MOSFET as Amplifying Device.

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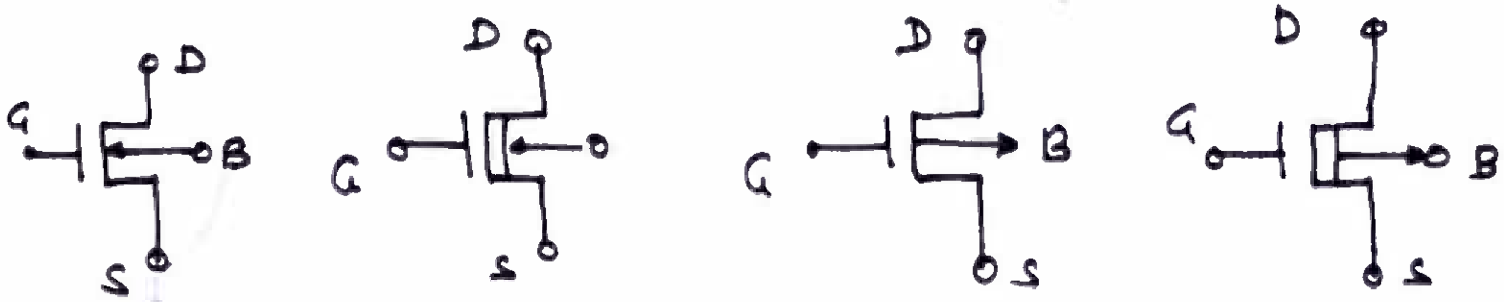
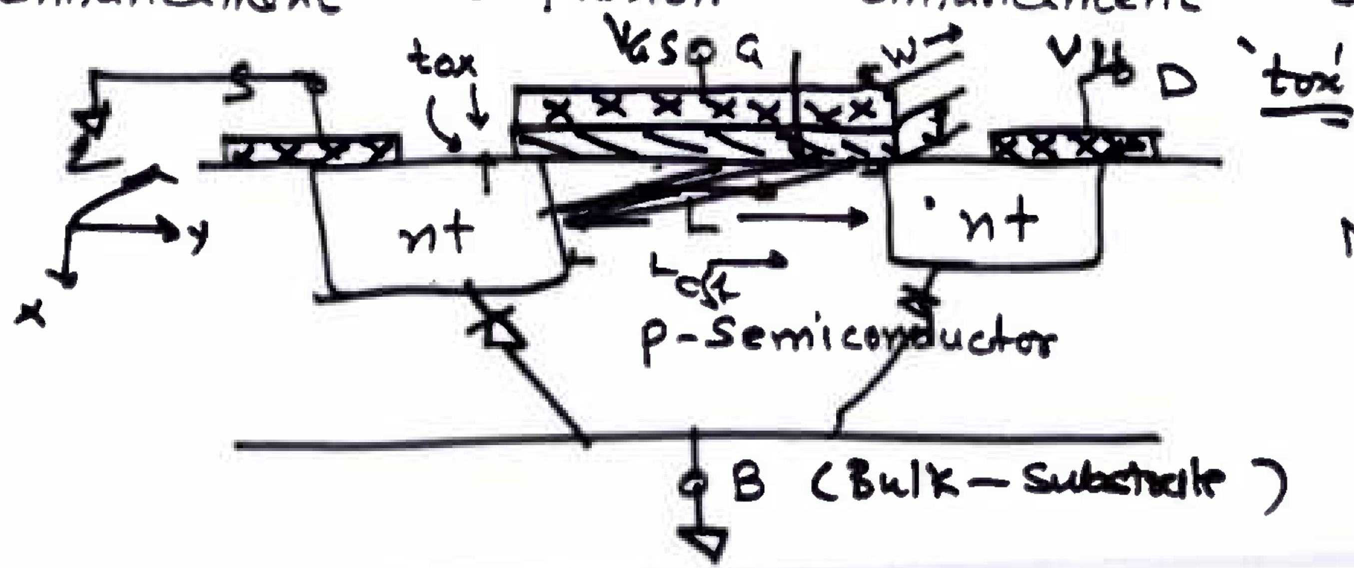


