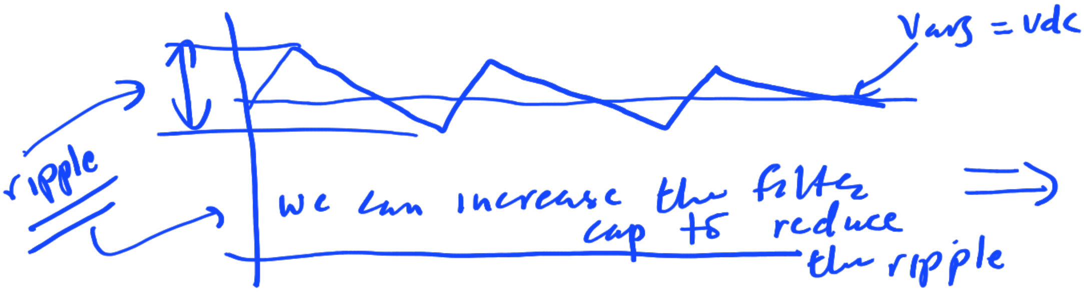
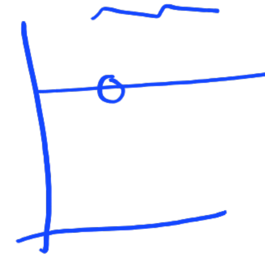
L28 - part 2



we can increase the filter cap to reduce the ripple ⟹

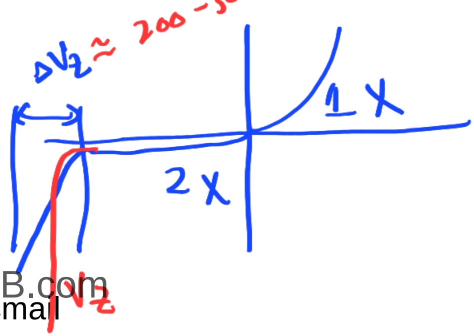


ENEE2360 Analog Electronics

T13:
Voltage Regulator

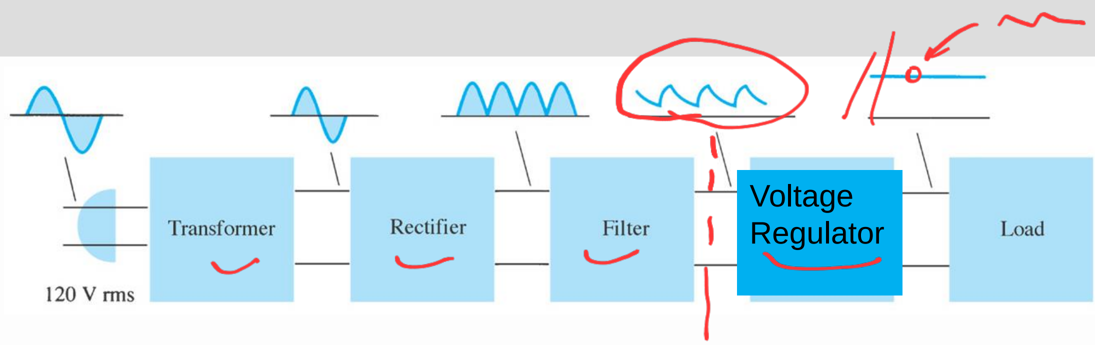
Instructor : Nasser Ismail

Zener can be used as voltage Regulator



CPU ⟹ 1.5 V ± 25 mV

Introduction

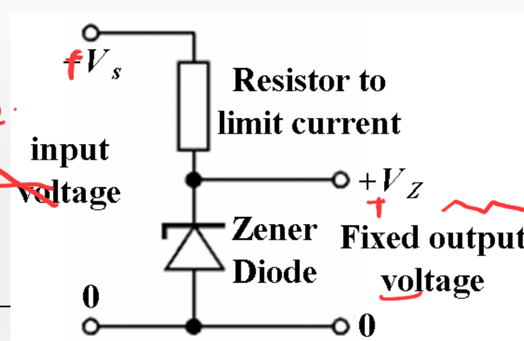


- ***Regulator***: a circuit used to produces a ***constant*** dc output voltage by reducing the ripple to negligible amount regardless of variation of input voltage and load within reasonable limits

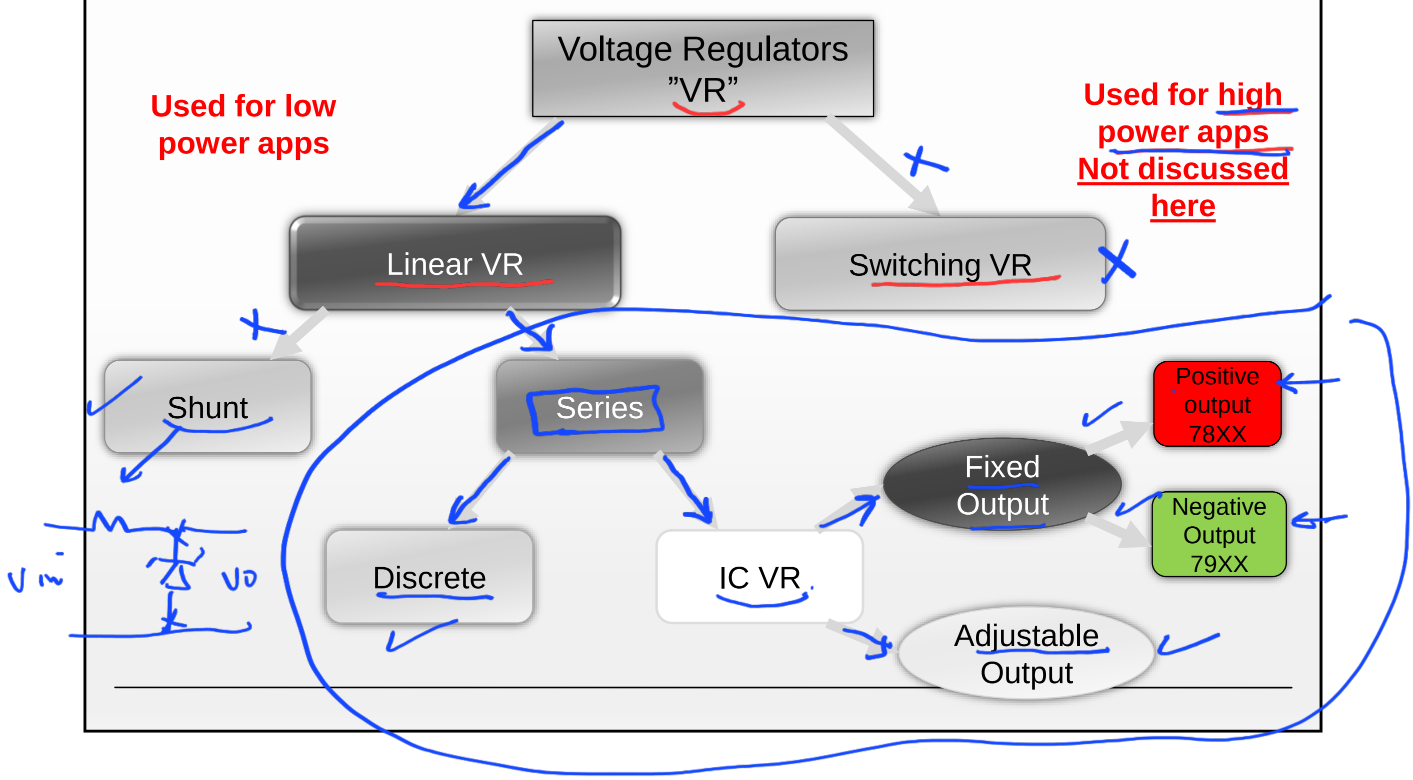
Voltage Regulators

The simplest voltage regulator is Zener diode regulator studied in details earlier

