ECEN 326
Electronic Circuits

Introduction

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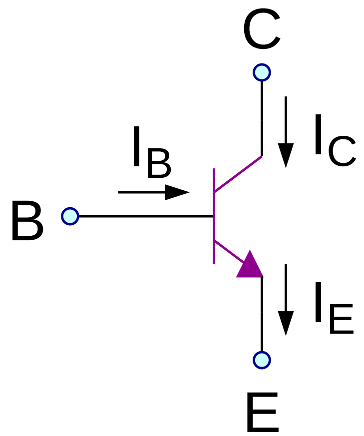
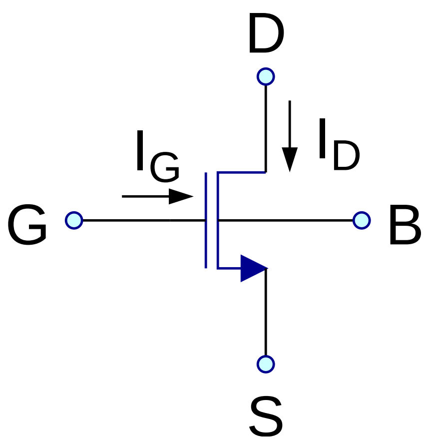
Department of Electrical and Computer Engineering

NPN & NMOS



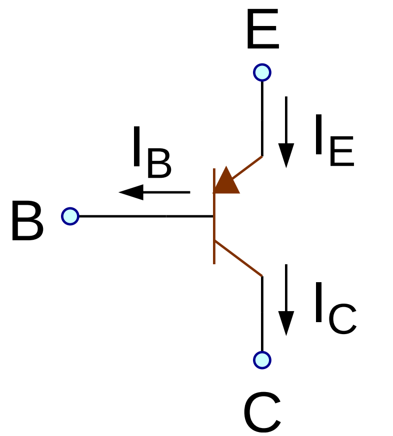
$$V_{CE} \geq V_{CE,sat} \Rightarrow \text{ACTIVE}$$

$$V_{BE} = 0.7 \text{ V}$$
$$I_C = \beta I_B$$
$$I_E = I_C + I_B$$



$$V_{DS} \geq V_{ov} \Rightarrow \text{ACTIVE}$$

$$V_{ov} = V_{GS} - V_{tn}$$
$$I_G = 0$$
$$I_D = \frac{k_n'}{2} \frac{W}{L} V_{ov}^2$$

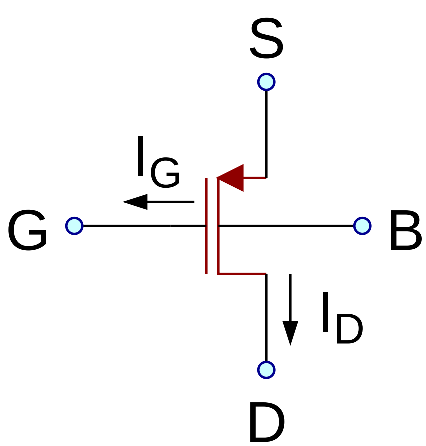


$$V_{EC} \geq V_{EC,sat} \Rightarrow \text{ACTIVE}$$

$$V_{EB} = 0.7 \text{ V}$$

$$I_C = \beta I_B$$

$$I_E = I_C + I_B$$

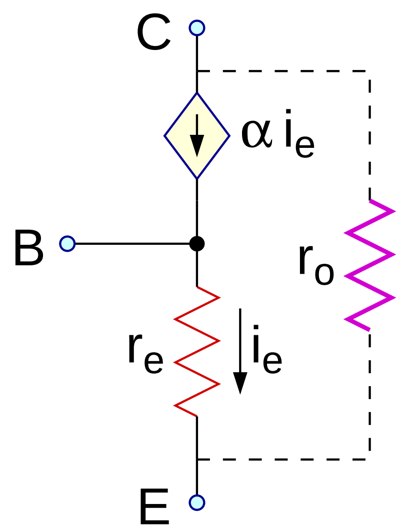


$$V_{SD} \geq V_{ov} \Rightarrow \text{ACTIVE}$$

$$V_{ov} = V_{SG} - |V_{tp}|$$

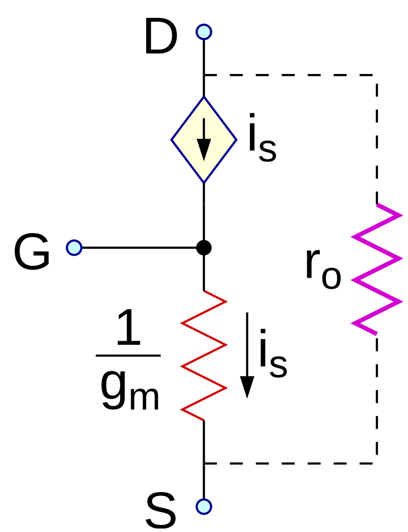
$$I_G = 0$$

$$I_D = \frac{k'_p}{2} \frac{W}{L} V_{ov}^2$$

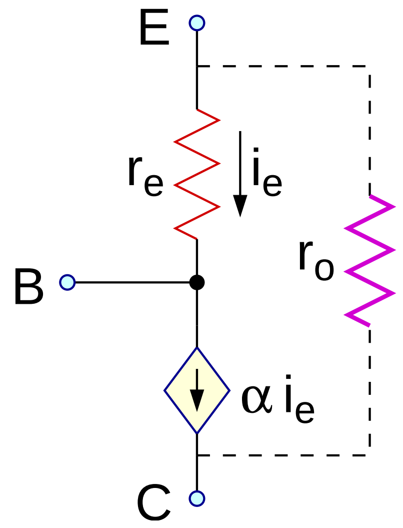


$$r_e = \frac{V_T}{I_E} = \frac{\alpha}{g_m} \approx \frac{1}{g_m}$$

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

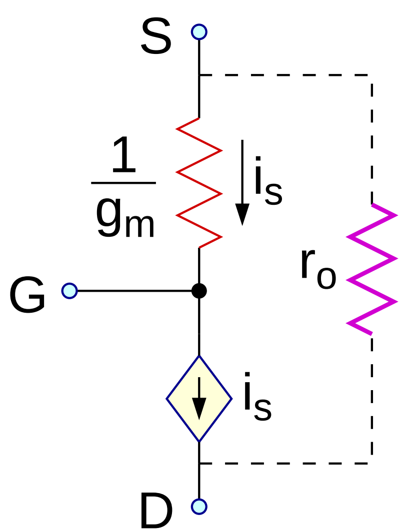


$$g_m = k_n' \frac{W}{L} V_{ov} = \sqrt{2k_n' \frac{W}{L} I_D}$$



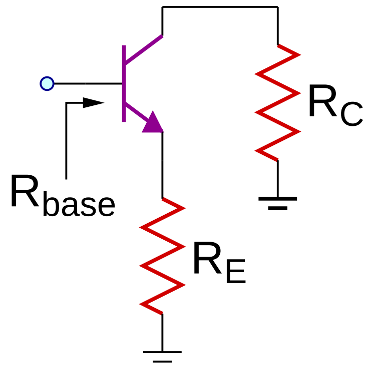
$$r_e = \frac{V_T}{I_E} = \frac{\alpha}{g_m} \approx \frac{1}{g_m}$$

