Voltage Regulator

ENEE236 – Analog Electronics
Instructor
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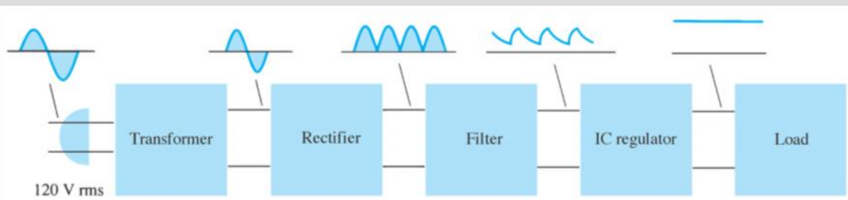
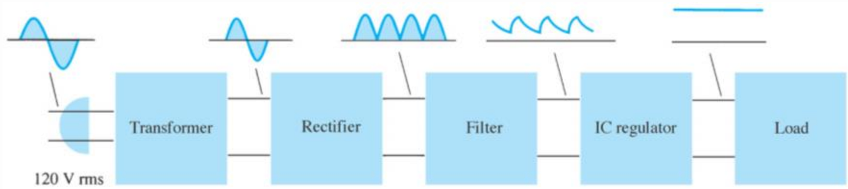
Introduction



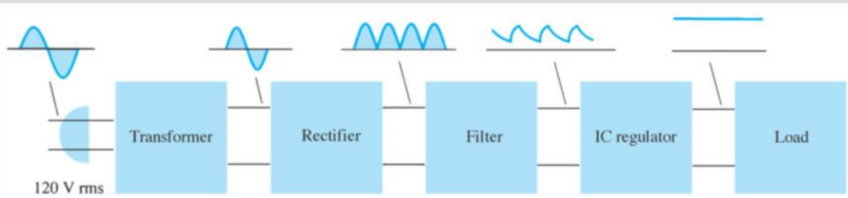
- ***Power supply***: a group of circuits that convert the ***standard ac voltage*** (220 V, 50 Hz or 110 V, 60 Hz) provided by the wall outlet to ***constant dc voltage***
- ***Transformer*** : a device that step up or step down the ***ac voltage*** provided by the wall outlet to a desired amplitude through the *action* of a *magnetic field*

Introduction



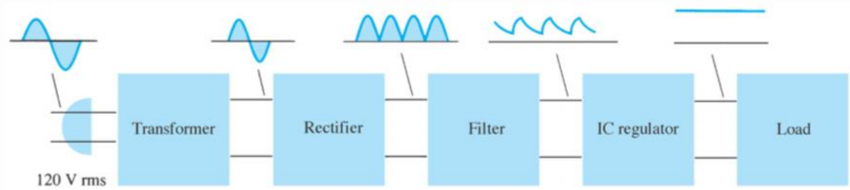
- ***Rectifier***: a diode circuits that converts the ***ac input voltage*** to a ***pulsating dc voltage***
- The pulsating dc voltage is **only suitable** to be used as a battery charger, but **not good enough** to be used as a dc power supply in a radio, stereo system, computer and so on.

Introduction



- There are two basic types of rectifier circuits:
  - Half-wave rectifier
  - Full-wave rectifier - Center-tapped & Bridge full-wave rectifier
- In summary, a full-wave rectified signal has **less ripple** than a half-wave rectified signal and is thus better to apply to a filter.

Introduction

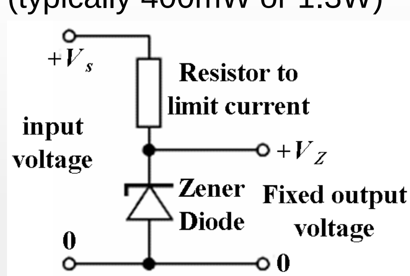


- ***Filter***: a circuit used to reduce the fluctuation in the rectified output voltage or ripple. This provides a ***steadier*** dc voltage.
- ***Regulator***: a circuit used to produces a ***constant*** dc output voltage by reducing the ripple to negligible amount. One part of power supply.