- Zener is used for low current power supplies –
  a simple voltage regulator can be made with a resistor and a zener diode connected in reverse.
- Zener diodes are rated by their breakdown voltage V_z and maximum power P_z (typically 400mW or 1.3W)



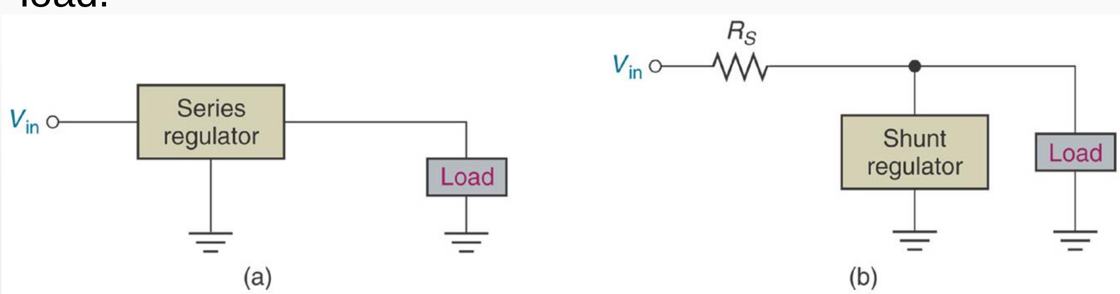
Types of Regulators



End of L28

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.



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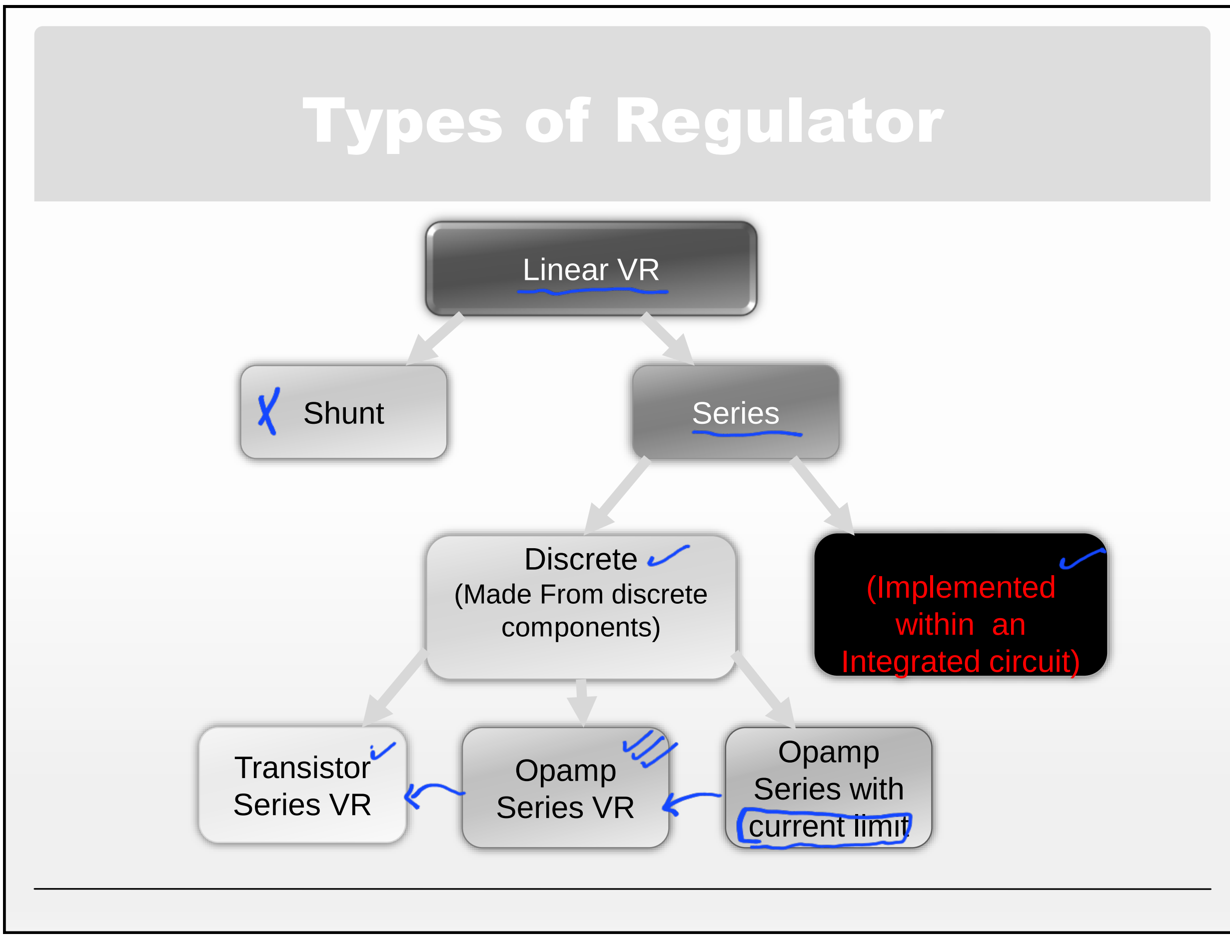
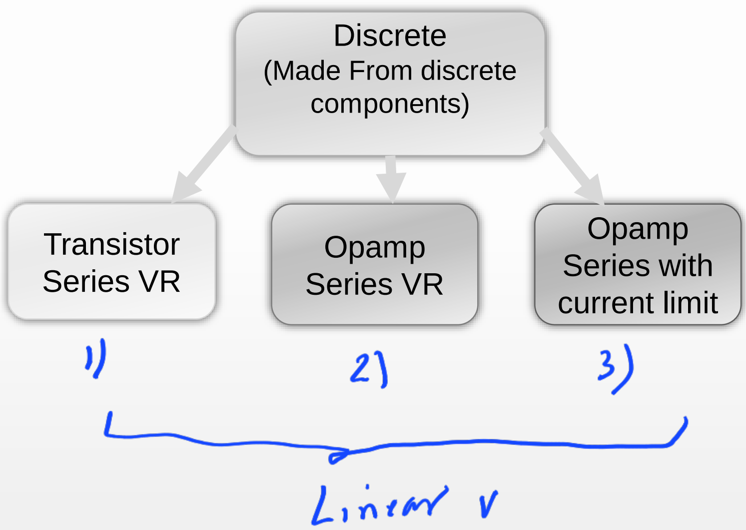
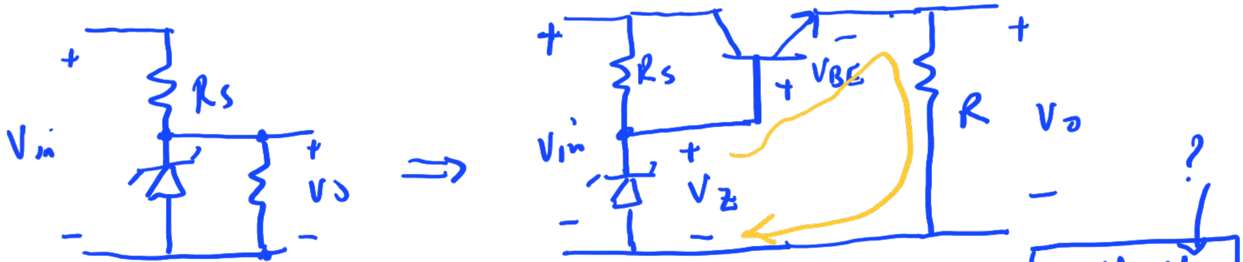

