PN junction

$$I_{tot} = A \cdot J_{tot}; \quad J_{tot} = J_{tot}^{drift} + J_{tot}^{diff}; \quad J_{tot}^{drift} = (\mu_n \cdot n + \mu_p \cdot p) \cdot q \cdot E; \quad J_{tot}^{diff} = q \cdot \left(D_n \cdot \frac{dn}{dx} - D_p \cdot \frac{dp}{dx} \right);$$

$$I_D = I_S \cdot (e^{\frac{V_F}{V_T}} - 1); \qquad r_D = \left(\frac{dI_D}{dV_F} \right)^{-1}; \qquad r_D \approx \frac{V_T}{I_D}, \ v_f \ll V_F; \qquad n_i \approx 5.2 \cdot 10^{15} \cdot T^{\frac{3}{2}} \cdot e^{-\frac{E_g}{2 \cdot k \cdot T}};$$

$$C_j = \frac{C_{j0}}{\sqrt{1 + \frac{V_R}{V_0}}}; \qquad C_{j0} = A \cdot \sqrt{\frac{\epsilon \cdot q}{2} \cdot \frac{N_A \cdot N_D}{N_A + N_D} \cdot \frac{1}{V_0}}; \qquad V_0 = V_T \cdot \ln \left(\frac{N_A \cdot N_D}{n_i^2} \right).$$

BJT

$$I_C = I_S \cdot e^{\frac{V_{BE}}{V_T}} \cdot (1 + \frac{V_{CE}}{V_A}); \qquad I_C \approx I_S \cdot e^{\frac{V_{BE}}{V_T}}, \ V_A \to \infty; \qquad I_S = \frac{q \cdot A \cdot D_n \cdot n_i^2}{W_B \cdot N_A}; \qquad V_A = \frac{I_C'}{\frac{dI_C}{dV_{CE}}};$$

$$\beta_F = \frac{I_C}{I_B} = \frac{1}{\frac{W_B^2}{2 \cdot \tau_b \cdot D_n} + \frac{D_p}{D_n} \cdot \frac{W_B}{L_p} \cdot \frac{N_A}{N_D}}; \qquad g_m = \frac{dI_C}{dV_{BE}} = \frac{I_C}{V_T}; \qquad r_\pi = \frac{dV_{BE}}{dI_B} = \frac{\beta_F}{g_m}; \qquad r_o = \frac{dV_{CE}}{dI_C} = \frac{V_A}{I_C}.$$

MOSFET

$$V_{ov} = V_{GS} - V_{th}; \qquad V_{th} = V_{th0} + \gamma \cdot \left(\sqrt{2 \cdot \phi_f + V_{Bias}} - \sqrt{2 \cdot \phi_f} \right); \qquad \gamma = \frac{1}{C_{ox}} \cdot \sqrt{2 \cdot q \cdot \epsilon \cdot N_A};$$

$$V_{DS}^{sat} \approx \begin{cases} 3 \cdot V_T, & 0 \le V_{ov} < 2 \cdot n \cdot V_T, \\ V_{GS} - V_{th}, & 2 \cdot n \cdot V_T \le V_{ov} \ll E_C \cdot L, \\ (V_{GS} - V_{th}) \cdot \left(1 - \frac{V_{GS} - V_{th}}{2 \cdot E_C \cdot L} \right), & V_{ov} \cong E_C \cdot L; \end{cases}$$

$$V_A = \frac{1}{\lambda} = \frac{I_D}{\frac{dI_D}{dV_{DS}}}; \qquad k' = \mu_n \cdot C_{ox};$$

