Small Signal Low Frequency MOS MODEL

Small Signal means amplitude of signal is very much smaller than (amplitude) or value of DC bias.

i.e.
$$v_{GS} = V_{GS} + v_{gs}$$
$$v_{DS} = V_{DS} + v_{ds}$$
$$i_{DS} = i_{ds} + I_{DS}$$

For a MOSFET with small signal input at Gate (v_{GS}) we have

$$i_{DS} = I_{DS} + i_{ds} = \frac{\beta}{2}\left[(V_{GS} + v_{gs}) - V_{TH}\right]^2 (1 + \lambda V_{DS})$$

Assuming $\lambda \to 0$

$$i_{DS} = \frac{\beta}{2}(V_{GS} - V_T)^2 + \frac{\beta}{2}(v_{gs})^2 + 2 \cdot \frac{\beta}{2}(V_{GS} - V_T)\, v_{gs}$$

For Small Signal case $v_{gs}^2 \to$ Small $\to$ Neglected

$$\therefore \; i_{DS} = I_{DS} + i_{ds}$$

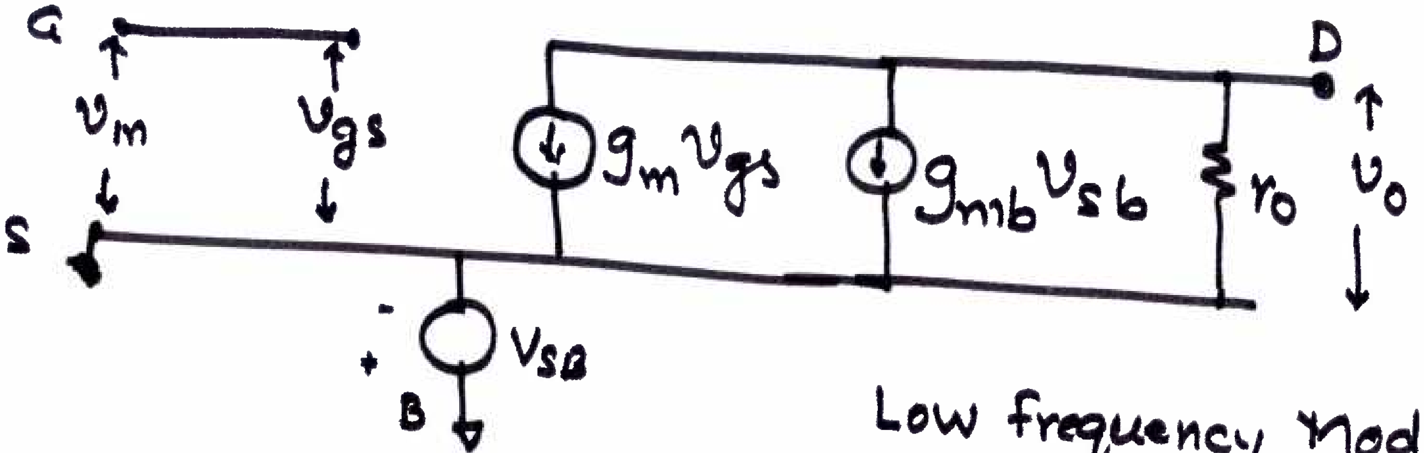
$$= \frac{\beta}{2}(V_{GS} - V_T)^2 + \beta(V_{GS} - V_T)\, v_{gs}$$

