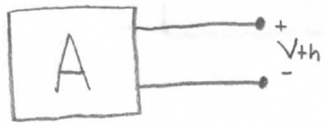
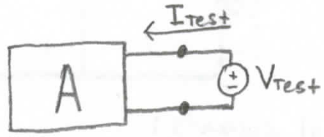
ELEC 301

Thenevin Equivilant



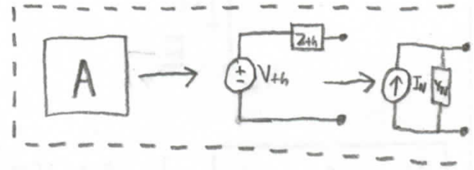


How to Calculate Z_{th}:

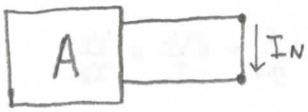
① Connect Test voltage V_{Test} (1 V)

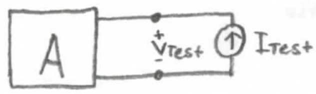
② Calculate I_{Test}

$\therefore Z_{th} = \frac{V_{Test}}{I_{Test}}$



Norton Equivilant





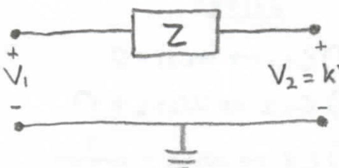
How to Calculate Y_N:

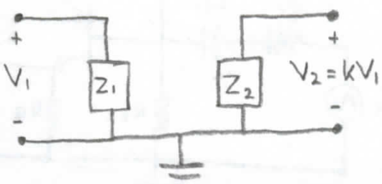
① Connect Test current I_{Test} (1A)

② Calculate V_{Test}

③ $Y_N = \frac{I_{Test}}{V_{Test}}$

Millers Thereom



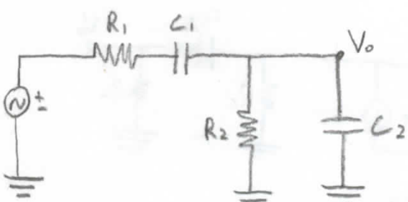


Where:

$$Z_1 = \frac{Z}{1-k}$$

$$Z_2 = \frac{Z}{1-1/k}$$

Circuit Behaviour



BAND-PASS

$C_1 >> C_2$

① **At DC ($\omega = 0$):**

C_1, C_2 are open. $V_o = 0$

② **At low frequency:**

C_1 is conducting. C_2 is open

$\therefore V_o$ = some value

③ **At high frequency:**

C_1 is shorted. C_2 is conducting

$\therefore V_o$ = Some Value

④ **At $\omega = \infty$:**

C_1, C_2 are shorted. $V_o = 0$

Frequency Response

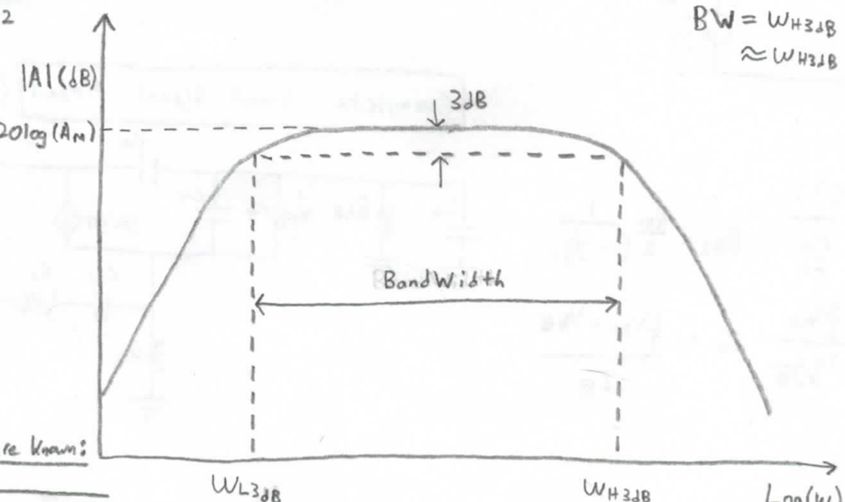
$$T(s) = \underbrace{A_M}_{\text{MidBand}} \cdot \underbrace{F_L(s)}_{\text{Low Freq Response}} \cdot \underbrace{F_H(s)}_{\text{High Freq Response}}$$