$$g_m = \frac{dI_D}{dV_{GS}}; \qquad C_{ox} = \frac{\epsilon_{ox}}{t_{ox}};$$

$$r_{in} \to \infty; \qquad r_o = \frac{dV_{DS}}{dI_D} = \frac{V_A}{I_D};$$

$$I_D = \begin{cases} \frac{W}{L} \cdot I_t \cdot e^{\frac{V_{GS} - V_{th}}{n \cdot V_T}} \cdot \left(1 - e^{-\frac{V_{DS}}{V_T}} \right), & 0 \le V_{ov} < 2 \cdot n \cdot V_T, \\ \frac{k'}{2} \cdot \frac{W}{L} \cdot \left(2 \cdot (V_{GS} - V_{th}) \cdot V_{DS} - V_{DS}^2 \right), & V_{DS} < V_{ov}, \quad 2 \cdot n \cdot V_T \le V_{ov} \ll E_C \cdot L, \\ \frac{k'}{2} \cdot \frac{W}{L} \cdot (V_{GS} - V_{th})^2 \cdot \left(1 + \frac{V_{DS}}{V_A} \right), & V_{DS} \ge V_{ov}, \quad 2 \cdot n \cdot V_T \le V_{ov} \ll E_C \cdot L, \\ \frac{k'}{2} \cdot \frac{1}{1 + \frac{V_{DS}}{E_c \cdot L}} \cdot \frac{W}{L} \cdot \left(2 \cdot (V_{GS} - V_{th}) \cdot V_{DS} - V_{DS}^2 \right), & V_{DS} < V_{ov}, \quad V_{ov} \cong E_C \cdot L, \\ \frac{k'}{2} \cdot \frac{1}{1 + \frac{V_{GS} - V_{th}}{E_c \cdot L}} \cdot \frac{W}{L} \cdot (V_{GS} - V_{th})^2, & V_{DS} \ge V_{ov}, \quad V_{ov} \cong E_C \cdot L, \quad E_C \not\to 0, \\ k' \cdot W \cdot (V_{GS} - V_{th}) \cdot E_C, & V_{DS} \ge V_{ov}, \quad V_{ov} \cong E_C \cdot L, \quad E_C \to 0; \end{cases}$$

$$g_m = \begin{cases} \frac{I_D}{n \cdot V_T}, & 0 \le V_{ov} < 2 \cdot n \cdot V_T, \\ \begin{matrix} k' \cdot \frac{W}{L} \cdot (V_{GS} - V_{th}) \\ = \sqrt{2 \cdot k' \cdot \frac{W}{L} \cdot I_D} \end{matrix}, & 2 \cdot n \cdot V_T \le V_{ov} \ll E_C \cdot L, \\ W \cdot C_{ox} \cdot v_{scl}, & V_{ov} \cong E_C \cdot L \end{cases} \qquad \frac{g_m}{I_D} = \begin{cases} \frac{1}{n \cdot V_T}, & 0 \le V_{ov} < 2 \cdot n \cdot V_T, \\ \frac{2}{V_{ov}}, & 2 \cdot n \cdot V_T \le V_{ov} \ll E_C \cdot L, \\ \frac{1}{V_{ov}}, & V_{ov} \cong E_C \cdot L \end{cases}$$

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Common Source/Emitter Amplifier

$$r_{in}^{cs} \to \infty; \qquad r_o^{cs} = \Big(r_o \cdot (1 + g_m \cdot R_S)\Big) \Big|\Big| \; R_D;$$

$$g_m^{cs} = \frac{g_m}{1 + g_m \cdot R_S}; \qquad a^{cs} = \frac{g_m \cdot R_D}{1 + g_m \cdot R_S};$$

$$r_{in}^{ce} \approx r_\pi + (\beta + 1) \cdot R_E; \qquad r_o^{ce} = \Big(r_o \cdot (1 + g_m \cdot R_E)\Big) \Big|\Big| \; R_C;$$

$$g_m^{ce} = \frac{g_m}{1 + g_m \cdot R_E}; \qquad a^{ce} = \frac{g_m \cdot R_C}{1 + g_m \cdot R_E}.$$

Common Drain/Collector Amplifier

$$r_{in}^{cd} \to \infty; \qquad r_o^{cd} = \frac{1}{g_m + g_{mb} + \frac{1}{r_o} + \frac{1}{R_L}};$$

$$g_m^{cd} = g_m; \qquad a^{cd} = \frac{g_m}{g_m + g_{mb} + \frac{1}{r_o} + \frac{1}{R_L}} \approx \frac{g_m \cdot R_L}{1 + g_m \cdot R_L};$$

$$r_{in}^{cc} = r_\pi + (\beta + 1) \cdot (R_L \,||\, r_o); \qquad r_o^{cc} = r_o \; \Big|\Big| \left(\frac{r_\pi + R_S}{\beta + 1}\right) \approx \frac{1}{g_m} + \frac{R_S}{\beta + 1};$$

$$g_m^{cc} = g_m + \frac{1}{r_\pi}; \qquad a^{cc} = \frac{1}{1 + \frac{R_S + r_\pi}{(\beta+1)\cdot(R_L \,||\, r_o)}} \approx \frac{g_m \cdot R_L}{1 + g_m \cdot R_L}.$$

