ENEE2360 Analog Electronics

T11:
Voltage Regulators

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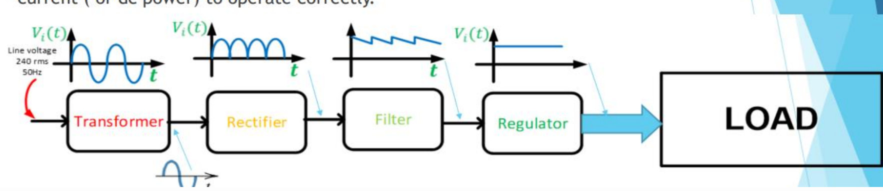
Dc Power Supply

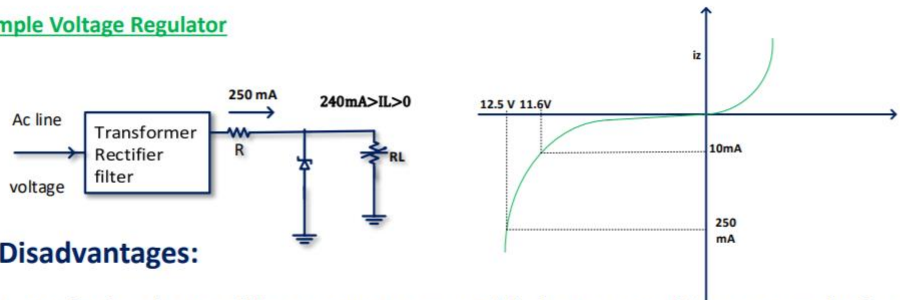
- All electronic circuits and systems require a stable source of dc voltage and current (or dc power) to operate correctly.



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

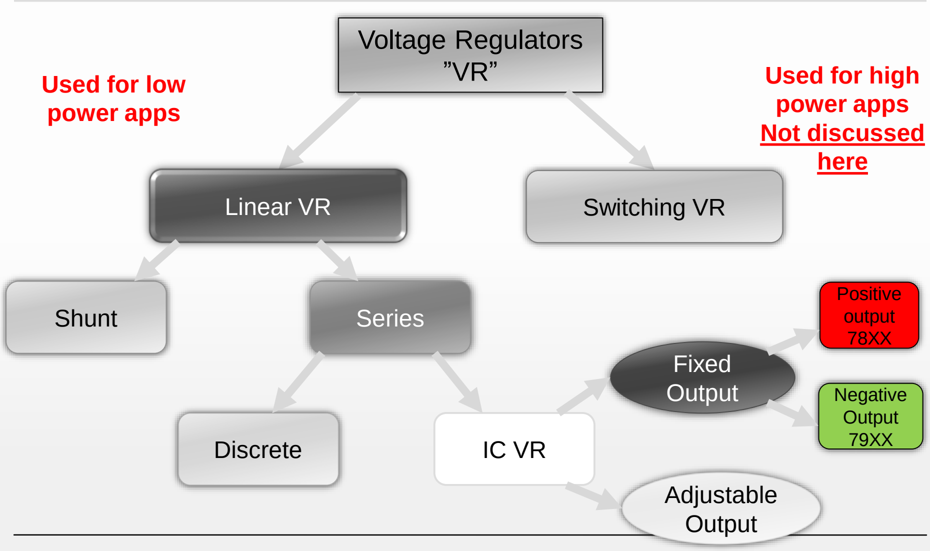
Simple Voltage Regulator



Disadvantages:

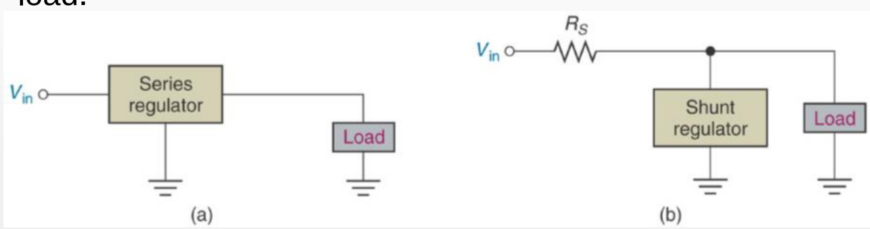
1. Variation in IL will cause Iz to vary.This in turns will cause variation in Vz=Vo
2. The Zener power dissipation will increase as IL decreases.

