Voltage Regulators

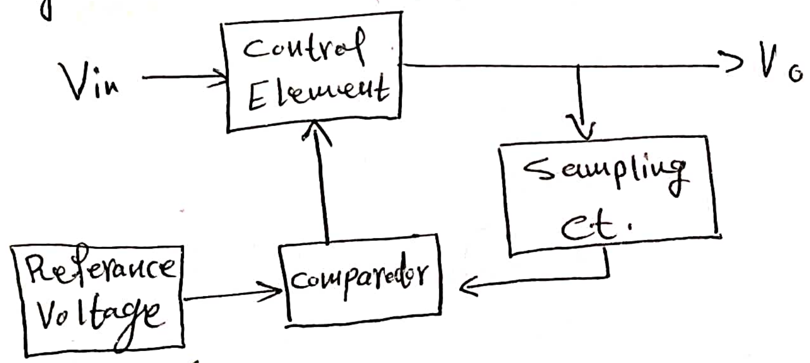
* A Voltage Regulator circuit is a ct. that provides a constant DC o/p voltage independent of i/P Voltage, o/p load current & Temperature.

Regulators

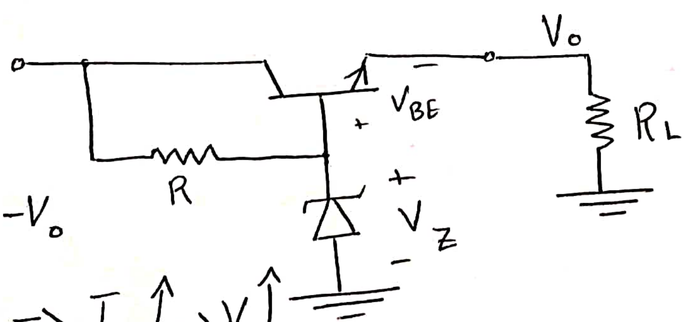
Linear Regulators | Switching Regulators

Linear Regulators :

1 Series-Regulator :



* Transistor series Voltage Regulator :



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

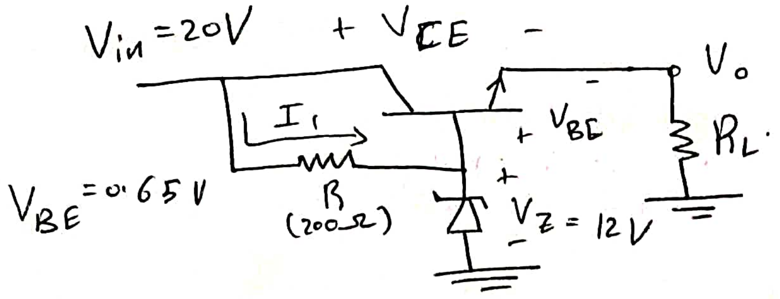
* if $V_o \downarrow \Rightarrow V_{BE}\uparrow \Rightarrow I_E \uparrow \Rightarrow V_o \uparrow$

$(V_o = I_E R_L)$

* if $V_o \uparrow \Rightarrow V_{BE}\downarrow \Rightarrow I_E \downarrow \Rightarrow V_o \downarrow$

$I_E = I_s e^{\frac{V_{BE}}{V_T}}$

EX:



Find:
1) V_o
2) V_{CE}
3) I_1

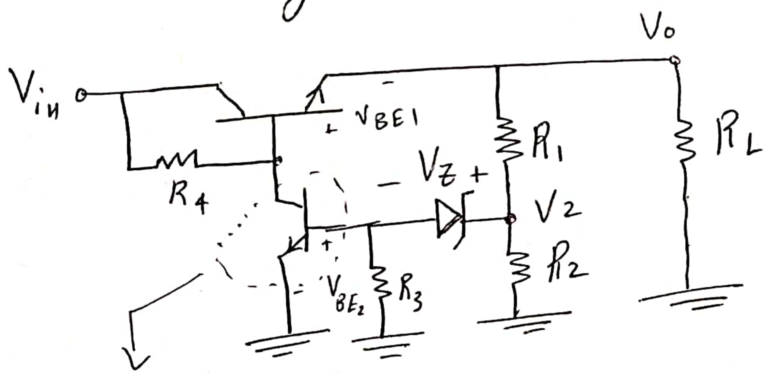
Sol:

1) $V_o = V_Z - V_{BE} = 12 - 0.65 = 11.35\,V$

2) $V_{CE} = \underset{(V_{in})}{20} - V_o = 20 - 11.35 = 8.65V$ (Active Mode)

3) $I_1 = \dfrac{V_{in} - V_Z}{R} = \dfrac{20 - 12}{200} = 40\,mA$

* Improved series Regulator



Adding An Amplifier in the feedback path increases feedback gain → detectes smaller changes in V_o → Retains more stable o/p Voltage.

