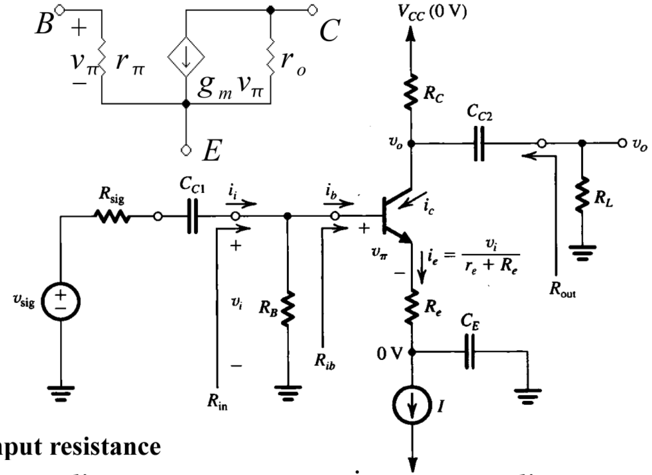
Common Emitter



input resistance

$$R_{ib} \equiv \frac{v_i}{i_b} \qquad i_b = (1-\alpha) i_e = \frac{i_e}{\beta+1} \qquad i_e = \frac{v_i}{r_e + R_e}$$

$$R_{ib} = (\beta+1)(r_e + R_e) \qquad R_{in} = R_B \| R_{ib}$$

voltage gain

$$v_o = -i_c (R_C \| R_L) = -\alpha i_e (R_C \| R_L)$$

$$A_v \equiv \frac{v_o}{v_i} = \frac{-\alpha (R_C \| R_L)}{r_e + R_e} = \frac{-\alpha R_C}{r_e + R_e} \simeq \frac{-R_C \| R_L}{r_e + R_e}$$

$$A_{vo} \equiv \frac{v_o}{v_{sig}} = \frac{-\alpha R_C}{r_e + R_e} = \frac{-g_m R_C}{1 + (R_e / r_e)} \simeq \frac{-g_m R_C}{1 + g_m R_e}$$

output resistance $R_{out} = R_C = r_o \| R_C$

SC current gain

$$i_{os} = -\alpha i_e \qquad i_i = v_i / R_{in}$$

$$A_{is} = \frac{-\alpha R_{in} i_e}{v_i} = \frac{-\alpha (R_B \| R_{ib})}{r_e + R_e} = -\beta$$

overall voltage gain (source to load)

$$G_v = \frac{v_i}{v_{sig}} \cdot A_v = \frac{-R_{in}}{R_{sig} + R_{in}} \frac{\alpha (R_C \| R_L)}{r_e + R_e}$$

$$\simeq \frac{\beta (R_C \| R_L)}{R_{sig} + (\beta+1)(r_e + R_e)}$$

other relationships

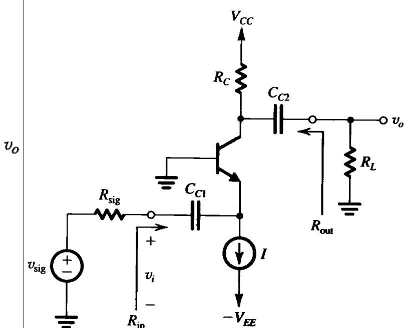
$$\frac{v_\pi}{v_i} = \frac{r_e}{r_e + R_e} \simeq \frac{1}{1 + g_m R_e}$$

bypassed CE

$$A_{vo} = -g_m (R_C \| r_o)$$

$$R_{in} = R_B \| [(\beta+1)[r_e + (r_o \| R_E \| R_L)]]$$

Common Base



$$R_{in} = r_e = R_E \| \frac{r_\pi}{\beta+1}$$

$$R_{out} \simeq R_C \| r_o$$

$$v_o = -\alpha i_e (R_C \| R_L)$$

$$i_e = -\frac{v_i}{r_e}$$

$$A_v \equiv \frac{v_o}{v_i} = \frac{\alpha}{r_e}(R_C \| R_L) = g_m (R_C \| R_L)$$

$$A_{vo} = g_m R_C \simeq g_m (R_C \| r_o) \qquad R_{out} = R_C$$

SC current gain

$$A_{is} = g_m \left(R_E \| \frac{r_\pi}{\beta+1}\right) = \frac{-\alpha i_e}{i_i} = \frac{-\alpha i_e}{-i_e} = \alpha$$