$$\therefore \; i_{ds} = \beta(V_{GS} - V_T)\, v_{gs}$$

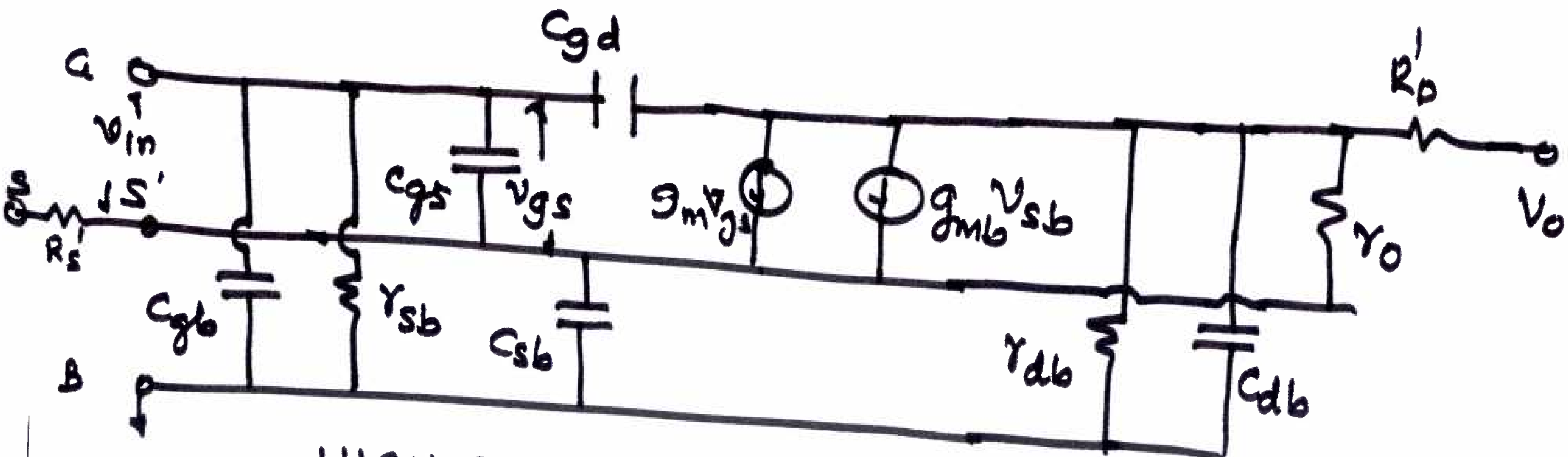
$$\frac{i_{ds}}{v_{gs}} = g_m = \beta(V_{GS} - V_T) = \frac{1}{2}\beta\frac{(V_{GS} - V_T)^2 \times 2}{(V_{GS} - V_T)}$$

$$= \sqrt{2\beta I_{DS}}$$

Small Signal MODEL

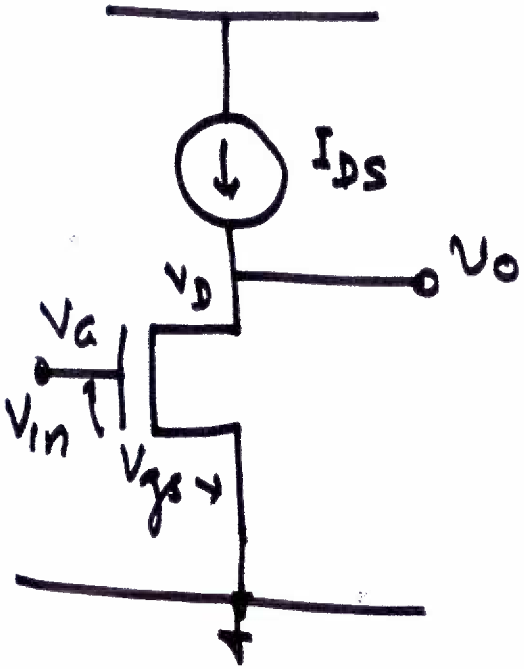


Low frequency Model



HIGH FREQUENCY SMALL SIGNAL MOS MODEL

Common Source Amplifier in an IC



Amplifier with constant current Biasing (I_{DS} const.)

