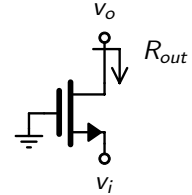
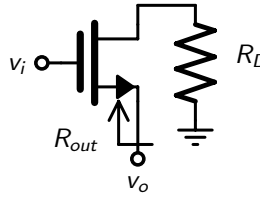
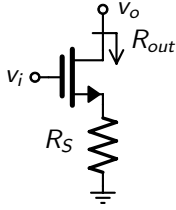


Equation Sheet

Constants: $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$; $q = 1.602 \times 10^{-19} \text{ C}$; $V_T = kT/q \approx 26\text{mV}$ at 300 K; $\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$; $k_{ox} = 3.9$; $C_{ox} = (k_{ox}\epsilon_0)/t_{ox}$; $\omega = 2\pi f$

NMOS: $k_n = \mu_n C_{ox}(W/L)$; $V_{tn} > 0$; $v_{DS} \geq 0$; $V_{ov} = V_{GS} - V_{tn}$
 (triode) $v_{DS} \leq V_{ov}$; $v_D < v_G - V_{tn}$; $i_D = k_n(V_{ov}v_{DS} - (v_{DS}^2/2))$; $r_{ds} = 1/(\mu_n C_{ox}(W/L)V_{ov})$
 (active) $v_{DS} \geq V_{ov}$; $i_D = 0.5k_n V_{ov}^2(1 + \lambda_n v_{DS}')$; $v_{DS}' = v_{DS} - V_{ov}$;
 $g_m = k_n V_{ov} = 2I_D/V_{ov} = \sqrt{2k_n I_D}$; $r_s = 1/g_m$; $r_o = L/(|\lambda_n'|I_D)$

PMOS: $k_p = \mu_p C_{ox}(W/L)$; $V_{tp} < 0$; $v_{SD} \geq 0$; $V_{ov} = V_{SG} - |V_{tp}|$
 (triode) $v_{SD} \leq V_{ov}$; $v_D > v_G + |V_{tp}|$; $i_D = k_p(V_{ov}v_{SD} - (v_{SD}^2/2))$; $r_{ds} = 1/(\mu_p C_{ox}(W/L)V_{ov})$
 (active) $v_{SD} \geq V_{ov}$; $i_D = 0.5k_p V_{ov}^2(1 + |\lambda_p|v_{SD}')$; $v_{SD}' = v_{SD} - V_{ov}$
 $g_m = k_p V_{ov} = 2I_D/V_{ov} = \sqrt{2k_p I_D}$; $r_s = 1/g_m$; $r_o = L/(|\lambda_p'|I_D)$



Accurate: $R_{out} = r_o + (1 + g_m r_o)R_S$
 $i_{sc} = (-g_m r_o v_i)/(r_o + (1 + g_m r_o)R_S)$
 $v_{oc} = -g_m r_o v_i$

$R_{out} = (r_o + R_D)/(1 + g_m r_o)$
 $i_{sc} = (g_m r_o v_i)/(r_o + R_D)$
 $v_{oc} = (g_m r_o v_i)/(1 + g_m r_o)$

$R_{out} = r_o$
 $i_{sc} = ((1 + g_m r_o)/r_o)v_i$
 $v_{oc} = (1 + g_m r_o)v_i$

$g_m r_o \gg 1$ $R_{out} = (1 + g_m R_S)r_o$
 $i_{sc} = -v_i/((1/g_m) + R_S)$
 $v_{oc} = -g_m r_o v_i$

$R_{out} = (1/g_m) + (R_D/g_m r_o)$
 $i_{sc} = (g_m r_o v_i)/(r_o + R_D)$
 $v_{oc} = v_i$

$R_{out} = r_o$
 $i_{sc} = g_m v_i$
 $v_{oc} = g_m r_o v_i$

Diff Pair: $A_d = g_m R_D$; $A_{CM} = -(R_D/(2R_{SS}))(\Delta R_D/R_D)$; $A_{CM} = -(R_D/(2R_{SS}))(\Delta g_m/g_m)$;
 $V_{OS} = \Delta V_t$; $V_{OS} = (V_{OV}/2)(\Delta R_D/R_D)$; $V_{OS} = (V_{OV}/2)(\Delta(W/L)/(W/L))$
Large signal: $i_{D1} = (I/2) + (I/V_{ov})(v_{id}/2)(1 - (v_{id}/2V_{ov})^2)^{1/2}$

1st order: step response $y(t) = Y_\infty - (Y_\infty - Y_{0+})e^{-t/\tau}$;
 unity gain freq for $T(s) = A_M/(1 + (s/\omega_{3dB}))$ for $A_M \gg 1 \Rightarrow \omega_t \simeq |A_M|\omega_{3dB}$

Freq: for real axis poles/zeros $T(s) = k_{dc} \frac{(1 + s/z_1)(1 + s/z_2) \dots (1 + s/z_m)}{(1 + s/\omega_1)(1 + s/\omega_2) \dots (1 + s/\omega_n)}$
 OTC estimate $\omega_H \simeq 1/(\sum \tau_i)$; dominant pole estimate $\omega_H \simeq 1/(\tau_{max})$
 STC estimate $\omega_L \simeq \sum 1/\tau_i$; dominant pole estimate $\omega_L \simeq 1/(\tau_{min})$

Miller: $Z_1 = Z/(1 - K)$; $Z_2 = Z/(1 - 1/K)$

Mos caps: $C_{gs} = (2/3)WLC_{ox} + WL_{ov}C_{ox}$; $C_{gd} = WL_{ov}C_{ox}$; $C_{db} = C_{db0}/\sqrt{1 + V_{db}/V_0}$;
 $\omega_t = g_m/(C_{gs} + C_{gd})$; for $C_{gs} \gg C_{gd} \Rightarrow f_t \simeq (3\mu V_{ov})/(4\pi L^2)$

Feedback: $A_f = A/(1 + A\beta)$; $x_i = (1/(1 + A\beta))x_s$; $dA_f/A_f = (1/(1 + A\beta))dA/A$; $\omega_{Hf} = \omega_H(1 + A\beta)$; $\omega_{Lf} = \omega_L/(1 + A\beta)$;
 Loop Gain $L \equiv -s_f/s_t$; $A_f = A_\infty(L/(1 + L)) + d/(1 + L)$; $Z_{port} = Z_{p^\circ}((1 + L_S)/(1 + L_O))$; $PM = \angle L(j\omega_t) + 180$;
 $GM = -|L(j\omega_{180})|_{db}$;
 Pole splitting $\omega_{p1}' \simeq 1/(g_m R_2 C_f R_1)$; $\omega_{p2}' \simeq (g_m C_f)/(C_1 C_2 + C_f(C_1 + C_2))$

Phase Margin: $PM = 90^\circ - \tan^{-1}(\omega_1/\omega_{p2})$; $K_{PM} \equiv \omega_1/\omega_{p2}$; $\omega_{p1} \approx (K_{PM}\omega_{p2}(1 + K_{PM}^2)^{1/2})/L_0$

Body Effect: $V_t = V_{t0} + \gamma(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f})$; $\gamma = \sqrt{2qN_A\epsilon_s/C_{ox}}$; $g_{mb} = \chi g_m$; $\chi = \gamma/(2\sqrt{2\phi_f + V_{SB}})$