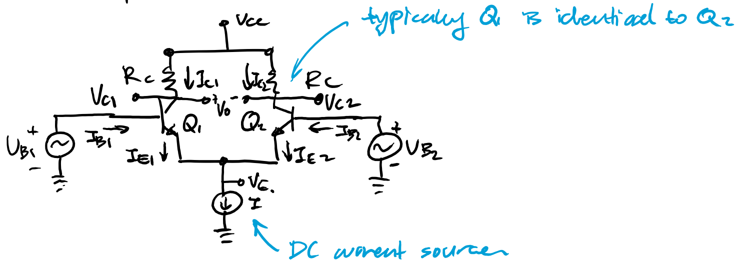
The Differential Amplifier

October 30, 2017 3:32 PM

+ doesn't need AC coupled (no C_{C1}, C_{C2})

Typical Diff. Amplifier:



If $V_{B1} = V_{B2}$, then $V_{BE1} = V_{BE2}$, thus $i_{E1} = i_{E2} = I_{E1} = I_{E2} = I/2$

where $i_C = I_S e^{V_{BE}/V_T}$

Thus $i_{E1} = \frac{I_S}{\alpha} e^{(V_{B1} - V_E)/V_T}$

$i_{E2} = \frac{I_S}{\alpha} e^{(V_{B2} - V_E)/V_T}$

Dividing by I:

$$\frac{i_{E1}}{I} = \frac{i_{E1}}{i_{E1} + i_{E2}}$$

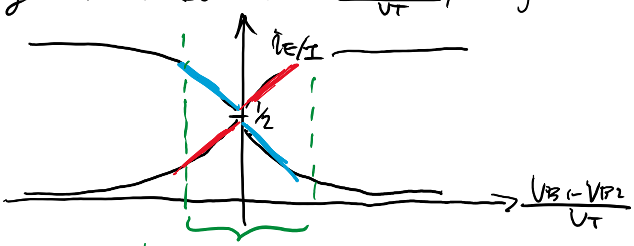
$$= \frac{1}{1 + \frac{i_{E2}}{i_{E2}}}$$

$$= \left(1 + e^{(V_{B2} - V_{B1})/V_T}\right)^{-1}$$

$$\longrightarrow i_{E1} = I \cdot \left(1 + e^{(V_{B2} - V_{B1})/V_T}\right)^{-1}$$

Similarly, $i_{E2} = I \cdot \left(1 + e^{(V_{B1} - V_{B2})/V_T}\right)^{-1}$

Plotting I_{E1} and I_{E2} wrt $\frac{V_{B1} - V_{B2}}{V_T}$, we get:



the relationships are reasonably linear in this region.

Small Signal Operation requires the differential voltage (in the linear region)

$$|V_d| = |V_{B2} - V_{B1}| \ll 2V_T.$$

Using the fact $i_{C1} = \alpha i_{E1}$ and approximating using taylor series,

so $i_{C1} \approx \frac{\alpha I}{2}\left(1 + \frac{V_d}{2V_T}\right)$

Similarly $i_{C2} \approx \alpha \frac{I}{2}\left(1 - \frac{V_d}{2V_T}\right)$

Consider V_d is evenly distributed. ($\pm V_d/2$ across each transistor), then

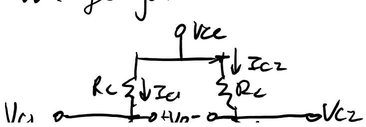
$$i_C = \alpha\frac{I}{2} \pm \frac{\alpha I}{2V_T} \cdot \frac{V_d}{2}$$

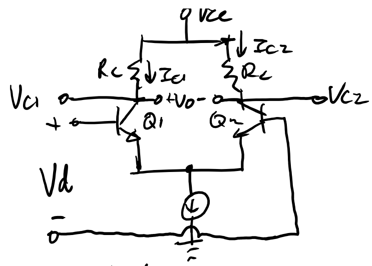
$$= I_C \pm g_m \frac{V_d}{2}$$

$$\Longrightarrow g_m = \frac{\alpha I}{2V_T}$$

$$\Longrightarrow i_c = g_m \frac{V_d}{2}$$

Calculating the voltage gain:



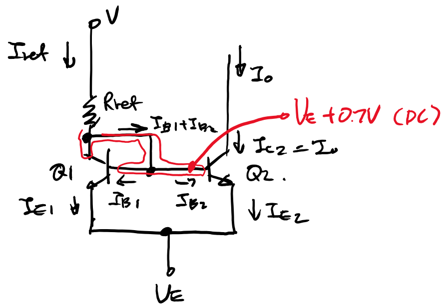


Using KVL, we conclude:

$$\frac{V_o}{V_d} = -g_m R_C$$

Current Mirror (Basic Current Source)

Typical current mirror setup:



Ohm's law: $I_{ref} = \dfrac{V-(V_E+V_{BE})}{R_{ref}}$

KCL: $I_{ref} + \cancel{I_{B1}} = I_{E1} + (\cancel{I_{B1}} + I_{B2})$

$= I_{E1} + I_{B2}$

KCL: $I_o = I_{C2} = I_{E2} - I_{B2}$

Since Q_1 and Q_2 are identical, $\underline{V_{B1} = V_{B2}}$

Thus $I_{E1} = I_{E2}$

$$I_{ref} = I_{E1} + I_{B2}$$

$$I_{ref} - I_o = I_{E1} + I_{B2} - (I_{E2} - I_{B2})$$

$$I_{ref} = 2I_{B2} + I_o.$$

$$I_o = I_{C2}$$

$$I_{ref} = I_o\left(1+\frac{2}{\beta}\right)$$

$$\rightarrow I_o = \frac{I_{ref}}{\left(1+\frac{2}{\beta}\right)}$$