Types of Regulator
Linear VR
✗ Shunt
Series
Discrete ✓
(Made From discrete components)
(Implemented within an Integrated circuit) ✓
Transistor Series VR ✓
Opamp Series VR ✓✓✓
Opamp Series with current limit

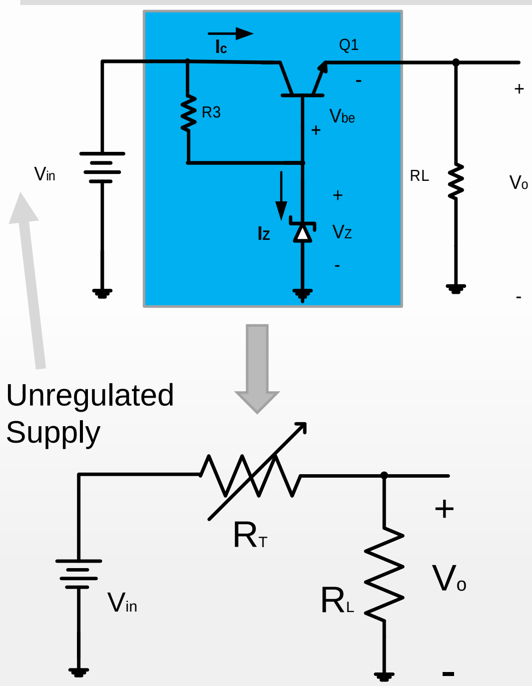
Discrete Regulators





$V_Z - V_{BE} - V_o = 0 \Rightarrow V_o = V_Z - V_{BE}$

Transistor Series VR

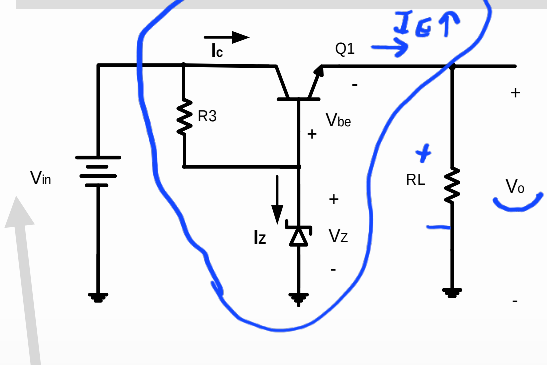


The Transistor behaves like a simple variable resistor whose resistance is determined by the operating conditions

$$V_O = \frac{R_L}{R_L + R_T} V_{IN}$$

RT is changed in response to changes in Vin and RL such that to keep Vo almost constant

Transistor Series VR



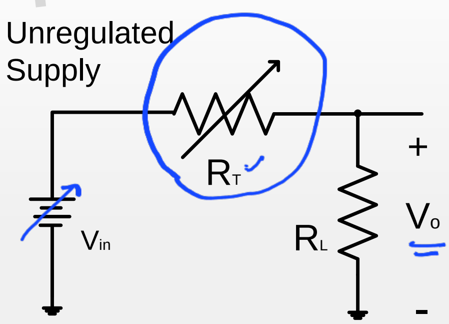
$$V_o + V_{be} = V_z$$

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

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

$\Leftarrow V_{be}$ is the control signal

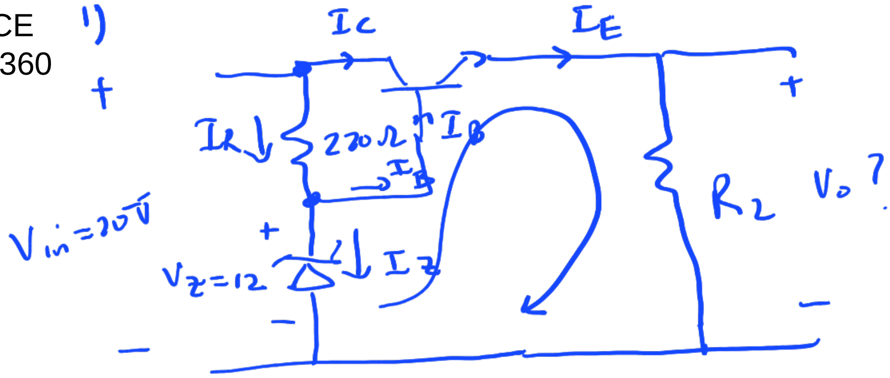
remember $I_C = I_S\left(e^{\frac{v_{be}}{\eta V_T}} - 1\right)$

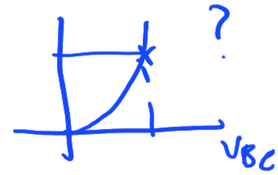


If $V_o \downarrow, (V_{be} = V_z - V_o)\uparrow,$

$I_C \uparrow \quad V_o \uparrow$

1)





