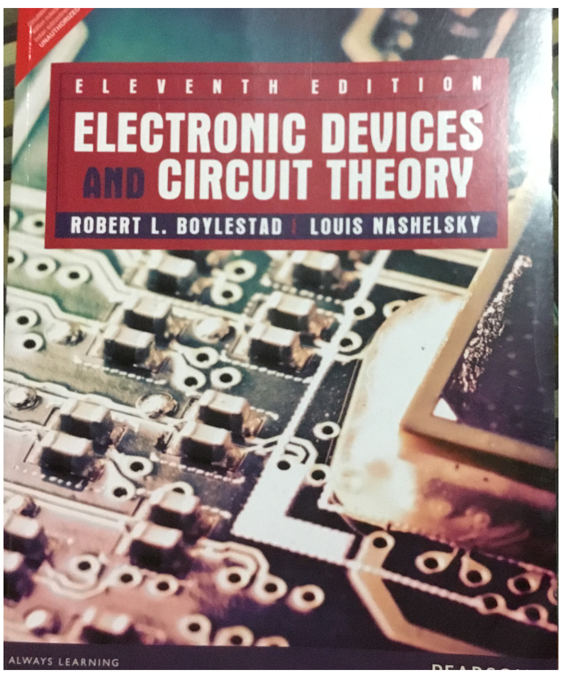
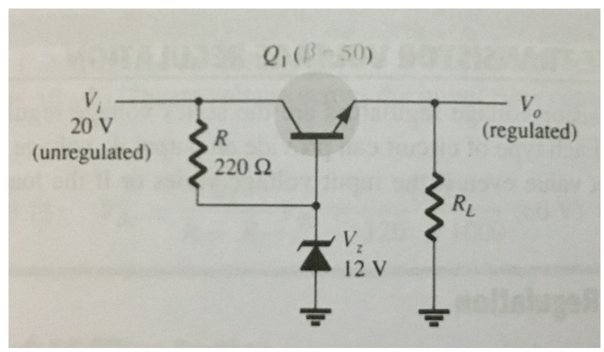
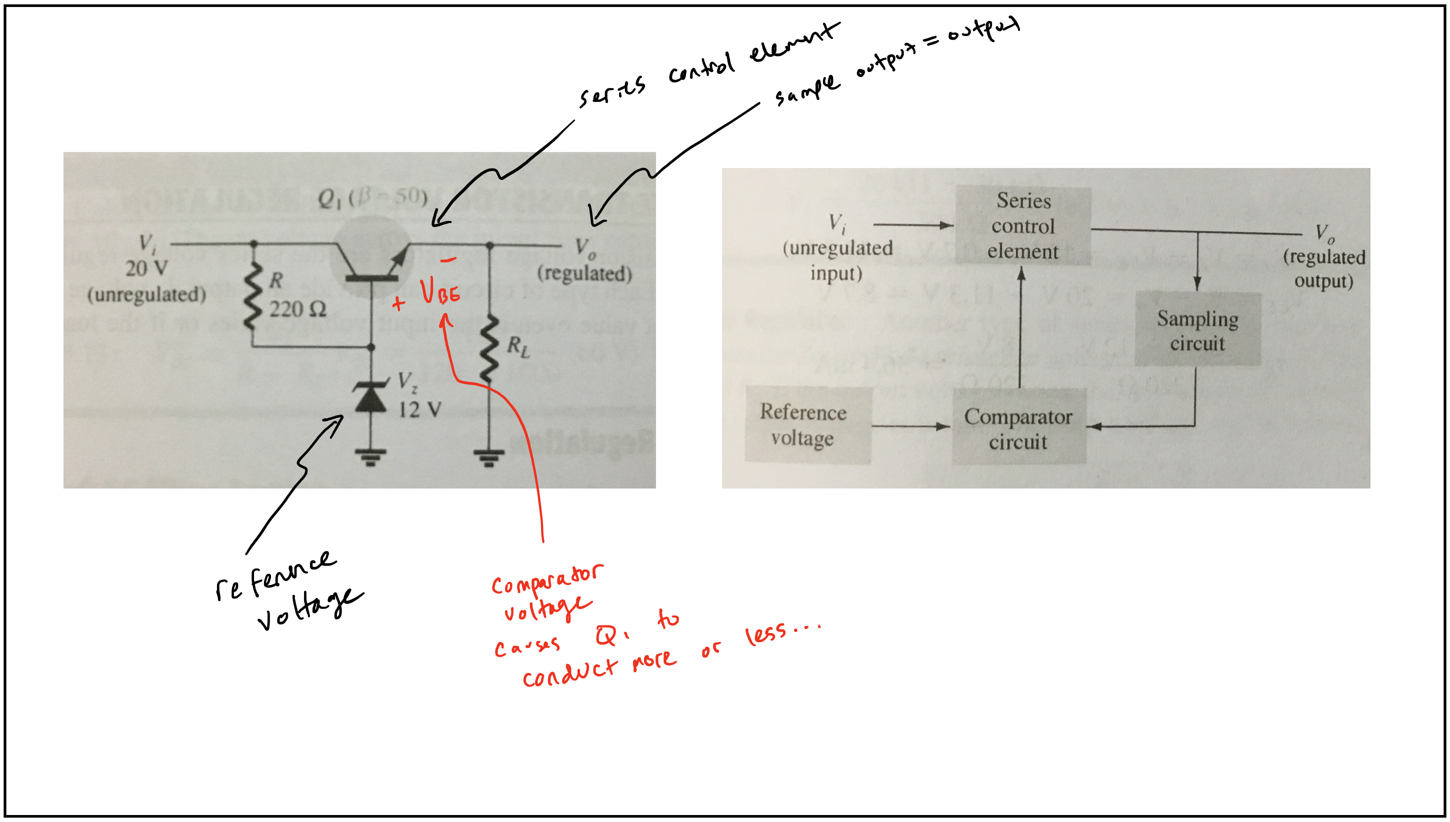
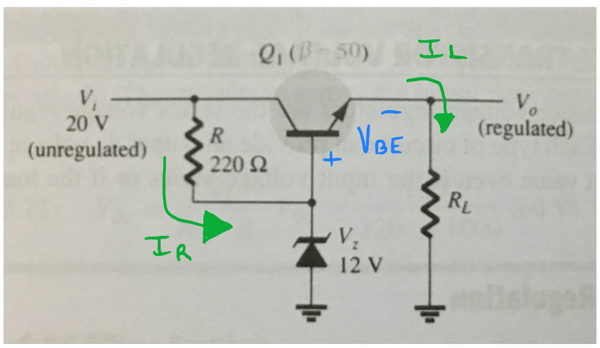