$$F_L(s) = \frac{(s+\omega_{Z1L})(s+\omega_{Z2L})\cdots(s+\omega_{ZnL})}{(s+\omega_{P1L})(s+\omega_{P2L})\cdots(s+\omega_{PnL})}$$

$$F_H(s) = \frac{\left(1+\frac{s}{\omega_{Z1H}}\right)\left(1+\frac{s}{\omega_{Z2H}}\right)\cdots\left(1+\frac{s}{\omega_{ZnH}}\right)}{\left(1+\frac{s}{\omega_{P1H}}\right)\left(1+\frac{s}{\omega_{P2H}}\right)\cdots\left(1+\frac{s}{\omega_{PnH}}\right)}$$

Magnitude Response (Generic Band-Pass Filter)

$$BW = \omega_{H3dB} - \omega_{L3dB}$$
$$\approx \omega_{H3dB} \; [\text{for } \omega_{H3dB} >> \omega_{L3dB}]$$



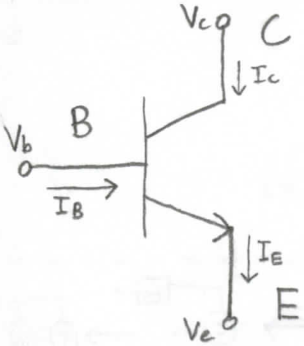
Finding Cut-off Frequencies

① **If locations of poles and zeros are known:**

$$\omega_{L3dB} = \sqrt{\omega_{P1L}^2 + \omega_{P2L}^2 \cdots - 2\omega_{Z1L}^2 - 2\omega_{Z2L}^2 \cdots}$$

$$\omega_{H3dB} = \sqrt{\left(\frac{1}{\omega_{P1H}}\right)^2 + \left(\frac{1}{\omega_{P2H}}\right)^2 \cdots - 2\left(\frac{1}{\omega_{Z1H}}\right)^2 - 2\left(\frac{1}{\omega_{Z2H}}\right)^2}$$

NPN BJT Transistor



Collector Current:

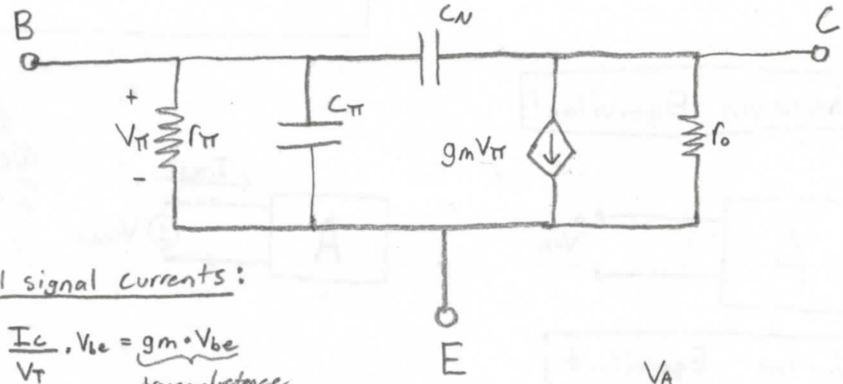
$I_C = \alpha I_E$

$I_C = \beta I_B$

$I_C = I_S e^{V_{BE}/V_T}$

$\alpha = \dfrac{\beta}{\beta+1}$

Complete Small Signal Model



$r_o \approx \dfrac{V_A}{I_C}$

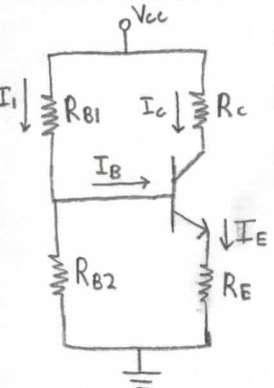
Small signal currents:

$i_c = \dfrac{I_C}{V_T} \cdot V_{be} = \underbrace{g_m}_{\text{transconductance}} \cdot V_{be}$