$I_Z \approx I_R = \frac{20-12}{220} = 36\,mA$

$I_R = I_B + I_Z$

$I_B << I_Z$

$V_o = V_Z - V_{BE}$; $V_{BE} \approx 0.7$

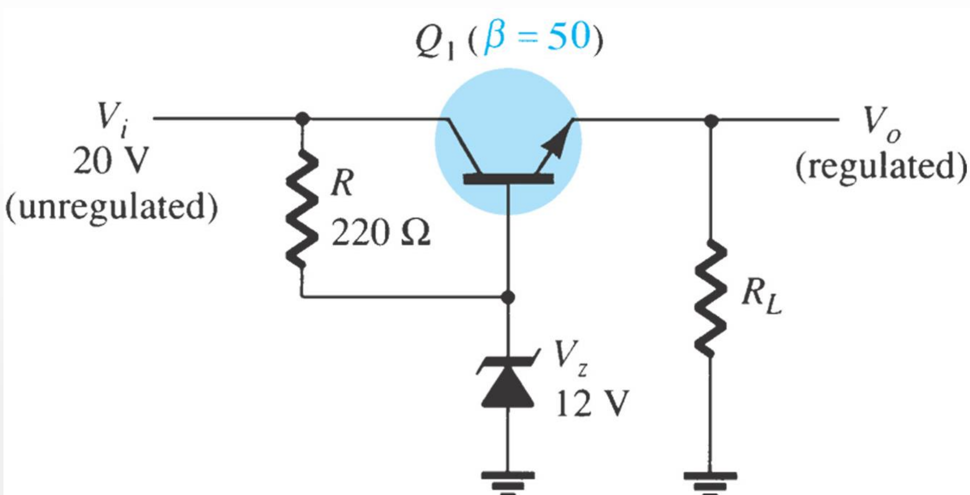
$V_o \cong 12 - 0.7 = 11.3\ V$

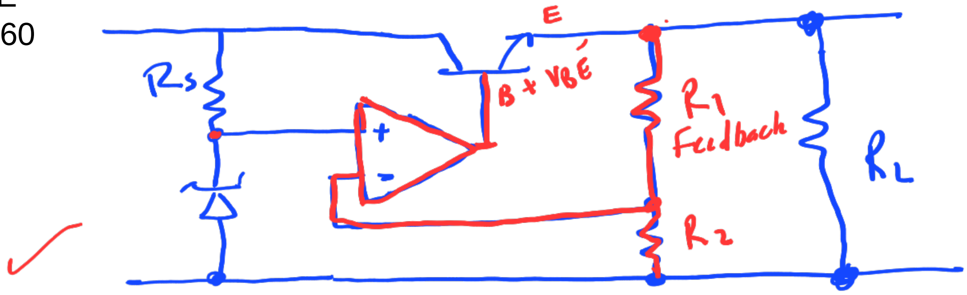
Example

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

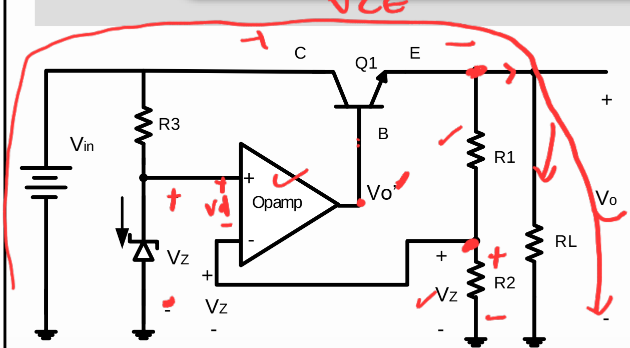
(Solution: V_o=Vz-Vbe=12-0.7=11.3 V;

$I_z \approx$(20-12)/220= 36 mA)



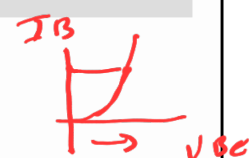


Opamp Series VR



$$V_i = V_o + V_{CE}$$

$$V_o' = A_d V_d$$



$$V_o' = A_d\left(V_Z - \frac{R_2}{R_2 + R_1}V_o\right)$$

$$\text{If } V_o \downarrow, V_o' \uparrow, V_{be}' \uparrow, I_E \uparrow, V_o \uparrow$$

V_{in}

BJT will operate in Linear mode

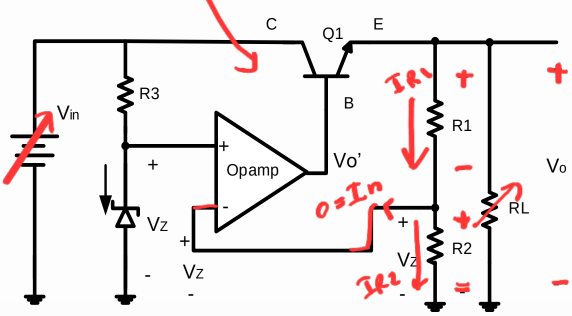
$V_{in} = V_o + V_{CE}$

$V_{CE} > V_{CE(sat)}$

make sure to have

$V_{in} > V_o + 2\,V$

Opamp Series VR



Resistors R_1, R_2 are for sampling of Vo (the current through these resistors must be small)

$$V_o = V_{R1} + V_{R2}$$

$$I_{R1} = I_{R2} = I$$

$$V_{R2} = V_Z$$

$$I = \frac{V_Z}{R_2}$$

$I_{R1} = I_{R2}$ in mA's

$V_+ = V_-$

$V_+ = V_Z$

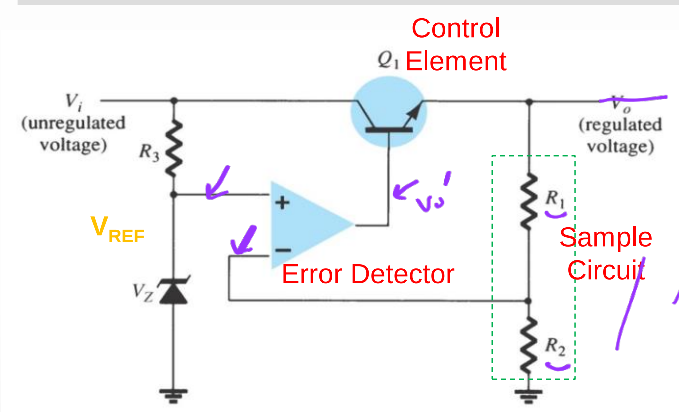
$V_- = \frac{R_2}{R_1+R_2} V_o$

$$V_Z = V_o \frac{R_2}{R_1 + R_2} = V_{R2}$$

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

**
1) $V_Z < V_o$
2) $V_{in} > V_o + 2$

Op-Amp Series Regulator



- The resistor R_1 and R_2 sense a change in the output voltage and provide a feedback voltage.
- Values must be high to limit current value to mA

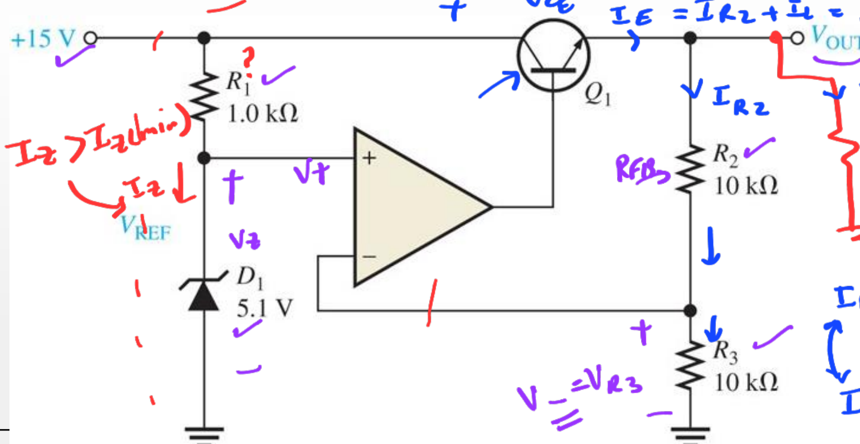
- The error detector compares the feedback voltage with a Zener diode reference voltage.
- The resulting difference voltage causes the transistor Q_1 to control the conduction to compensate the variation of the output voltage.
- The output voltage will be maintained at a constant value of:

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

Example

- Determine the output voltage for the regulator below.

