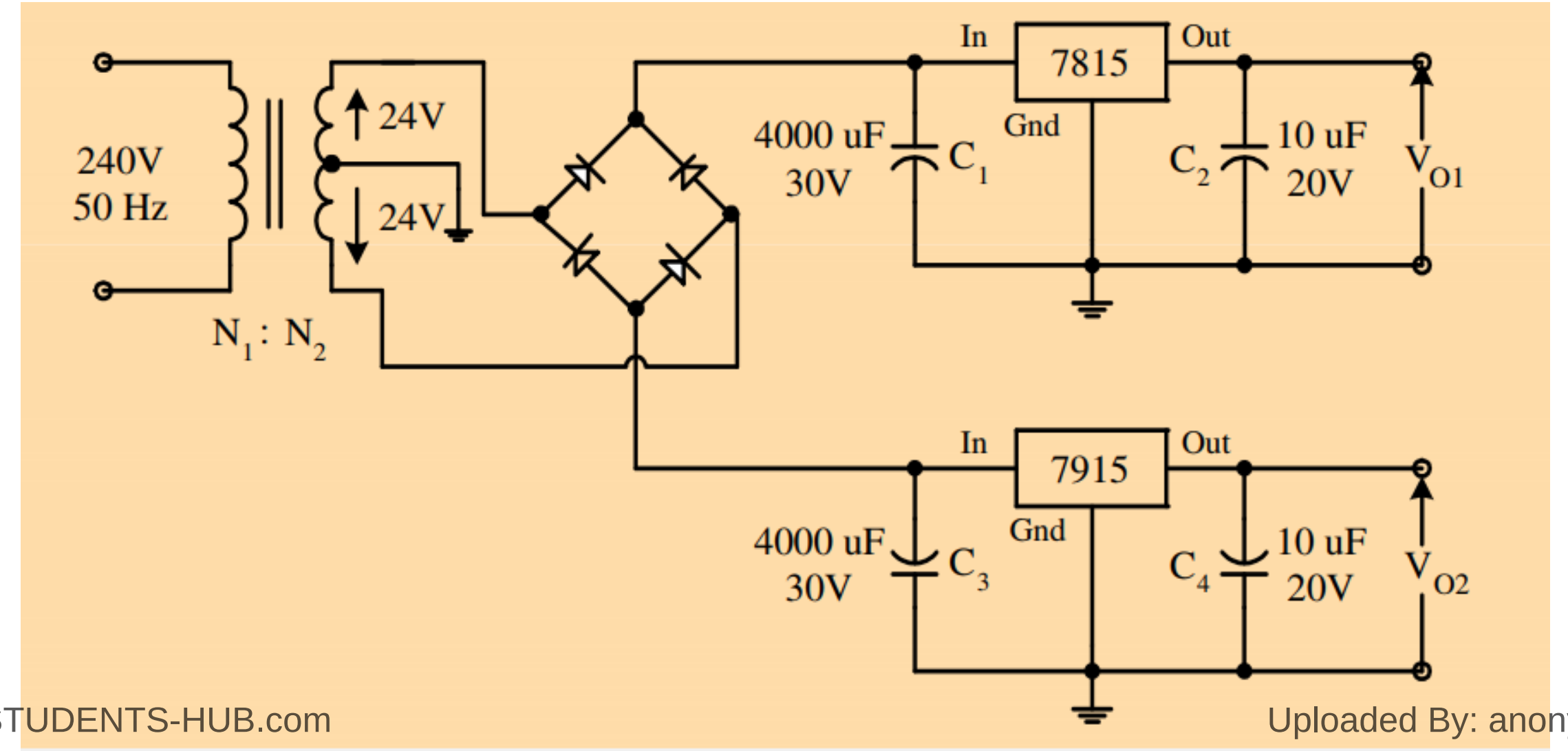
Dc Power Supply



Voltage Regulator

Three Terminal Circuit Regulators

Dual Polarity Dc Power Supply



Voltage Regulator

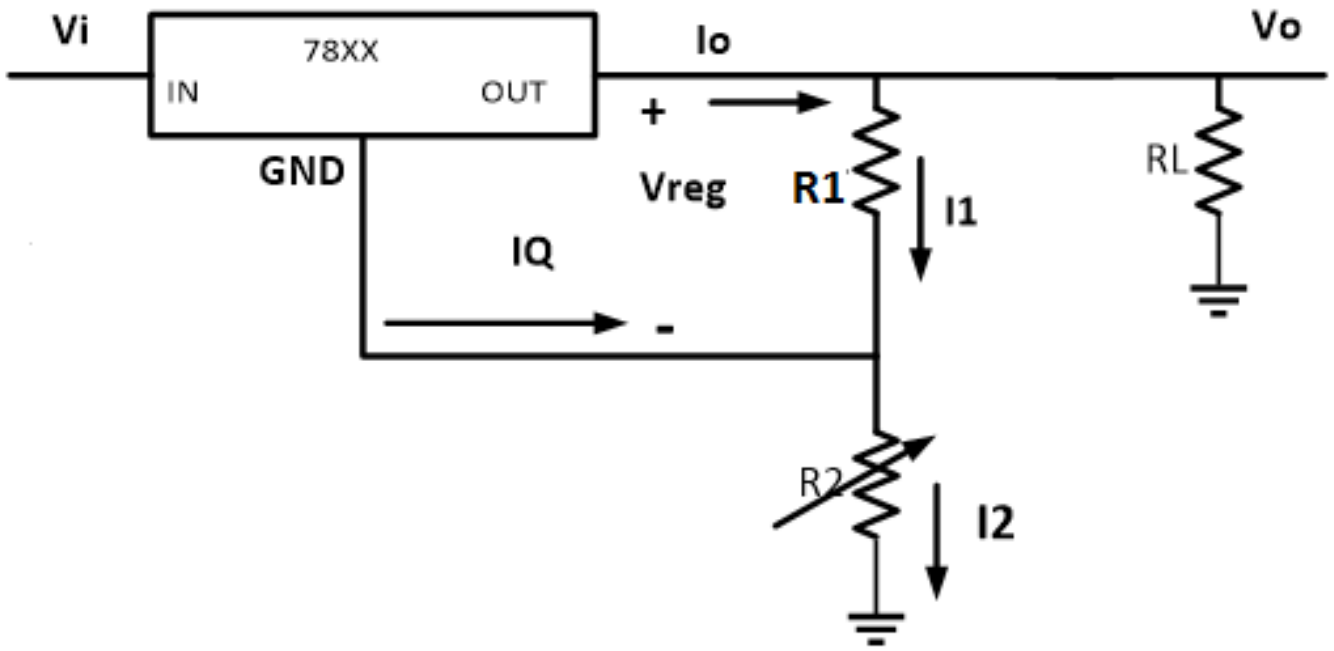
Changing the fixed Voltage Regulator to adjustable