Common Gate/Base Amplifier

$$r_{in}^{cg} = \frac{1}{g_m} \cdot \left(1 + \frac{R_D}{r_o}\right); \qquad r_o^{cg} \approx r_o \cdot (1 + g_m \cdot R_S); \qquad V_A \to \infty \implies r_o \to \infty;$$

$$g_m^{cg} = g_m; \qquad a^{cg} = g_m \cdot \left(R_D \; \Big|\Big| \; r_o^{cg}\right) = g_m \cdot R_D; \qquad a_i^{cg} = 1;$$

$$r_{in}^{cb} \approx \frac{\alpha}{g_m} \cdot \left(1 + \frac{R_C}{r_o}\right) \approx \frac{1}{g_m} \cdot \left(1 + \frac{R_C}{r_o}\right); \quad r_o^{cb} \approx r_o \cdot \Big(1 + g_m \cdot (R_E \,||\, r_\pi)\Big); \quad V_A \to \infty \implies r_o \to \infty;$$

$$g_m^{cb} = g_m; \qquad a^{cb} = g_m \cdot \left(R_C \,||\, r_o^{cb}\right) \approx g_m \cdot R_C; \qquad a_i^{cb} = \alpha = \frac{\beta}{\beta + 1}.$$

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MOSFET/BJT Cascode Amplifier

$$r_{in}^{mcas} \to \infty; \qquad r_o^{mcas} = r_{o1} + r_{o2} + g_{m2} \cdot r_{o1} \cdot r_{o2} \approx g_{m2} \cdot r_{o1} \cdot r_{o2}$$

$$g_m^{mcas} = g_m; \qquad a^{mcas} = g_m \cdot \left(R_D \,||\, r_o^{mcas}\right);$$

$$r_{in}^{bcas} = r_\pi; \qquad r_o^{bcas} \approx \left(1 + g_m \cdot (r_{o2} \,||\, r_\pi)\right) \cdot r_{o1};$$

$$g_m^{bcas} = g_m; \qquad a^{bcas} = g_m \cdot \left(R_C \,||\, r_o^{bcas}\right)$$

MOSFET/BJT Differntial Pair

Amplifications: $a_{dm} = \left.\frac{v_{od}}{v_{id}}\right|_{v_{ic}=0}$; $a_{cm} = \left.\frac{v_{oc}}{v_{ic}}\right|_{v_{id}=0}$; $a_{dmcm} = \left.\frac{v_{od}}{v_{ic}}\right|_{v_{id}=0}$; $a_{cmdm} = \left.\frac{v_{oc}}{v_{id}}\right|_{v_{ic}=0}$;

MOSFET Differential Mode: $r_{in}^{dm} \to \infty$; $r_o^{dm} \approx R_D$; $g_m^{dm} = g_m$; $a^{dm} = -g_m \cdot R_D$;

MOSFET Common Mode: $r_{in}^{cm} \to \infty$; $r_o^{cm} \approx R_D$; $g_m^{cm} = \frac{g_m}{1 + 2 \cdot g_m \cdot R_{Tail}}$;

$$a^{cm} = -g_m^{cm} \cdot R_D; \qquad CMRR = \frac{a^{dm}}{a^{cm}} = 1 + 2 \cdot g_m \cdot R_{Tail};$$

BJT Differential Mode: $r_{in}^{dm} = 2 \cdot r_\pi$; $r_o^{dm} \approx R_C$; $g_m^{dm} = g_m$; $a^{dm} = -g_m \cdot R_C$;