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



$$V_o = V_Z\left(1 + \frac{R_2}{R_3}\right) = 5.1\left(1 + \frac{10k}{10k}\right) = 5.1 \times 2 = 10.2\ V$$

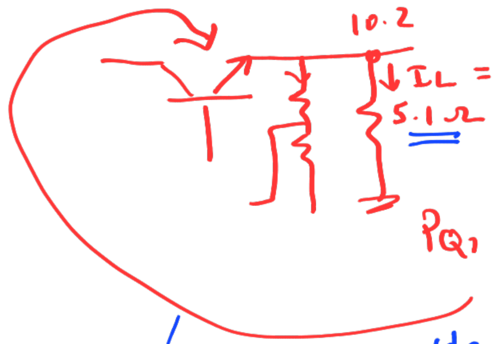
$I_E = I_{R2} + I_L = 1.005\ A$

$I_L = \frac{10.2}{10.2\ \Omega} = 1A$

$I_{R2} = \frac{10.2}{R_2 + R_3} = \frac{10.2}{20k} \approx 0.5\ mA$

$$P_{Q_1} = V_{CE} \cdot I_E = (V_{in} - V_o) \cdot I_E = (15 - 10.2) \times 1.005 = 4.824\ \text{Watt}$$

we bought a 5 W BJT for this design

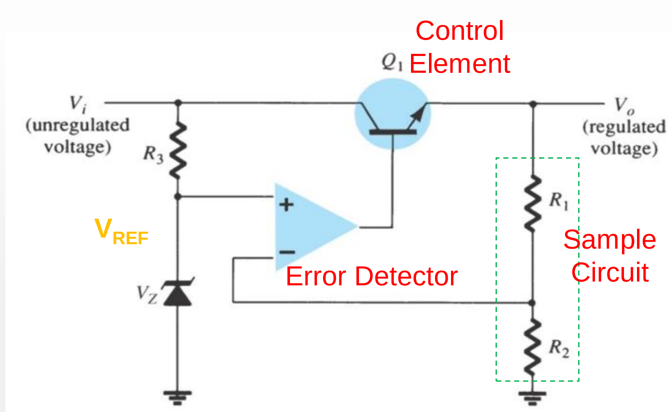


$P_{Q_1} = (4.8) \times 2$
$= 9.6\ W$

the 5W BJT will be damaged

Choosing the right Transistor

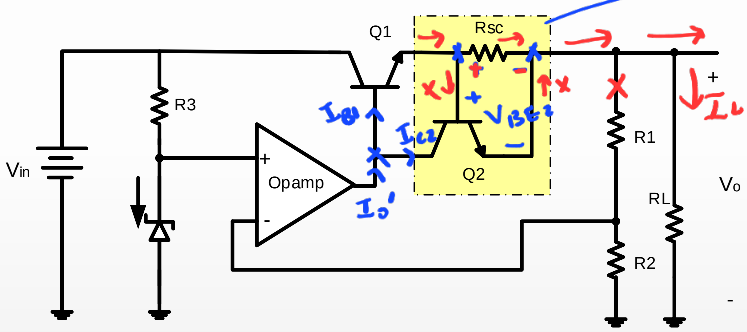
- The transistor must be chosen such that its power rating is suitable
- P_Q > or = V_{CE}*I_E **otherwise BJT will be damaged**
- V_{CE}=Vc-V_E=Vin-Vo
- I_E=I_L+I_{R1} , but I_L>> I_{R1}



Opamp Series VR with current limit

Current Limiting Circuit

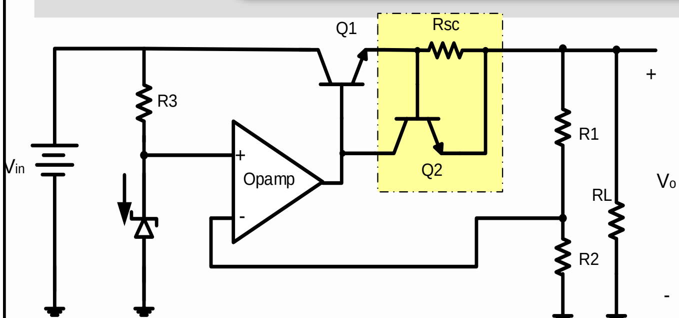
In order to protect the transistor from damage when a very high current passes through it due to a short circuit or excessive current demand at the load



1) In normal operation Q2 is off since $V_{be2} = V_{Rsc} < 0.7\ \text{V}$

$$2)\ R_{SC} = \frac{V_{be}}{I_{L(Max)}} = \frac{0.7\ \text{V}}{I_{L(Max)}}$$

Opamp Series with current limit



3) When $I > I_{L(Max)}$, Q2 conducts since $V_{be2} = V_{Rsc} \cong 0.7\text{ V}$

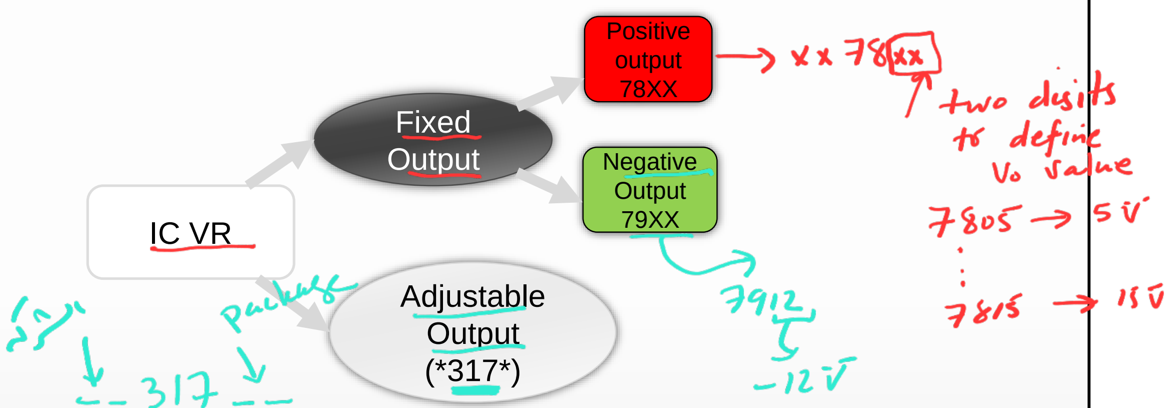
4) Some of I_{B1} is diverted through Q2 (I_{C2})

