A Simple Design Example for a CS Amplifier

Given $\mu C_{ox} = 100 \mu A/V^2$, $L = 0.8\mu$

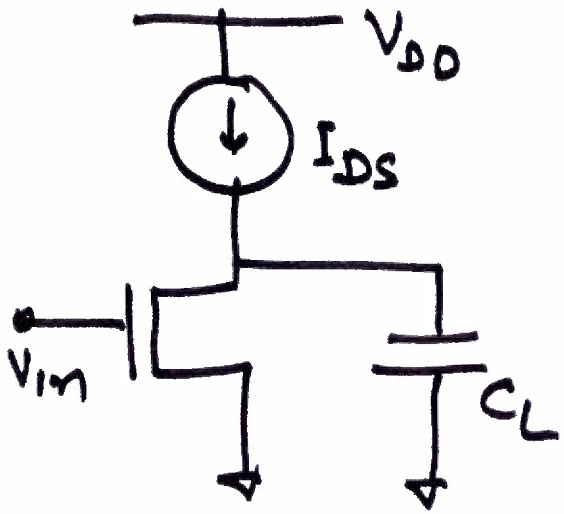
$V_A = 50V$

$\alpha = 1.25$

$C_L = 0.1\ pf$

$BW = 2\ MHz$

$Gain \geq 200$



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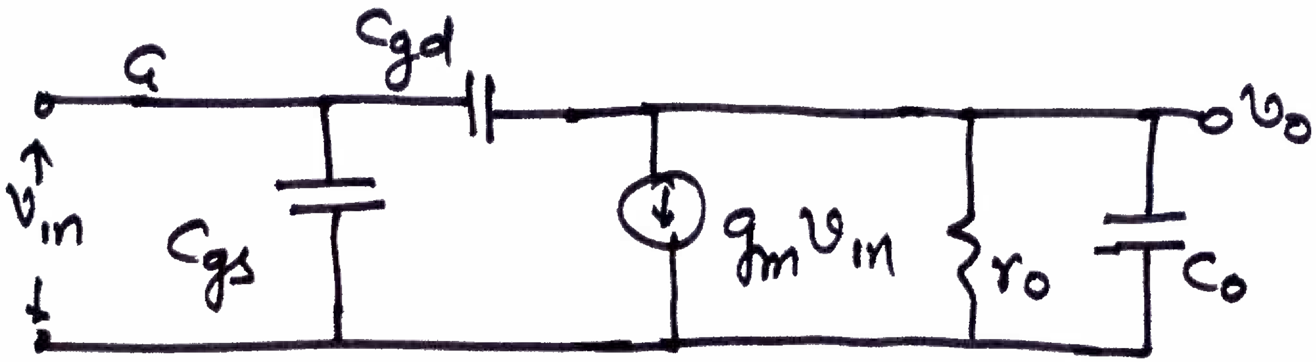
Equivalent Circuit (First Order)



Assume

$$\frac{1}{\omega C_{gs}} \rightarrow \infty$$

Using Kirchoff law

$$sC_{gd}(v_{in} - v_o) - g_m v_{in} - \frac{v_o}{r_o} - sC_o v_o = 0$$

$$v_{in}(sC_{gd} - g_m) - v_o\left(sC_{gd} + \frac{1}{r_o} + sC_o\right) = 0$$

or $$\frac{v_o}{v_{in}} = -\frac{g_m - sC_{gd}}{\frac{1}{r_o} + s(C_{gd} + C_o)}$$

or $A_v(s) = \dfrac{V_o(s)}{V_{in}(s)} = -g_m r_o \dfrac{1 - sC_{gd}/g_m}{1 + s\, r_o(C_{gd} + C_o)}$

$$A_v(s) = +A_v(0) \frac{1 - sC_{gd}/g_m}{1 + s(r_o \cdot C_L)}$$

$$C_o + C_{gd} = C_L$$

We have 1 'zero' and 1 'pole'.
Neglect 'zero' assuming it is far off compared to pole frequency
This is possible in most cases as $r_o >> \frac{1}{g_m}$

Then $A_v(s) = A_{vo} \dfrac{1}{1 + s.r_o C_L}$

$\therefore$ Bandwidth $= \dfrac{1}{r_o C_L} = \omega_{-3db}$

and D.C. Gain $= A_{vo} = -g_m r_o$

Then Gain Bandwidth Product GBW is

$$= \frac{g_m}{C_L}$$

Using these expressions we solve our Problem

$$g_m = \sqrt{2\frac{\beta}{\alpha} I_{DS}}$$

Fixed I_{DS} biasing

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$$r_o \simeq \frac{V_A}{I_{DS}}$$

(i) We start with r_o

$$r_o = \frac{1}{2\pi \cdot BW \cdot C_L} = \frac{1}{6.28 \times 2\times10^6 \times 10^{-13}}$$

$$\cong 0.8 \text{ M}\Omega$$

(ii) I_{DS} evaluation

$$I_{DS} = \frac{V_A}{r_o} = \frac{50}{0.8\times10^6} \simeq 62.5\ \mu A = 62.5\ \mu A$$