We have $I_{DS} = f(V_G \,\&\, V_D)$

$$\therefore \Delta I_{DS} = \frac{\partial I_{DS}}{\partial V_G} \cdot \Delta V_G + \frac{\partial I_{DS}}{\partial V_D} \cdot \Delta V_D$$

By definition $g_m = \dfrac{\partial I_{DS}}{\partial V_G}$ & $g_o = \dfrac{\partial I_{DS}}{\partial V_D}$

$$\therefore \Delta I_{DS} = g_m \Delta V_G + g_o \Delta V_D$$

or $$dI_{DS} = g_m \, dV_G + g_o \, dV_D$$

But $v_{in} = dV_G$ and $v_o = dV_D$

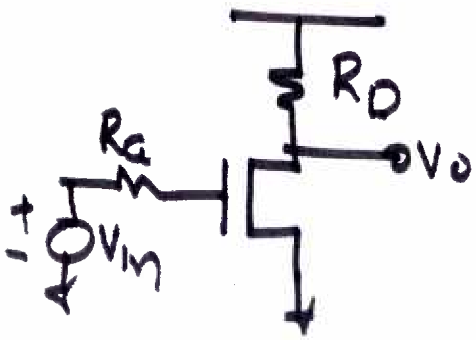
$$\therefore \quad dI_{DS} = g_m v_{in} + g_o v_o$$

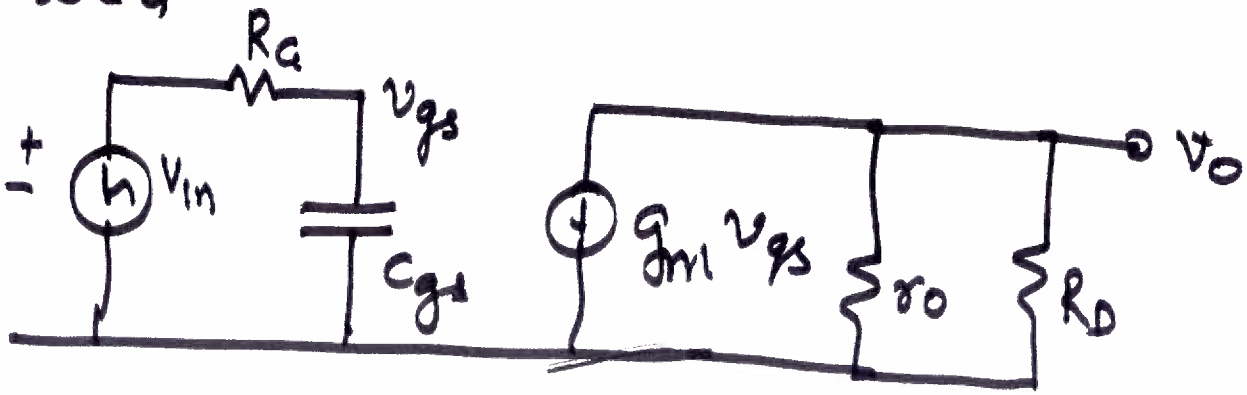
As Amplifier is biased by Constant Current Source I_{DS}, Hence $dI_{DS} = 0$

$$\therefore \quad 0 = g_m v_{in} + g_o v_o$$

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

If we take First Order Model of MOSFET with Resistive load





If $r_{od} = r_o$

Then $A_{vo} = -g_m r_o$ or $\left|\dfrac{r_o}{A_{vo}}\right| = \dfrac{1}{g_m}$

We can see that

$$\frac{g_m}{I_{DS}} = \frac{2}{V_{ov}} \quad \& \quad \frac{g_m}{C_{gs}} = \frac{3}{2}\,\mu \frac{V_{ov}}{L^2}$$

Can be termed as Figures of Merit

Hence Major decision for any Analog Designer is to choose V_{ov} appropriately, so that