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

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

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

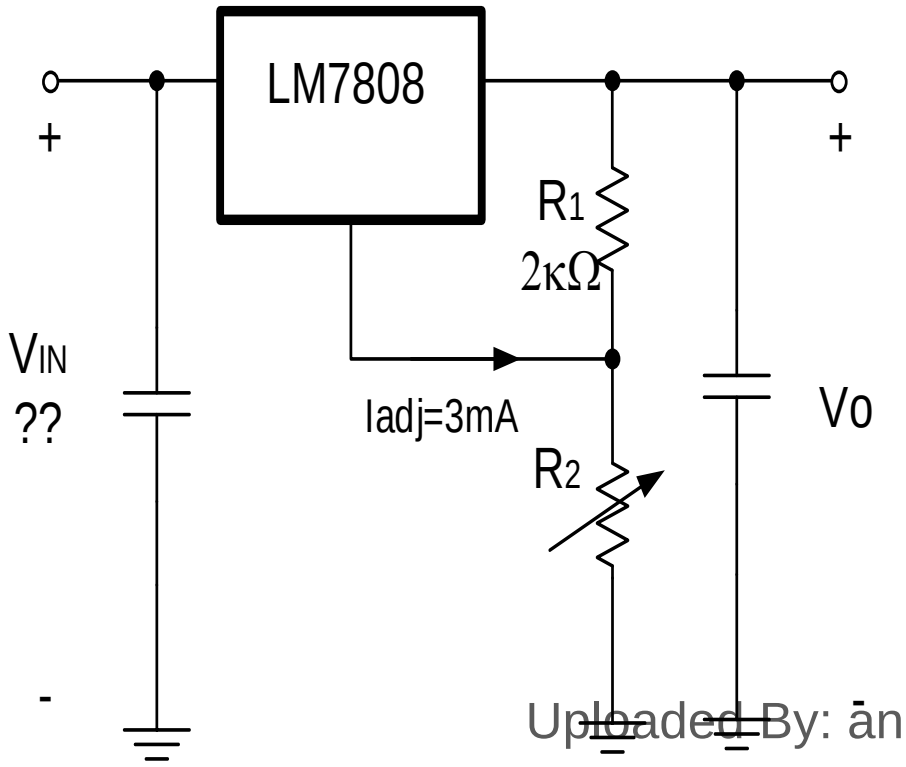
$$\therefore Vo = V_{REG}\left(1 + \frac{R_2}{R_1}\right) + R_2 I_Q$$