Simple series Voltage regulator circuit.

Note: It's in the emmiter follower configuration


series control element
sample output = output
Q1 (β = 50)
Vi
20 V
(unregulated)
R
220 Ω
+ VBE −
Vo
(regulated)
RL
Vz
12 V
reference voltage
Comparator voltage
causes Q1 to conduct more or less...
Vi
(unregulated input)
Series control element
Vo
(regulated output)
Sampling circuit
Reference voltage
Comparator circuit



Basic operation (feedback describing regulating operation)

$R_L \downarrow \quad V_o \downarrow \quad V_{BE} \uparrow \quad I_L \uparrow \quad V_o \uparrow$

assume current through resistor stays momentarily constant

feedback

$I_L = I_E = \alpha I_s e^{V_{BE}/V_T}$

$$\frac{12 - V_{BE}}{R_L} = \alpha I_s e^{V_{BE}/V_T}$$

This is the equation to solve!

Benefit: Zener current & voltage pretty constant w/ changing loads.

Disadvantage: V_o limited to V_z values...

Analysis

$V_o = 12 - V_{BE} \simeq 12 - 0.7 = 11.3\,V$

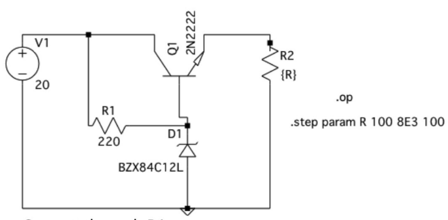
$V_{CE} = V_i - V_o = 20 - 11.3V = 8.7\,V$

$I_R = \dfrac{20 - 12}{220} = 36.4\,mA$

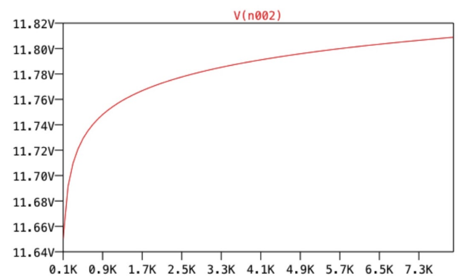
$I_L = I_E \simeq I_C$

If $R_L = 1k\Omega \rightarrow I_L = \dfrac{11.3\,V}{1k\Omega} = 11.3\,mA$

$I_B = I_C/\beta = \dfrac{11.3\,mA}{50} = 226\,\mu A \rightarrow I_z = I_R - I_B = 36.4\,mA - 226\,\mu A = 36\,mA$

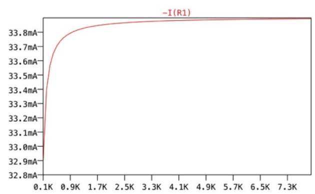


Output voltage as a function of load resistance RL



RL

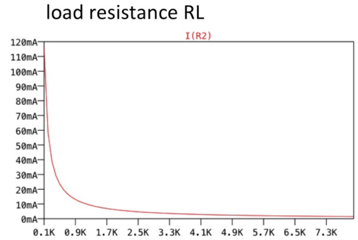
Current through R1 as a function of load resistance RL



