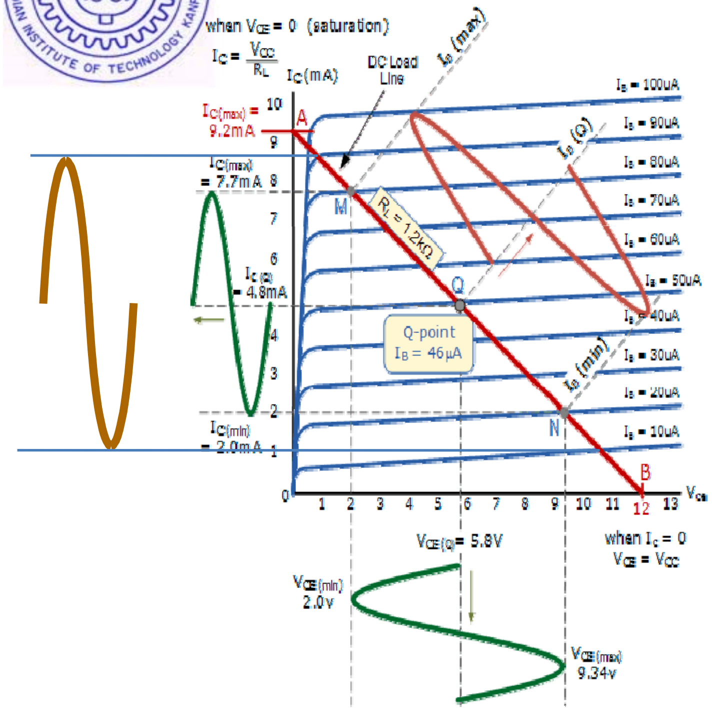
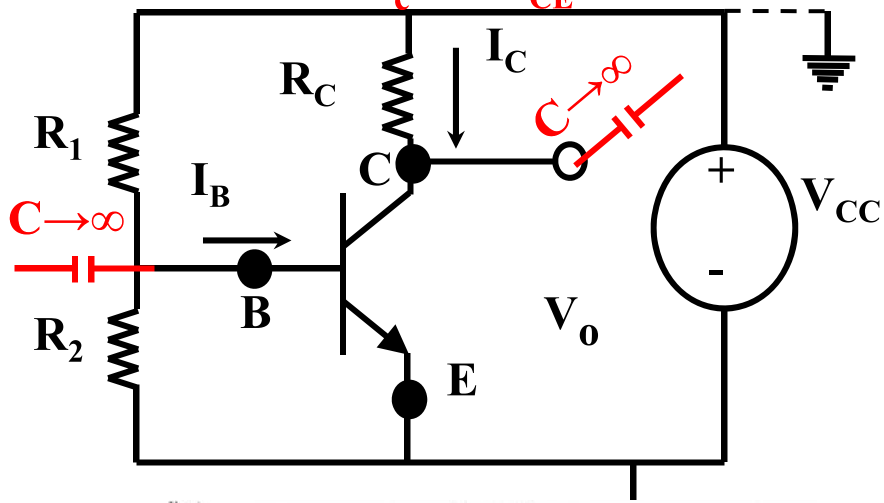
ESc201, Lecture 20: BJT Amplifier (Small signal Model)

$$V_{CE_Q} = \frac{V_{cc} - 0.7}{2}$$

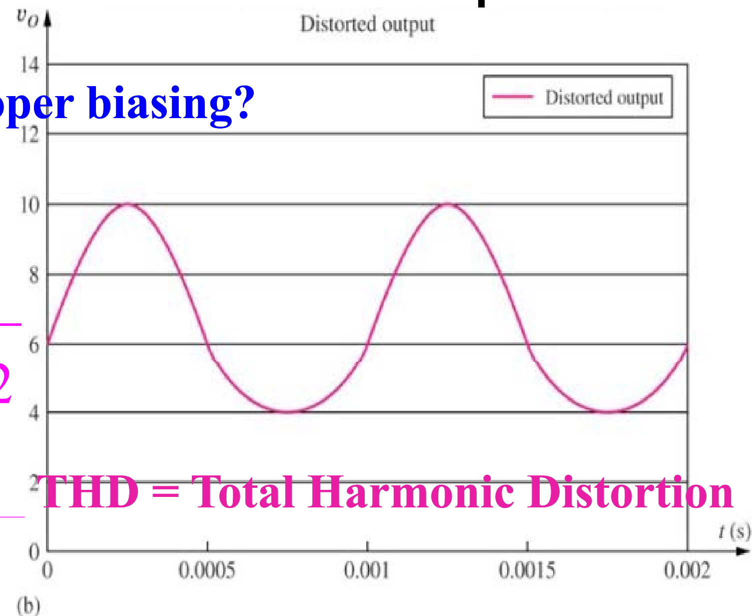
Rule of thumb: Equal division of V_{cc} between R_c and V_{CE}



R_1 and R_2 that $I_B << I_2$. So that $I_1 \approx I_2$. Base current shouldn't disturb voltage divider action. Thus, Q-point is independent of base current as well as current gain.