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**



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

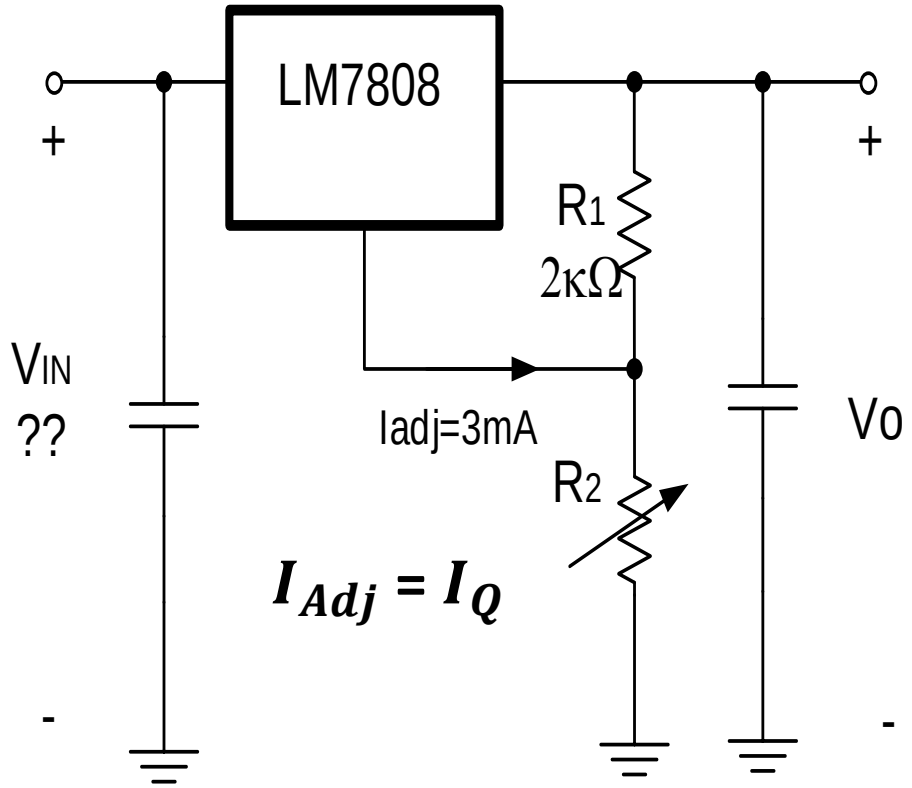
$$\therefore Vo = V_{REG}\left(1+\frac{R_2}{R_1}\right)+R_2 I_Q$$

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

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

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

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



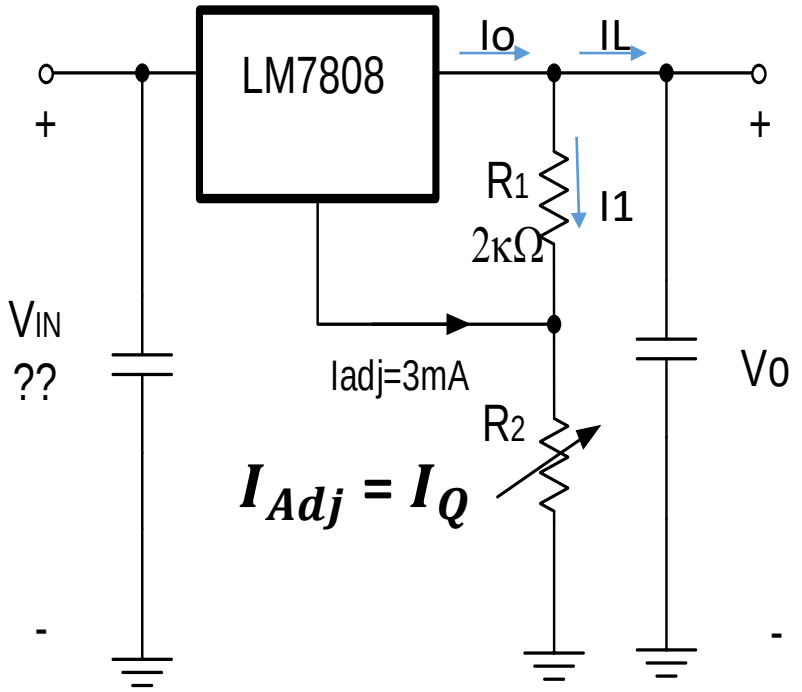
What is the range of values of VIN required for proper operation of the circuit ?