NMOS Enhancement | NMOS Depletion | PMOS Enhancement | PMOS Depletion



$V_{GS} - V_{DS} > V_T$

$V_{GS} - V_T > V_{DS}$

NMOS(EM) Transistor Cross-Section

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Threshold Voltage V_T

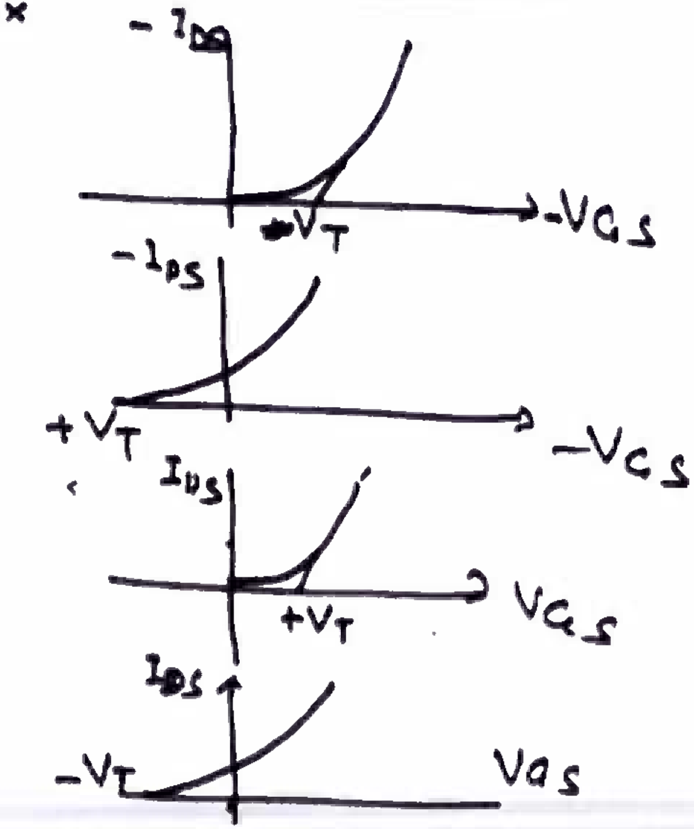
$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} \qquad V_T = \phi_{ms} \pm 2\phi_F - \frac{Q_{ox}}{C_{ox}} - \frac{\pm Q_B}{C_{ox}}$$

(EM) P-channel :— V_T is −ve

(DM) P-channel :— V_T is +ve

(EM) N-Channel :— V_T is +ve

(DM) N-Channel :— V_T is −ve



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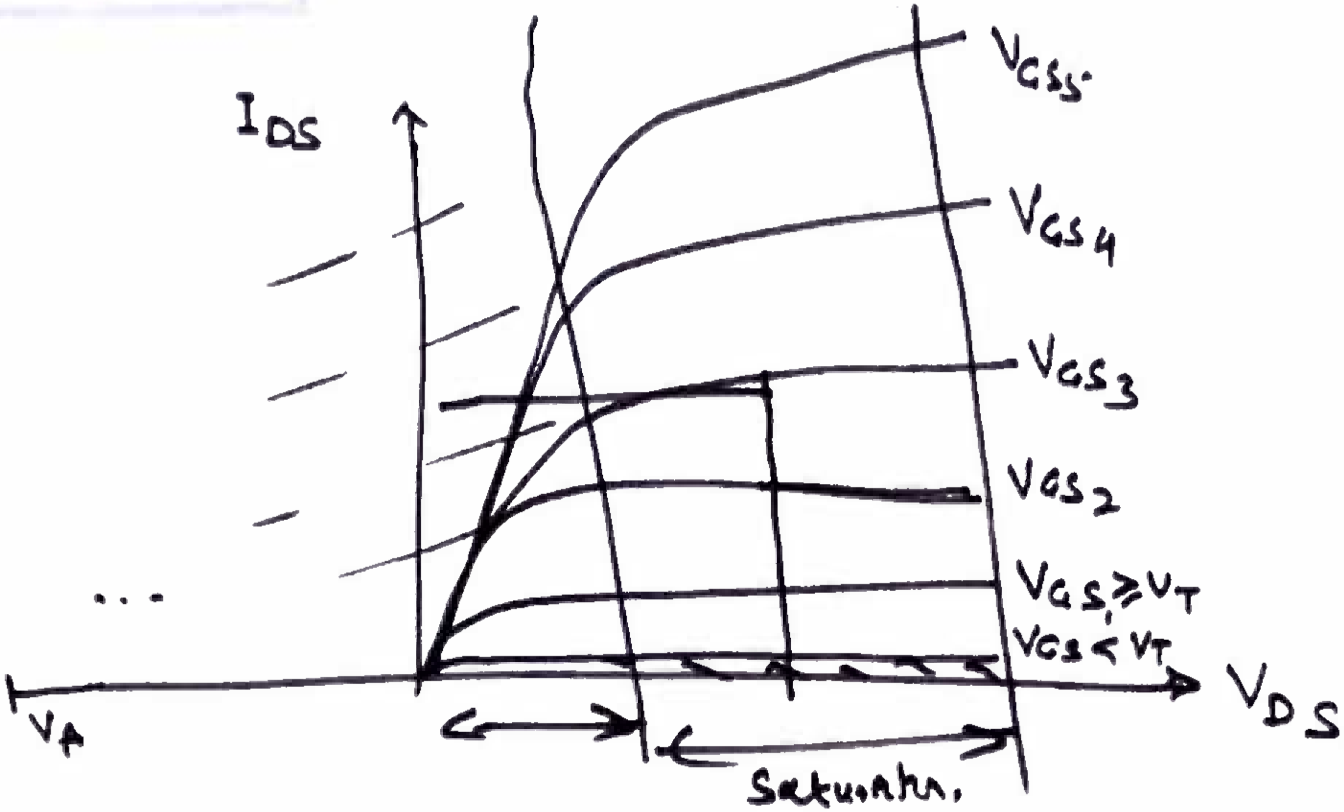