Now $|A_{vo}| = g_m r_o$

$$\therefore \; g_m = \frac{240}{0.8 \times 10^{6}} = 300 \times 10^{-6} \text{ S}$$

But $g_m = \sqrt{2 \frac{\mu C_{ox}}{\alpha} \left(\frac{W}{L}\right) I_{DS}}$

$$\therefore \; \frac{W}{L} = \frac{g_m^2 \alpha}{2 \mu C_{ox} I_{DS}} = \frac{(300 \times 10^{-6})^2 \times 1.25}{2 \times 100 \times 10^{-6} \times 62.5 \times 10^{-6}}$$

$$\simeq 9$$

Given $L = 0.8\mu$ $\quad \therefore \; \boxed{W = 0\cancel{\cdot 7}2\,\mu}$

We see

$$\frac{g_m}{I_{DS}} = \frac{300\times10^{-6}}{62.5\times10^{-6}} = \frac{600}{125} = \frac{24}{5}$$

$$= 4.8 \text{ (Per Volt)}$$

Modification

Lets put limit on I_{DS} to lower value (Lower Power Dissipation)

We have seen that $W \propto \frac{1}{V_{ov}} \sim \frac{g_m}{I_{DS}}$

$\therefore$ If I use lower I_{DS}, I need Larger Width Device.

If specs say 'Reduced Area' is necessary

This can be actually done by optimisation.

However Long Channel Model may not suffice

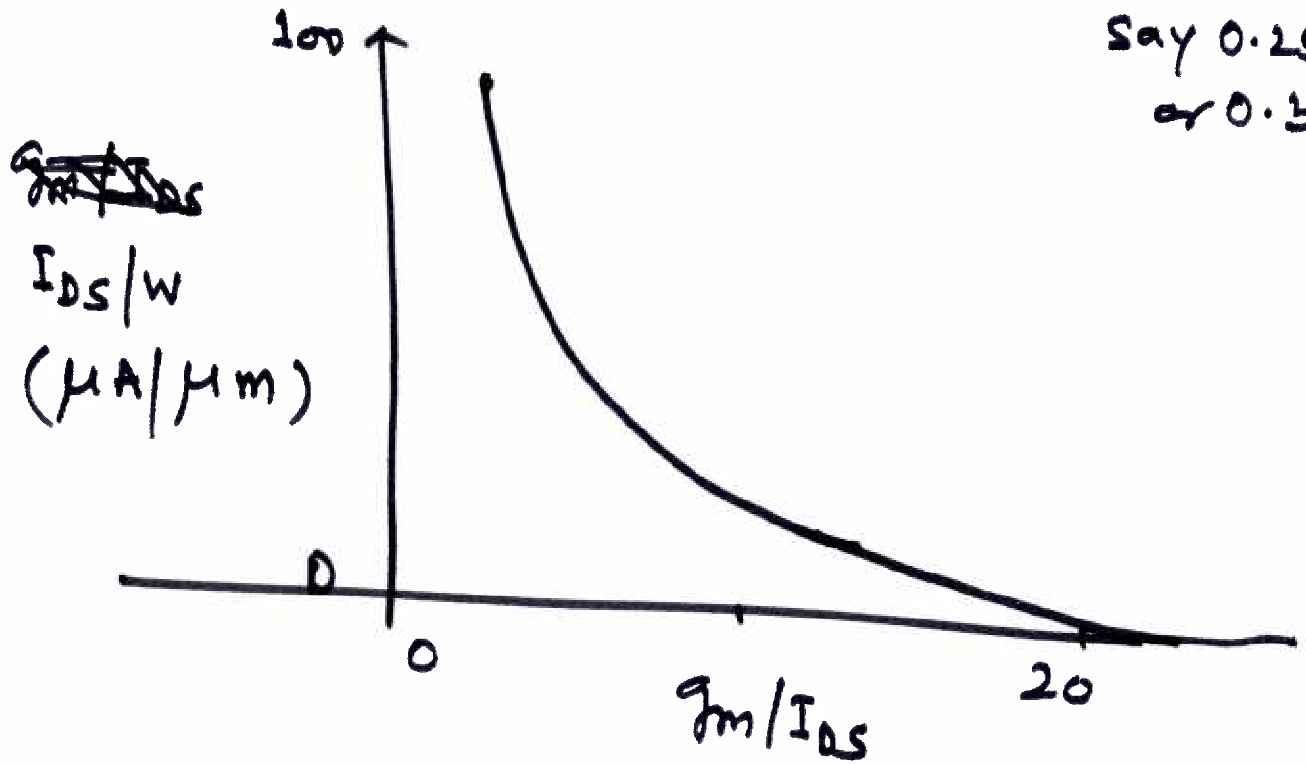
If Design requires smaller area for the circuit, ~~then~~ as well as Low Power, we have trade-off at hand.