Types of Regulators

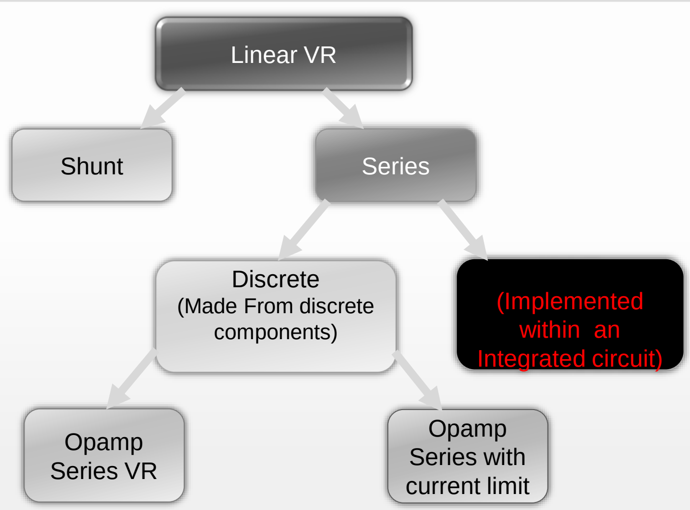


Types of Regulator

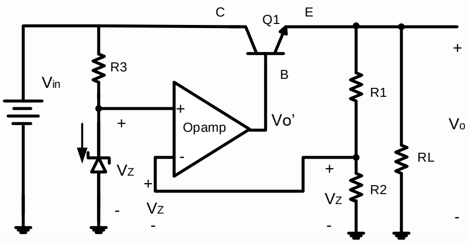
- Fundamental classes of voltage regulators are **linear regulators** and **switching regulators**.
- Two basic types of linear regulator are the **series regulator** and the **shunt regulator** .
- The series regulator is connected in **series** with the load and the shunt regulator is connected in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



Types of Regulator



Opamp Series VR



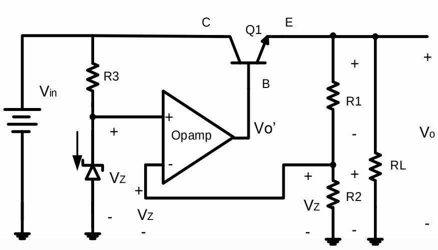
$$V_i = V_o + V_{CE}$$

$$V_o' = A_d V_d$$

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

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

Opamp Series VR



Resistors R_1, R_2 are for sampling of Vo

(the current through these resistors must be small)

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

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

$$V_{R2} = V_Z$$

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

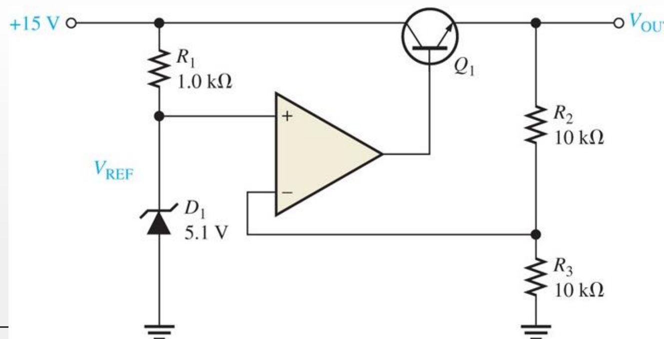
$$V_Z = V_o \frac{R_2}{R_1 + R_2}$$

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

Example

- Determine the output voltage for the regulator below.

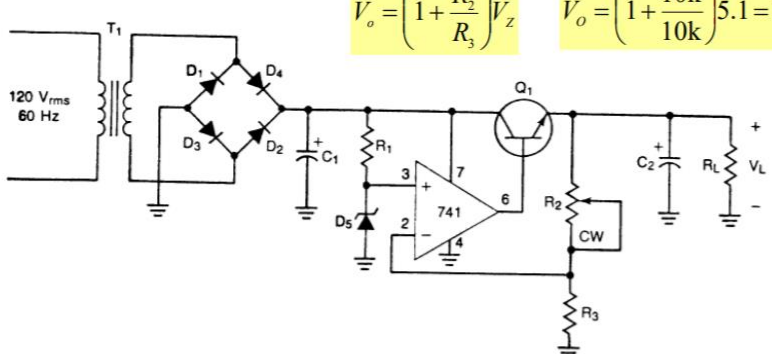
$$V_o = \left(1 + \frac{R_2}{R_3}\right) V_Z \Rightarrow V_O = \left(1 + \frac{10\text{k}}{10\text{k}}\right) 5.1 = 10.2\text{ V}$$