$i_b = \dfrac{g_m}{\beta} \cdot V_{be}$

$r_\pi = \dfrac{V_{be}}{i_b} = \dfrac{\beta}{g_m} = \beta \dfrac{V_T}{I_C} = \dfrac{V_T}{I_B}$

Bias Circuit



$V_{BE} = 0.7V$

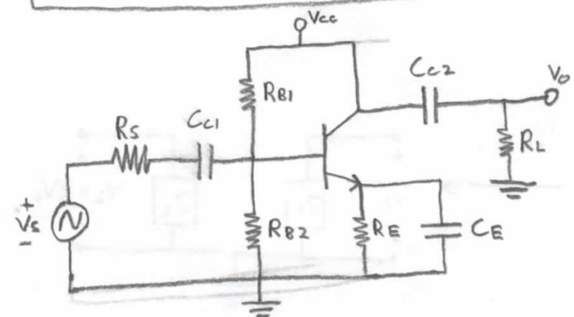
1/3 Rule (Version 2):

1. $V_C = \frac{2}{3} V_{CC}$
2. $V_E = \frac{1}{3} V_{CC}$
3. $I_1 = \dfrac{I_E}{\sqrt{\beta}}$

Resistor Values:

1. $R_C = \dfrac{1}{3} \dfrac{V_{CC}}{I_C} \approx R_E$
2. $R_{B1} = \dfrac{\frac{2}{3} V_{CC} - V_{BE}}{I_E/\sqrt{\beta}}$
3. $R_{B2} = \dfrac{\frac{1}{3} V_{CC} + V_{BE}}{I_E/\sqrt{\beta} - I_B}$

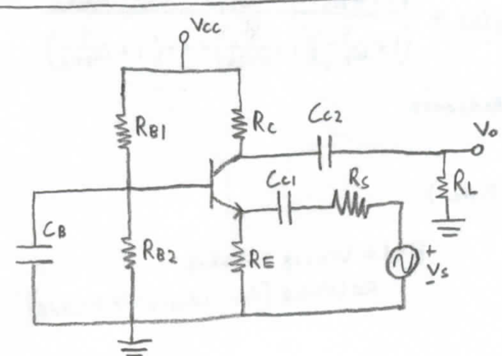
Common Emitter Amplifier



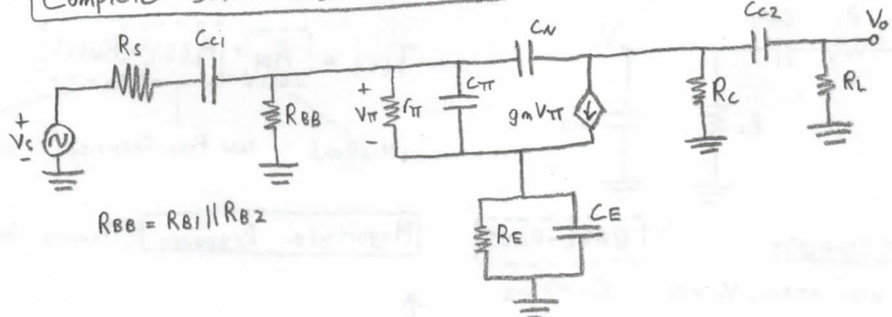
Zeroes:

1. $C_{C1} \rightarrow \omega_{LZ1} = 0$
2. $C_{C2} \rightarrow \omega_{LZ2} = 0$
3. $C_E \rightarrow \omega_{LZ3} = \dfrac{1}{R_E C_E}$

Common Base Amplifier

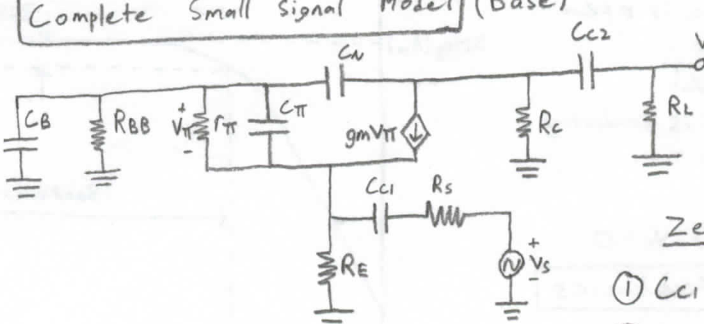


Complete Small Signal Model (Emitter)