For lower Power, we reduce I_{DS}

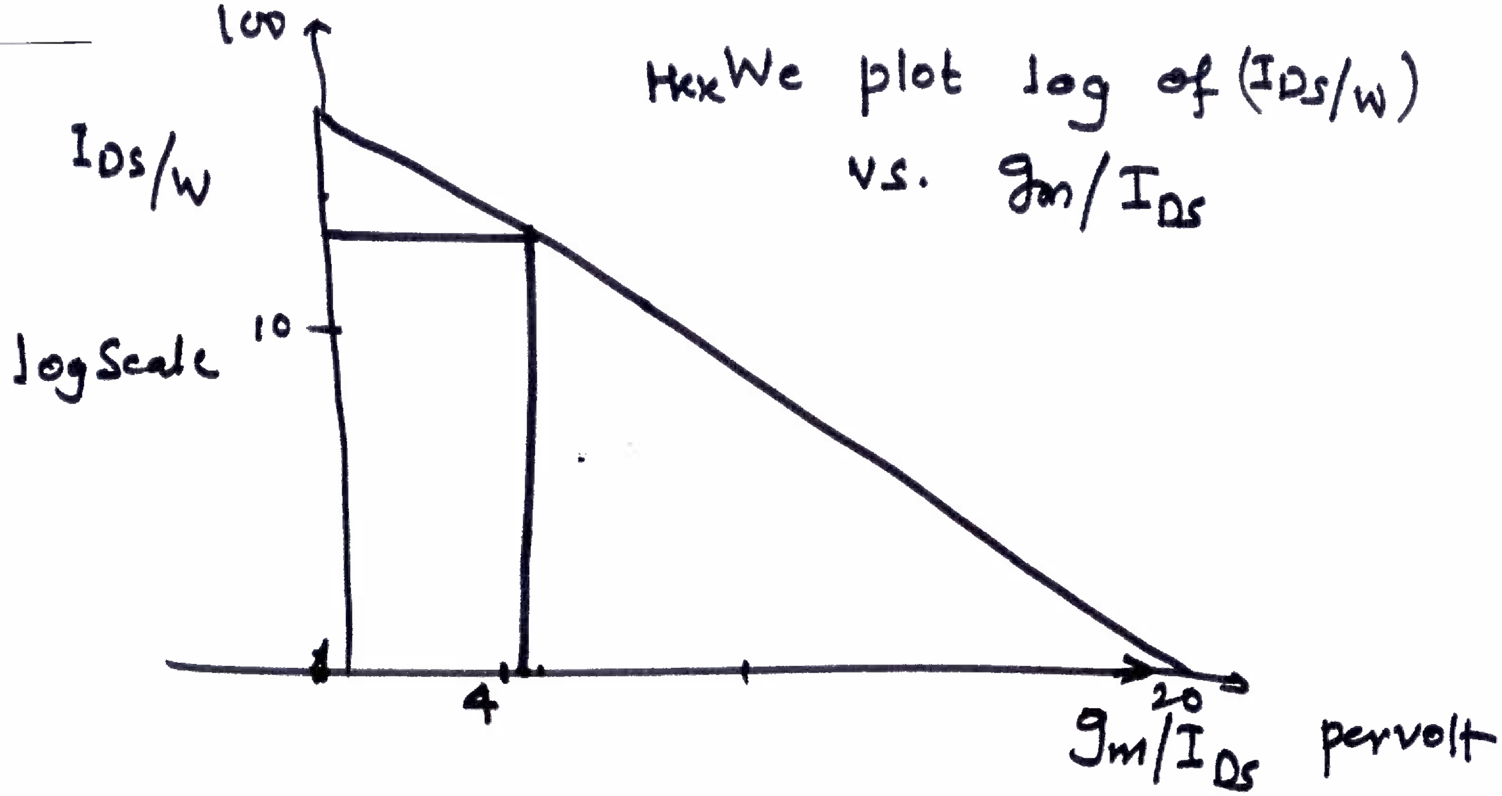
Hence for a fixed g_m (Gain constant), $\frac{g_m}{I_{DS}}$ increases. Since $\frac{1}{V_{OV}} \propto \frac{g_m}{I_{DS}}$, reduction in V_{OV} will occure at Lower I_{DS}.

But $W \propto \frac{1}{V_{OV}}$, which means W will increase at reduced I_{DS}. Which in turns means Increase of area

We use $\frac{g_m}{I_{DS}}$ as Design Variable, then we plot I_{DS}/W as g_m/I_{DS} (For a Tech node say 0.25μ or 0.35μ)



We plot log of (I_{DS}/W) vs. g_m/I_{DS}



For our problem $g_m/I_{DS} = 4.8 \ V^{-1}$

Let us say from Graph we have $\frac{I_{DS}}{W} \approx 40 \ \mu A/\mu m$ for $g_m/I_{DS} = 4.8 /V$

But we have $I_{DS} = 62.5 \ \mu A$ $\therefore W = \frac{I_{DS}}{I_{DS}/W} = \frac{62.5}{40}$

or $W = \frac{12.5}{8} = 1.56 \ \mu m$.