* Assuming the Zener is not loading the divider ($R_1 - R_2$):

$$\Rightarrow V_2 = \frac{V_o}{R_1 + R_2} \cdot R_2 \quad , \quad V_2 = V_{BE2} + V_Z$$

→ if $V_o \downarrow \rightarrow V_2 \downarrow \rightarrow V_{BE2} \downarrow \rightarrow V_{CE2} \uparrow \rightarrow V_{BE_1} \uparrow \rightarrow V_o \uparrow$

$V_{CE_2} = V_{in} - I_1 R_4 \simeq V_{in} - I_{C_2} R_4$

EX: for an improved series Regulator:

$R_1 = 50\,K\Omega$, $R_2 = 43.75\,K\Omega$, $V_Z = 6.3V$

$V_o = 15V$ drops by $0.1\,V$ find change in V_{BE2}.

Let $V_o = 15V$, $V_o' = 15 - 0.1 = 14.9\,V$

Sol:

$$V_2 = \frac{R_2}{R_1 + R_2}(V_o) = \frac{43.75}{93.75}(15) = 7V$$

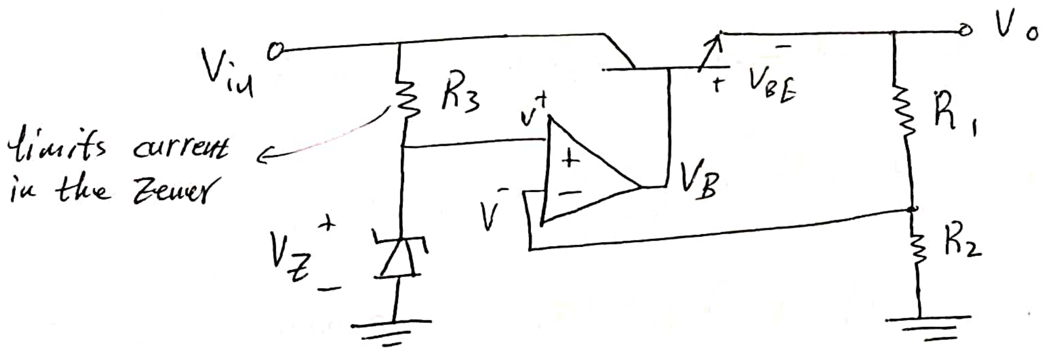
$$V_2' = \frac{R_2}{R_1 + R_2}(V_o') = \frac{43.75}{93.75}(14.9) = 6.953\,V$$

$$V_{BE2} = V_2 - V_Z = 7 - 6.3 = 0.7V$$

$$V_{BE2}' = 6.953 - 6.3 = 0.653\,V$$

$$\Rightarrow \Delta V_{BE2} = 0.7 - 0.653 = 0.047V$$

* op-Amp series Regulator:



$$\Rightarrow V^+ = V_Z$$

$$V^- = \frac{V_o}{R_1 + R_2}, \quad V_B \propto (V_Z - V^-)$$

As $V_o \downarrow \rightarrow V^- \downarrow \rightarrow V_B \uparrow \rightarrow V_{BE} \uparrow \rightarrow I_E \uparrow \rightarrow V_o \uparrow$

* To find V_o: op-Amp here is acting as non-inverting Amplifier. [neglecting effect of V_{BE}]

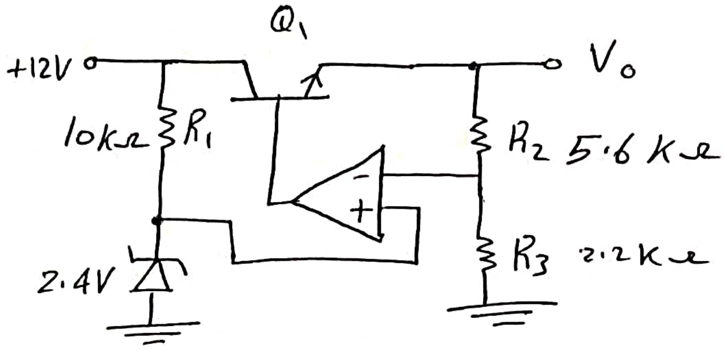
$$V_o = \left(1 + \frac{R_1}{R_2}\right) V_Z$$

Q1 - For the shown series Regulator

a- find the output Voltage (V_o).

b- if R_3 increased to 4.7K, what happens to V_o.

c- if the Zener Voltage is 2.7V instead of 2.4V what will V_o be ?