I_{B1} is reduced so that I_L is limited to a maximum value calculated as: $I_{L(Max)} = \frac{V_{be}}{R_{SC}} = \frac{0.7\text{ V}}{R_{SC}}$

5) Since V_{be2} cannot exceed 0.7 V, $V_{R_{SC}}$ is limited

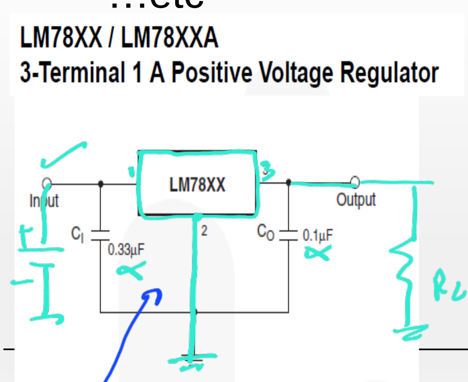
6) This is constant current limiting

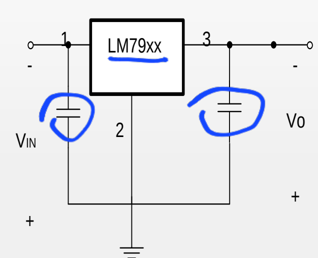
IC Voltage Regulator

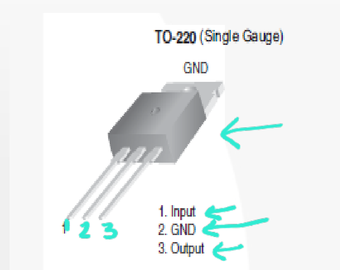


3 Terminal IC Voltage Regulators

- Fixed output voltage type
- Two families exist:
- Fixed positive output (78xx) , where xx defines the value of output voltage such as 5, 6, 8,9,12 …etc
- Fixed negative output (79xx) , where xx defines the value of output voltage such as -5, -6, -8,-9,-12 …etc







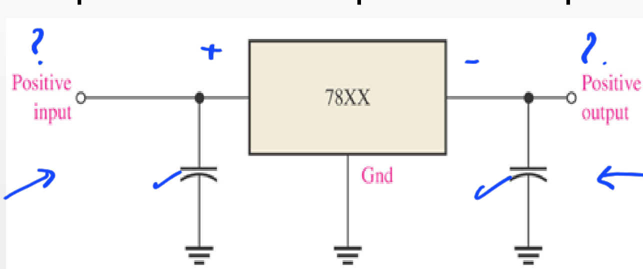
Ci, Co ← provided in data sheet (no calculations)

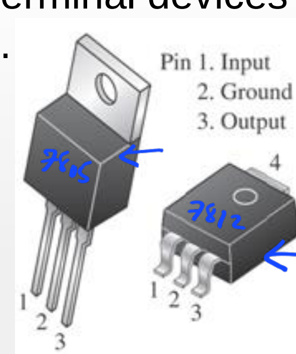
Fixed Voltage Regulator (for reference only)

- The fixed voltage regulator has an unregulated dc input voltage V_i applied to one input terminal, a regulated output dc voltage V_o from a second terminal, and the third terminal connected to ground.

Fixed-Positive Voltage Regulator

- The series 78XX regulators are the three-terminal devices that provide a fixed positive output voltage.





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

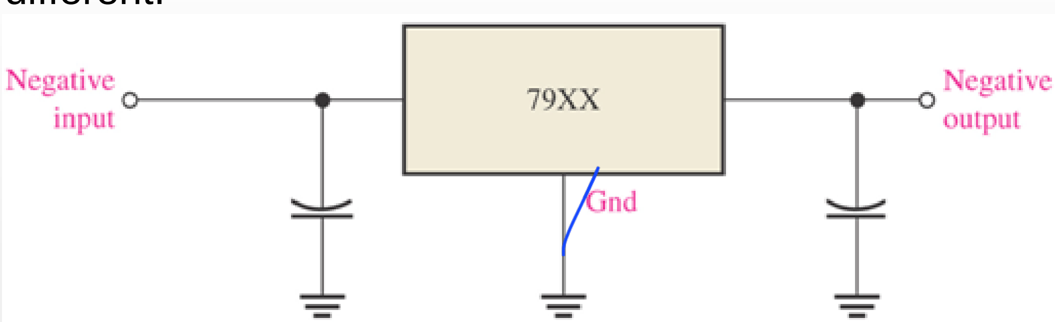
Vin must be higher than Vo by at least 2V for proper operation of the voltage regulator

$V_o \geq V_{in} + 2$

Fixed Voltage Regulator

Fixed-Negative Voltage Regulator

- The series 79XX regulators are the three-terminal IC regulators that provide a fixed negative output voltage.
- This series has the same features and characteristics as the series 78XX regulators except the pin numbers are different.



Fixed Voltage Regulator

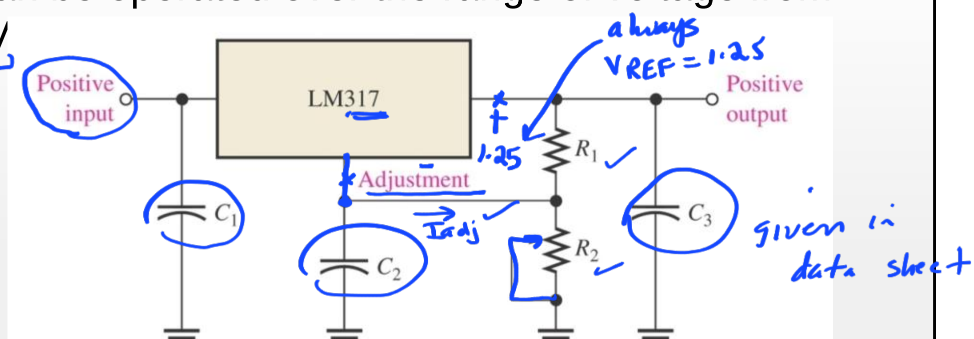
Negative-Voltage Regulators in the 79XX Series