Practical DC Power supply

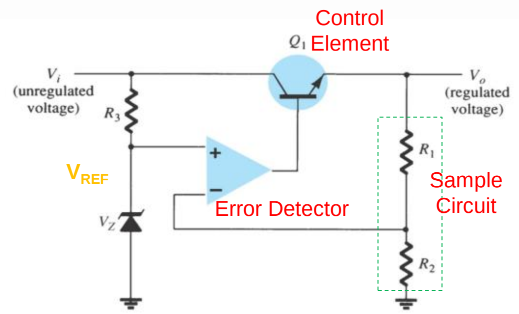
Determine the output voltage for the regulator below if R3 = R2 = 10K and Vz = 5.1V

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



Choosing the right Transistor

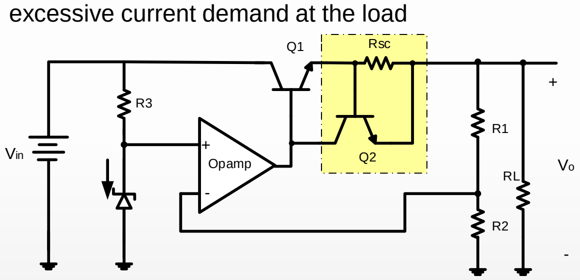
- The transistor must be chosen such that its power rating is suitable
- P_Q > or = V_{CE}*I_E **otherwise BJT will be damaged**
- $V_{CE}=V_C-V_E=V_{in}-V_o$
- $I_E=I_L+I_{R1}$, but $I_L >> I_{R1}$



Opamp Series VR with current limit

Current Limiting Circuit

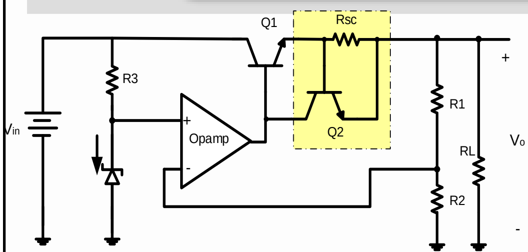
In order to protect the transistor from damage when a very high current passes through it due to a short circuit or excessive current demand at the load



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 $V_{be2} = V_{Rsc} \cong 0.7\ V$

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

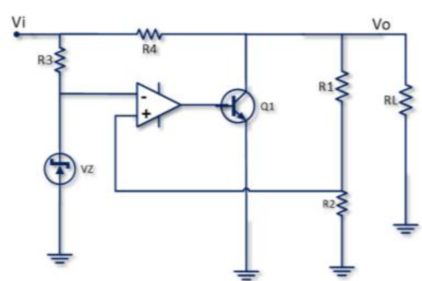
5) Since V_{be2} cannot exceed 0.7 V, $V_{R_{SC}}$ is limited

6) This is constant current limiting

Op-Amp Shunt Regulator

An Op-amp used in Shunt voltage regulators

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



Operation:

$$Vop = AdVd$$

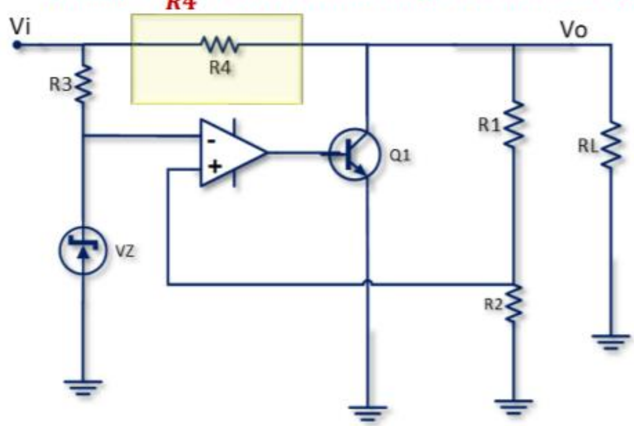
$$Vop = Ad\left(\frac{R2}{R1 + R2}Vo - Vz\right)$$

IF Vo ↓ V(+) ↓ Vop ↓ VBE ↓ VBE = Vop $I_C = I_S\left(e^{\frac{VBE}{\eta V_T}} - 1\right)$

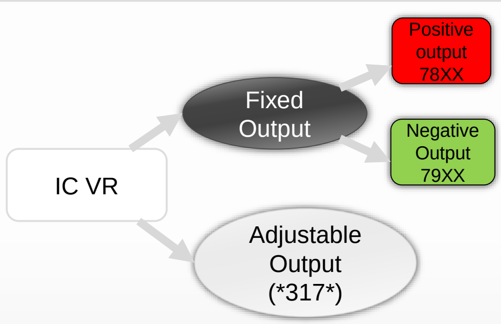
$\therefore$ *The transistor conduct Less, Ic ↓, IL ↑ Vo ↑*