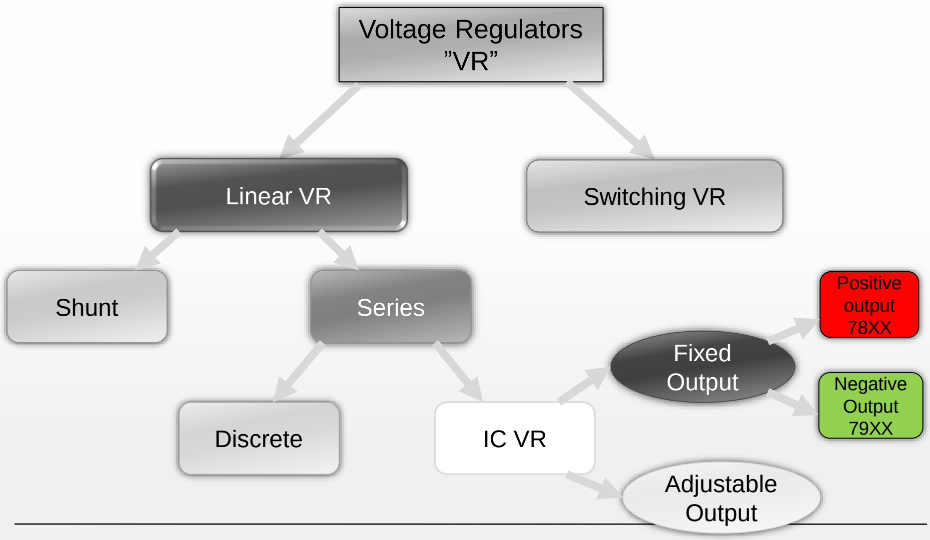
Voltage Regulators

Regulator - Zener diode regulator

- 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)

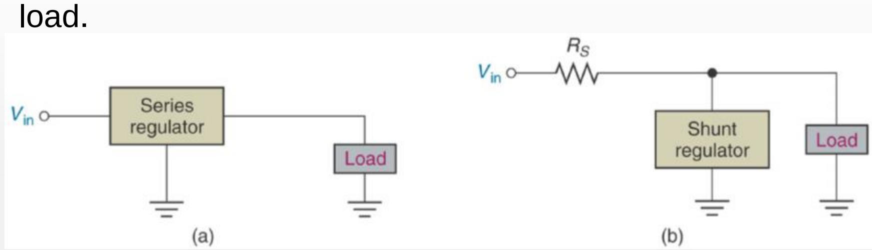


Types of Regulators

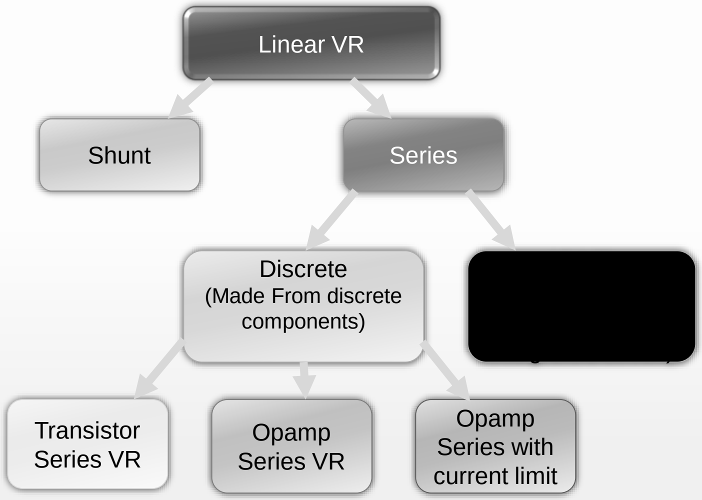


Types of Regulator

- 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.

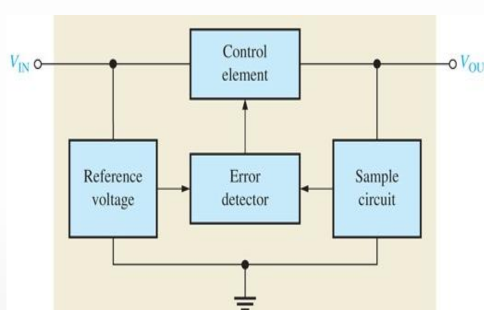


Types of Regulator

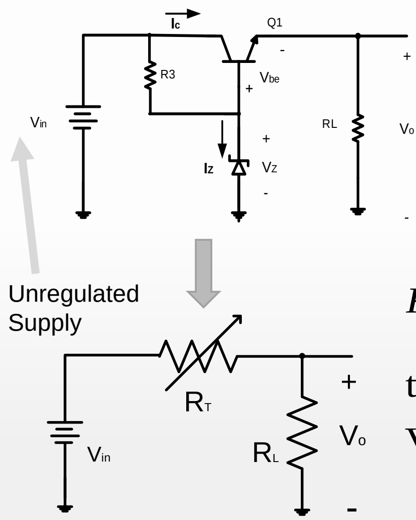


Series Regulator Circuit

- **Control element** in series with load between input and output.
- Output **sample circuit** senses a change in output voltage.
- **Error detector** compares sample voltage with reference voltage → causes control element to compensate in order to maintain a constant output voltage.