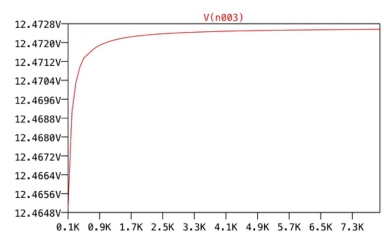
RL

Zener diode voltage as a function of load resistance RL

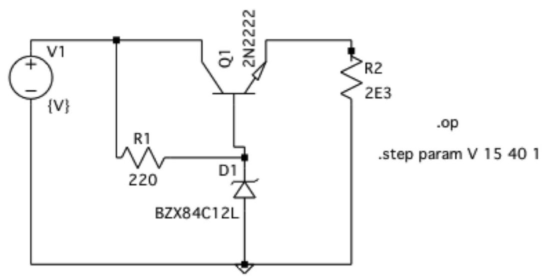
Output current as a function of load resistance RL



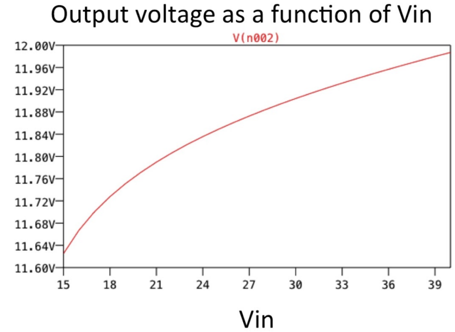
RL



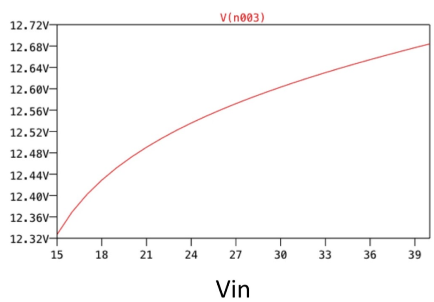
RL



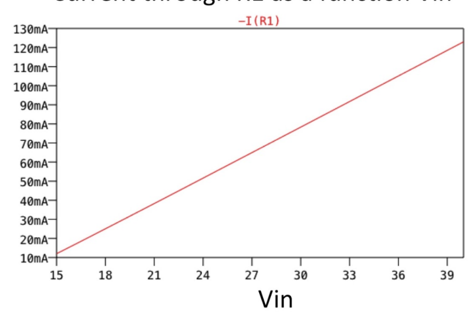
Output voltage as a function of Vin

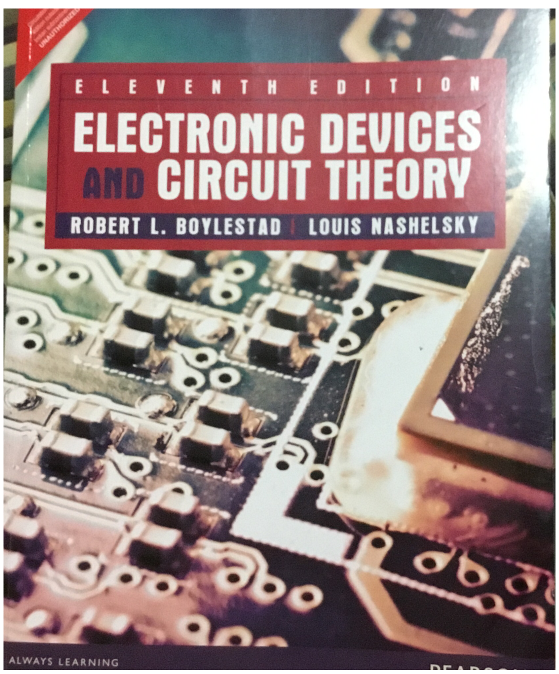


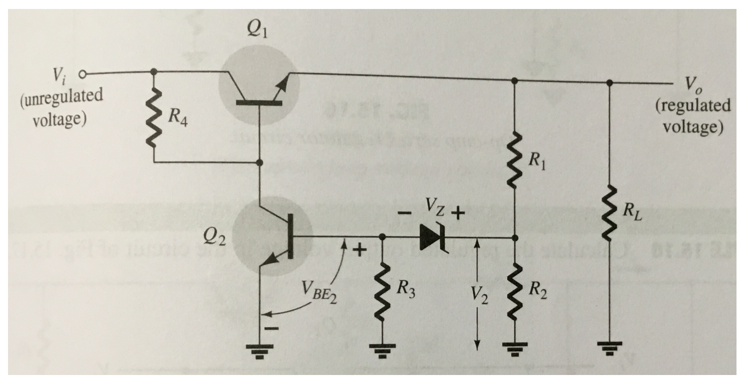
Zener voltage as a function of Vin



Current through R1 as a function Vin

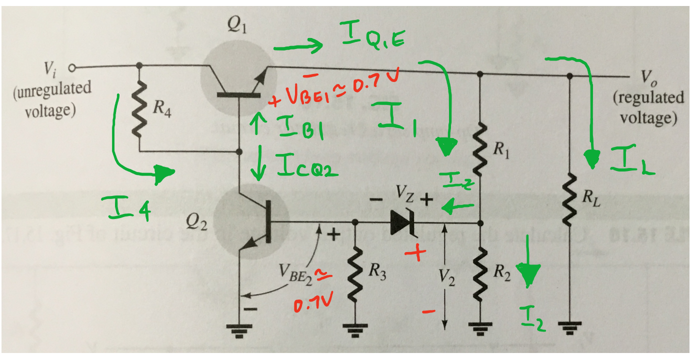






"Improved" series voltage regulator

The only improvement I really see over previous regulator is that V_o is set by V_Z and R_1 & R_2 ... so you can set V_o to any arbitrary value (not just those determined by V_Z)



Arrow analysis:

$R_L \downarrow \quad V_o \downarrow \quad I_1 \downarrow \quad V_2 \downarrow \quad V_{BE} \downarrow \quad I_{CQ2} \downarrow$

$\rightarrow I_{B1} \uparrow \quad I_{Q_1E} \uparrow \quad I_L \uparrow$

$\rightarrow V_o \uparrow$

assume current through resistor stays momentarily constant.