Output characteristics of NMOS (EM)

MOSFET Operation

$$I_{DS} = \mu C_{ox}\left(\frac{W}{L}\right)\left[(V_{GS}-V_T)V_{DS} - \frac{1}{2}V_{DS}^2\right] \quad V_{GS}-V_T > V_{DS}$$

Linear Mode

$$V_{GS}-V_T = V_{OV} = V_{Exc}$$

$$I_{DS} = \frac{1}{2}\mu C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2(1+\lambda V_{DS}) \quad V_{GS}-V_T < V_{DS}$$

$$\boxed{\lambda = \frac{\lambda'}{L}} \quad \text{Also} \quad \boxed{\lambda = \frac{1}{V_A}} \qquad \boxed{g_m r_o}$$

$\mu_n = 600\ cm^2/V\,sec$ $\quad \mu_p = 200\ cm^2/V\,sec.$

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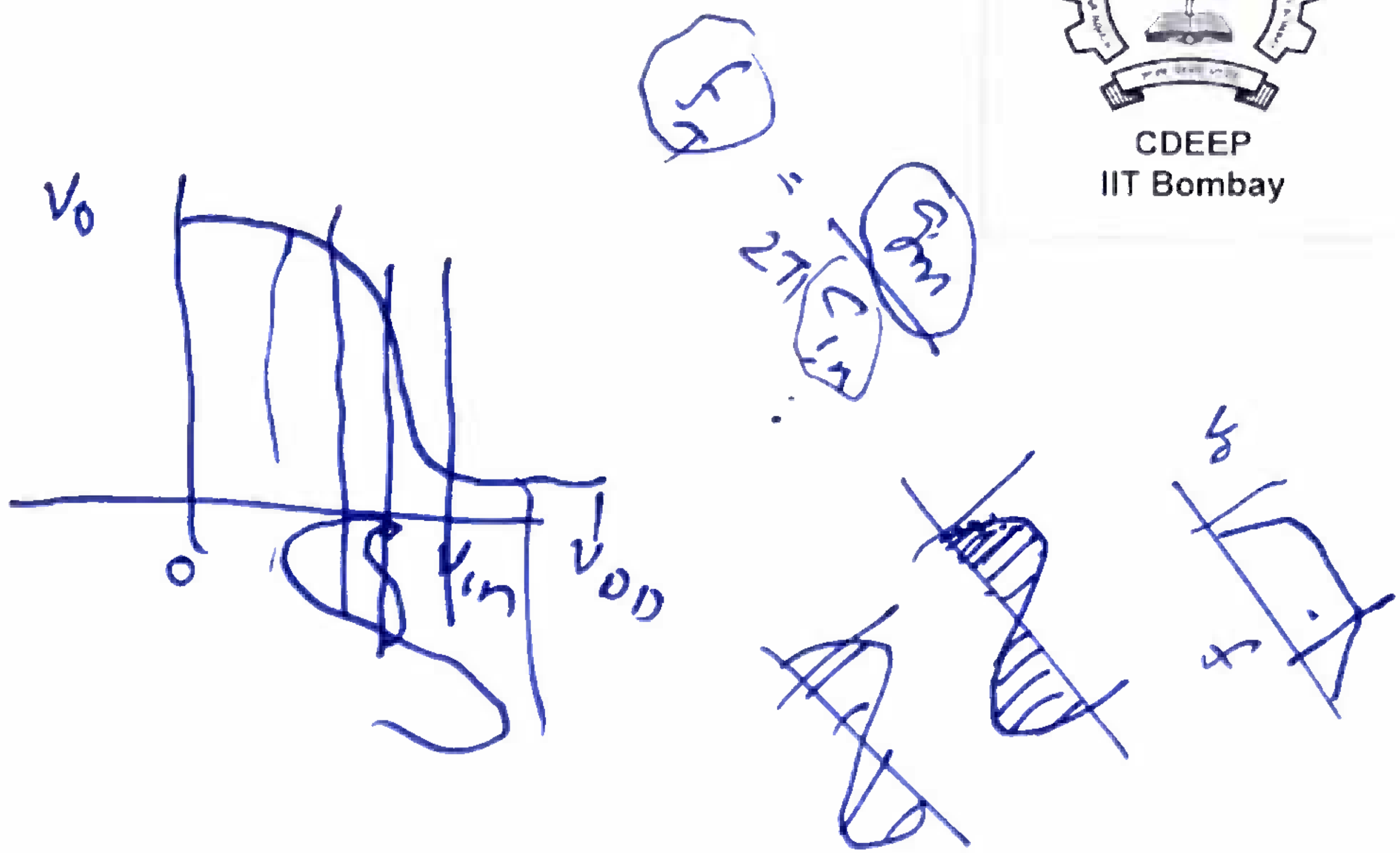

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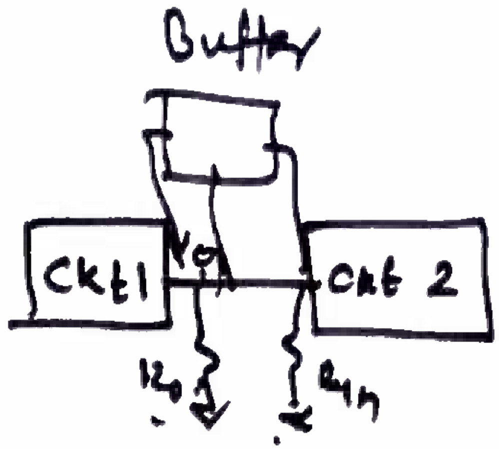

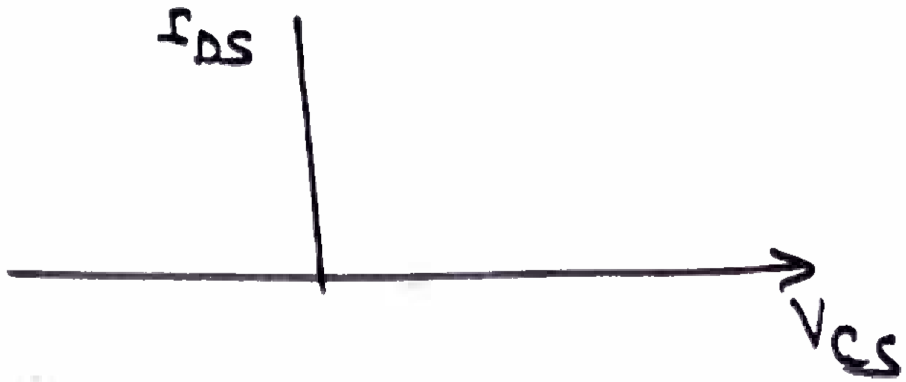

Course Name
Analog Circuits

Lecture No. 5

Instructor's Name
Prof. A. N. Chandorkar

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Small Signal Model

(i) g_m (ii) Capacitances

(iii) Output Resistance

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Major Small signal Parameters for MOSFET