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

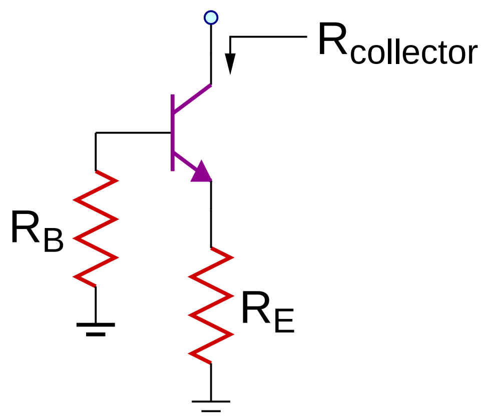


$$g_m = k_p' \frac{W}{L} V_{ov} = \sqrt{2 k_p' \frac{W}{L} I_D}$$

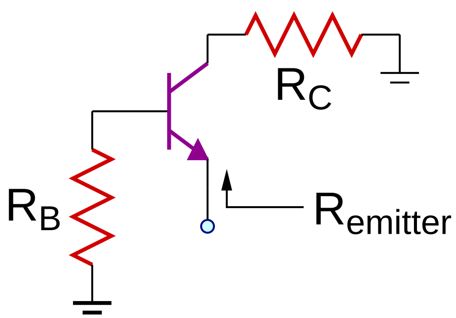
BJT Node Resistances



$$R_{base} = (\beta + 1)(r_e + R_E)$$



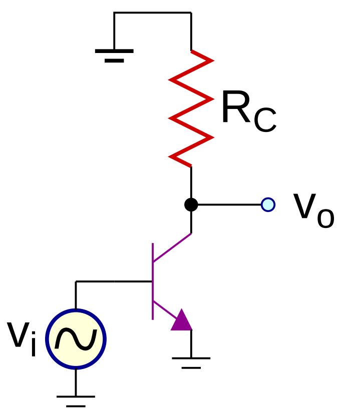
$$R_{collector} = \infty$$



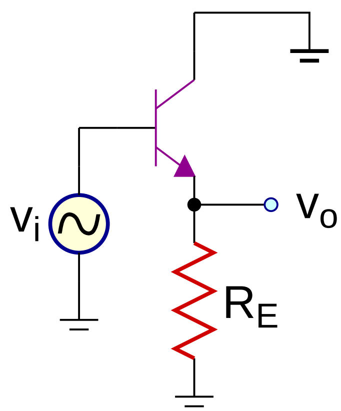
$$R_{emitter} = r_e + \frac{R_B}{\beta + 1}$$

BJT Amplifiers

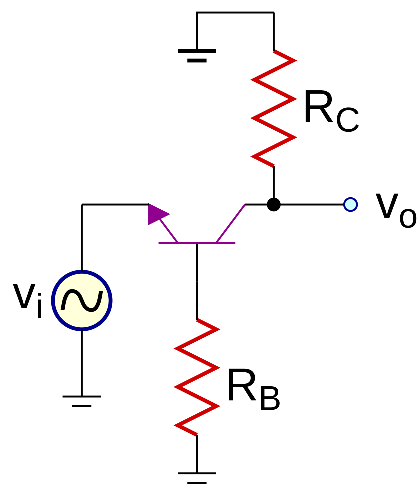
AC, $r_o = \infty$



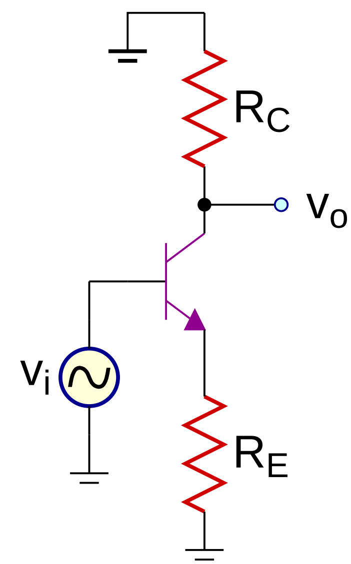
$$\frac{v_o}{v_i} = \frac{-\alpha R_C}{r_e}$$



$$\frac{v_o}{v_i} = \frac{R_E}{r_e + R_E}$$

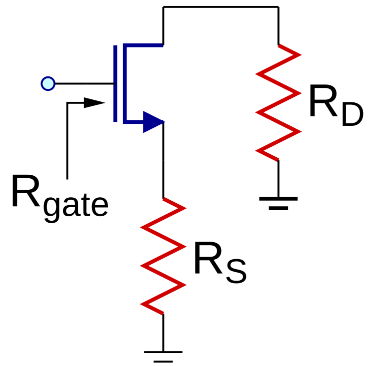


$$\frac{v_o}{v_i} = \frac{\alpha R_C}{R_{emitter}}$$

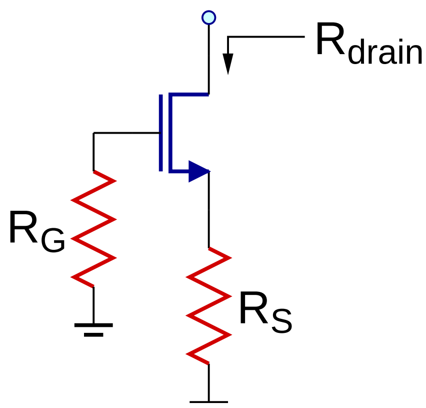


$$\frac{v_o}{v_i} = \frac{-\alpha R_C}{r_e + R_E}$$

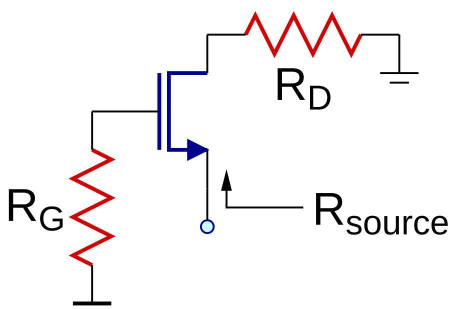
MOS Node Resistances



$$R_{gate} = \infty$$

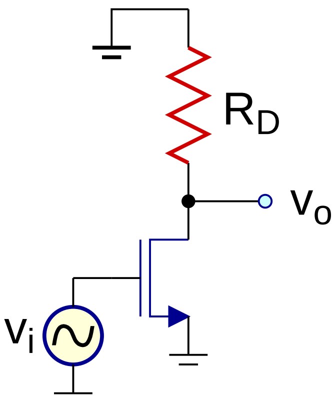


$$R_{drain} = \infty$$

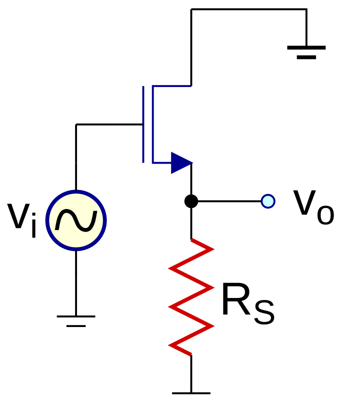


$$R_{source} = \frac{1}{g_m}$$

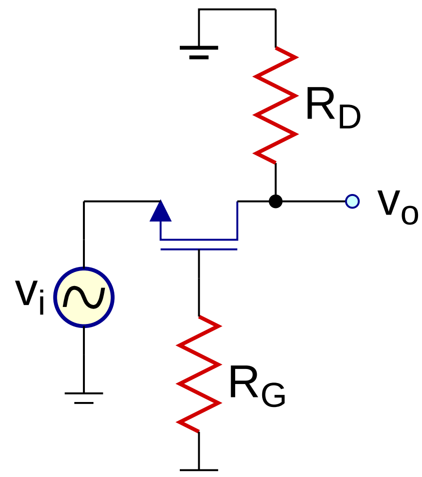
MOS Amplifiers



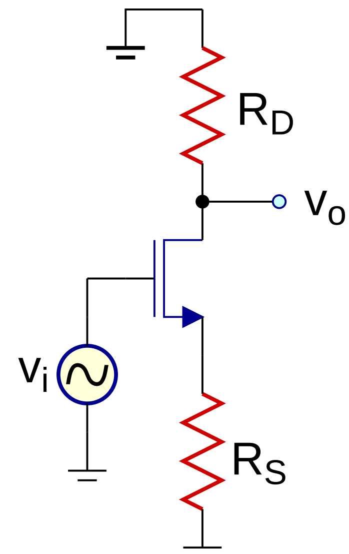
$$\frac{v_o}{v_i} = \frac{-R_D}{\frac{1}{g_m}}$$