Transistor Series VR

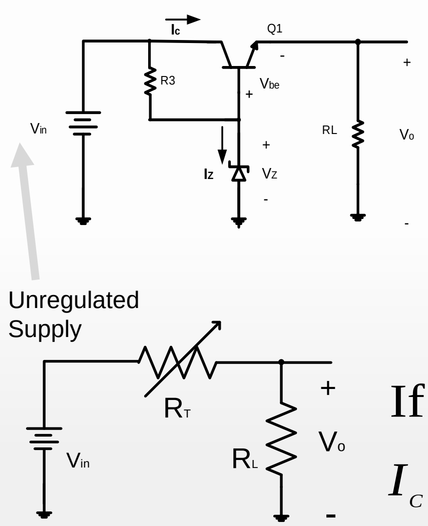


The Transistor behaves like a simple variable resistor whose resistance is determined by the operating conditions

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

Ratio of $\frac{R_L}{R_T}$ must remain constant to keep V_o constant assuming V_{IN} is constant

Transistor Series VR



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

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

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

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

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

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

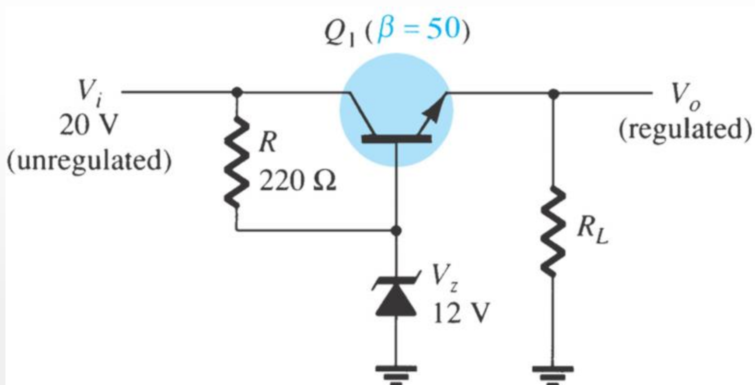
$I_C \uparrow, R_T \downarrow, V_o \uparrow$

Example

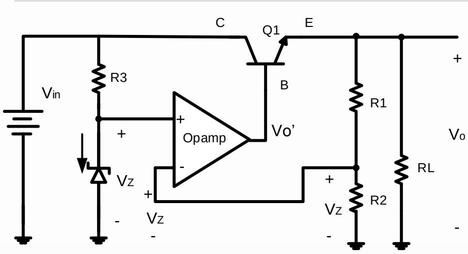
- Calculate the output voltage and Zener current for R_L=1kΩ.

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

I_z≈(20-12)/220= 36 mA)



Opamp Series VR



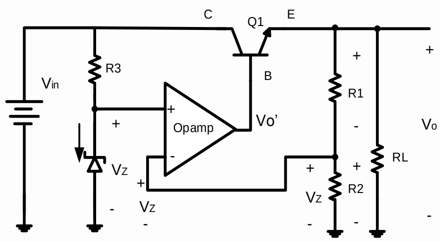
$$V_i = V_o + V_{CE}$$

$$V_o^{'} = A_d V_d$$

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

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)

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

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

$$V_{R2} = V_Z$$

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

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

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

Summary of Op-Amp Series VR

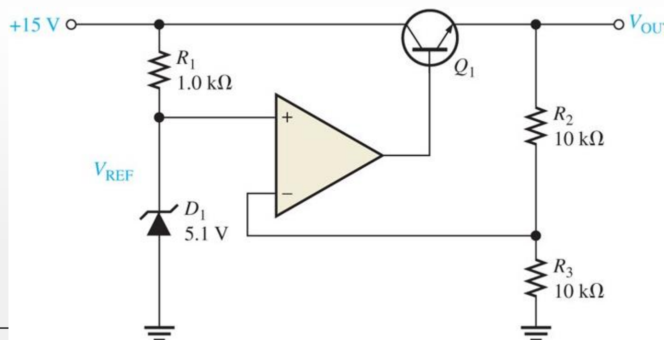
- The resistor R_1 and R_2 sense a change in the output voltage and provide a feedback voltage.
- The error detector compares the feedback voltage with a Zener diode reference voltage.
- The resulting difference voltage causes the transistor Q_1 to control the conduction to compensate the variation of 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.