BJT Common Mode: $r_{in}^{cm} = r_\pi + (\beta + 1) \cdot 2 \cdot R_{Tail}$; $r_o^{cm} \approx R_C$; $g_m^{cm} = \frac{g_m}{1 + 2 \cdot g_m \cdot R_{Tail}}$;

$$a^{cm} = -g_m^{cm} \cdot R_C; \qquad CMRR = \frac{a^{dm}}{a^{cm}} = 1 + 2 \cdot g_m \cdot R_{Tail}.$$

Operational Amplifier

Non-inverting amplificaton : $a^+ = \left(1 + \frac{R_2}{R_1}\right) \cdot \frac{1}{\frac{1}{a} \cdot \left(1 + \frac{R_2}{R_1}\right) + 1} \approx 1 + \frac{R_2}{R_1}$;

Inverting amplificaton : $a^- = -\frac{R_2}{R_1} \cdot \frac{1}{\frac{1}{a} \cdot \left(1 + \frac{R_2}{R_1}\right) + 1} \approx -\frac{R_2}{R_1}$;

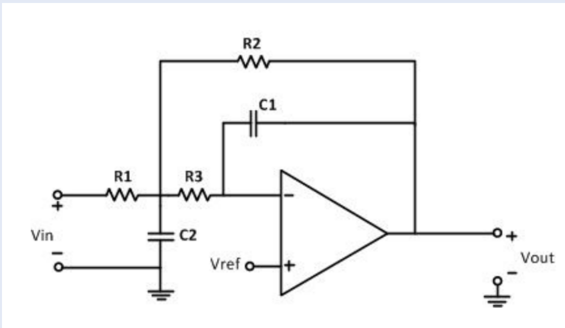
Output voltages : $v_o^{int} = -\frac{1}{R \cdot C} \cdot \int v_s \, dt$; $v_o^{diff} = -\frac{1}{R \cdot C} \cdot \frac{dv_s}{dt}$;

$$v_o^{DISO} = -v_1 \cdot \frac{R_3}{R_1} + v_2 \cdot \frac{R_4}{R_2 + R_2} \cdot \left(1 + \frac{R_3}{R_1}\right) = \left.\frac{R_3}{R_1} \cdot (v_2 - v_1)\right|_{\substack{R_1 = R_2, \\ R_3 = R_4}}$$

$$v_o^{instr} = \frac{R_4}{R_3} \cdot \left(1 + \frac{2 \cdot R_2}{R_1}\right) \cdot (v_2 - v_1)$$

Active Amplifiers

MFB

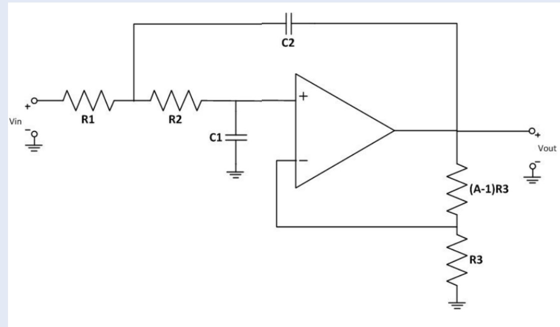


$$R_2 = \frac{a_1 - \sqrt{a_1^2 - \frac{4 \cdot b_1 \cdot C_1}{C_2} \cdot (1 + |A_0|)}}{4 \cdot \pi \cdot f_g \cdot C_1};$$

$$R_1 = \frac{R_2}{|A_0|}; \qquad R_3 = \frac{b_1}{4 \cdot \pi^2 \cdot C_1 \cdot C_2 \cdot R_2};$$

$$C_2 \geq \frac{4 \cdot b_1 \cdot (1 + |A_0|)}{a_1^2} \cdot C_1.$$

Sallen-Key



$$R_1 = \frac{a_1 \pm \sqrt{a_1^2 - 4 \cdot b_1 \cdot \frac{C_1 + (1 - A_0) \cdot C_2}{C_2}}}{4 \cdot \pi \cdot f_g \cdot (C_1 + (1 - A) \cdot C_2)};$$

$$R_2 = \frac{b_1}{4 \cdot \pi^2 \cdot f_g^2 \cdot R_1 \cdot C_1 \cdot C_2}$$

$$\frac{C_1}{C_2} \leq \frac{a_1^2}{4 \cdot b_1} + (A_0 - 1).$$

Load Regulators

$$V_{dropout} = I_L \cdot R_{DS(on)}.$$