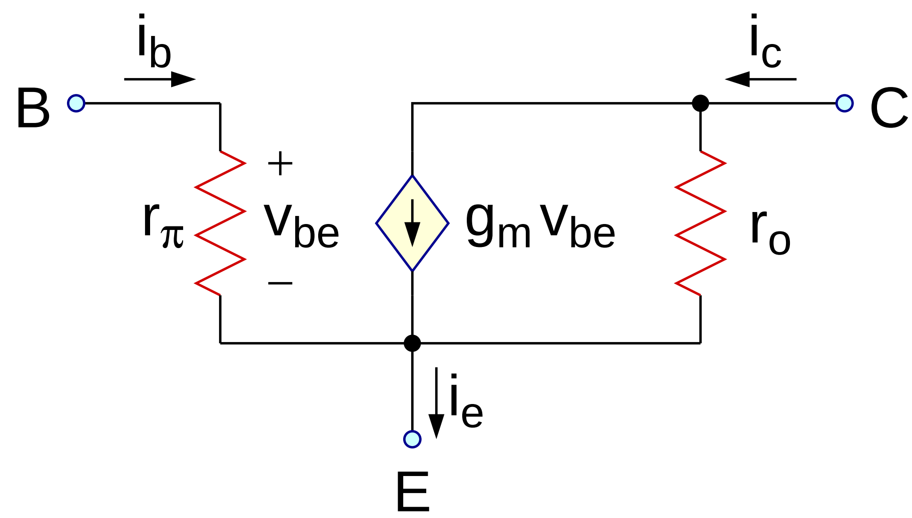
$$\frac{v_o}{v_i} = \frac{R_S}{\frac{1}{g_m} + R_S}$$



$$\frac{v_o}{v_i} = \frac{R_D}{R_{source}}$$



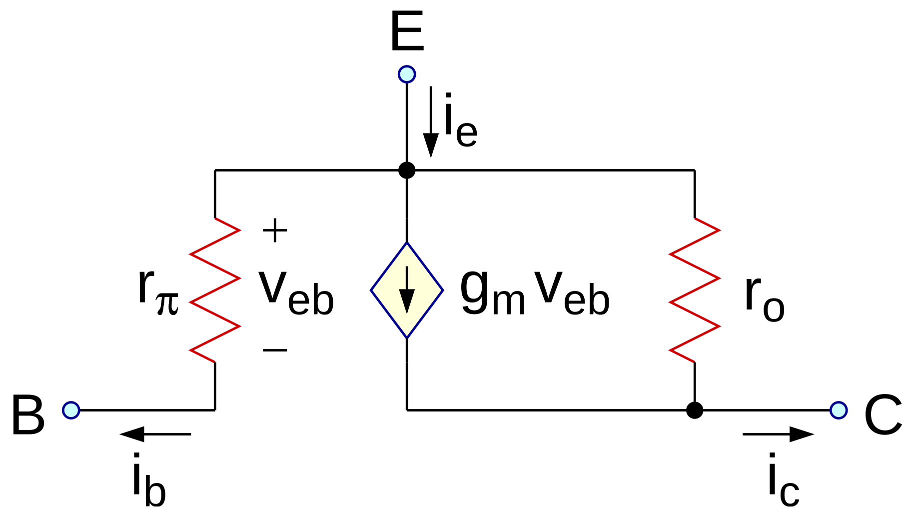
$$\frac{v_o}{v_i} = \frac{-R_D}{\frac{1}{g_m} + R_S}$$