Current Limiting

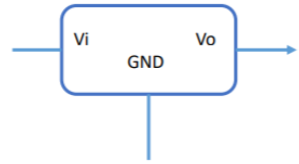
$$IL, \max = \frac{Vi}{R4} \quad (Current\ Limiting)\ When\ RL = 0\ (SHORTED)$$



IC Voltage Regulator



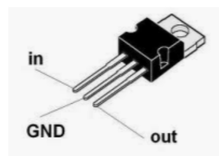
Three Terminal Circuit Regulators



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

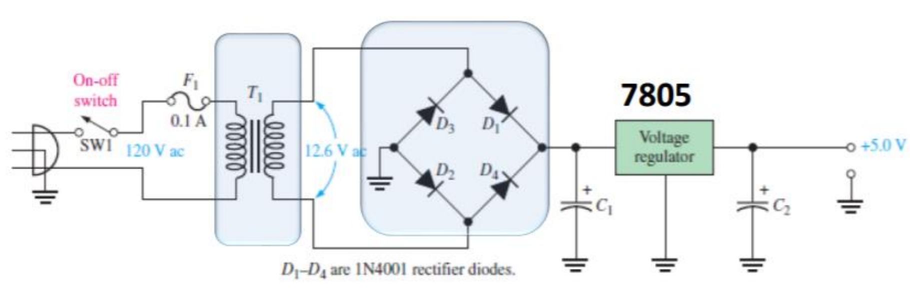
IC Part	Output Voltage (V)	Minimum V_i (V)
7805	+5	+7.3
7806	+6	+8.3
7808	+8	+10.5
7810	+10	+12.5
7812	+12	+14.5
7815	+15	+17.7
7818	+18	+21.0
7824	+24	+27.1

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

Fixed Voltage Regulator

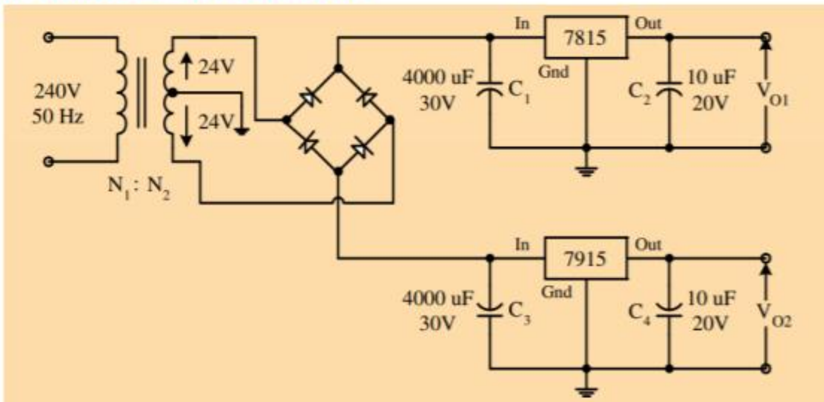
Negative-Voltage Regulators in the 79XX Series

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



Three Terminal Circuit Regulators

Dual Polarity Dc Power Supply



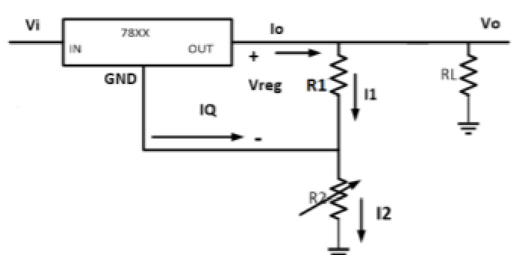
Changing the fixed Voltage Regulator to adjustable

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

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

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

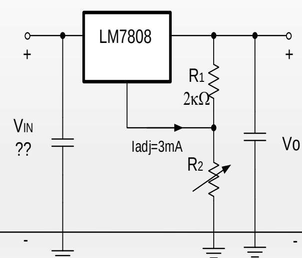
$$\therefore Vo = V_{REG}\left(1+\frac{R_2}{R_1}\right)+R_2 I_Q$$