① g_m = Transconductance $= \dfrac{\partial I_{DS}}{\partial V_{GS}}$

$$g_{m_{linear}} = \frac{\partial}{\partial V_{GS}}\left[\frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)\left\{(V_{GS}-V_T)V_{DS} - \frac{1}{2}V_{DS}^2\right\}\right]$$

As $V_{GS} - V_{DS} > V_{DS}$ $\therefore$ $\frac{1}{2}V_{DS}^2$ can be neglected

$$g_{m_{linear}} = \frac{\partial}{\partial V_{GS}}\left[\frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)V_{DS}\right]$$

We define $\beta'_n = \dfrac{\mu_n C_{ox}}{1}$, $\beta_n = \beta'_n\left(\dfrac{W}{L}\right)$

Then $g_{m_{linear}} = \beta_n V_{DS}$

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In Sat. Mode

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} = \frac{\partial}{\partial V_{GS}}\left[\frac{\beta_n}{2} (V_{GS} - V_T)^2 (1 + \lambda V_{DS}) \right]$$

Assume λ is very small, then $(1+\lambda V_{DS}) \rightarrow 1$

$$\therefore \quad g_m = \beta_n' (V_{GS} - V_T)(W/L)$$

$$g_m = \frac{\beta_n}{2} (V_{GS} - V_T)^2 \frac{2}{(V_{GS} - V_T)} = \frac{2 I_{DS}}{(V_{GS} - V_T)} = \frac{2 I_{DS}}{V_{OV}}$$

or $\boxed{g_m = \frac{2 I_{DS}}{V_{OV}}}$ or $g_m = \sqrt{2 \beta_n I_{DS}}$

(2) Output Resistance $r_o = \frac{1}{\lambda I_{DS}} = \frac{V_A}{I_{DS}} = \frac{L}{\lambda' I_{DS}}$ $\quad \lambda = \frac{\lambda'}{L}$

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Comparision between BJT & MOSFET

In MOS $$\frac{g_m}{I_{DS}} = \frac{2}{V_{OV}}$$

Typically V_{OV} is of the order of 200 mV or so

$$\therefore \frac{g_m}{I_{DS}} \simeq \frac{2}{200\ mV} = \frac{2000}{200} = 10.$$

for higher V_{OV}, $\frac{g_m}{I_{DS}} < 10$

In BJT $$\frac{g_m}{I_C} = \frac{q}{kT} = 38 \quad (T = 300^\circ K)$$

clearly $$\frac{g_m}{I_C} >> \frac{g_m}{I_{DS}}$$

∴ BJT is normally better than MOSFET for g_m values.

Limitation of MOSFET Small Signal Model.

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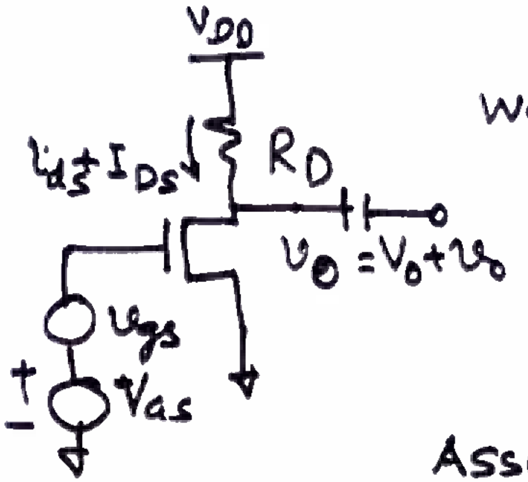

We have $v_{GS} = v_{gs} + V_{GS}$
 ac + DC

$$\therefore\ i_{DS} = \frac{\beta_n}{2}\left[V_{GS} - V_T + v_{gs}\right]^2\left[1 + \lambda V_{DS}\right]$$