Early Effect $\longrightarrow$ $\mathbf{r_o}$

$$g_m = \frac{I_C}{V_T} \qquad r_o = \frac{V_A}{I_C}$$

$$r_\pi = \frac{\beta}{g_m} \qquad V_T = \frac{kT}{q}$$



Early Effect $\longrightarrow$ $\mathbf{r_o}$

$$g_m = \frac{I_C}{V_T} \qquad r_o = \frac{V_A}{I_C}$$

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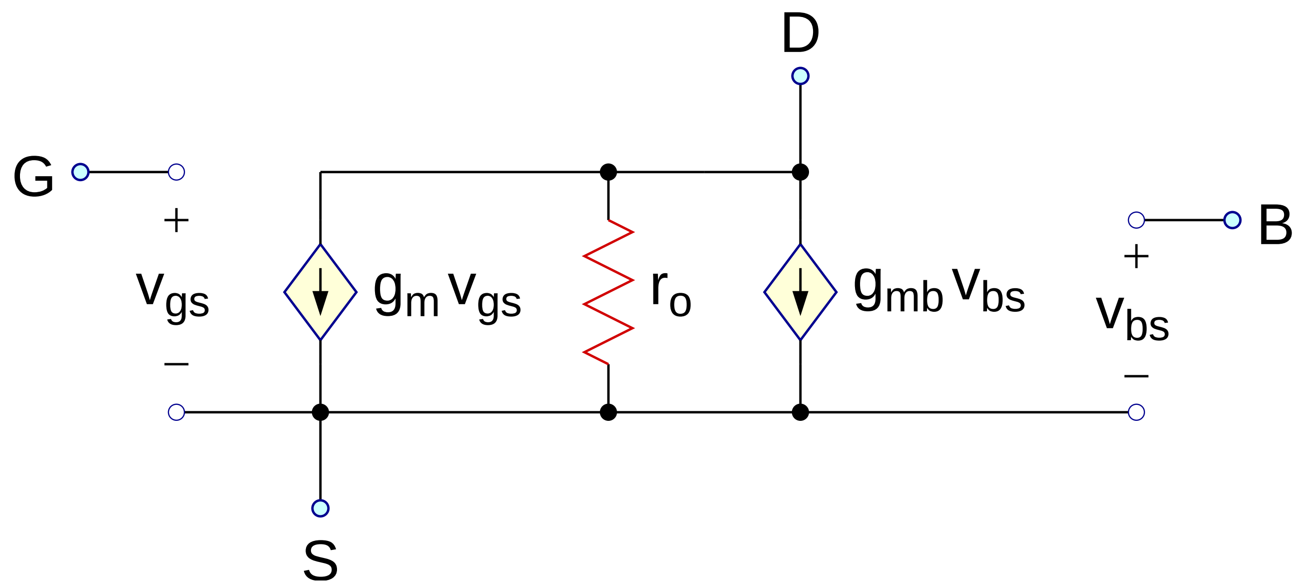
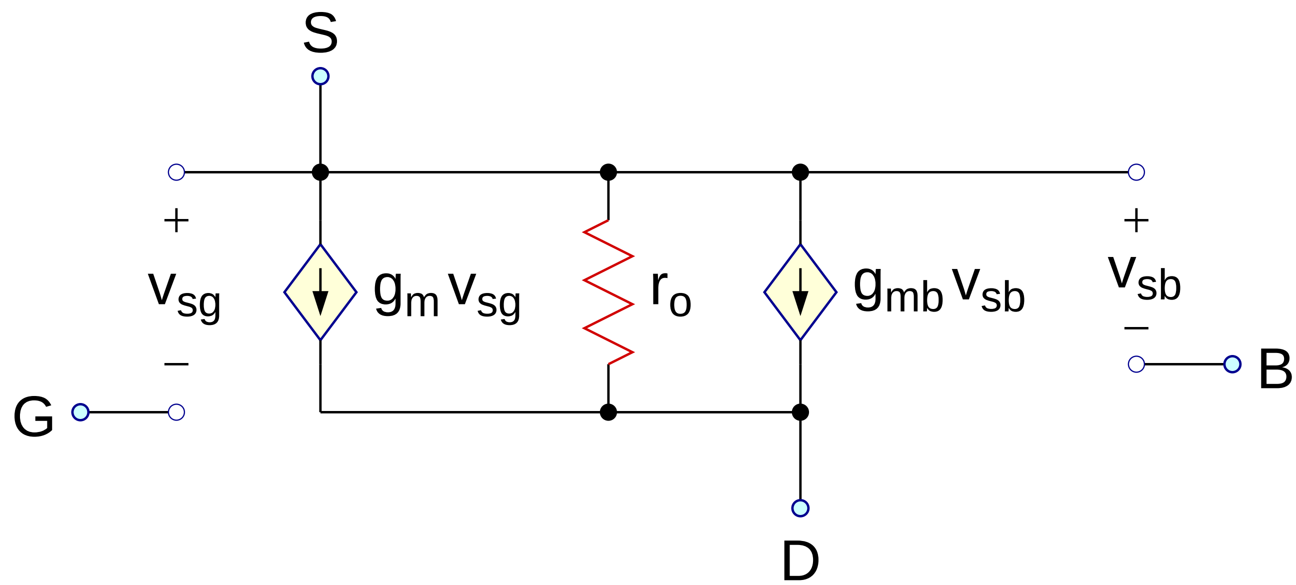


Channel Length Modulation $\rightarrow$ $\mathbf{r_o}$

Body Effect $(\mathbf{V_t}=\mathbf{V_{t0}}+\gamma\left[\sqrt{|-2\phi_F+V_{SB}|}-\sqrt{|-2\phi_F|}\,\right]) \rightarrow \mathbf{g_{mb}}$

$$\mathbf{g_m} = \sqrt{2k_n'\frac{W}{L}I_D} \qquad \mathbf{r_o} = \frac{1}{\lambda_n I_D}$$

$$\mathbf{g_{mb}} = \chi \mathbf{g_m} \qquad \mathbf{k_n'} = \mu_n C_{ox}$$



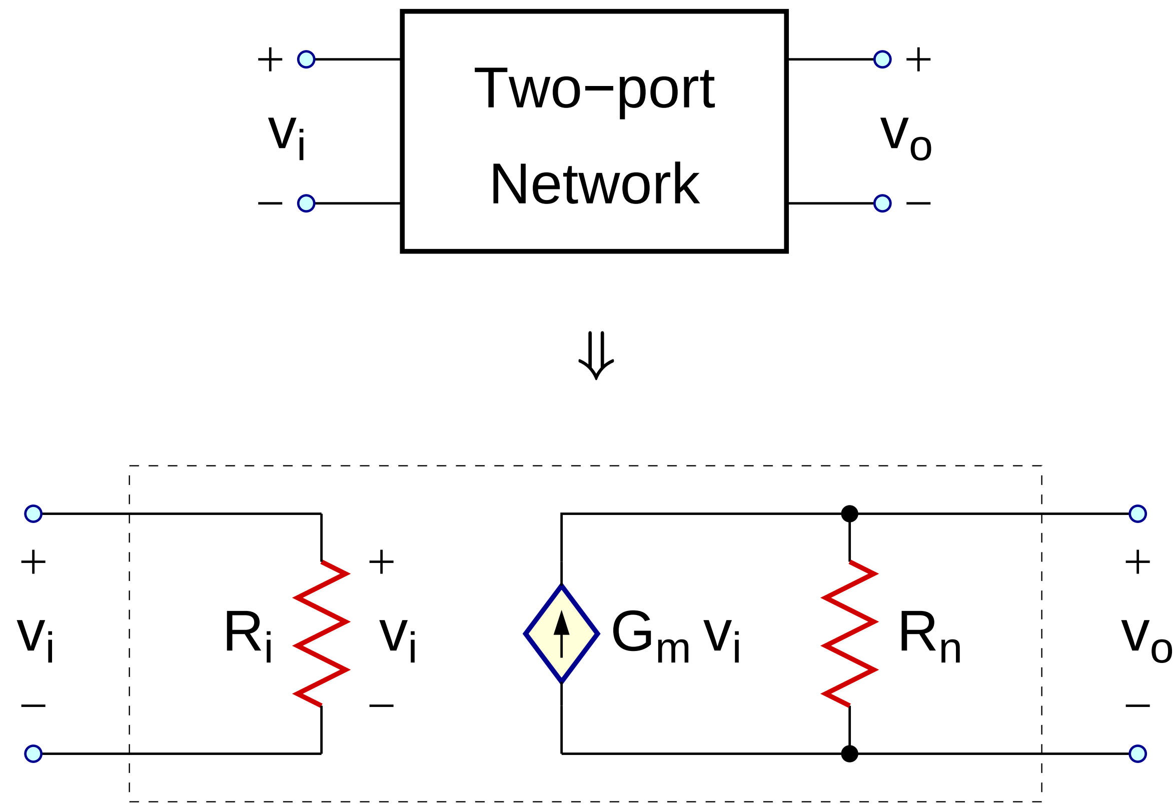
Channel Length Modulation $\rightarrow$ $\mathbf{r_o}$

Body Effect ($\mathbf{V_t = V_{t0} + \gamma \left[\sqrt{|-2\phi_F + V_{SB}|} - \sqrt{|-2\phi_F|}\right]}$) $\rightarrow$ $\mathbf{g_{mb}}$