I_Q *is in milliampere and change with temperature*

Adjustable Voltage Regulator based on 78xx family

- 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



Voltage Regulators

- **Solution**

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

$$V_{o(MAX)} = V_{R1} + V_{R2} = I_{REG}(R_1) + (I_{REG} + I_{adj})(R_2)$$

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

$$V_{o(MAX)}\,\big|_{R2=3k\Omega} = \frac{V_{REG}}{R_1}(R_1 + R_2) + I_{adj}(R_2)$$

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

$$= (4mA).(5k\Omega) + 9V = 29V$$

Voltage Regulators

- **Solution**

V_{IN} must be higher than Vo by at least 2 volts

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

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

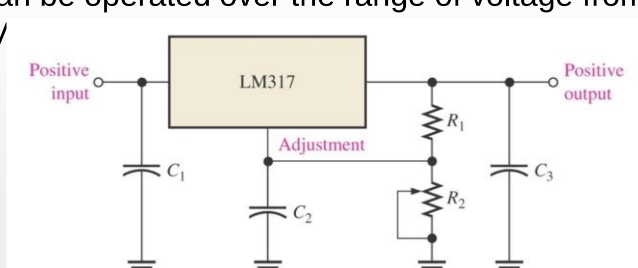
Power Dissipation of LM7808:

$$P_{(LM7808)} \cong (V_{IN} - V_O) * I_L = (31 - 8) * 0.25 = 5.75\,W$$

Adjustable-Voltage Regulator

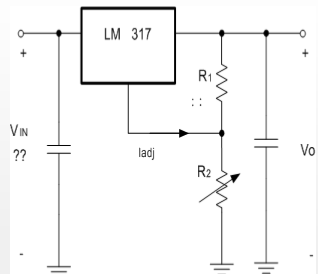
Adjustable-Voltage Regulator

- 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



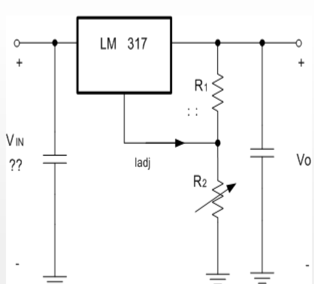
Voltage Regulators

- 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
- $Vo=V_{R1}+V_{R2}$
- $V_{R1}=V_{REF}=I_{R1}*R1$
- $I_{R1}=I_{REF}=V_{REF}/R1$
- $V_{R2}=(I_{REF}+I_{ADJ})*R2$
- $Vo=I_{REF}*(R1+R2)+Iadj*R2$



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 ?



Voltage Regulators

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

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

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

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

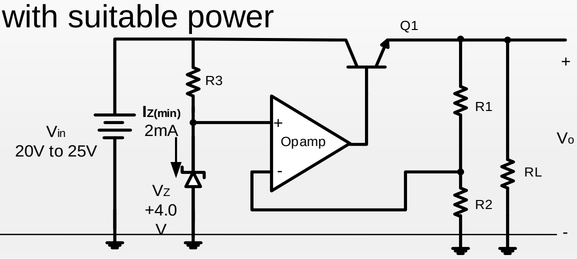
The input voltage must be higher than the output by at least 2 V

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

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

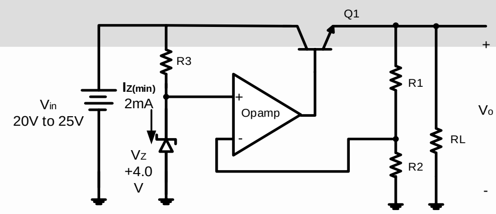
Voltage Regulators example

- 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 =100Ω and when R_L =8Ω.
- 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

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

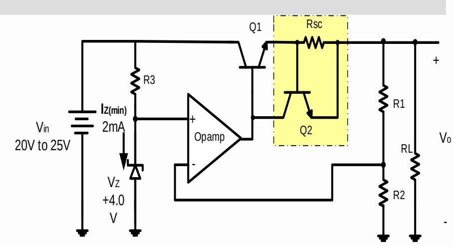
$$\therefore \frac{R1}{R2} = \frac{V_O}{V_Z} - 1 = \frac{12}{4} - 1 = 2$$

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

$$\therefore R_2 = 10\ k\Omega$$

Voltage Regulators

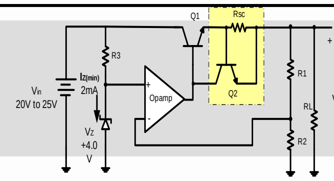
- **SOLUTION**



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 $I_{L(max)}$,

$\therefore V_O = 12\text{ V}$ 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

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

Example Continued

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

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

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

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

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