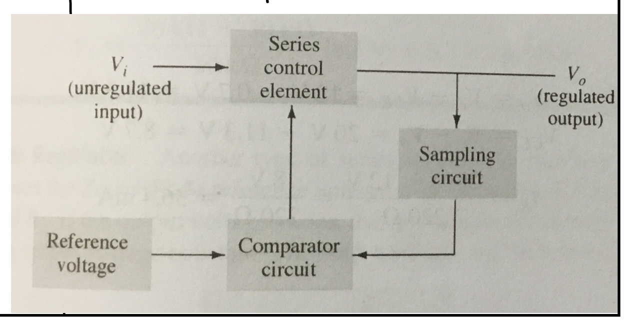
After many Spice simulations, I see that this circuit is very dependent on resistor values! If R4 or R3 are too small then the system will not work...

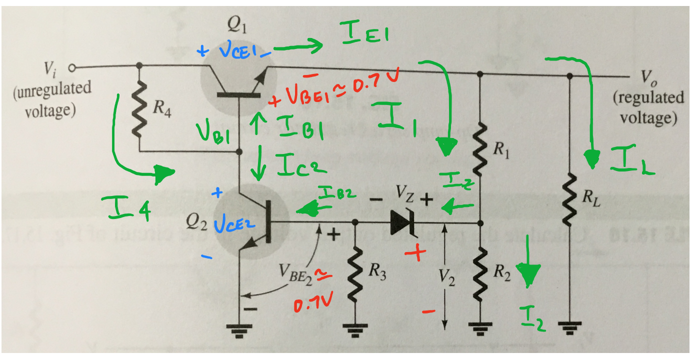
Example: $R_1 = 20k\Omega$, $R_2 = 30k\Omega$, $V_Z = 8.3V$

$$V_2 = V_{BE2} + V_Z \simeq 9V$$

$$9V = V_o \frac{R_2}{R_2 + R_1}$$

$$V_o = \frac{(9)(R_2 + R_1)}{R_2} = \frac{9 \cdot 50k}{30k} \simeq 15V$$





Assumptions

- Q_1 & Q_2 are in active region

$\therefore$ $V_{BE_1} \simeq 0.7V$ $\quad V_{CE1} > 0.2V$

$V_{BE_2} \simeq 0.7V$ $\quad V_{CE2} > 0.2V$

$I_{E1} \cong \beta I_{B1}$ $\quad V_{B1} \simeq V_o + 0.7V$

$I_{E2} \cong \beta_2 I_{B2}$

Assume I_{B1} stays same

Another arrow analysis (Start w/ input)

$V_i \uparrow$ $\quad I_4 \uparrow$ $\quad I_{C2} \uparrow$ $\quad I_{B2} \uparrow$

$V_{BE2} \uparrow$ $\quad I_z \uparrow$

Since $I_z \ll I_1$ & I_2

Nothing else changes!

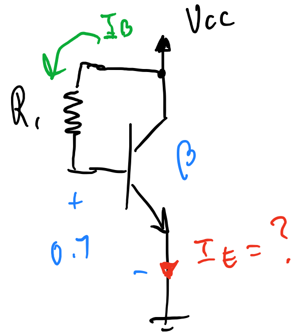
so V_o stays the same which agrees w/ assumption that I_{B1} stays the same.