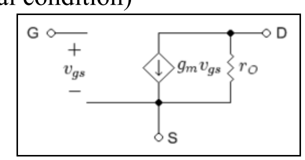
overall voltage gain

$$\frac{v_i}{v_{sig}} = \frac{R_i}{R_{sig} + R_i} = \frac{r_e}{R_{sig} + r_e}$$

$$G_v = \frac{r_e}{R_{sig} + r_e} g_m (R_C \| R_L) = \frac{\alpha (R_C \| R_L)}{R_{sig} + r_e}$$

FET small signal model (with or without r_O)

$v_{gs} \ll 2(V_{GS} - V_t)$ (small signal condition)



$$i_d = k'_n \frac{W}{L}(V_{GS} - V_t) v_{gs}$$

$$g_m = \frac{i_d}{v_{gs}} = k'_n \frac{W}{L}(V_{GS} - V_t)$$

$$A_v \equiv \frac{v_d}{v_{gs}} = -g_m R_D = -g_m (R_D \| r_o)$$

$$r_0 = \frac{|V_A|}{I_D} = \frac{1}{\lambda I_D} \qquad V_A = \frac{1}{\lambda} \qquad i_D = \frac{1}{2} k'_n \frac{W}{L}(v_{GS} - V_t)^2$$

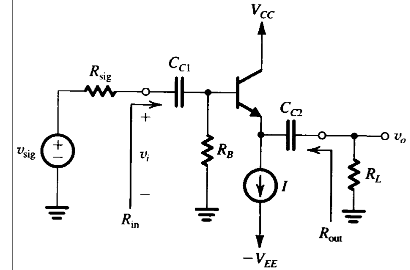
$$I_{DQ} = \frac{1}{2} k'_n \frac{W}{L}(V_{GSQ} - V_t)^2 \qquad V_{DQ} = V_{DD} - R_{DQ} I_{DQ}$$

$$v_{GS} = V_{GSQ} + v_{gs} \qquad v_{OV} = V_{GSQ} - V_t$$

$$v_D = V_{DD} - R_D (I_{DQ} + i_d) = V_{DQ} - R_D i_d$$

$$v_d = -i_d R_D = -gm\, v_{gs} R_D$$

Common Collector/Emitter Follower



$$A_i = \frac{i_{load}}{i_{source}} \gg 1$$

$$i_e = (\beta+1) i_B$$

i_e is output,

i_B is input

$$R_{ib} = (\beta+1)[r_e + (r_o \| R_L \| R_E)]$$

$$R_{in} = R_B \| R_{ib} = R_1 \| R_2 \| R_B$$

$$G_v = \frac{R_B}{R_{sig} + R_B} \cdot \frac{(\beta+1)(r_o \| R_L)}{(R_{sig} \| R_B) + (\beta+1)[r_e + (r_o \| R_L)]}$$

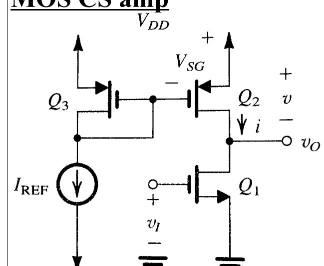
$$= \frac{R_B}{R_{sig} + R_B} \frac{(r_o \| R_L)}{\frac{R_{sig} \| R_B}{\beta+1} + r_e + (r_o \| R_L)} = \frac{v_o}{v_{sig}}$$

$$G_{vo} = \frac{R_B}{R_{sig} + R_B} \frac{r_o}{\frac{R_{sig} \| R_B}{\beta+1} + r_e + r_o}$$

$$R_{out} = r_o \| \left(r_e + \frac{R_{sig} \| R_B}{\beta+1}\right) \simeq r_e + \frac{R_{sig} \| R_B}{\beta+1} = r_e \| R_E \| r_o$$

$$A_{vo} = \frac{v_o}{v_i} = \frac{(\beta+1)(r_o \| R_E)}{r_\pi + (\beta+1)(r_o \| R_E)} \qquad r_e = \frac{R_\pi}{\beta+1}$$