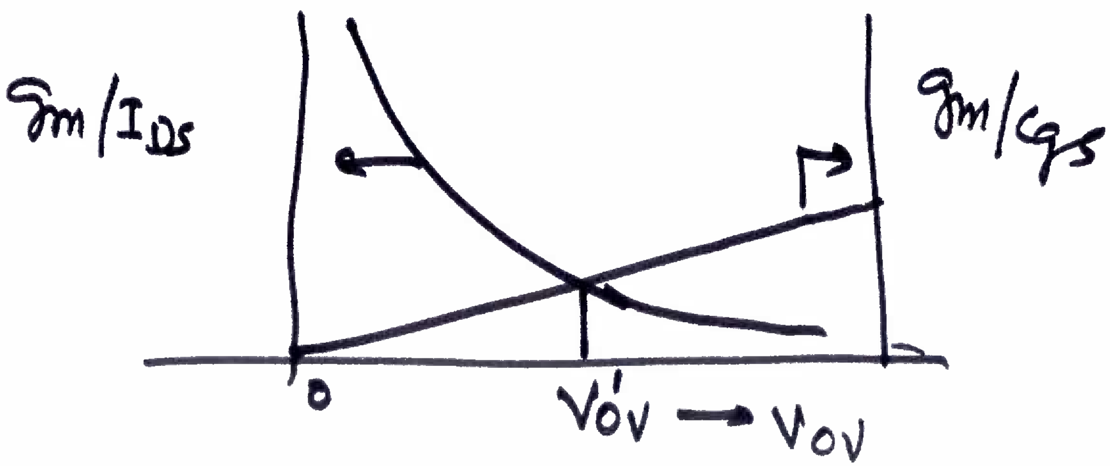
1. Power Dissipation 2 Gain & 3. Bandwidth specs are met

We have observed that Performance of MOSFET Amplifier can be defined by two 'figure of Merit', namely

$$\frac{g_m}{I_{DS}} \quad \text{and} \quad \frac{g_m}{C_{gs}}$$

where

$$\frac{g_m}{I_{DS}} = \frac{2}{V_{ov}} \quad \text{and} \quad \frac{g_m}{C_{gs}} = \frac{3}{2}\left(\frac{\mu}{L^2}\right) V_{ov}.$$



optimum value of $V_{ov} = V'_{ov}$ from Figure.

Hence Designer should make reasonable correct choice of V_{ov}.

CDEEP
IIT Bombay

Anothe Figure of Merit could be defined as Product

$$FM_3 = \frac{g_m}{I_{DS}} \cdot \frac{g_m}{C_{gs}} = \frac{2}{V_{ov}} \cdot \frac{3}{2}\left(\frac{\mu}{L^2}\right)V_{ov}$$

$$= 3\left(\frac{\mu}{L^2}\right)$$

Which is not a function of V_{ov}.

Hence to Improve FM_3, we must reduce Channel Length L.

FM3 essentially represents SPEED & POWER Efficiency together.

Think How about Av ??

Then

$$H(s) = \frac{v_o(s)}{v_{in}(s)} = -g_m(r_o \| R_D) \cdot \frac{1}{1 + s R_G C_{gs}}$$

We can use $g_m = \dfrac{2I_{DS}}{V_{ov}}$

$C_{gs} = \frac{2}{3} W \cdot L\, C_{ox}$ $\quad (\sim C_{ox})$

& $r_o = \dfrac{1}{\lambda I_{DS}}$

Then $A_v(s) = H(s) = A_{vo} \dfrac{1}{1 + s(R_g C_{gs})}$

where $A_{vo} = -g_m(r_o \| R_D) \simeq -g_m R_D$ if $R_D \ll r_o$

$= g_m r_o$ if $R_D \gg r_o$

↳ say from Current Source

From $A_v(s)$, we see we have a pole at $\omega_o = \dfrac{1}{R_G C_{gs}}$, which is therefore the <u>Bandwidth</u>.

If we write $C_{gs} = \frac{2}{3} W L C_{ox}$

Recall $C_{ox}\mu \frac{W}{L} V_{ov} = g_m$

$$\therefore \quad C_{ox} = g_m \left(\frac{L}{W}\right)(V_{ov})^{-1}\frac{1}{\mu}$$

$$C_{ox} = \frac{A_{vo}}{(r_o \| R_D)} \cdot \frac{L}{W} \cdot \frac{1}{V_{ov}} \cdot \frac{1}{\mu}$$, We define $r_{od} = r_o \| R_D$

$$\therefore \quad C_{gs} = \frac{2}{3} W L \cdot \frac{A_{vo}}{r_{od}} \left(\frac{L}{W}\right) \frac{1}{V_{ov}} \cdot \frac{1}{\mu}$$

$$\therefore \quad \omega_o = \frac{3}{2}\frac{r_{od}}{R_G} \cdot \frac{1}{A_{vo}} \frac{\mu}{L^2} V_{ov}$$