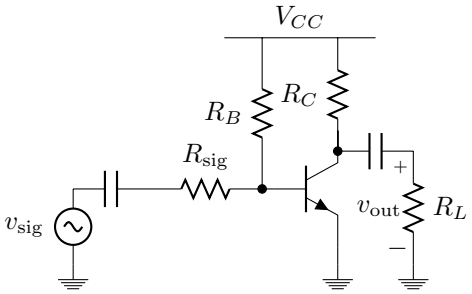
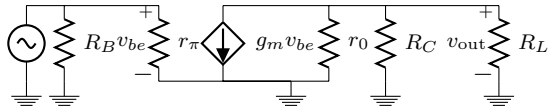
Common Emitter



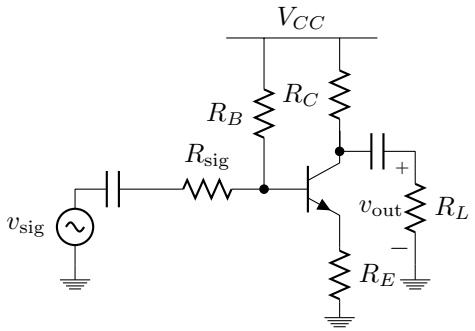
$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$
$$I_C = \beta I_B$$
$$V_C = V_{CC} - I_C R_C > 0.3\text{V}$$
$$g_m = \frac{I_C}{V_t}$$
$$r_\pi = \frac{\beta}{g_m}$$
$$r_0 = \frac{V_A}{I_C}$$
$$R_{\text{in}} = R_B \parallel r_\pi$$
$$R_{\text{out}} = R_C \parallel r_0$$
$$A_V = -g_m R_{\text{out}}$$
$$A_{\text{overall}} = A_V \frac{R_{\text{in}}}{R_{\text{sig}} + R_{\text{in}}} \frac{R_L}{R_{\text{out}} + R_L}$$
$$G_m = -g_m$$



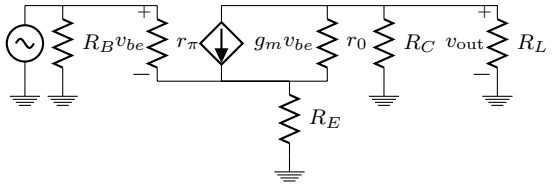
For base voltage divider:

$$V_B = \frac{V_{CC}}{R_{B1}} + \frac{V_{BE}}{\beta R_E}\,(R_{B1} \parallel R_{B2} \parallel \beta R_E).$$

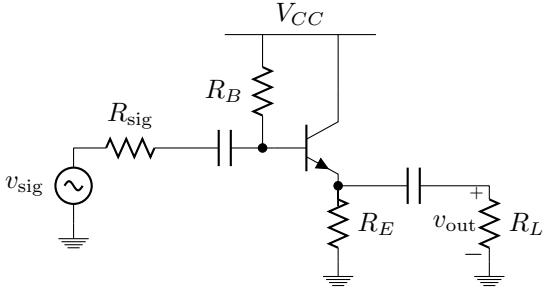
Emitter Degeneration



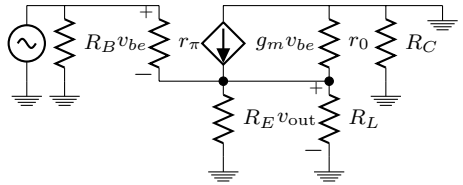
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta R_E}$$
$$I_C = \beta I_B$$
$$V_{CE} = V_{CC} - I_C(R_C + R_E) > 0.3\text{V}$$
$$g_m = \frac{I_C}{V_t}$$
$$r_\pi = \frac{\beta}{g_m}$$
$$r_0 = \frac{V_A}{I_C}$$
$$R_{\text{in}} = R_B \parallel [r_\pi + (\beta + 1)R_E]$$
$$R_{\text{out}} = R_C$$
$$A_V = \frac{-\beta R_C}{r_\pi + (\beta + 1)R_E}$$
$$A_{\text{overall}} = A_V \frac{R_{\text{in}}}{R_{\text{sig}} + R_{\text{in}}} \frac{R_L}{R_{\text{out}} + R_L}$$
$$G_m = \frac{-\beta}{r_\pi + (\beta + 1)R_E}$$