Sol :

a- $$V_o = \left(1+\frac{R_2}{R_3}\right) V_Z$$
$$= \left(1+\frac{5.5}{2.2}\right)(2.4) = 8.5\ V$$

b- $$V_o = \left(1+\frac{5.5}{4.7}\right)(2.4) = 5.26\ V$$

c- $$V_o = \left(1+\frac{5.5}{2.2}\right)(2.7) = 9.57\ V$$

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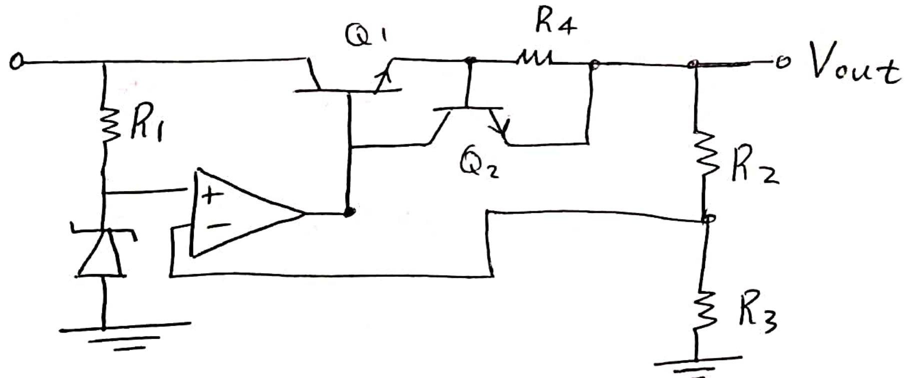
short-circuit or over load protection :



* if the current passing through R_4 is small that $I_{out} R_4 < 0.7V$
  ↳ Q_2 is cut-off & has no-effect.

* if the o/p current is high enough that $I_{out} R_4 = 0.7V$
  ↳ Q_2 switches on → decreasing I_{B1} & hence limiting the o/p current at : $\boxed{I_{L(max)} = \frac{0.7}{R_4}}$

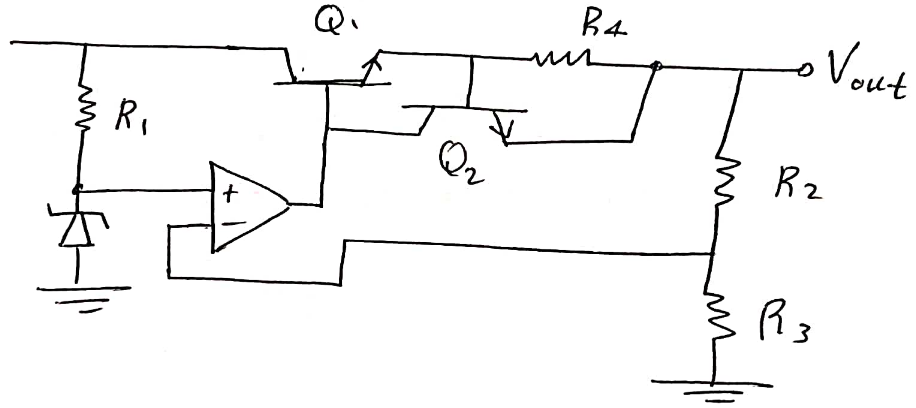
Q2- A series voltage Regulator with constant-current limiting is shown.

a- find the value of R4 if the load current to be limited to max. value of 250 mA.

b- what power rating must R4 have.

c- if R4 is halved, what is the max. load current.