Assuming λ v.small

We have $i_{ds} = i_{DS} - I_{DS}$

$$= \frac{\beta_n}{2}\left[\{(V_{GS}-V_T) + v_{gs}\}^2\right] - \frac{\beta_n}{2}\left[(V_{GS}-V_T)^2\right]$$

$$= \frac{\beta_n}{2}\left[(V_{GS}-V_T)^2 + v_{gs}^2 + 2(V_{GS}-V_T)v_{gs}\right] - \frac{\beta_n}{2}\left[(V_{GS}-V_T)^2\right]$$

$$= 2\frac{\beta_n}{2}(V_{GS}-V_T)v_{gs}\left[1 + \frac{v_{gs}}{2(V_{GS}-V_T)}\right]$$

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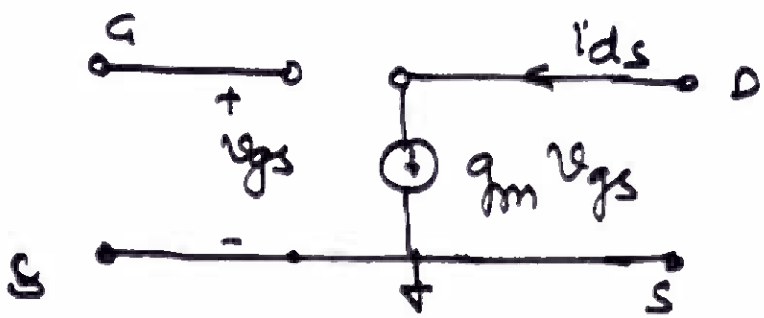
$$\therefore \; i_{ds} = g_m v_{gs}\left[1 + \frac{v_{gs}}{2(V_{GS}-V_T)}\right]$$

If $v_{gs} << [2(V_{GS}-V_T)] \Rightarrow$ Small Signal

Then $\boxed{i_{ds} = g_m v_{gs}}$

Equivalent Model :



Equivalent Model with r_o

$$v_o = -g_m v_{gs}(r_o \| R_D)$$

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We see $v_{in} = v_{gs}$

and $v_o = -g_m v_{gs} \cdot r_o = -g_m r_o v_{in}$

$$\therefore \boxed{\frac{v_o}{v_{in}} = A_v = -g_m r_o}$$

$$g_m = \frac{2 I_{DS}}{V_{OV}}, \quad r_o = \frac{1}{\lambda I_{DS}}$$

$$\therefore g_m r_o = \frac{2 I_{DS}}{V_{OV}} \cdot \frac{1}{\lambda I_{DS}} = \frac{2}{\lambda V_{OV}} = \frac{2}{\lambda (V_{GS} - V_T)}$$

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$$\omega_T = \frac{g_m}{C_{in}} \quad \text{or} \quad f_T = \frac{g_m}{2\pi C_{in}}$$

When Device is in Saturation we can say $C_{in} = C_{gs} + C_{gd} + C_{gb}$, but $C_{gd} = C_{gb} = 0$

$$= C_{gs} = C_{ox} \cdot W \cdot L$$

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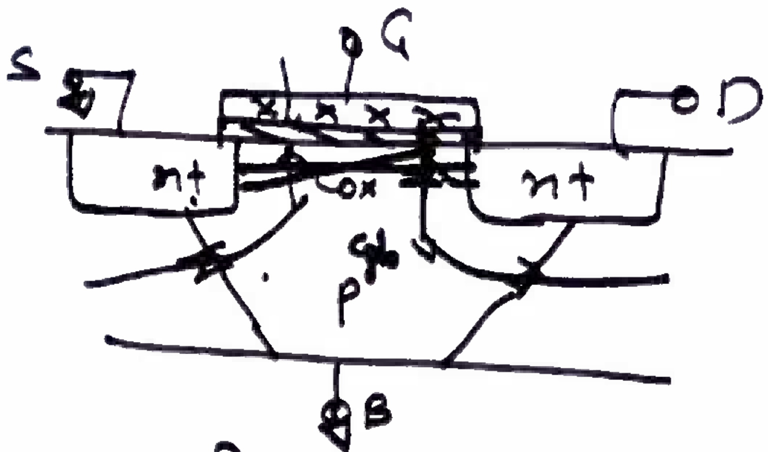
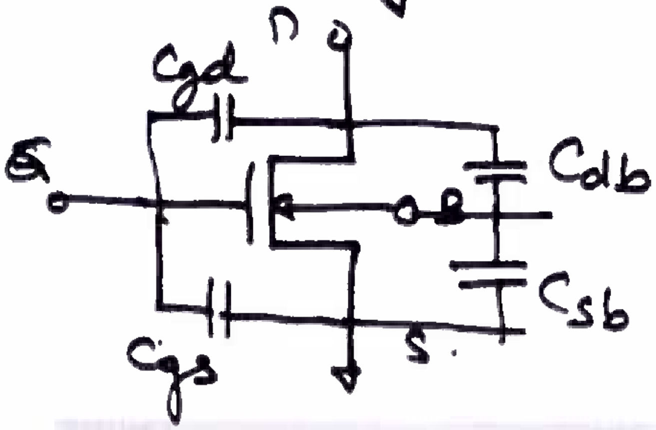
Capacitances in a MOSFET