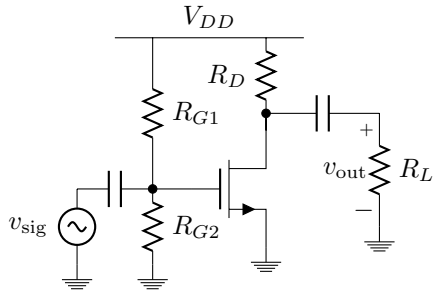
Emitter Follower



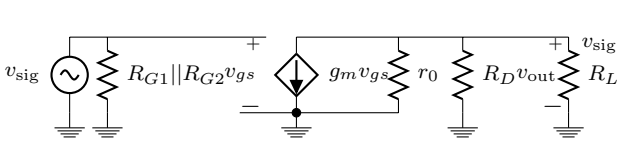
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta R_E}$$
$$I_C = \beta I_B$$
$$V_B = V_{CC} - I_B R_B$$
$$V_E = V_B - V_{BE}$$
$$g_m = \frac{I_C}{V_t}$$
$$r_\pi = \frac{\beta}{g_m}$$
$$r_0 = \frac{V_A}{I_C}$$
$$R_{\text{in}} = R_B \parallel [r_\pi + (\beta + 1)(R_E \parallel R_L \parallel r_0)]$$
$$R_{\text{out}} = \left(\frac{r_\pi + R_{\text{sig}} \parallel R_B}{\beta + 1}\right) \parallel R_E \parallel r_0$$
$$A_{\text{overall}} = \frac{g_m(R_E \parallel R_L \parallel r_0)}{(1 + \frac{R_{\text{sig}}}{R_B})[1 + g_m(R_E \parallel R_L \parallel r_0)] + g_m \frac{R_{\text{sig}}}{\beta}}$$



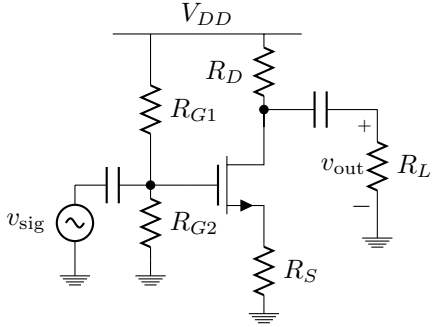
Common Source



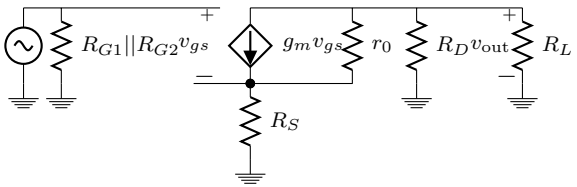
$$V_{GS} = V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}} > V_{th}$$
$$I_D = \mu_n C_{ox}\left({}^{W}/_{L}\right){}^{1}/_{2}(V_{GS}-V_{th})^2$$
$$V_D = V_{DD} - I_D R_D > V_G - V_{th}$$
$$g_m = \frac{2I_D}{V_{GS}-V_{th}}$$
$$r_0 = {}^{V_A}/_{I_D}$$
$$R_{\text{in}} = R_{G1} \parallel R_{G2}$$
$$R_{\text{out}} = R_D \parallel r_0$$
$$A_V = -g_m R_{\text{out}}$$
$$A_{\text{overall}} = A_V \frac{R_{\text{in}}}{R_{\text{sig}}+R_{\text{in}}}\frac{R_L}{R_{\text{out}}+R_L}$$
$$G_m = -g_m$$