Sol:



a- $I_{L_{max}} = \dfrac{0.7}{R_4}$

$\Rightarrow R_4 = \dfrac{0.7}{0.25} = 2.8\,\Omega$

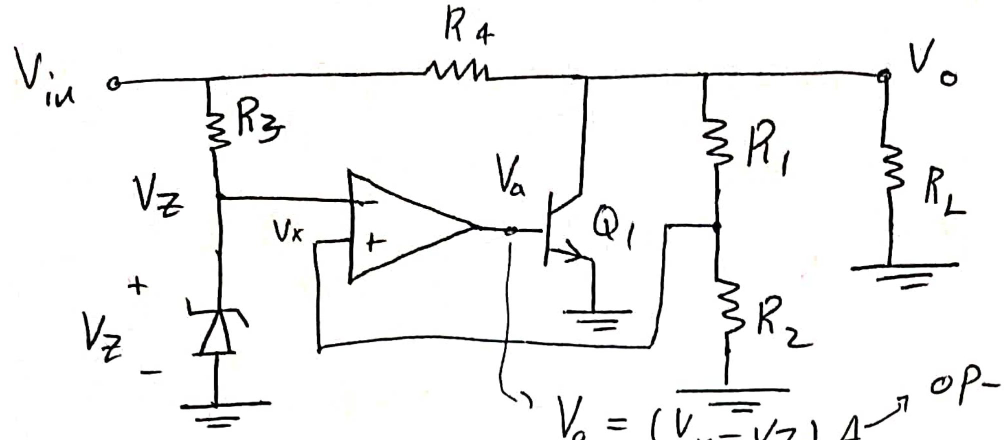
b- $P = I^2 R$

$\Rightarrow P_{rated} = (I_{L_{max}})^2 R_4 = (2.8)(0.25)^2 = 0.175\,W$

c- if $R_4' = \dfrac{R_4}{2} = 1.4\,\Omega$

$\Rightarrow I_{L_{max}} = \dfrac{0.7}{1.4} = 500\,mA$

OP-Amp shunt Voltage Regulator :



$V_a = (V_x - V_Z)\,A$ ← op-Amp gain

as $V_o \uparrow \rightarrow V_x \uparrow \Rightarrow V_a \uparrow \Rightarrow$ Q_1 conducts higher current

↳ less current through R_L ($I_L \downarrow$)

↳ $V_o \downarrow$

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

↳ loop will try to eliminate difference between V_X & V_Z .

at $V_X = V_Z \Rightarrow V_Z = \dfrac{R_2}{R_1 + R_2} V_o$

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

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* $I_{s.c} = \dfrac{V_{in}}{R_4}$ (short ct. current)

Q3 - For an op-Amp shunt Regulator if

$R_4 = 100\ \Omega$, $R_3 = 12K\Omega$, $R_1 = 10K\Omega$, $R_2 = 3.9K\Omega$

$V_Z = 5.1\ V$

a- Assume I_L remains constant & V_{in} changes by 1V what change in collector current of Q_1 will take place?

b- with constant V_{in} if R_L changed from $1K\Omega$ to $1.2K\Omega$ (Neglecting change in V_o) find change in shunt current through Q_1 .

a- $\because V_o$ is constant $\rightarrow I_L \rightarrow$ constant

$$\Rightarrow \Delta I_c = \frac{\Delta V_{in}}{R_4} = \frac{1V}{100} = 10\,mA$$

b- $V_o = \left(1 + \frac{R_1}{R_2}\right) V_Z = \left(1 + \frac{10}{3.9}\right)(5.1) = 18.2V$

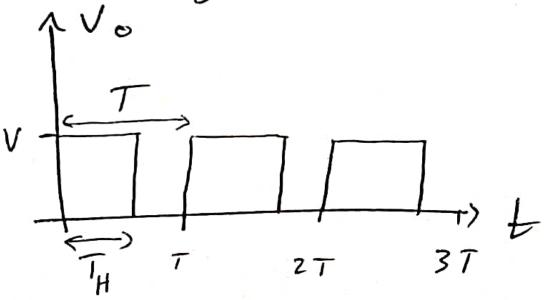
$$I_{L_1} = \frac{18.2}{1K} = 18.2\,mA$$

$$I_{L_2} = \frac{18.2}{1.2K} = 15.2\,mA$$

$$\Rightarrow \Delta I_L = \Delta I_c = 3\,mA$$

Switching Regulators :