MOS CS amp



$$A_v = -g_{m1} (r_{o1} \| r_{o2})$$

$$r_o = \frac{V_A}{I_O} \qquad R_{out} = r_{o1} \| r_{o2}$$

$$I_{REF} = I_O = \frac{V_A}{r_{o1} + r_{o2}}$$

$$g_{m1} = 2\sqrt{\frac{1}{2} k'_n \left(\frac{W}{L}\right)_1 I_O} \qquad i_D = \frac{1}{2} k'_n \frac{W}{L}(V_{OV})^2$$

$$V_{OV} = V_{GS} - V_t$$

General BJT Relationships

$$r_e=\frac{V_T}{I}=\frac{\alpha}{g_m} \qquad r_o=\frac{V_A+V_{CE}}{I_C}$$

$i_c=g_m v_{be}$ small signal current/voltage

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

$$I_B=\frac{I_E}{(\beta+1)}$$

$$I_E=\frac{V_{BB}-V_{BE}}{R_E+R_B/(\beta+1)} \quad \text{(1 supply)}$$

$$I_E=\frac{V_{EE}-V_{BE}}{R_E+R_B/(\beta+1)} \quad \text{(2 supply)}$$

active mode (for pnp replace v_{BE} with v_{EB})

$$i_E=i_C+i_B \qquad i_B=(1-\alpha)i_E \qquad i_C=\alpha i_E \qquad i_C=\beta i_B$$

$$i_C=I_S e^{v_{BE}/V_T} \qquad i_B=\frac{i_C}{\beta} \qquad i_E=\frac{i_C}{\alpha}$$

$V_{BB}\gg V_{BE}$ (small signal condition?)

$$R_E\gg\frac{R_B}{\beta+1}$$

Typical Characteristics

$V_T=25\,mV \qquad v_{BE}=v_{EB}=0.7\text{V} \qquad v_{CE}=0.2\text{V}$

Transconductance related equations

if $v_{be}\ll V_T$ then $i_C\simeq I_C\left(1+\frac{v_{ve}}{V_T}\right)$

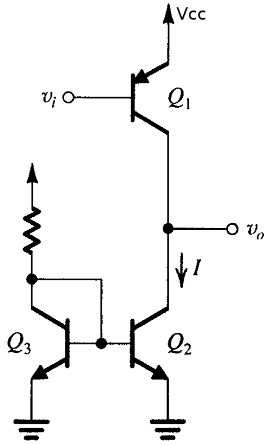
$$i_c=\frac{I_C}{V_T}v_{be}=g_m v_{be} \qquad g_m=\frac{I_{CQ}}{V_T}=\frac{\alpha I_{EQ}}{V_T}$$

$$r_e=\frac{\alpha}{g_m}$$

Gain

$$A_V=\frac{R_{\text{in}}}{R_{\text{in}}+R_{sig}}A_{VP}\frac{R_L}{R_L+R_{out}} \qquad A_{VO}=\frac{v_{out}}{v_{\text{in}}}$$

BJT CE amp



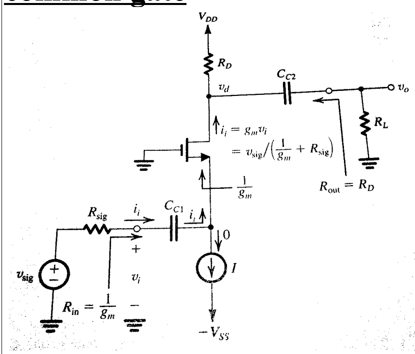
$$\frac{I_O}{I_{REF}}=\frac{Q_{2\text{area}}}{Q_{1\text{area}}}$$