$R_{BB} = R_{B1} \| R_{B2}$

Complete Small Signal Model (Base)



Zeroes:

1. $C_{C1} \rightarrow \omega_{LZ1} = 0$
2. $C_{C2} \rightarrow \omega_{LZ2} = 0$
3. $C_B \rightarrow \omega_{LZ3} = \dfrac{1}{R_{BB} C_B}$

1/3 Rule (Version 1):

1. $V_B = \frac{1}{3} V_{CC}$
2. $V_C = \frac{2}{3} V_{CC}$
3. $I_1 = \dfrac{I_E}{\sqrt{\beta}}$

$R_C = \dfrac{1}{3} \dfrac{V_{CC}}{I_C}$

$R_{B1} = \dfrac{\frac{2}{3} V_{CC}}{I_E/\sqrt{\beta}}$

$R_{B2} = \dfrac{R_{B1}}{2} \dfrac{1}{\left(1 - \frac{1}{\sqrt{\beta}}\right)}$

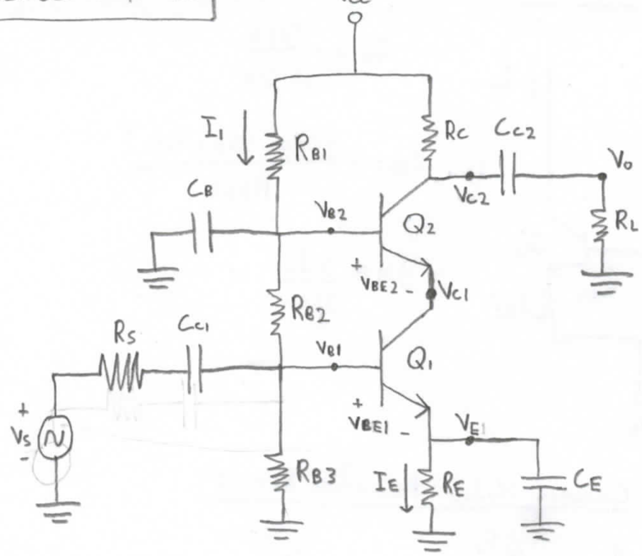
$R_E = \dfrac{\frac{1}{3} V_{CC} - V_{BE}}{I_E}$

Useful:

$g_m = \dfrac{I_C}{V_T}$

$r_\pi = \dfrac{\beta}{g_m}$

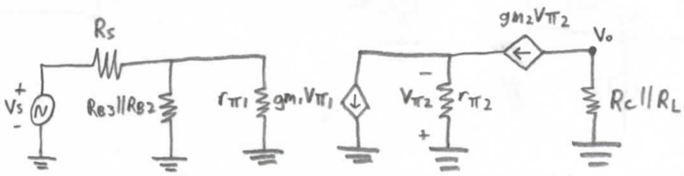
Cascode Amplifier



1/4 Rule Biasing:

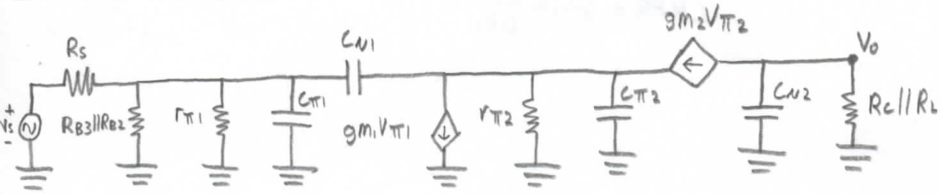
1. $V_{C2} = 3/4\ V_{CC}$
2. $V_{C1} = 1/2\ V_{CC}$
3. $V_E = 1/4\ V_{CC}$
4. $I_1 = 0.1 I_E$

Small Signal Model at Mid Band:



$$A_M = -g_{m2}(R_C \| R_L) \cdot \frac{R_{B3} \| R_{B2} \| r_{\pi 1}}{R_S + R_{B3} \| R_{B2} \| r_{\pi 1}}$$

Small signal model at High FREQ:

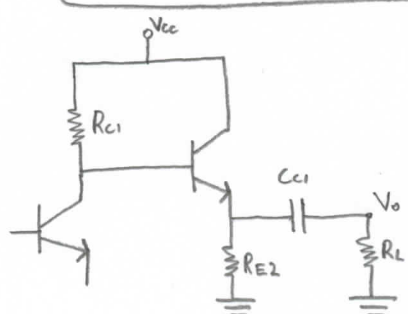


$$W_{HP1} = \frac{1}{[R_S \| R_{B2} \| R_{B3} \| r_{\pi 1}](C_{\pi 1} + 2C_{\mu 1})}$$

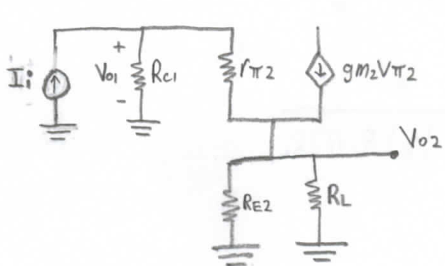
$$W_{HP2} = \frac{1}{\left(\frac{r_{\pi 2}}{1+\beta_2}\right)(C_{\pi 2} + 2C_{\mu 1})}$$

$$W_{HP3} = \frac{1}{(R_C \| R_L)(C_{\mu 2})}$$

Common Collector Amplifier



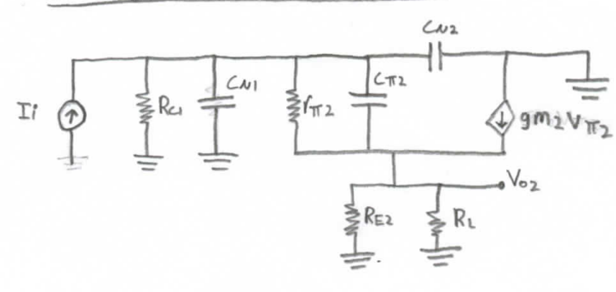
Small signal model at Mid Band:



$$R_o = R_{E2} \| \frac{r_{\pi 2} + R_{C1}}{1+\beta_2}$$

$$\frac{i_{e2}}{I_i} = \frac{R_{C1}}{R_{E2} \| R_L}$$

Small signal model at high FREQ:



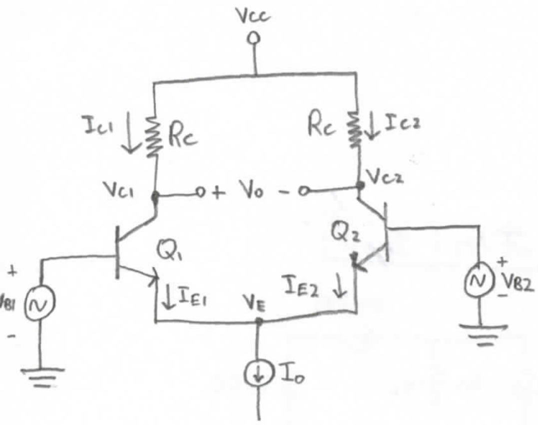
$$W_{HP1} = \frac{1}{R_{C1}(C_{\mu 1} + C_{\mu 2})}$$

$$W_{HP2} = \frac{1+\beta_2}{r_{\pi 2} C_{\pi 2}}$$

$$W_{ZH} = \frac{1+\beta_2}{r_{\pi 2} C_{\pi 2}}$$

Pole-zero Cancellation

Differential Amplifier

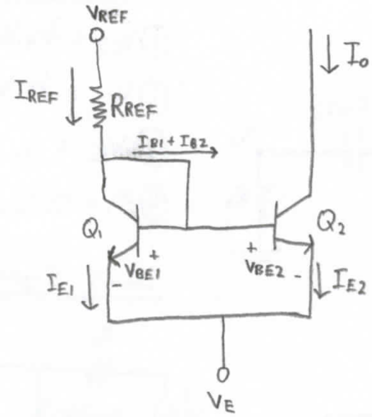


$$A_M = -g_m R_c \left[\frac{2r_\pi}{2r_\pi + R_s}\right]\left[\frac{R_L}{R_L + 2R_c}\right] \qquad K = -g_m R_c \cdot \frac{R_L}{R_L + 2R_c}$$