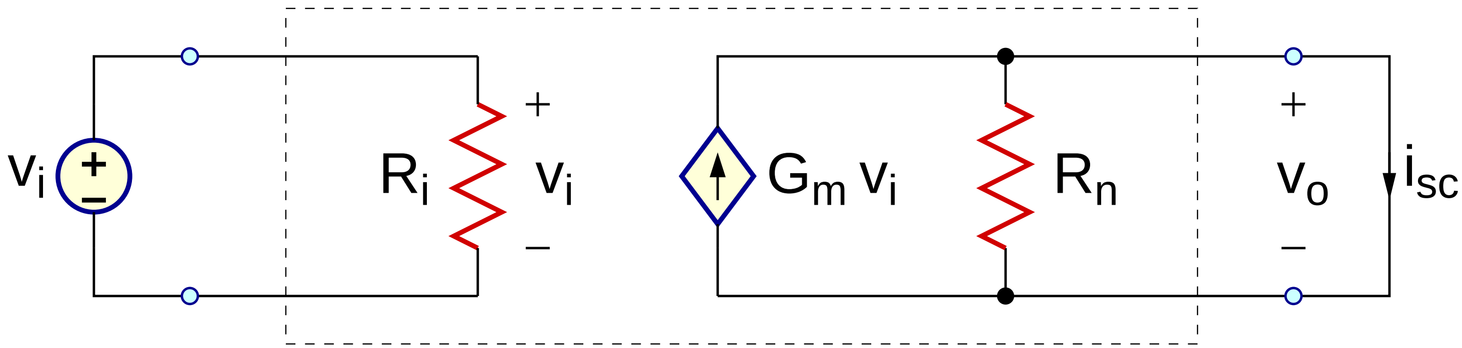
$$\mathbf{g_m = \sqrt{2k'_p \frac{W}{L} I_D}} \qquad \mathbf{r_o = \frac{1}{\lambda_p I_D}}$$

$$\mathbf{g_{mb} = \chi g_m} \qquad \mathbf{k'_p = \mu_p C_{ox}}$$

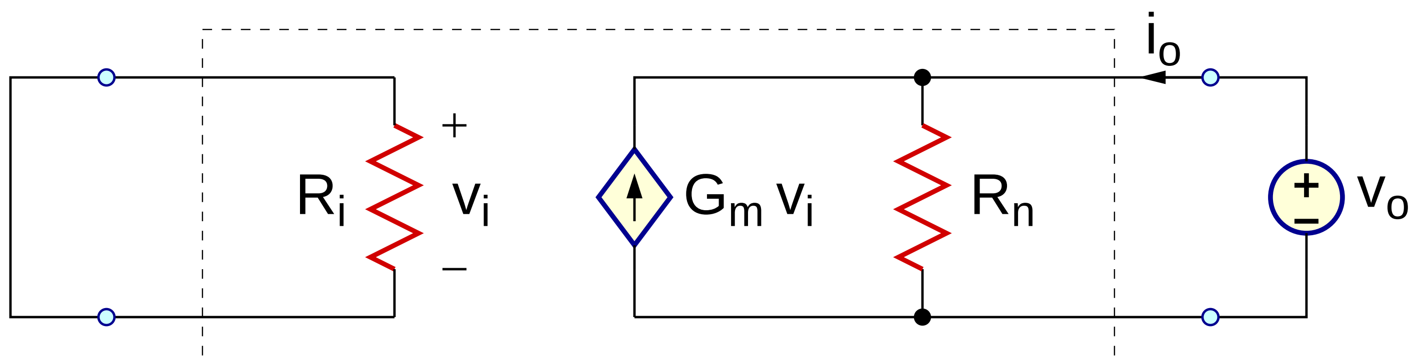
Two-Port Modeling of Amplifiers



$$\frac{v_o}{v_i} = G_m R_n$$



$$G_m = \left.\frac{i_{sc}}{v_i}\right|_{v_o=0}$$



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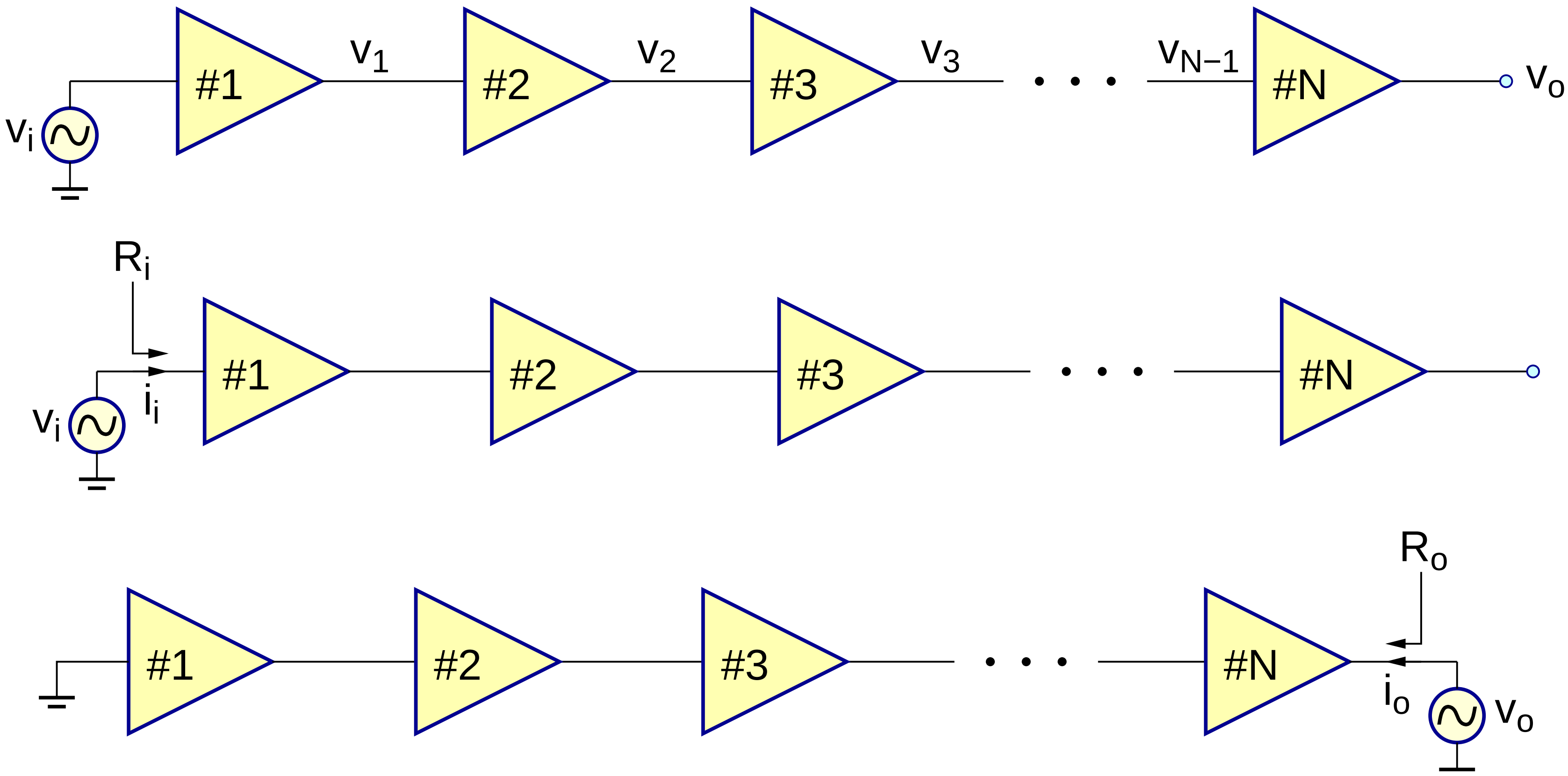
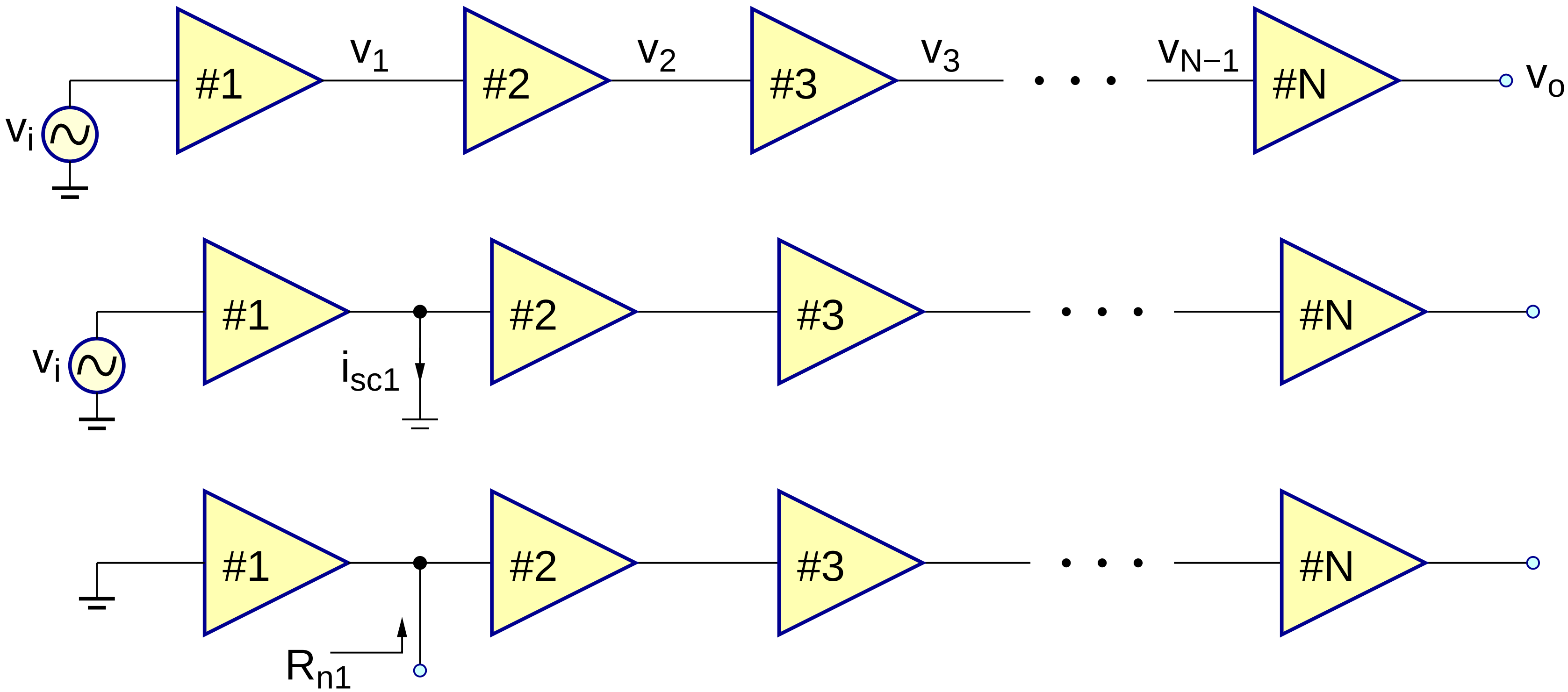
Two-Port Modeling of Amplifiers



