

Formula Sheet

DIODE

$$I_D = I_S (e^{V_D/V_T} - 1), \text{ where } V_T = \frac{k_B T}{q} = 26 \text{ mV}$$

NMOS	PMOS
Cut-off $V_{GS} < V_{tn}, I_D = 0$ Triode Region (Linear) $V_{GS} > V_{tn} \ \& \ V_{DS} < V_{DSP} = V_{GS} - V_{tn}$ $I_D = \frac{W}{L} \mu_n C_{ox} \left((V_{GS} - V_{tn}) V_{DS} - \frac{V_{DS}^2}{2} \right)$ Active Region (Saturation) $V_{GS} > V_{tn} \ \& \ V_{DS} \geq V_{DSP} = V_{GS} - V_{tn}$ $I_D = \frac{W}{L} \frac{\mu_n C_{ox}}{2} (V_{GS} - V_{tn})^2 [1 + \lambda V_{DS}]$	Cut-off $V_{SG} < V_{tp} , I_D = 0$ Triode Region (Linear) $V_{SG} < V_{tp} \ \& \ V_{SD} > V_{SDP} = V_{SG} - V_{tp} $ $I_D = \frac{W}{L} \mu_p C_{ox} \left((V_{SG} - V_{tp}) V_{SD} - \frac{V_{SD}^2}{2} \right)$ Active Region (Saturation) $V_{SG} < V_{tp} \ \& \ V_{SD} \leq V_{SDP} = V_{SG} - V_{tp} $ $I_D = \frac{W}{L} \frac{\mu_p C_{ox}}{2} (V_{SG} - V_{tp})^2 [1 + \lambda V_{SD}]$

Body Effect

$$V_t = V_{to} + \gamma \left(\sqrt{|V_{SB}| + 2\phi_F} - \sqrt{2\phi_F} \right)$$

Small Signal Characteristics (NMOS):

$$g_m = \sqrt{2\mu_n C_{ox} \frac{W}{L} I_D}; \quad r_{ds} = \frac{|V_A|}{I_D} = \frac{1}{\lambda I_D}$$

BIPOLAR (NPN forward active $I_B > 0, V_{CE} > V_{CE,sat}$)

$$I_C = I_S e^{V_{BE}/V_T} \cdot \left(1 + \frac{V_{CE}}{V_A} \right) \cong I_S e^{V_{BE}/V_T} \text{ where } V_T = \frac{k_B T}{q} = 26 \text{ mV}$$

$$I_C = \alpha I_E = \beta I_B \cdot \left(1 + \frac{V_{CE}}{V_A} \right) \cong \beta I_B \quad \alpha = \frac{\beta}{\beta + 1}$$

Small Signal Characteristics:

$$g_m = \frac{I_C}{V_T}; \quad \beta = g_m r_\pi; \quad r_\pi = r_e (\beta + 1); \quad r_e = \frac{V_T}{I_E}; \quad r_o = \frac{|V_A|}{I_C}; \quad \omega_T = \frac{g_m}{C_\pi + C_\mu}$$