Why need to do proper biasing?



$v(t) = V_O$ **dc**

$+V_1(\sin\omega_O t+\varphi_1)$ **desired output**

$+V_2(2\sin\omega_O t+\varphi_2)$ **2nd harmonic distortion**

$+V_3(3\sin\omega_O t+\varphi_3)$ **3rd harmonic distortion**

$+\ldots$ **Higher Order distortion**

$$\mathrm{THD} = 100\% \times \frac{\sqrt{\sum_{2}^{\infty} V_n^{\,2}}}{V_1}$$

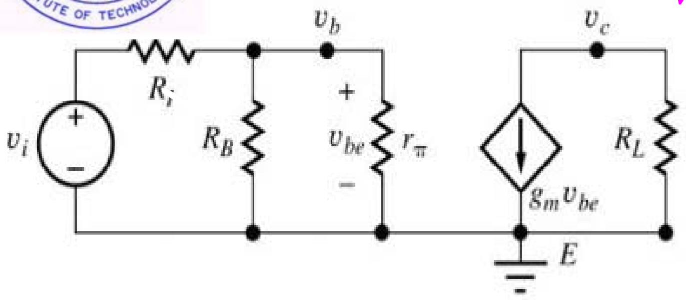
THD = Total Harmonic Distortion

Numerator= sum of rms amplitudes of distortion terms, Denominator = desired component

But this design is not protected against Q-Point variation with β. So R_E is required for that.

ESc201, Lecture 20: Bipolar Junction Transistor (Small signal Model)

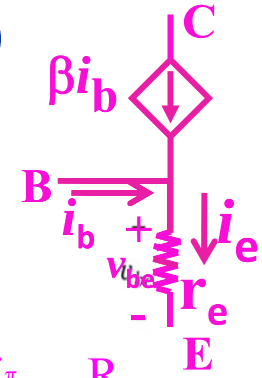
Without R_E



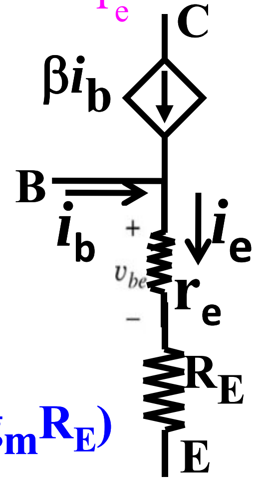
$$A_v = \frac{v_o}{v_i} = \left(\frac{v_o}{v_b}\right)\left(\frac{v_b}{v_i}\right) = -\frac{\beta i_b R_L}{i_b r_\pi}\left(\frac{v_b}{v_i}\right)$$

$$= -\frac{\beta R_L}{r_\pi}\frac{r_\pi}{\{R_i + r_\pi\}} = -\frac{\beta R_L}{\{R_i + r_\pi\}}$$

$$= -\frac{\beta R_L}{\{R_i + (\beta+1)r_e\}} \cong -\frac{\beta R_L}{\{(\beta+1)r_e\}} \overset{R_i \ll r_\pi}{\cong} -\frac{R_L}{r_e}$$



$$A_v \overset{R_E}{=} -\frac{\beta R_L}{\{R_i + (\beta+1)(r_e + R_E)\}} \overset{R_i \ll r_\pi}{\cong} -\frac{\beta R_L}{\{(\beta+1)(r_e + R_E)\}} \overset{r_e \ll R_E}{\cong} -\frac{R_L}{R_E}$$



Effect of adding R_E

1. **The voltage gain is now less dependent on β.**
2. **The input resistance is increased by a factor of $(1+g_m R_E)$.**
3. **The base to collector voltage gain is reduced by $1/(1+g_m R_E)$**
4. **For the same nonlinear distortion the input can be increased by factor of $(1+g_m R_E)$**
5. **The frequency response in significantly improved.**

As a particular example for β=100, R_L= 4.12kΩ, R_E=300Ω, and a $C_{Emitter\text{-}Collector}$=0.5pF

Without R_E the values are :