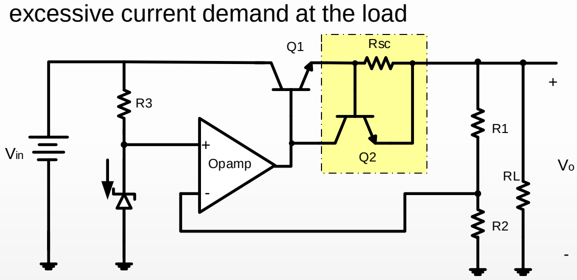
$$V_o = \left(1 + \frac{R_2}{R_3}\right) V_Z \Rightarrow V_O = \left(1 + \frac{10k}{10k}\right) 5.1 = 10.2\text{ V}$$



Opamp Series VR with current limit

Current Limiting Circuit

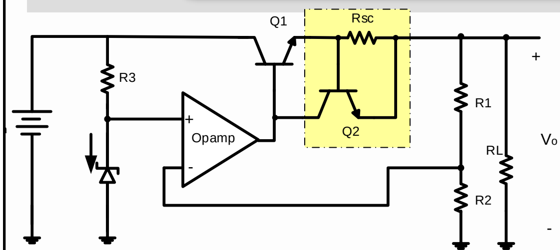
In order to protect the transistor from damage when a very high current passes through it due to a short circuit or excessive current demand at the load



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

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

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})

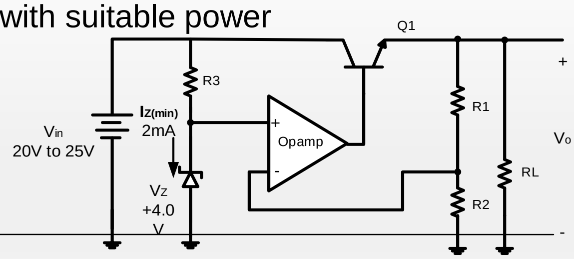
I_{B1} is reduced so that I_L is limited to a maximum value calculated as : $I_{L(Max)} = \frac{V_{be}}{R_{SC}} = \frac{0.7\ V}{R_{SC}}$

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

6) This is constant current limiting

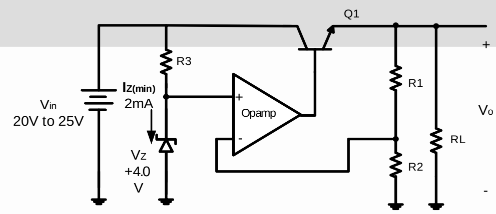
Voltage Regulators example

- 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

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

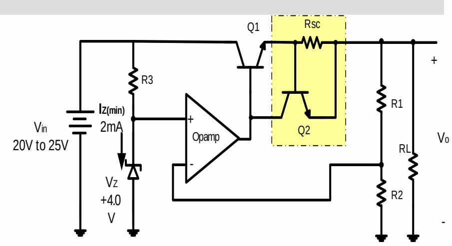
$$\therefore \frac{R1}{R2} = \frac{V_O}{V_Z} - 1 = \frac{12}{4} - 1 = 2$$

choose $R_1 = 20\ k\Omega$

$\therefore R_2 = 10\ k\Omega$

Voltage Regulators

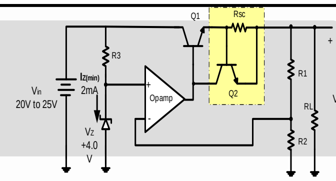
- **SOLUTION**



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

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

Example Continued

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

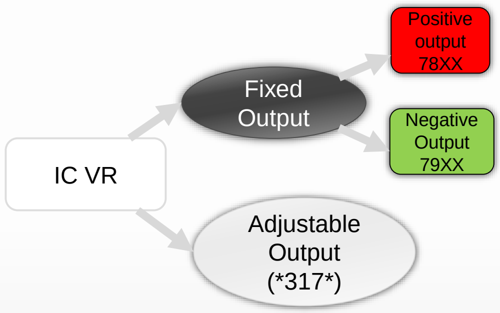
$$V_{CE(MAX)} = V_{IN(MAX)} - V_{O(MIN)} = 25 - 8 = 17\text{ V}$$