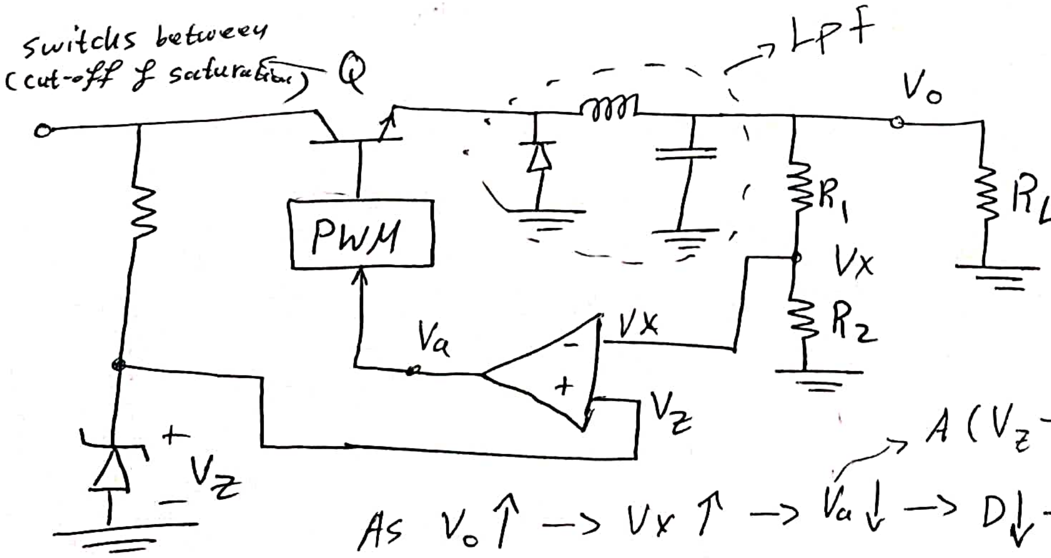
* By switching the o/p Voltage we can get different equivalent DC Voltage (current)
  ↳ using PWM



Duty cycle

$$\Rightarrow D = \frac{T_H}{T}$$

$$\Rightarrow V_{d.c} = \frac{1}{T}\int_0^T V_o\,dt = \frac{1}{T}\int_0^{T_H} V_H\,dt = V_H\left(\frac{T_H}{T}\right) = V_H \cdot D$$



$A(V_Z - V_x)$

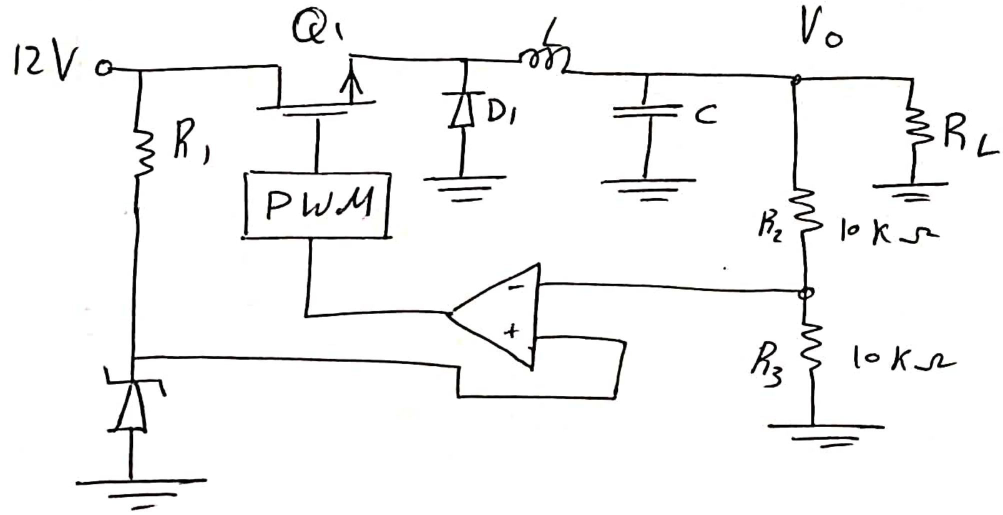
As $V_o \uparrow \rightarrow V_x \uparrow \rightarrow V_a \downarrow \rightarrow D \downarrow \rightarrow Q$ conducts less current

$V_o \downarrow$

$\boxed{8}$

Q4- For the shown Regulator, if the switching frequency is 10KHz & off-Time is 60 μs

a) What is the o/p Voltage? (Neglect V_{DS} Drop).



b) find the percent duty cycle

c) when does the diode D_1 turns on (forward-biased)?

Sol:

a) $V_o = V_{in}\left(\frac{T_H}{T}\right)$, $T_{off} = 60\,\mu s$

$T = \frac{1}{f}$, $f = 10\,KHz$ → $T_{ON} = 100 - 60 = 40\,\mu s$

$= \frac{1}{10^4} = 10^{-4} = 100\,\mu sec$

$\Rightarrow V_o = 12\left(\frac{40}{100}\right) = 4.8\,V$

b) $D = \frac{40}{100} * 100\% = 40\%$

c) D_1 will be forward biased when Q_1 Turns-off