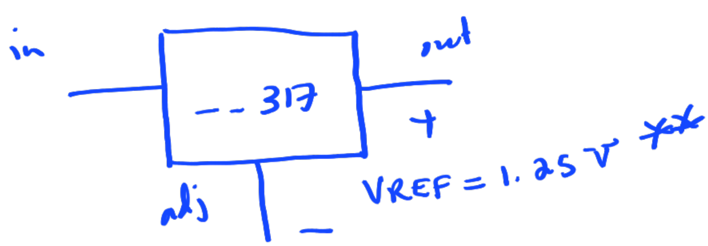
IC Part	Output Voltage (V)	Minimum V_i (V)
7905	-5	-7.3
7906	-6	-8.4
7908	-8	-10.5
7909	-9	-11.5
7912	-12	-14.6
7915	-15	-17.7
7918	-18	-20.8
7924	-24	-27.1

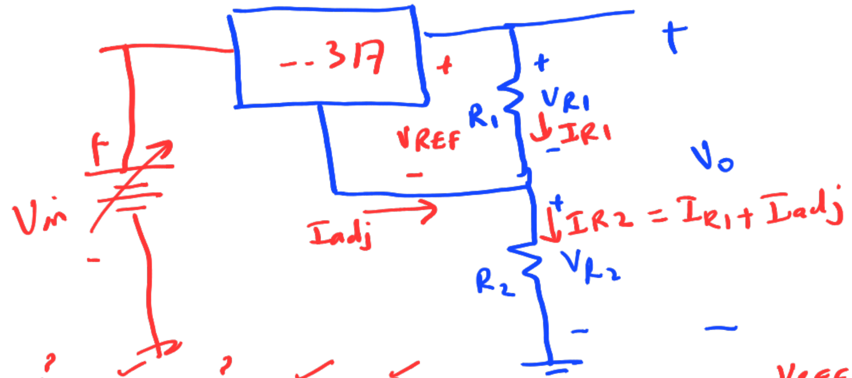
Adjustable-Voltage Regulator

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



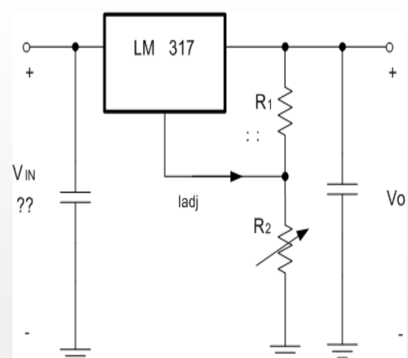




$V_o = V_{R1} + V_{R2} = I_{R1} \cdot R_1 + (I_{R1} + I_{adj}) \cdot R_2 \; ; \; I_{R1} = \frac{V_{R1}}{R_1} = \frac{V_{REF}}{R_1} = \frac{1.25}{R_1}$

Voltage Regulators

- Iadj=~ 50 uA (constant From data sheet)
- V_{REF}=1.25 (always true for the 317 family)
- Vo=~ 1.25 – 35V
- Vo is defined by proper choice of R1 & R2
- $V_o = V_{R1} + V_{R2}$
- $V_{R1} = V_{REF} = I_{R1} * R1$
- $I_{R1} = I_{REF} = V_{REF}/R1$
- $V_{R2} = (I_{REF} + I_{ADJ}) * R2$
- $V_o = I_{REF} * (R1+R2) + Iadj * R2$

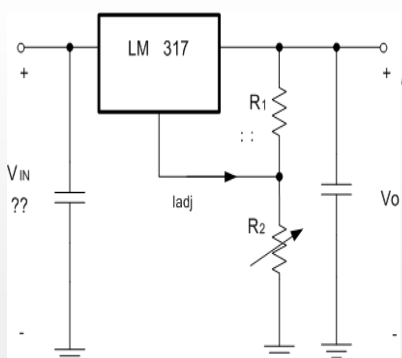


Example

- Given R1=220 Ω ; R2=5kΩ potentiometer
- Iadj=~ 50 uA (constant From data sheet)
- Find Vo(min) and Vo(max)
- Find range of Vin ?

$R_{2(min)} = 0\,\Omega$

$R_{2(max)} = 5k\,\Omega$



Note **

$V_{in} \geq V_o + 2$ always

$$V_o = I_{REF}(R_1 + R_2) + I_{adj}(R_2)$$

$$I_{REF} = I_{R1} = \frac{1.25}{220} = 5.68\,mA \quad ; I_{adj} = 50\,\mu A$$

$$V_o|_{max,\ R_2 = 5k} = 5.68\,mA\,(220 + 5k) + 50\mu \times 5k = 29.91\,V$$

$$V_{in(max)} \geq 29.91 + 2$$

$$V_o|_{min,\ R_2 = 0} = 1.25\,V \quad , V_{in(min)} = 1.25 + 2 = 3.25\,V$$

Voltage Regulators

$$I_{REF} = \frac{V_{REF}}{R_1} = \frac{1.25}{220\,\Omega}$$

$$V_O = I_{REF}(R_1 + R_2) + I_{adj}(R_2)$$

$$V_{O(MAX)}\,\big|_{R2=5k\Omega} = (26.66 + 0.25) = 29.91\,V$$

$$V_{O(MIN)}\,\big|_{R2=0k\Omega} = V_{REF} = 1.25\,V$$

The input voltage must be higher than the output by at least 2 V

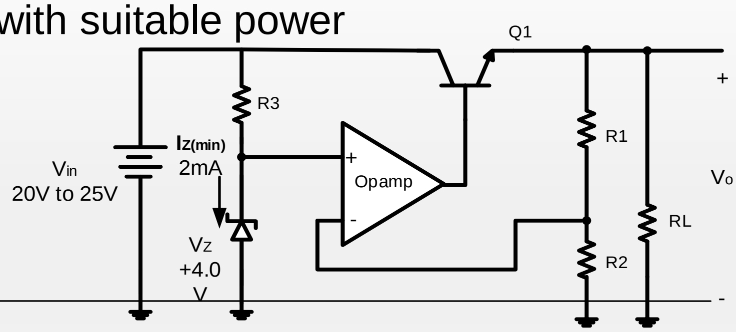
$$V_{IN(MIN)} \cong 1.25 + 2 = 3.25\,V$$

$$V_{IN(MAX)} \cong 29.91 + 2 = 31.91\,V$$

other examples
next lecture

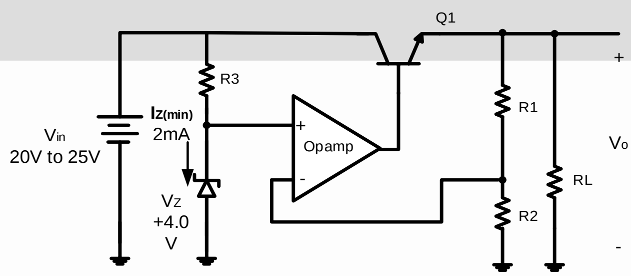
Voltage Regulators example

- 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



Example Continued

- **SOLUTION**



$$1)\ R_3 \le \frac{V_{IN(Min)} - V_Z}{I_{Z(Min)}}$$

$$R_3 \le \frac{20-4}{2\ mA} = 8\ k\Omega \ \text{ in order to make sure } I_Z > I_{Z(Min)}$$