- $I_z \ll I_1$ & I_2

$$\therefore \quad \frac{0.7}{R_3} + \frac{I_{C2}}{\beta} \ll \frac{V_z + 0.7}{R_2}$$

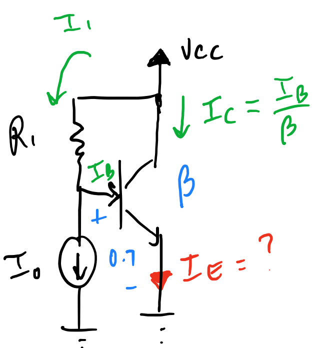
$$\Rightarrow \boxed{\frac{0.7}{R_3} + \frac{(V_i - V_{B1})}{\beta R_4} \ll \frac{V_z + 0.7}{R_2}}$$

Scratch



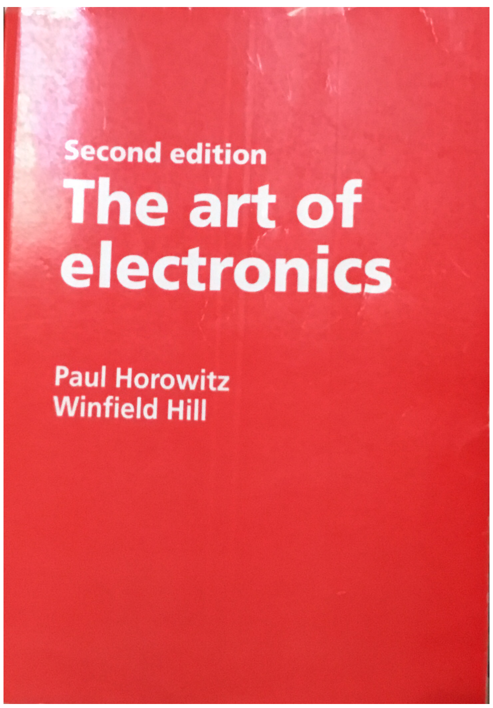
$$\frac{V_{cc} - 0.7}{R_1} = I_B \cong \frac{I_E}{\beta}$$

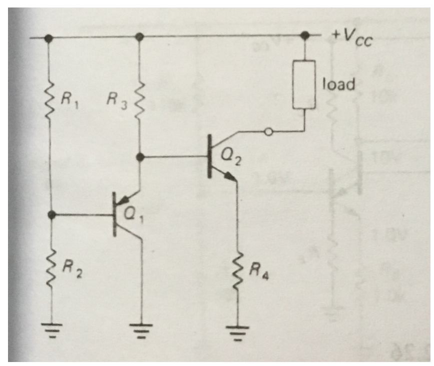
$$\rightarrow \quad I_E = \frac{\beta}{R_1}\left(V_{cc} - 0.7\right)$$



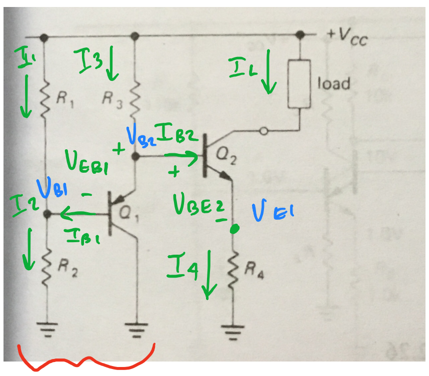
$$I_1 = I_B + I_0 \rightarrow \boxed{\frac{V_{cc} - 0.7}{R_1} = I_B + I_0}$$

?





Temperature compensated current source



Emitter follower

- The basic idea: supply constant current through load.
- problem this circuit tries to fix: β and V_{BE} change w/ temperature w/ changes w/ load current

$V_{BE} \rightarrow$ changes $(-2mV/°C)$ temp dependence

$V_{BE} \rightarrow$ changes $(-0.0001\Delta V_{CE})$ Early effect

Analysis:

$$I_1 + I_{B1} = I_2 \qquad \simeq 0 \text{ for } R_3\beta >> R_1$$

$$\frac{V_{CC}-V_{B1}}{R_1} + \frac{V_{CC}-(V_{B1}+V_{EB1})}{R_3\beta} = I_2 \qquad \frac{R_2}{R_2+R_1}V_{CC}$$