Vin must be higher than Vo by at least 2V

When Vo = 8V , Vin = 8+2= 10V

When Vo = 29V , Vin = 29+2= 31V

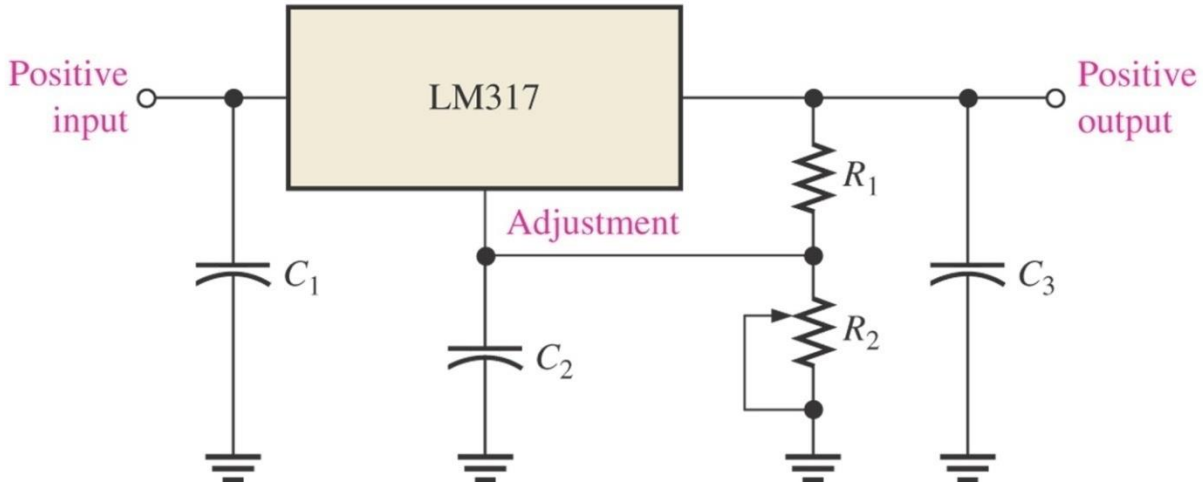
Vo = 8V when R2 = 0Ω
Vo = 29V when R2 = 3KΩ



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 37 V.