$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$

In Saturation

$$C_{gs} \simeq \frac{1}{2} C_{ox} A_G \quad \left(\tfrac{2}{3} C_{ox}\right)$$

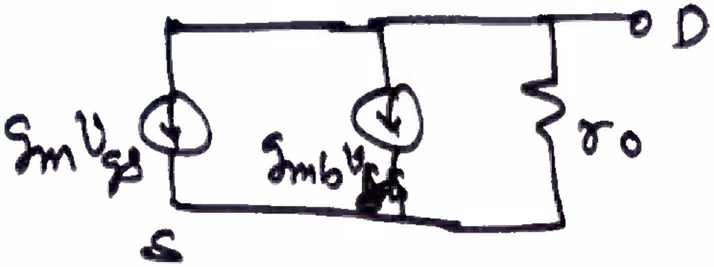
$$C_{gd} = \tfrac{1}{2} C_{ox} \cdot A_G$$

$$C_{sb} = \frac{C_{sbo}}{\left(1 + \frac{V_{SB}}{\phi_{SB}}\right)^{1/2}}$$

$$C_{db} = \frac{C_{dbo}}{\left(1 + \frac{V_{DB}}{\phi_{db}}\right)^{1/2}}$$

$$C_{in} = C_{gs} + C_{gd} \simeq C_{ox} \cdot A_G = C_{ox} W \cdot L$$

Substrate Bias Effect on g_m



Let V_{bs} be -ve bias on Substrate ($V_s = 0$)

Then $V_T = V_{T0} + \gamma\left[(2\phi_F + V_{SB})^{1/2} - (2\phi_F)^{1/2}\right]$

Since $I_{DS} = \frac{\beta}{2}\left[V_{GS} - V_{T0} - \gamma\left\{(2\phi_F + V_{SB})^{1/2} - (2\phi_F)^{1/2}\right\}\right]$

$$\frac{\partial I_{DS}}{\partial V_{SB}} = \text{is finite} = g_{mb}$$

Evaluating $g_{mb} = \frac{\gamma}{2\sqrt{2\phi_F + V_{SB}}} \cdot g_m = g_m \eta$