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

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

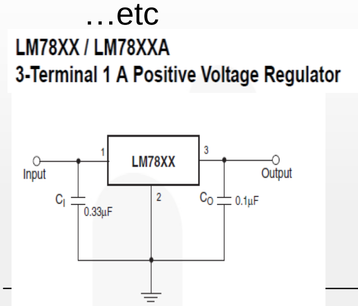
$$P_{Q1} = 17\text{ V} * 1.0004\text{ A} = 17.0068\text{ W}$$

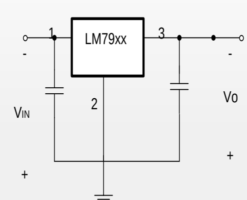
IC Voltage Regulator

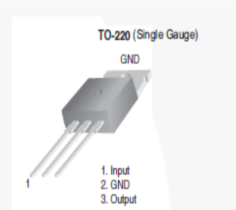


3 Terminal IC Voltage Regulators

- 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





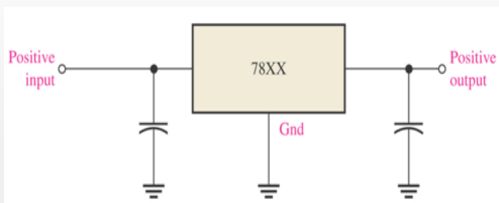


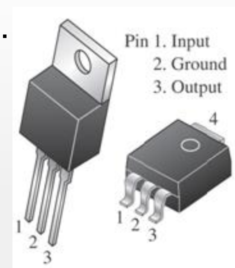
Fixed Voltage Regulator
(for reference only)

- 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

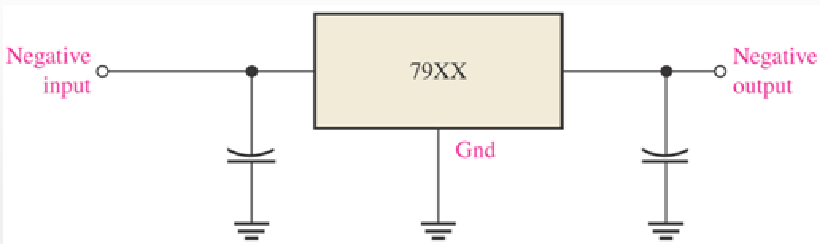
IC Part	Output Voltage (V)	Minimum V_i (V)
7805	+5	+7.3
7806	+6	+8.3
7808	+8	+10.5
7810	+10	+12.5
7812	+12	+14.5
7815	+15	+17.7
7818	+18	+21.0
7824	+24	+27.1

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

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.



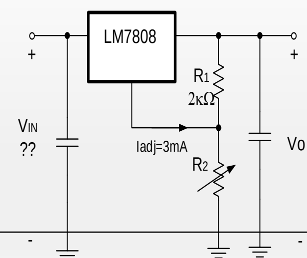
Fixed Voltage Regulator

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 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**

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

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

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

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

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

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

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

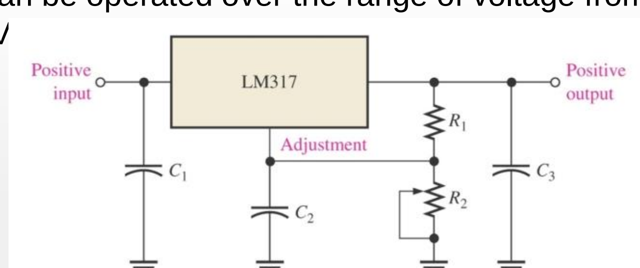
Power Dissipation of LM7808:

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

Adjustable-Voltage Regulator

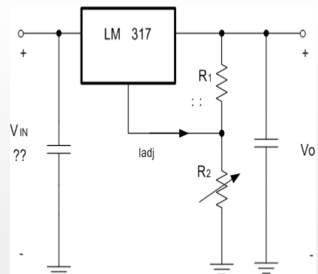
Adjustable-Voltage Regulator

- 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



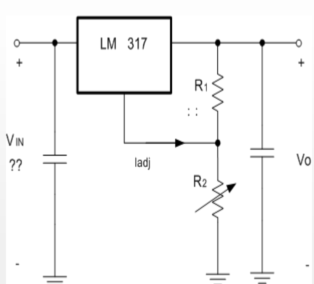
Voltage Regulators

- 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

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

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

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

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

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

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

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