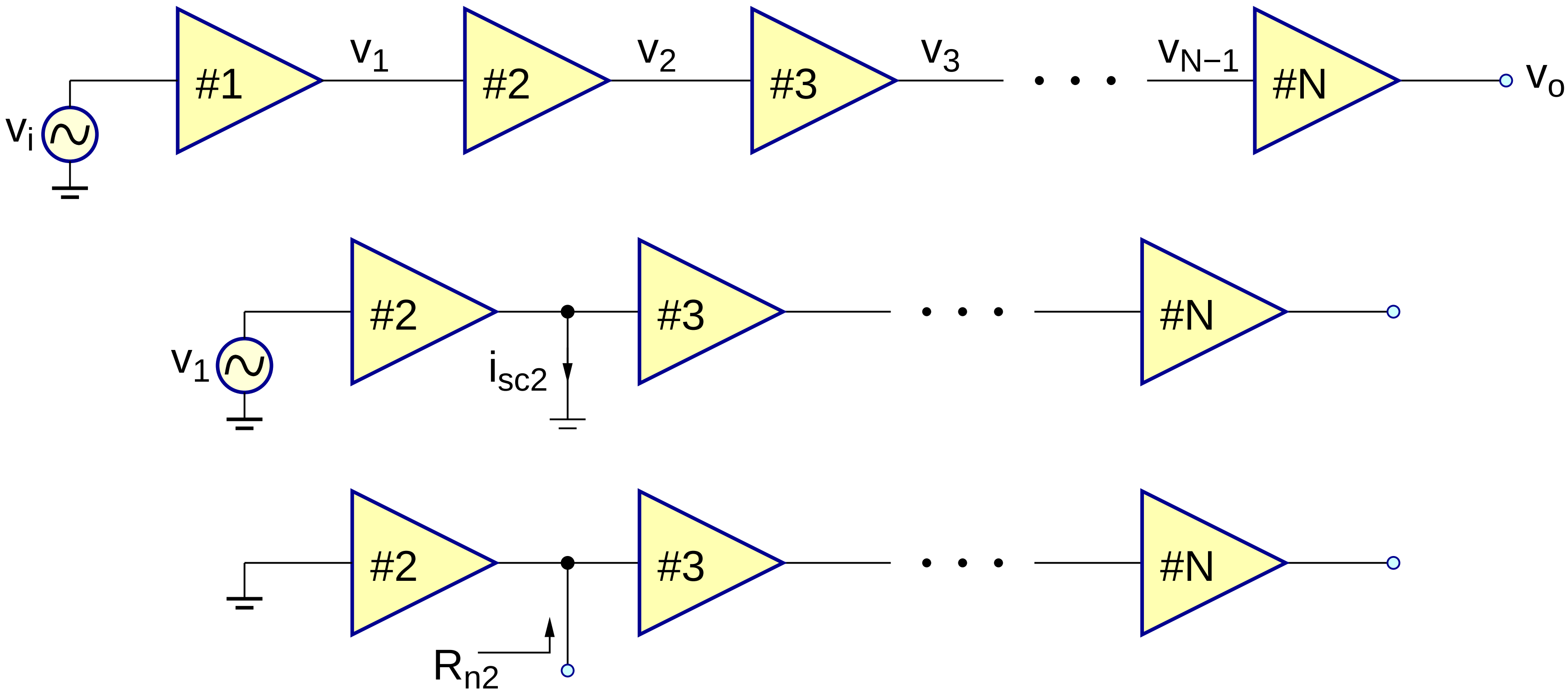
$$\frac{v_o}{v_i} = \frac{v_1}{v_i}\,\frac{v_2}{v_1}\cdots\frac{v_o}{v_{N-1}} \qquad R_i = \frac{v_i}{i_i} \qquad R_o = \frac{v_o}{i_o}$$