Typically $\eta = 0.6$

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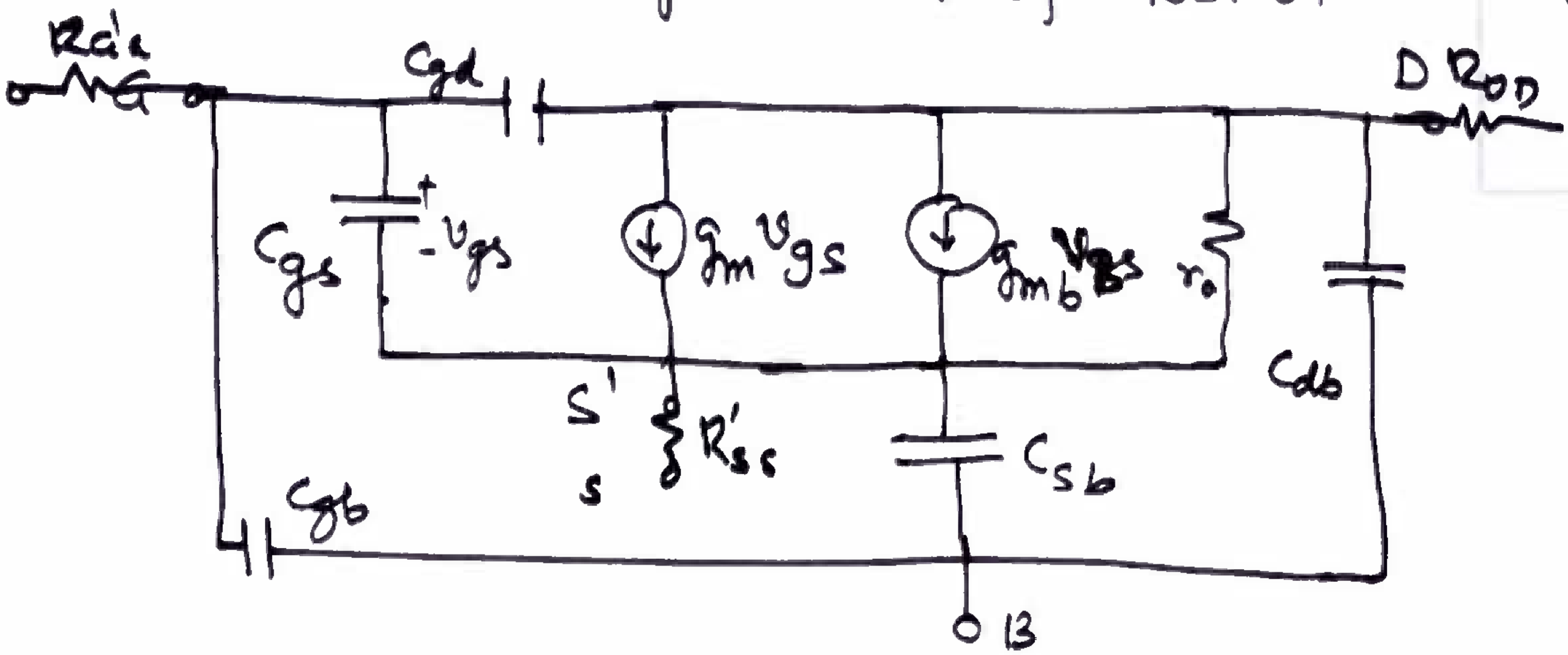
Small Signal Model of MOSFET



Typical Common Source Amplifier

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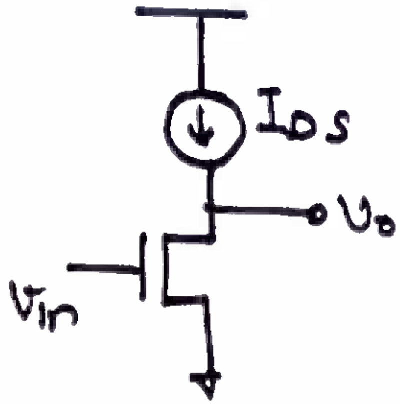
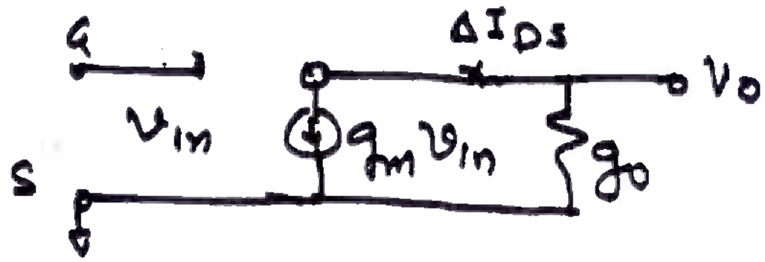


Current Source Biasing

from Two port eq. ckt

$$\Delta I_{DS} = g_m v_{in} + g_o v_o$$



$$\therefore \quad g_m = \left.\frac{\Delta I_{DS}}{v_{in}}\right|_{v_o = 0} \quad \& \quad g_o = \left.\frac{\Delta I_{DS}}{v_o}\right|_{v_{in} = 0}$$

Since I_{DS} is Fixed $\Delta I_{DS} = 0$

$$\therefore \quad 0 = g_m v_{in} + g_o v_o \quad \text{or} \quad \frac{v_o}{v_{in}} = -\frac{g_m}{g_o} = -g_m r_o$$