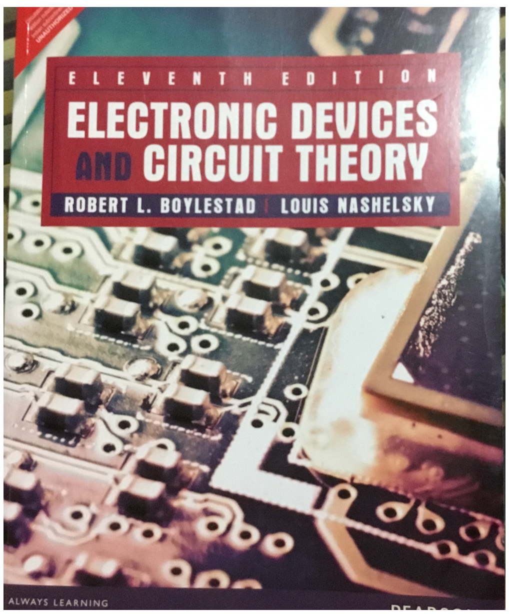
$$\rightarrow V_{B1} \simeq \text{constant} = \frac{R_2}{R_2+R_1}V_{CC}$$

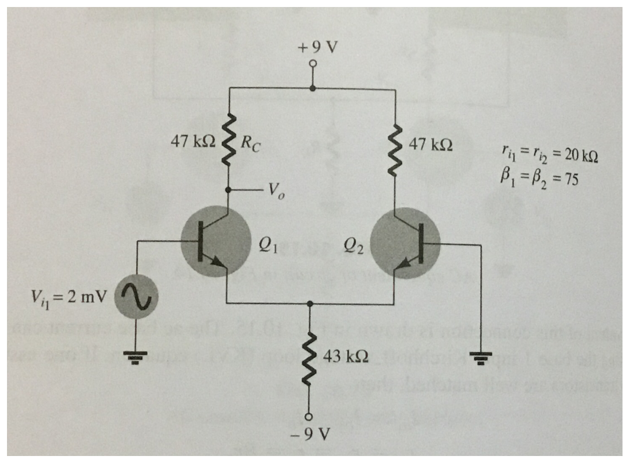
$$\rightarrow V_{B2} = V_{B1} + V_{EB1}$$

$$\rightarrow V_{E1} = V_{B1} + V_{EB1} - V_{EB2} \rightarrow$$

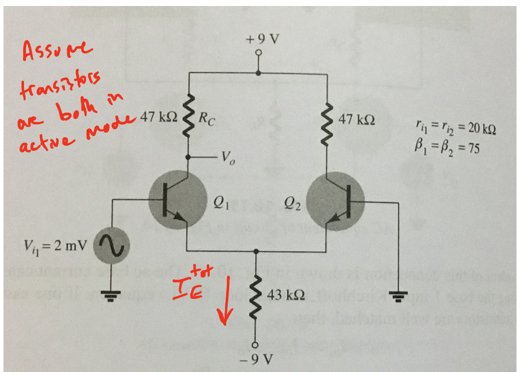
$$I_4 = \frac{V_{B1}+V_{EB1}-V_{EB2}}{R_4}$$

A change in V_{EB1} is counteracted by an opposite change in V_{EB2}.





Differential amplifier circuit



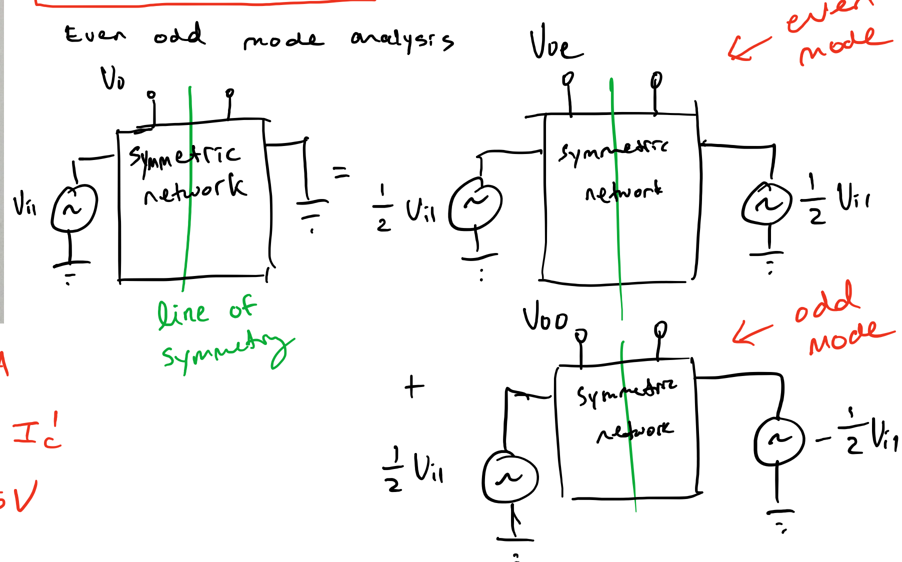
DC Bias: $I_E^{tot} = \dfrac{9-0.7}{43k\Omega} = 193\mu A$