Two-Port Modeling of Amplifiers

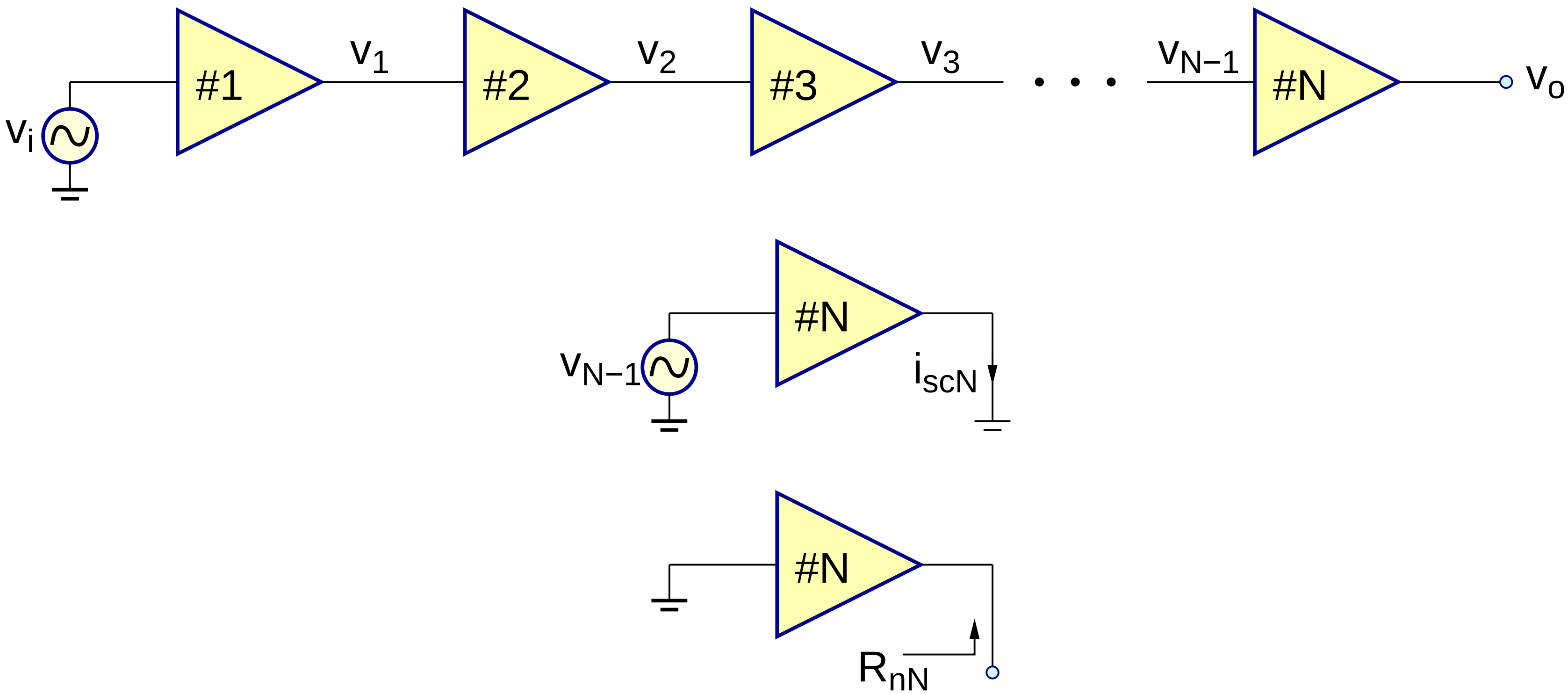


$$G_{m1} = \frac{i_{sc1}}{v_i} \qquad \frac{v_1}{v_i} = G_{m1} R_{n1}$$

Two-Port Modeling of Amplifiers

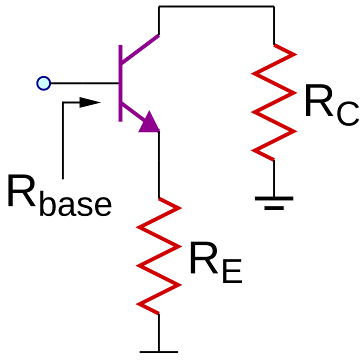


$$G_{m2} = \frac{i_{sc2}}{v_1} \qquad \frac{v_2}{v_1} = G_{m2} R_{n2}$$

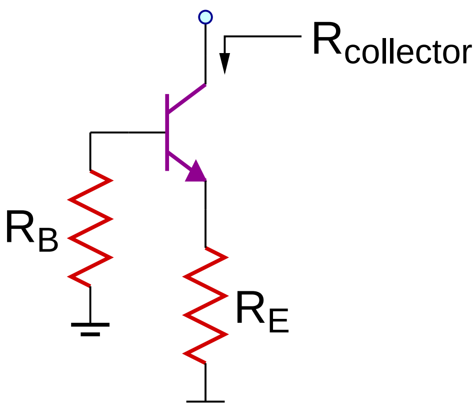


$$G_{mN} = \frac{i_{scN}}{v_{N-1}} \qquad \frac{v_o}{v_{N-1}} = G_{mN} R_{nN}$$

BJT Node Resistances

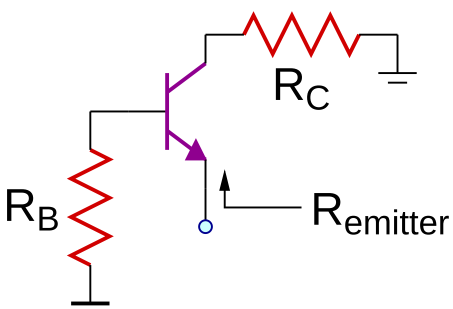


$$R_{base} = r_\pi + (\beta+1)R_E \, \frac{r_o + \dfrac{R_C}{\beta+1}}{r_o + R_C + R_E}$$



$$R_{collector} = g'_m r_o R_x + r_o + R_x$$

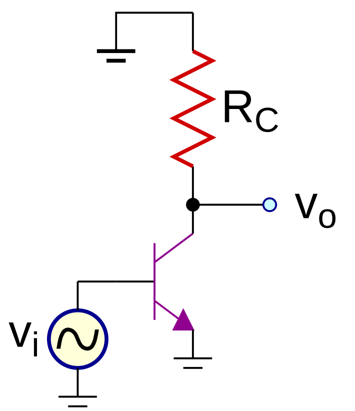
$$g'_m = g_m \, \frac{r_\pi}{r_\pi + R_B} \,, \qquad R_x = R_E \,\|\, (r_\pi + R_B)$$



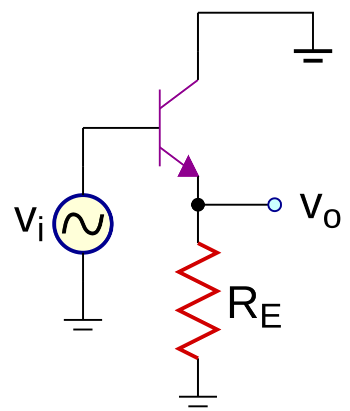
$$R_{emitter} = (r_\pi + R_B) \,\|\, \left[\left(\frac{1}{g'_m} \,\|\, r_o \right) \left(1 + \frac{R_C}{r_o} \right) \right]$$

$$g'_m = g_m \, \frac{r_\pi}{r_\pi + R_B}$$

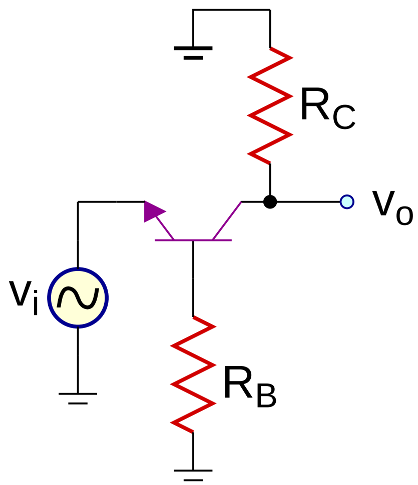
Calculation of $\mathbf{G_m}$ and $\mathbf{R_n}$ is not necessary if $\mathbf{r_o}$ is grounded, since it can be combined with either $\mathbf{R_E}$ or $\mathbf{R_C}$.