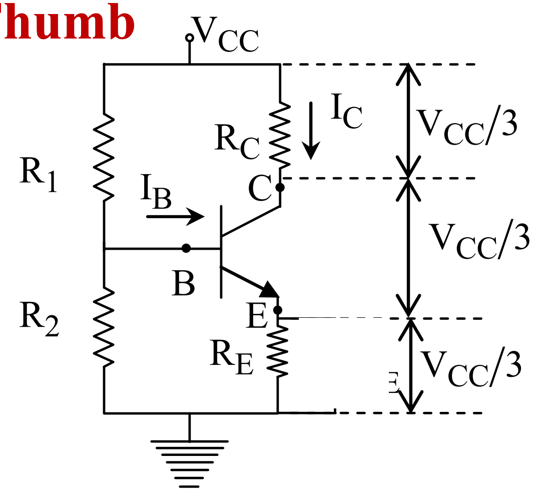
$A_{mid\ freq}$= -153, f_H= 1.56 MHz (~Bandwidth), GBWP (Gain Bandwidth Product) =239MHz.

With R_E the values are :

$A_{mid\ freq}$= -11.0, f_H= 13.9 MHz, GBWP =153 MHz.

And R_{in} must have increased by approximately a ratio of (153/11)=14 times.

4-Resistor Bias Network for BJT - $V_{cc}/3$ Rule of Thumb



$$I_E = \frac{V_{BB} - V_{BE} - R_B I_B}{R_E} \cong \frac{V_{BB} - V_{BE}}{R_E} \quad \text{for } R_B I_B << (V_{BB} - V_{BE})$$

This implies that $I_B << I_2$. So that $I_1 = I_2$. So base current doesn't disturb voltage divider action. Thus, Q-point is independent of base current as well as current gain.

Also, V_{BB} is designed to be large enough that small variations in V_{BE} assumed value of won't affect I_E.

Current in base voltage divider network is limited by choosing $I_2 \leq I_C/5$. This ensures that power dissipation in bias resistors is < 17 % of total quiescent power consumed by circuit and $I_2 >> I_B$ for $\beta > 50$.

Design Guidelines

1. **Choose Thevenin equivalent base voltage** $\frac{V_{CC}}{4} \leq V_{BB} \leq \frac{V_{CC}}{2}$
2. **Select R_1 to set $I_1 = 9I_B$.** $R_1 = \frac{V_{BB}}{9I_B}$
3. **Select R_2 to set $I_2 = 10I_B$.** $R_2 = \frac{V_{CC} - V_{BB}}{10I_B}$
4. **R_E is determined by V_{BB} and desired I_C.** $R_E \cong \frac{V_{BB} - V_{BE}}{I_C}$
5. **R_C is determined by desired V_{CE}.**
($V_{cc}/3$ or ~$V_{cc}/2$ in the absence of R_E, as the case may be) $R_C \cong \frac{V_{CC} - V_{CE}}{I_C} - R_E$

ESc201, Lecture 20: BJT Amplifier (Small signal Model)

Example: Design 4-resistor bias circuit with given parameters.

Given data: I_C =750 mA, β_F = 100, V_{CC} = 15 V, V_{CE} = 5 V.

Assumption: Forward-Active operation region, V_{BE} = 0.7 V

Rule of thumb ($V_{cc}/3$): Divide (V_{CC} - V_{CE}) equally between R_E & R_C. or V_E=5V & V_C=10V.

$$R_C = \frac{V_{CC} - V_C}{I_C} = 6.67\text{k}\Omega \qquad R_E = \frac{V_E}{I_E} = 6.60\text{k}\Omega \qquad \therefore\ V_B = V_E + V_{BE} = 5.7\text{V}$$

$$I_B = \frac{I_C}{\beta_F} = 7.5\mu\text{A} \quad I_2 = 9I_B = 67.5\mu\text{A}, \quad I_1 = 10I_B = 75\mu\text{A}$$

$$R_1 = \frac{V_B}{10I_B} = 76\text{k}\Omega \qquad R_2 = \frac{V_{CC} - V_B}{9I_B} = 138\text{k}\Omega$$

$$A_v = \frac{v_o}{v_i} = \left(\frac{v_o}{v_b}\right)\left(\frac{v_b}{v_i}\right) = -\frac{\alpha i_e R_L}{i_e(r_e + R_E)}\left(\frac{v_b}{v_i}\right)$$

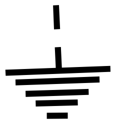
$$= -\frac{\alpha i_e R_L}{i_e(r_e + R_E)} \frac{i_i[R_B||(\beta+1)(r_e + R_E)]}{i_i\{R_i + [R_B||(\beta+1)(r_e + R_E)]\}}$$

$$\cong -\frac{(\beta/(\beta+1))R_L}{(r_e + R_E)} \frac{(\beta+1)(r_e + R_E)}{\{R_i + (\beta+1)(r_e + R_E)\}}$$