$\therefore\ I_E' = I_E^{tot}/2 = 96.5\mu A \approx I_C'$

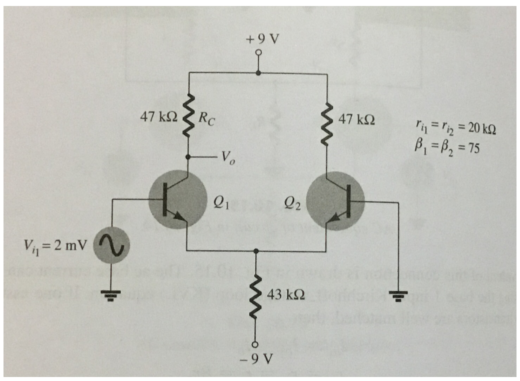
$V_{C1} = \dfrac{V_{CC} - I_C'}{47k\Omega} = 4.5V$

Goal: Find V_o

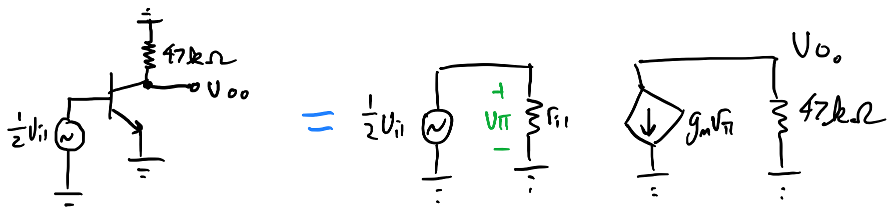
Even odd mode analysis



total output = $V_{oe} + V_{oo}$



Odd mode (AC eq)

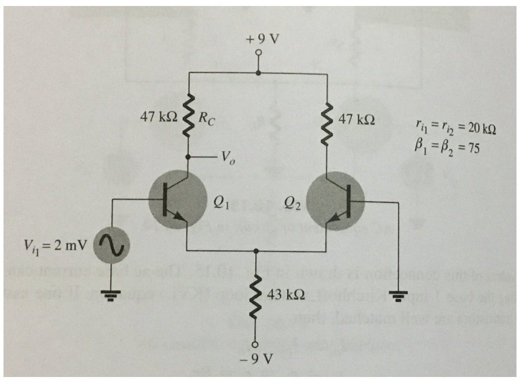


$$g_m = \frac{q I_c}{kT} = \frac{I_c}{26mV} = \frac{96.5\mu A}{26mV} = 0.0037$$

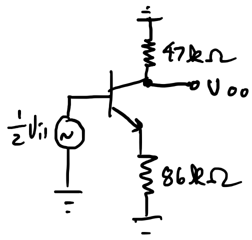
$$\therefore V_{oo} = -\frac{1}{2} V_{i1}\, g_m\, 47k\Omega$$

$$= \left(-\frac{1}{2}\right)(2mV)(0.0037)(47E3)$$

$$= -173.9mV \simeq -0.175\,V$$



even mode (AC eq)



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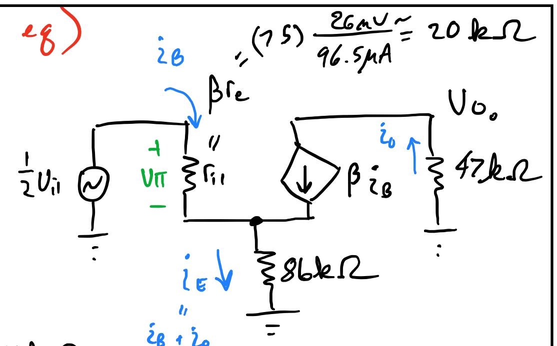


$$\frac{1}{2}V_{i1} = i_B r_{i1} + i_E\, 86k\Omega$$
$$= i_B r_{i1} + (i_B + i_o)\, 86k\Omega = i_B r_{i1} + i_B(1+\beta)\, 86k\Omega$$
$$= i_B(r_{i1} + 1 + \beta\, 86k\Omega) \simeq i_B \beta\, 86k\Omega$$

$$\rightarrow i_B = \frac{\frac{1}{2}V_{i1}}{(86k\Omega)\beta} \rightarrow i_o = \frac{\frac{1}{2}V_{i1}}{(86k\Omega)}$$

$$\rightarrow V_{oe} = -i_o\, 47k\Omega = -\frac{47k\Omega}{(86k\Omega)}\frac{1}{2}V_{i1} = \left(-\frac{1}{4}\right)(2mV)$$
$$= -0.5mV$$