If $I_{Z(max)}$ was known, then lower limit for R3 can also be found

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

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

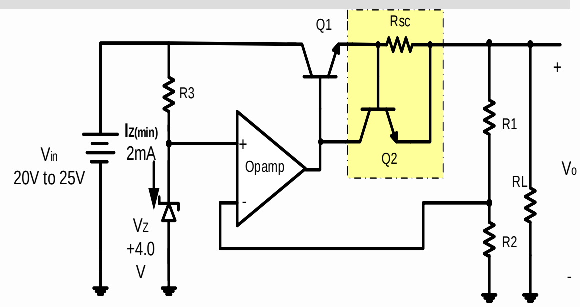
➡

choose $R_1 = 20\ k\Omega$

$\therefore R_2 = 10\ k\Omega$

Voltage Regulators

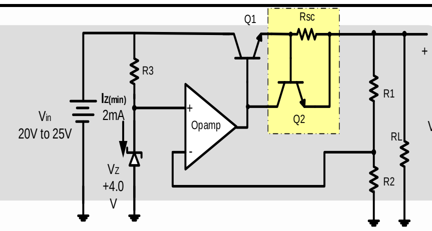
- **SOLUTION**



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

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

Ex. Continued



- **SOLUTION**

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

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

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

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

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

Example Continued

$$P_{Q1} = V_{CE(MAX)} * I_{E(MAX)}$$

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

$$I_{E(MAX)} = I_{R1} + I_{L(MAX)} = \frac{V_Z}{R_1} + I_{L(MAX)}$$

$$= \frac{8\ V}{20\ k\Omega} + 1\ A = 1.0004\ A$$

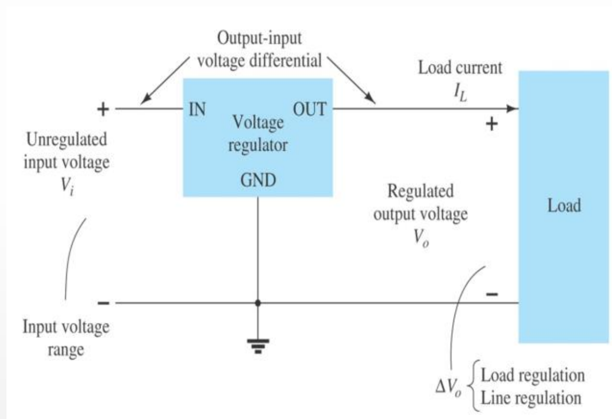
$$P_{Q1} = 17\ V * 1.0004\ A = 17.0068\ W$$

The End

- Good Luck in your exams

Switching Regulator

- The switching regulator is a type of regulator circuit which its efficient transfer of power to the load is greater than series and shunt regulators because the transistor is not always conducting.
- The switching regulator passes voltage to the load in pulses, which then filtered to provide a smooth dc voltage.



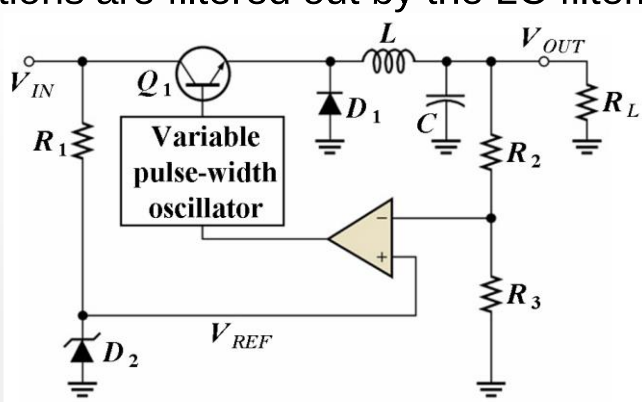
Switching Regulator

- The switching regulator is **more efficient** than the linear series or shunt type.
- This type regulator is ideal for high current applications since less power is dissipated.
- Voltage regulation in a switching regulator is achieved by the on and off action limiting the amount of current flow based on the varying line and load conditions.
- With switching regulators 90% efficiencies can be achieved.

Switching Regulator

Step-Down Configuration

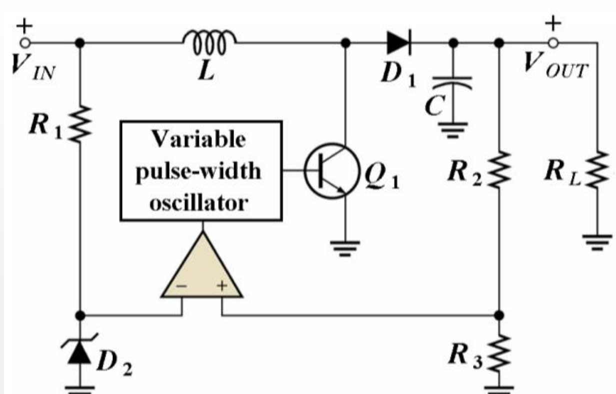
- With the step-down (output is less than the input) configuration the control element Q_1 is pulsed on and off at variable rate based on the load current.
- The pulsations are filtered out by the LC filter.



Switching Regulator

Step-up configuration

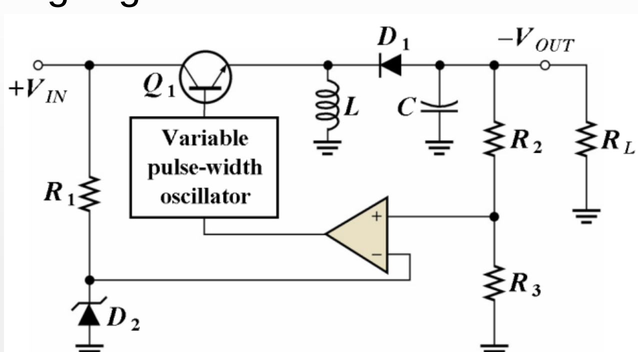
- The difference is in the placement of the inductor and the fact that Q_1 is shunt configured.
- During the time when Q_1 is off the V_L adds to V_C stepping the voltage up by some amount.



Switching Regulator

Voltage-inverter configuration

- output voltage is of opposite polarity of the input.
- This is achieved by V_L forward-biasing reverse-biased diode during the off times producing current and charging the capacitor for voltage production during the off times.
- With switching regulators 90% efficiencies can be achieved.



Summary

- Voltage regulators keep a constant dc output despite input voltage or load changes.
- The two basic categories of voltage regulators are linear and switching.
- The two types of linear voltage regulators are series and shunt.
- The three types of switching are step-up, step-down, and inverting.

Summary

- Switching regulators are more efficient than linear making them ideal for low voltage high current applications.
- IC regulators are available with fixed positive or negative output voltages or variable negative or positive output voltages.
- Both linear and switching type regulators are available in IC form.
- Current capacity of a voltage regulator can be increased with an external pass transistor.