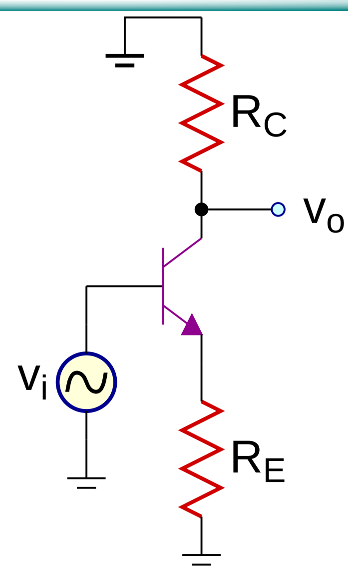


$$\frac{v_o}{v_i} = -\alpha\frac{R_C \| r_o}{r_e}$$



$$\frac{v_o}{v_i} = \frac{R_E \| r_o}{r_e + (R_E \| r_o)}$$





$$G_m = g'_m + \frac{1}{r_o}$$

$$g'_m = g_m \frac{r_\pi}{r_\pi + R_B}$$

$$R_n = R_C \| r_o$$

$$\frac{v_o}{v_i} = G_m R_n$$

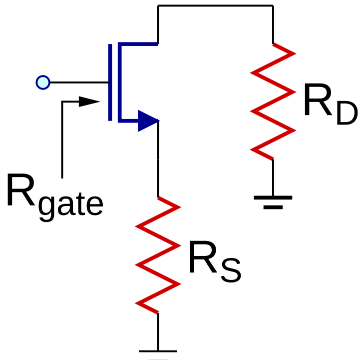
$$G_m = -g_m \frac{1 - \dfrac{R_E}{\beta r_o}}{1 + g_m R_E \left(1 + \dfrac{1}{\beta} + \dfrac{1}{g_m r_o}\right)}$$

$$\approx -\frac{g_m}{1 + g_m R_E}$$

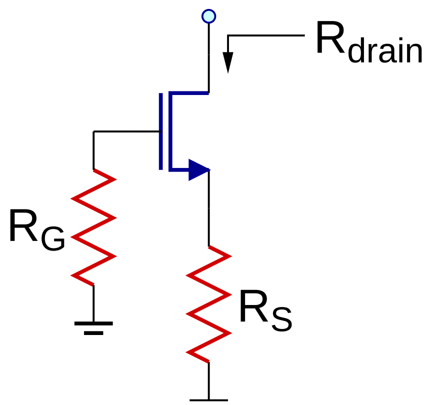
$$R_n = R_C \| [g_m r_o (R_E \| r_\pi) + r_o + (R_E \| r_\pi)]$$

$$\frac{v_o}{v_i} = G_m R_n$$

MOS Node Resistances

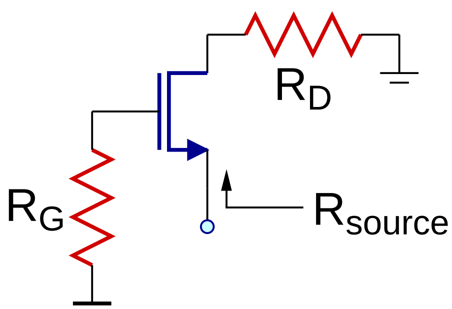


$$R_{gate} = \infty$$



$$R_{drain} = g'_m r_o R_S + r_o + R_S$$

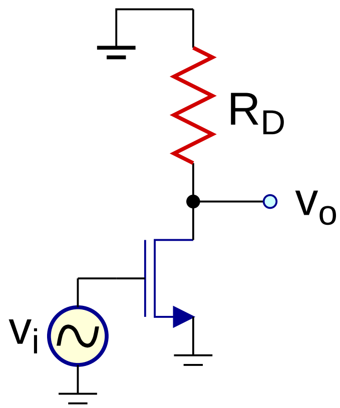
$$g'_m = g_m + g_{mb}$$

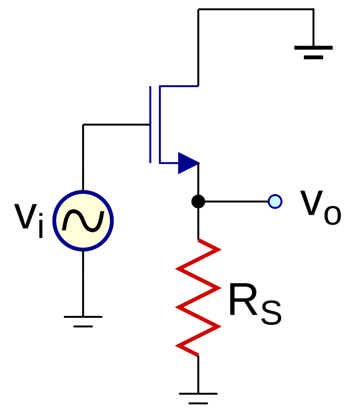


$$R_{source} = \left(\frac{1}{g'_m} \| r_o\right)\left(1 + \frac{R_D}{r_o}\right)$$

$$g'_m = g_m + g_{mb}$$

Calculation of $\mathbf{G_m}$ and $\mathbf{R_n}$ is not necessary if $\mathbf{r_o}$ is grounded, since it can be combined with either $\mathbf{R_D}$ or $\mathbf{R_S}$.

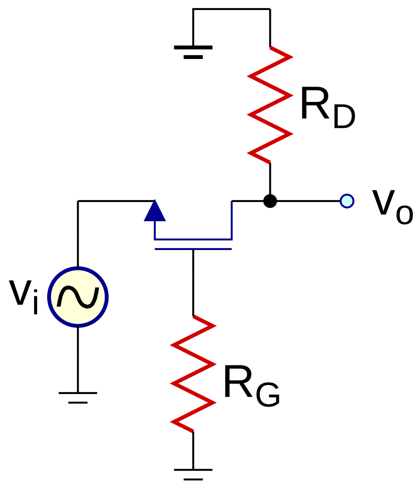




$$\frac{v_o}{v_i} = -\frac{R_D \parallel r_o}{\dfrac{1}{g_m}}$$

$$\frac{v_o}{v_i} = \frac{R_S \parallel r_o \parallel \dfrac{1}{g_{mb}}}{\dfrac{1}{g_m} + \left(R_S \parallel r_o \parallel \dfrac{1}{g_{mb}}\right)}$$

MOS Amplifiers

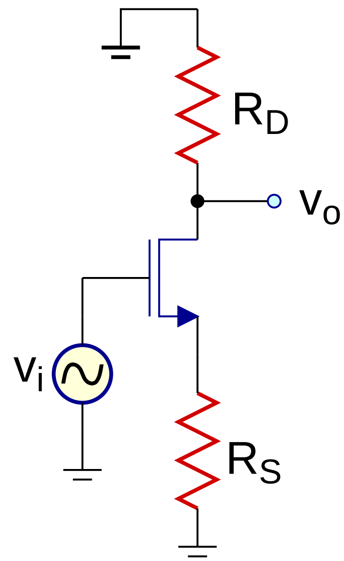


$$G_m = g'_m + \frac{1}{r_o}$$

$$g'_m = g_m + g_{mb}$$

$$R_n = R_D \| r_o$$

$$\frac{v_o}{v_i} = G_m R_n$$



$$G_m = -\frac{g_m}{1 + g'_m R_S + \frac{R_S}{r_o}}$$

$$g'_m = g_m + g_{mb}$$

$$R_n = R_D \| (g'_m r_o R_S + r_o + R_S)$$

$$\frac{v_o}{v_i} = G_m R_n$$