$$R_{total}=R_C=r_{o1}\|r_{o2}$$

$$r_o=\frac{V_A}{I}$$

$$\frac{\partial I_o}{\partial V_{C2}}=\frac{I}{r_{o2}}$$

common gate



$$R_{\text{in}}=\frac{1}{g_m}$$

$$R_{out}=R_o=R_D$$

$$A_{vo}=g_m R_D$$

$$A_v=g_m(R_D\|R_L)$$

$$i_i=\frac{v_i}{R_{\text{in}}}=g_m v_i$$

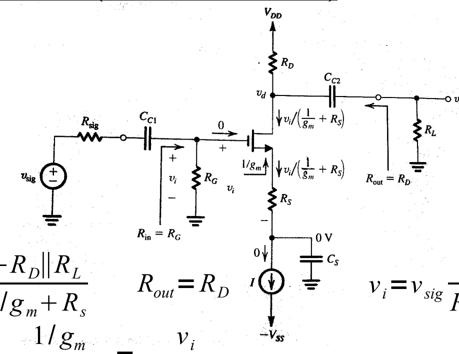
$$v_i=v_{sig}\frac{R_{\text{in}}}{R_{\text{in}}+R_{sig}}=\frac{1/g_m}{1/g_m+R_{sig}}=v_{sig}\frac{1}{1+g_m R_{sig}}$$

$$v_o=v_d=-i_d(R_D\|R_L)=g_m(R_D\|R_L)v_i$$

$$G_v=\frac{R_{\text{in}}}{R_{\text{in}}+R_{sig}}A_v=\frac{g_m(R_D\|R_L)}{1+g_m R_{sig}} \qquad i_d=i=-i_i=-g_m v_i$$

Amplifier Application

common source (w/ source resistance)



$$A_v=\frac{-R_D\|R_L}{1/g_m+R_s} \qquad R_{out}=R_D \qquad v_i=v_{sig}\frac{R_G}{R_G+R_{sig}}$$

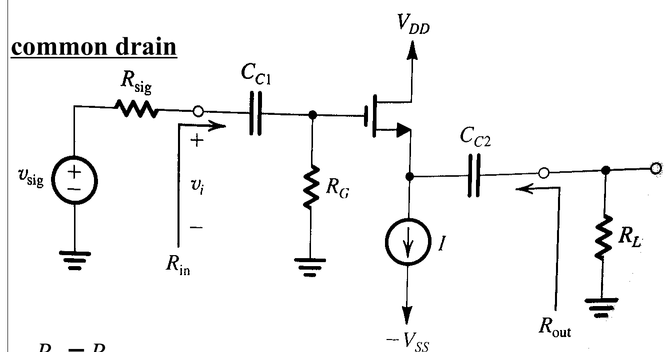
$$v_{gs}=v_i\frac{1/g_m}{1/g_m+R_s}=\frac{v_i}{1+g_m R_s}$$

$$i_d=i=\frac{v_i}{1/g_m+R_S}=\frac{g_m v_i}{1+g_m R_s}$$

$$v_o=-i_d(R_D\|R_L)=\frac{-g_m(R_D\|R_L)}{1+g_m R_s}v_i \qquad A_{vo}=\frac{-g_m R_D}{1+g_m R_s}$$

$$A_v=\frac{-g_m(R_D\|R_L)}{1+g_m R_s} \qquad G_v=\frac{-R_G}{R_G+R_{sig}}\frac{g_m(R_D\|R_L)}{1+g_m R_s}$$

common drain



$$R_{\text{in}}=R_G$$

$$v_i=v_{sig}\frac{R_{\text{in}}}{R_{\text{in}}+R_{sig}}=v_{sig}\frac{R_G}{R_G+R_{sig}} \qquad v_i\simeq v_{sig}$$

$$v_o=v_i\frac{R_L\|r_o}{(R_L\|r_o)+1/g_m} \qquad A_v=\frac{R_L\|r_o}{(R_L\|r_o)+1/g_m}$$

$$A_{vo}=\frac{r_o}{r_o+1/g_m}$$

for $r_o\gg R_L$, $A_v\simeq\frac{R_L}{R_L+1/g_m}$ and

$$G_v=\frac{R_G}{R_G+R_{sigh}}\frac{R_L\|r_o}{(R_L\|r_o)+1/g_m}$$

for $r_o\gg r/g_m$, $R_{out}=\frac{1}{g_m}\|r_o\simeq\frac{1}{g_m}$