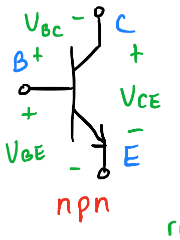
Since $V_{oe} \ll V_{oo}$

$\rightarrow V_o \simeq V_{oo}$

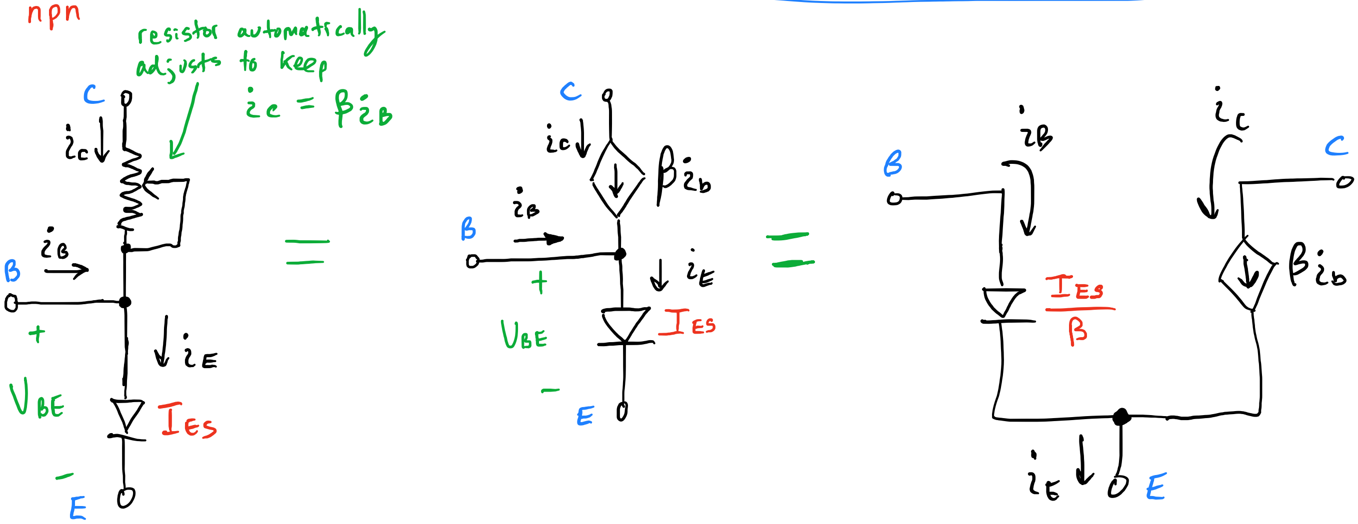
$$\rightarrow V_o = -0.175V = -175mV$$

Large signal models

Forward-active : $V_{BE} > 0$, $V_{BC} < 0$, $V_{CE} > 0$

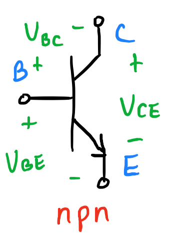


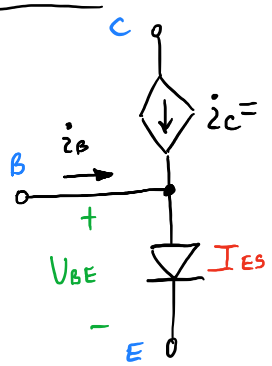
Three equivalent large signal models



Large signal models

Forward-active : $V_{BE} > 0$, $V_{BC} < 0$, $V_{CE} > 0$





$$i_C = \beta i_B = \alpha i_E = \alpha I_{ES}\left(e^{V_{BE}/V_T} - 1\right)$$

$\alpha = \frac{\beta}{\beta+1} = 0.98 - 0.99$ typically

So we can view (CCCS symbol) as a CCCS or a VCCS!

$\alpha I_{ES} \equiv I_S$

V_T = thermal voltage $\frac{kT}{q} \simeq 26$ mV @ 300K

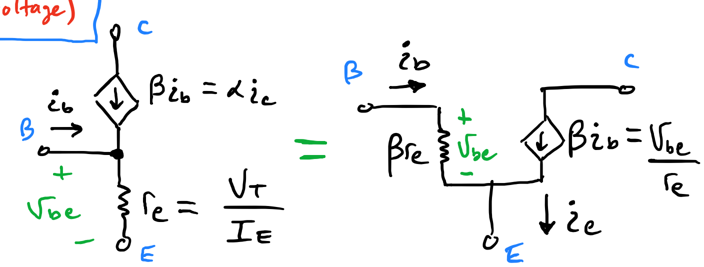
I_{ES} = reverse saturation current of base-emitter diode (on order of 10^{-15} to 10^{-12} amperes).

This determines the voltage drop accross diode (e.g. 0.3V, 0.65V, etc.)

very simple Ebers-Moll model in forward-active mode (ignores early voltage)

Small signal: $v_{BE} = V_{BE} + v_{be}$

- v_{BE}: instantaneous total
- V_{BE}: quiescent large signal
- v_{be}: incremental small signal (wiggle)



Useful basic BJT configurations for analog electronics design