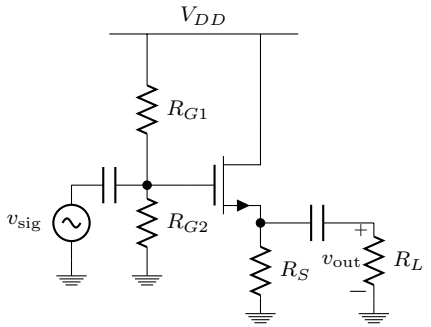
Source Degeneration



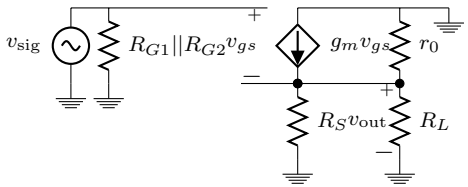
$$I_D = \mu_n C_{ox}\left({}^{W}/_{L}\right){}^{1}/_{2}(V_{GS}-V_{th})^2$$
$$V_S = I_D R_S$$
$$V_G = V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}}$$
$$V_D = V_{DD} - I_D R_D$$
$$g_m = \frac{2I_D}{V_{GS}-V_{th}}$$
$$r_0 = {}^{V_A}/_{I_D}$$
$$R_{\text{in}} = R_{G1} \parallel R_{G2}$$
$$R_{\text{out}} = R_D$$
$$A_V = \frac{-g_m R_D}{1+g_m R_S}$$
$$A_{\text{overall}} = -g_m R_D \parallel r_0 \parallel R_L$$
$$G_m = \frac{-g_m}{1+g_m R_D}$$



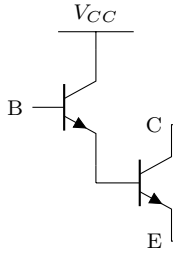
Source Follower



$$V_G = V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}}$$
$$V_S = I_D R_S$$
$$I_D = \mu_n C_{ox}\left({}^{W}/_{L}\right){}^{1}/_{2}(V_{GS}-V_{th})^2$$
$$g_m = \frac{2I_D}{V_{GS}-V_{th}}$$
$$r_0 = {}^{V_A}/_{I_D}$$
$$R_{\text{in}} = R_{G1} \parallel R_{G2}$$
$$R_{\text{out}} = R_S \parallel r_0 \parallel {}^{1}/_{g_m}$$
$$A_V = g_m R_{\text{out}}$$
$$A_{\text{overall}} = A_V \frac{R_{\text{in}}}{R_{\text{sig}}+R_{\text{in}}}\frac{R_L}{R_{\text{out}}+R_L}$$



Darlington Pair



$$\beta_C = \beta(\beta + 1)$$
$$g_m = {}^1\!/_2 g_{m2}$$
$$r_\pi = \frac{\beta_C}{g_m}$$
$$r_0 = r_{02}$$
$$(V_{BE})_C = 2V_{BE}$$

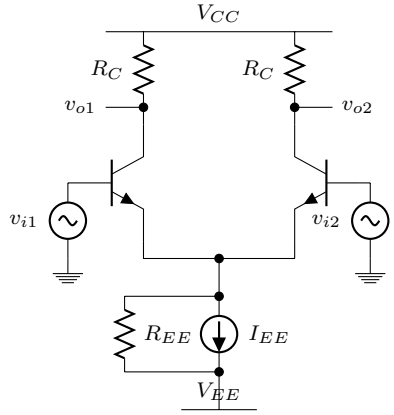
Active Load

$$R_{\text{out},n} = r_{0,n}\,(1 + g_{m,n} r_{\pi,n} \parallel R_E)$$
$$R_{\text{out}} = R_{\text{out},n} \parallel R_{\text{out},p}$$

Push–Pull Output

$$\langle P_{\text{supply}} \rangle = \frac{2V_{CC}^2}{\pi R_L}$$
$$\langle p_L \rangle = \frac{|v_{\text{sig}}|^2}{2R_L}$$
$$\text{Efficiency} = \frac{\langle p_L \rangle}{\langle P_{\text{supply}} \rangle}$$

Differential Amplifier

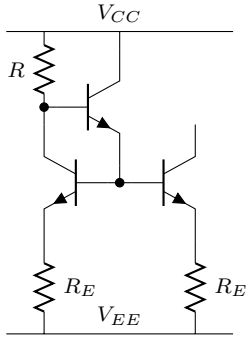


$$R_{\text{in},dm} = 2r_\pi \qquad R_{\text{in},cm} = r_\pi(1 + 2g_m R_{EE})$$
$$R_{\text{out},dm} = 2R_C \parallel r_0 \qquad R_{\text{out},cm} = R_C$$
$$A_{V,dm} = -g_m R_C \parallel r_0 \qquad A_{V,cm} = \frac{-g_m R_C}{1 + 2g_m R_{EE}}$$
$$v_{i,dm} = v_{i1} - v_{i2} \qquad v_{i,cm} = {}^1\!/_2(v_{i1} - v_{i2})$$
$$v_{o,dm} = A_{V,dm} v_{i,dm} \qquad v_{o,cm} = A_{V,cm} v_{i,cm}$$
$$v_{o1} = v_{o,cm} + {}^1\!/_2 vo, dm \qquad v_{o2} = v_{o,cm} - {}^1\!/_2 vo, dm$$
$$\text{CMRR} = \left| \frac{A_{V,dm}}{A_{V,cm}} \right|$$