$$W_{HP1} = \frac{1}{\left[\frac{C_\pi}{2} + \frac{C_N}{2}(1-K)\right] 2r_\pi \| R_s}$$

$$W_{HP2} = \frac{1}{\frac{C_N}{2}\left(1 - \frac{1}{K}\right) R_L \| 2R_c}$$

Current Mirror



$$I_o = \frac{I_{REF}}{1 + 2/\beta}$$

$$I_{REF} = \frac{V_{REF} - (V_E + V_{BE1})}{R_{REF}}$$

$$g_m = \frac{\alpha I_o}{2V_T}$$

Common Mode Rejection Ratio:

$$A_{cm} = \frac{\Delta R_c}{2R}$$

$$CMRR = g_m 2R \frac{R_c}{\Delta R_c}$$

Useful information.

$$i_C = I_C + i_c$$

$$I_C = \alpha I_E$$

$$I_C = \beta I_B$$

$$I_C = I_S e^{\frac{V_{BE}}{V_T}}$$

$$\alpha = \frac{\beta}{\beta + 1}$$

$$\beta = \frac{\alpha}{1 - \alpha}$$

$$v_{BE} = V_{BE} + v_{be}$$

$$i_C = I_S e^{\frac{v_{BE}}{V_T}} = I_S e^{\frac{V_{BE}}{V_T}} e^{\frac{v_{be}}{V_T}} = I_C e^{\frac{v_{be}}{V_T}}$$

$$i_C \approx I_C + \frac{I_C}{V_T} v_{be}$$

$$i_c = \frac{I_C}{V_T} v_{be} = g_m v_{be}$$

$$g_m = \left.\frac{\partial i_C}{\partial v_{BE}}\right|_{i_C = I_C}$$

$$i_B = I_B + i_b = \frac{i_C}{\beta} = \frac{I_C}{\beta} + \frac{i_c}{\beta} = \frac{I_C}{\beta} + \frac{g_m}{\beta} v_{be}$$

$$i_b = \frac{g_m}{\beta} v_{be}$$

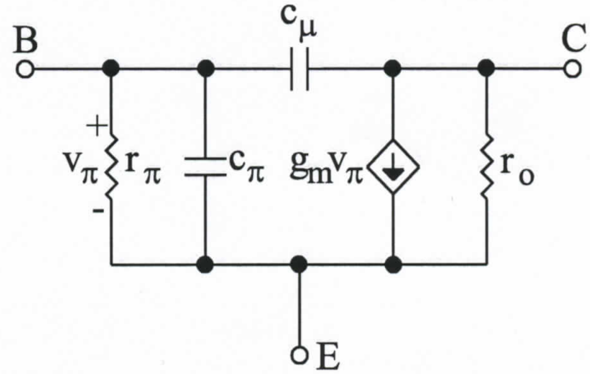
$$r_\pi \equiv \frac{v_{be}}{i_b}$$

$$r_\pi = \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \beta \frac{V_T}{I_C} = \frac{\beta V_T}{\beta I_B} = \frac{V_T}{I_B}$$

$$C \equiv \frac{dQ}{dV}$$

$$r_o = \left[\left.\frac{\partial i_C}{\partial v_{CE}}\right|_{v_{BE} = \text{constant}} \right]^{-1}$$

$$r_o \approx \frac{V_A}{I_C}$$



Small-Signal Model

$$A_f = \frac{A}{1 + A\beta}$$

h-parameters

$$V_1 = h_{11} I_1 + h_{12} V_2$$

$$I_2 = h_{21} I_1 + h_{22} V_2$$

y-parameters

$$I_1 = y_{11} V_1 + y_{12} V_2$$

$$I_2 = y_{21} V_1 + y_{22} V_2$$

z-parameters

$$V_1 = z_{11} I_1 + z_{12} I_2$$

$$V_2 = z_{21} I_1 + z_{22} I_2$$

g-parameters

$$I_1 = g_{11} V_1 + g_{12} I_2$$

$$V_2 = g_{21} V_1 + g_{22} I_2$$