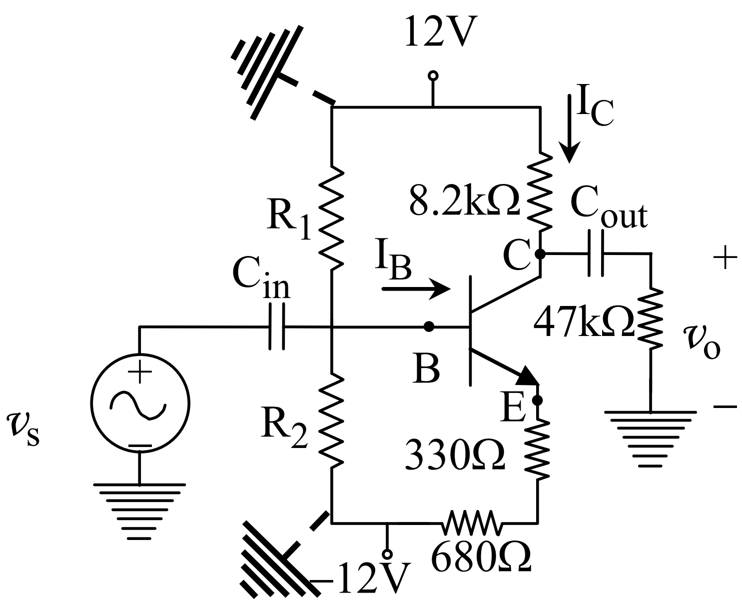
$$= -\frac{\beta R_L}{\{R_i + r_\pi + (\beta+1)R_E\}}$$

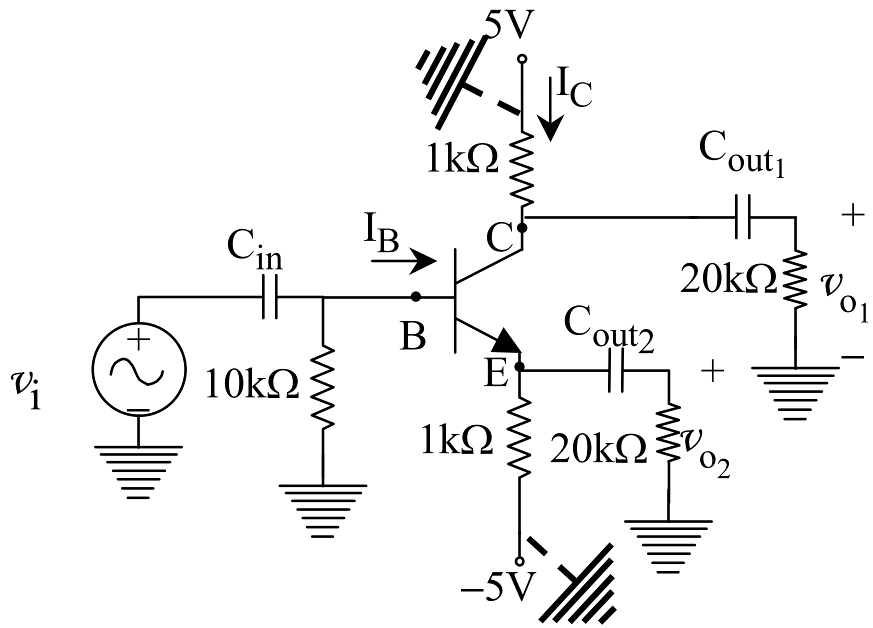
$$\cong -\frac{\beta R_L}{\{R_i + r_\pi + (\beta+1)R_E\}} \cong -\frac{\beta R_L}{\{(\beta+1)R_E\}}\Bigg|_{R_E \gg r_e}$$

$$\frac{A_v(\text{with } R_E)}{A_v(\text{without } R_E)} = \frac{-\dfrac{\beta R_L}{\{R_i + r_\pi + (\beta+1)R_E\}}}{-\dfrac{\beta R_L}{\{R_i + r_\pi\}}} \cong \frac{1}{1 + \dfrac{\beta R_E}{r_\pi}} = \frac{1}{1 + g_m R_E}$$



Signifies short for all A.C. to ground.





Class Average:

MiniQ1 → 4.35/10

MiniQ2→ 5.91/10

MiniQ3 → 1.57/10

MajQ1 → 3.23/10

ESc201, Lecture 16: Power Supply