

**Constants:**  $k = 1.38 \times 10^{-23} \text{ JK}^{-1}$ ;  $q = 1.602 \times 10^{-19} \text{ C}$ ;  $V_T = kT/q \approx 26 \text{ mV}$  at  $300 \text{ }^\circ\text{K}$ ;

$\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$ ;  $k_{\text{ox}} = 3.9$ ; **caps:**  $C_{\text{ox}} = (k_{\text{ox}}\epsilon_0)/t_{\text{ox}}$ ;  $C_j = C_{j0}/(1 + V_R/\phi_0)^{M_j}$ ;

**NMOS:**  $\beta_n = \mu_n C_{\text{ox}}(W/L)$ ;  $V_{in} > 0$ ;  $V_{DS} \geq 0$ ; (triode)  $I_D = \beta_n((V_{GS} - V_{in})V_{DS} - (V_{DS}^2/2))$ ; (active)  $I_D = 0.5\beta_n(V_{GS} - V_{in})^2$ ;

(triode)  $V_{DS} \leq (V_{GS} - V_{in})$ ; (active)  $V_{DS} \geq (V_{GS} - V_{in})$ ;  $V_{in} = V_{in0} + \gamma(\sqrt{V_{SB} + \phi_s} - \sqrt{\phi_s})$ ;

(subthreshold)  $I_D = I_{D0} e^{((V_{GS} - V_{in})/(nV_T))} (1 - e^{-V_{DS}/V_T})$ ;

**PMOS:**  $\beta_p = \mu_p C_{\text{ox}}(W/L)$ ;  $V_{ip} < 0$ ;  $V_{DS} \leq 0$ ; (triode)  $I_D = \beta_p((V_{GS} - V_{ip})V_{DS} - (V_{DS}^2/2))$ ; (active)  $I_D = 0.5\beta_p(V_{GS} - V_{ip})^2$ ;

(triode)  $V_{DS} \geq (V_{GS} - V_{ip})$ ; (active)  $V_{DS} \leq (V_{GS} - V_{ip})$ ;

**Simple cap model:**  $C_g = C_{\text{ox}}WL$ ; if  $L_{\text{min}}$ :  $C_{gu} \equiv C_{\text{ox}}L_{\text{min}}$ ;  $C_g = C_{gu}W$ ;  $C_d = C_s = C_{du}W$ ;

**CMOS inverter:**  $V_{\text{TH}} = (V_{\text{DD}} + V_{ip} + V_{in}r)/(1 + r)$ ;  $r = \sqrt{(\mu_n(W/L)_n)/(\mu_p(W/L)_p)}$ ;

**RC delay est:**  $t_{dr} = t_{df} = 1.2\tau$ ;  $\tau = R_{\text{eq}}C$ ;  $R_{\text{eqn}} = 2.5/(\mu_n C_{\text{ox}}(W/L)_n(V_{\text{DD}} - V_{in}))$ ;  $R_{\text{eqp}} = 2.5/(\mu_p C_{\text{ox}}(W/L)_p(V_{\text{DD}} + V_{ip}))$ ;