Diff. Amp. with Active Load

$$R_{\text{out},dm} = r_{0,pnp} \parallel r_{0,npn}$$
$$A_{V,dm} = g_m R_{\text{out},dm}$$

Current Mirror



$$I = \frac{V_{CC} - 2V_{BE} - V_{EE}}{R + R_E}$$
$$R_{\text{out}} = r_o(1 + g_m r_\pi \parallel R_E)$$

Multistage Amplifier

$$R_{\text{out1}} = R_{\text{in2}}$$

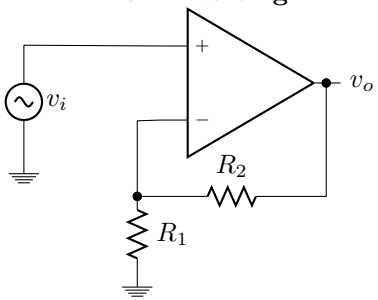
Factor $\dfrac{R_{\text{in2}}}{R_{\text{out1}} + R_{\text{in2}}}$ into gain.

$$A_V = A_{V1} A_{V2} \frac{R_{\text{in2}}}{R_{\text{out1}} + R_{\text{in2}}}$$

OPERATIONAL AMPLIFIERS

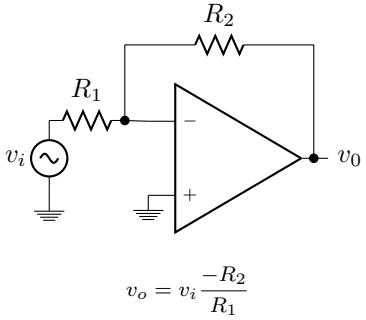
$$v_+ = v_-$$
$$i_+ = i_- = 0$$

Non-Inverting



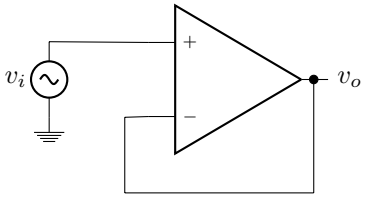
$$v_o = v_i \frac{R_1 + R_2}{R_1}$$

Inverting



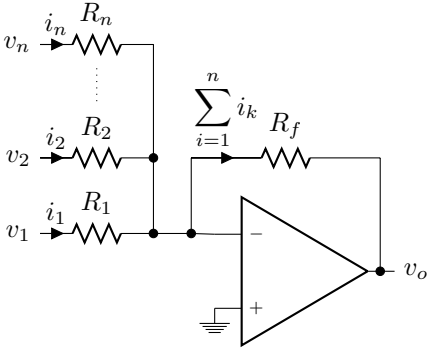
$$v_o = v_i \frac{-R_2}{R_1}$$

Follower



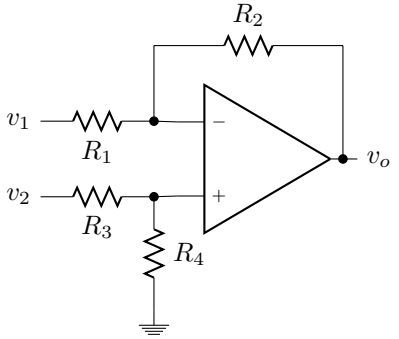
$$v_o = v_i$$

Adder



$$v_o = -R_f \left(\frac{v_1}{R_1} + \frac{v_2}{R_2} + \ldots + \frac{v_n}{R_n} \right)$$

Subtractor



$$v_o = \frac{R_4}{R_3 + R_4} \frac{R_1 + R_2}{R_1} v_2 - \frac{R_2}{R_2} v_1$$