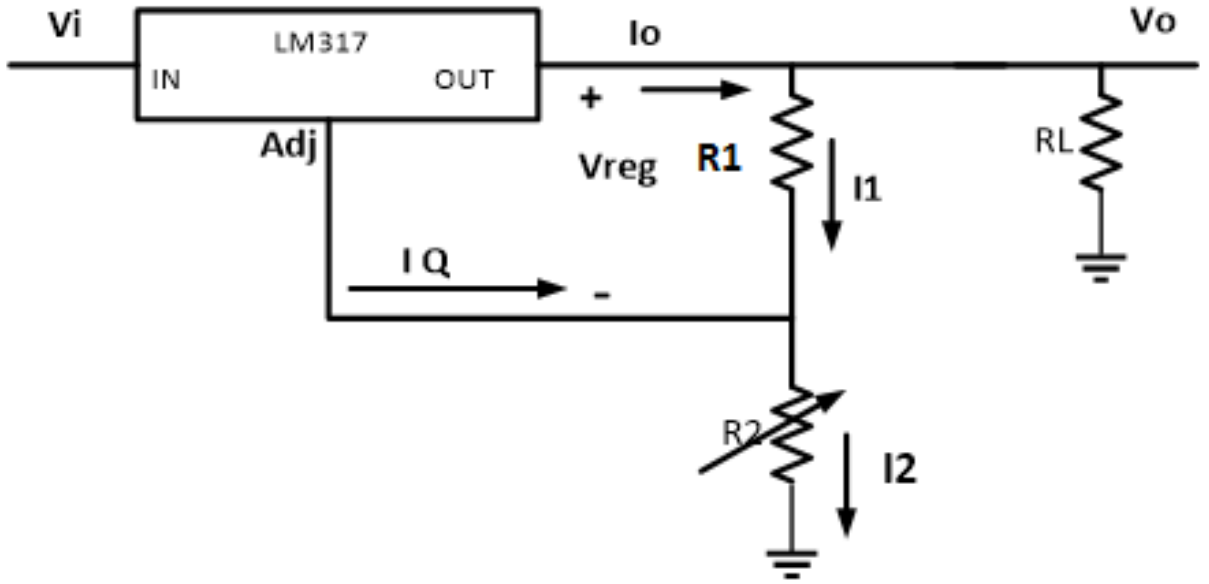
Voltage Regulator

2- Adjustable Voltage regulator

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

Io,max =1.5 A

V_{REG} = 1.25 V



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

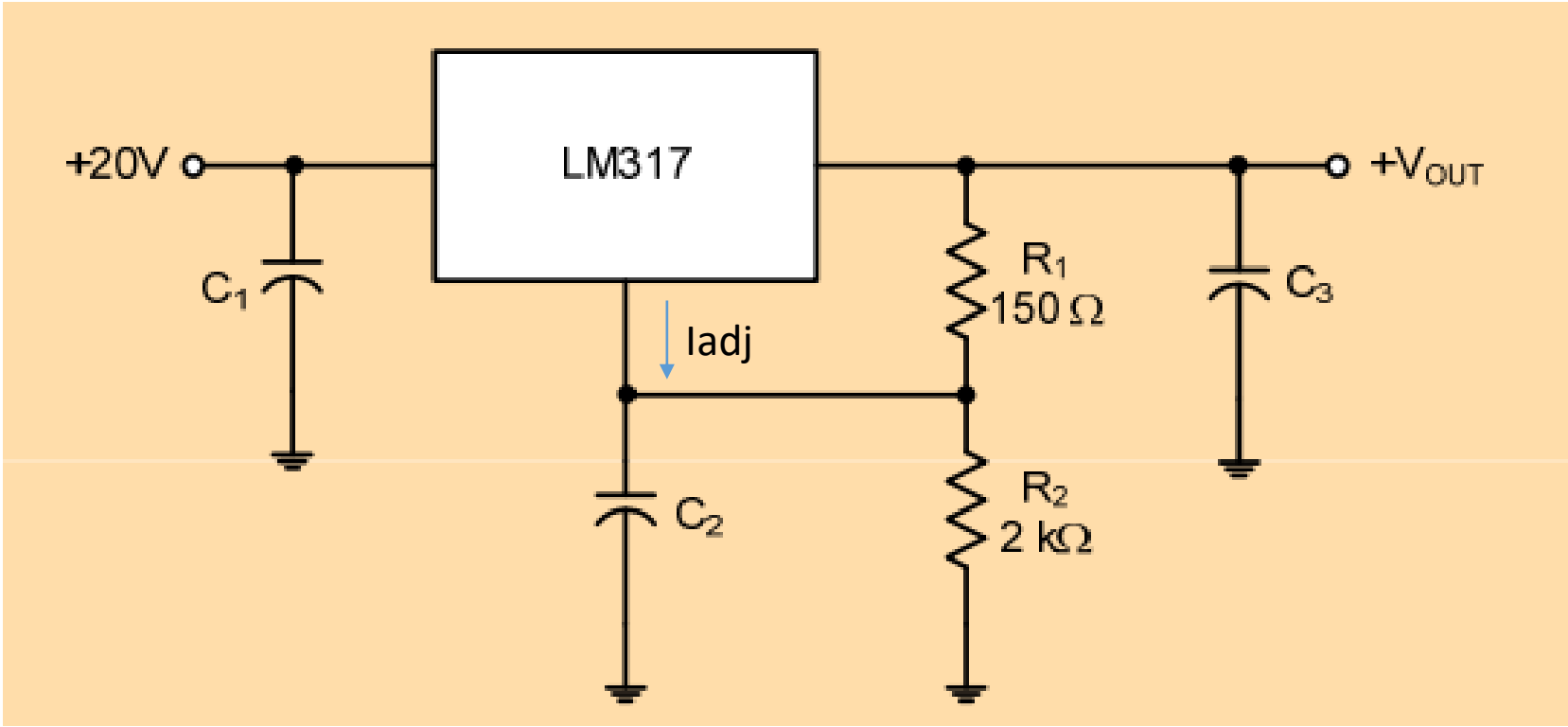
$$Vo = V_{REG} + R_2(I_1 + I_Q)$$

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

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

What is the value of the output Vou?

Assume Iadj = 50 µA



$$V_{OUT} = 1.25V\left(1+\frac{2k\Omega}{150\Omega}\right)+(50\mu A)(2k\Omega)$$

$$= 18.02\,V$$

Adjustable Negative Linear Voltage Regulators