Basic MOSFET Equations

N-channel MOSFET Equations (simple model)

$$I_{DS} = 0 \qquad V_{GS} \le V_T \qquad \text{Cut Off}$$

$$I_{DS} = K'\frac{W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right](1 + \lambda V_{DS}) \qquad V_{GS} > V_T,\ V_{DS} \le V_{GS} - V_T \qquad \text{Triode}$$

$$I_{DS} = \frac{1}{2}K'\frac{W}{L}(V_{GS} - V_T)^2(1 + \lambda V_{DS}) \qquad V_{GS} > V_T,\ V_{DS} > V_{GS} - V_T \qquad \text{Saturation}$$

$$V_T = V_{T0} + \gamma\left(\sqrt{|\Phi + V_{SB}|} - \sqrt{\Phi}\right) \qquad \Phi = 2\Phi_F$$

$$K' = \mu C_{ox} \qquad C_{ox} = 3.45\,fF/\mu^2 \text{ for t = 10 nm}$$

$$g_m = \sqrt{2I_{DS}K'\frac{W}{L}} = K'\frac{W}{L}(V_{GS} - V_T) = \frac{2I_{DS}}{(V_{GS} - V_T)}$$

$$g_{mb} = \frac{g_m\gamma}{2\sqrt{\Phi + V_{SB}}} = \eta g_m \qquad r_o = \frac{1}{\lambda I_{DS}}$$

P-channel MOSFET Equations (simple model)

1) Multiply all voltages by –1
2) Compute current as for n-channel
3) Multiply current by –1

OR

$$I_{SD} = 0 \qquad V_{SG} \le |V_T| \qquad \text{Cut Off}$$

$$I_{SD} = K_P'\frac{W}{L}\left[(V_{SG} - |V_T|)V_{SD} - \frac{V_{SD}^2}{2}\right](1 + \lambda V_{SD}) \qquad V_{SG} > |V_T|,\ V_{SD} \le V_{SG} - |V_T| \qquad \text{Triode}$$

$$I_{SD} = \frac{1}{2}K_P'\frac{W}{L}(V_{SG} - |V_T|)^2(1 + \lambda V_{SD}) \qquad V_{SG} > |V_T|,\ V_{SD} > V_{SG} - |V_T| \qquad \text{Saturation}$$

$$V_T = V_{T0} - \gamma\left(\sqrt{|\phi + V_{BS}|} - \sqrt{\phi}\right)$$

$$K_P' = \mu_p C_{ox}$$

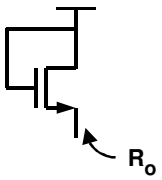
$$g_m = \sqrt{2I_{SD}K_P'\frac{W}{L}} = K'\frac{W}{L}(V_{SG} - |V_T|) = \frac{2I_{SD}}{(V_{SG} - |V_T|)}$$

$$g_{mb} = \frac{g_m\gamma}{2\sqrt{\Phi + V_{BS}}} = \eta g_m \qquad r_o = \frac{1}{\lambda I_{SD}}$$

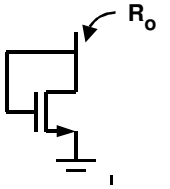
Useful Formulas for CMOS Circuit Design

Diode connected NFET

Into source: $R_o = \dfrac{1}{g_m + g_{mb} + g_0}$

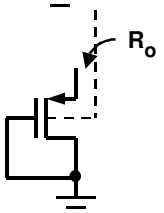


Into drain (source at ground) $R_o = \dfrac{1}{g_m + g_o}$

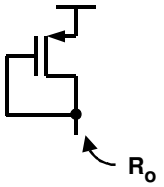


Diode connected PFET

Into source: $R_o = \dfrac{1}{g_m + g_{mb} + g_0}$

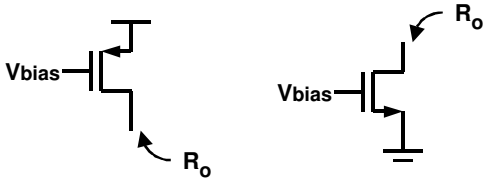


Into drain (source at Vdd) $R_o = \dfrac{1}{g_m + g_o}$



PFET and NFET current source

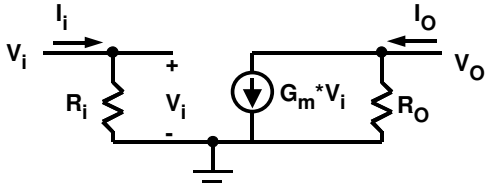
Into drain: $R_o = r_o$



For amplifiers in general

Voltage gain: $A_v = -G_m R_o$

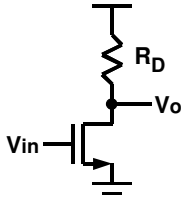
Current gain: $A_i = G_m R_{in}$



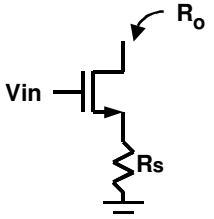
Common source amplifier

$R_o = r_o \parallel R_D$

$G_m = g_m$



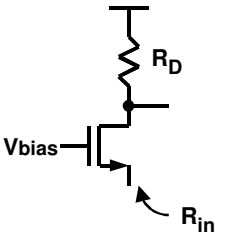
Common source amplifier with source degeneration

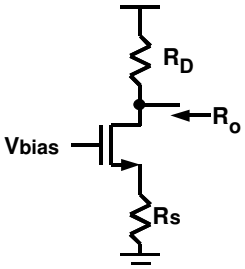


$$R_o = R_S + [1 + (g_m + g_{mb})R_S]r_o = r_o + [1 + (g_m + g_{mb})r_o]R_S$$

$$G_m = \frac{g_m}{1 + (g_m + g_{mb} + g_o)R_S}$$

Common gate amplifier



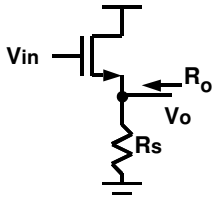


$$R_{in} = \frac{R_D + r_0}{1 + (g_m + g_{mb})r_0} = \frac{\frac{R_D}{r_0} + 1}{g_m + g_{mb} + g_0}$$

$R_o = R_D \,||\, \{R_S + [1 + (g_m + g_{mb})R_S]r_o\}$, R_S is input source resistance

$$G_m = g_m + g_{mb}$$

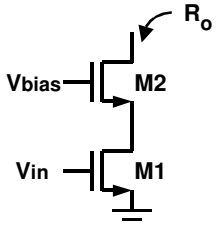
Common drain amplifier or source follower



$$R_o = \frac{1}{g_m + g_{mb} + g_o + g_S} \text{ , where } g_S = \frac{1}{R_S}$$

$$G_m = g_m$$

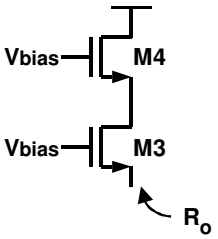
Cascode (common source amplifier with common gate)



$$R_o = r_{o2} + [1 + (g_{m2} + g_{mb2})r_{o2}]r_{o1} = r_{o1} + [1 + (g_{m2} + g_{mb2})r_{o1}]r_{o2}$$

$$G_m = g_{m1}$$

Cascode current source



$$R_o = r_{o4} + [1 + (g_{m3} + g_{mb3})r_{o4}]r_{o3}$$