8/10/18 High frequency analysis of MOSFET

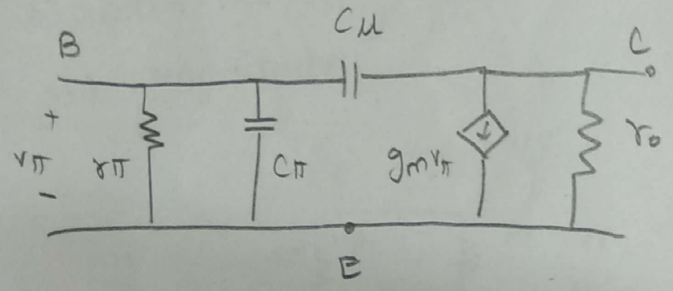
→ High frequency equivalent circuit

→ Short circuit current gain

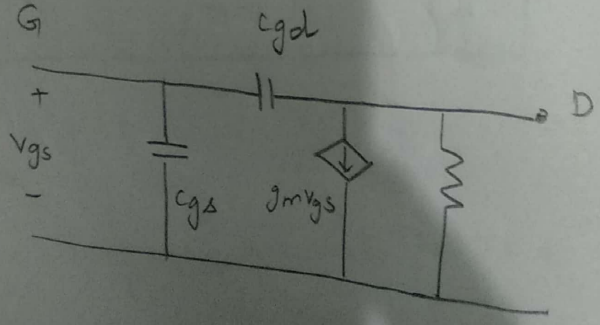
→ Unity gain BW (or) unity gain cutoff freq (f_T)

→ Miller capacitance (C_M)

BJT high freq ckt :

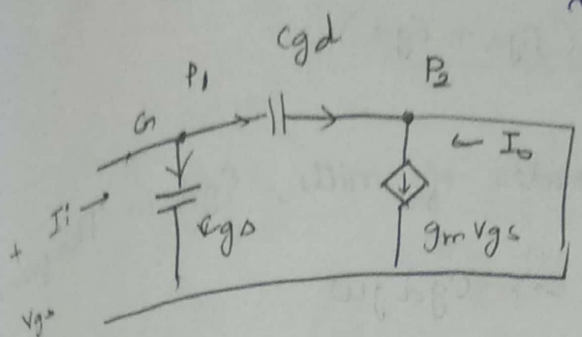


MOSFET high freq ckt



Short circuit current gain Ais:

$\lambda = 0$, $r_o = \infty$ (Short circuit output)



$$Ais = \frac{I_o}{I_i}$$

Write KCL at node P_1,

$$I_i = \frac{V_{gs}}{\frac{1}{j\omega C_{gs}}} + \frac{V_{gs}}{\frac{1}{j\omega C_{gd}}}$$

$$I_i = j\omega C_{gs} V_{gs} + j\omega C_{gd} V_{gs}$$

$$I_i = j\omega V_{gs} (C_{gs} + C_{gd}) \rightarrow (1)$$

Write KCL at node P_2,

$$I_o + \frac{V_{gs}}{\frac{1}{j\omega C_{gd}}} = g_m V_{gs}$$

$$I_o = g_m V_{gs} - V_{gs} j\omega C_{gd}$$

$$I_o = V_{gs} (g_m - j\omega C_{gd}) \rightarrow (2)$$

$$\frac{I_o}{I_i} = \frac{V_{gs} (g_m - j\omega C_{gd})}{V_{gs} j\omega (C_{gs} + C_{gd})}$$

$$A_{is} = \frac{g_m - j\omega C_{gd}}{j\omega (C_{gs} + C_{gd})} \quad \rightarrow (3)$$

g_m is in order of milli. C_{gd} in Pico farad

$\therefore g_m >> C_{gd} j\omega$

$$A_{is} \simeq \frac{g_m}{j\omega (C_{gs} + C_{gd})} \quad \rightarrow (4)$$

$$|A_{is}| = \frac{g_m}{\sqrt{\omega^2 (C_{gs} + C_{gd})^2}}$$

$$|A_{is}| = \frac{g_m}{\omega (C_{gs} + C_{gd})} \quad \rightarrow (5)a$$

$$|A_{is}| = \frac{g_m}{2\pi f (C_{gs} + C_{gd})} \quad \rightarrow (5)b$$

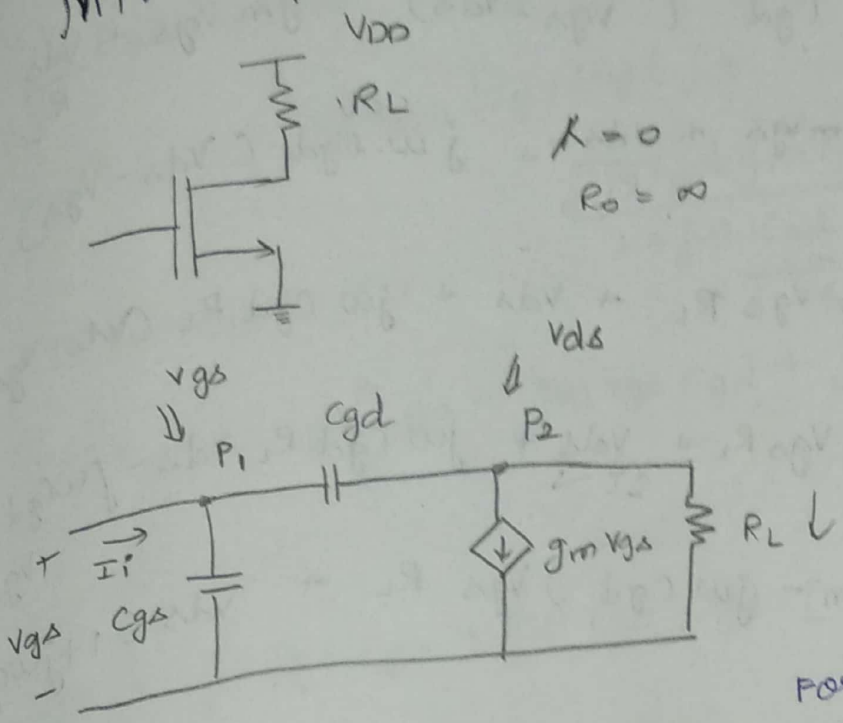
Unity gain BW (f_T):

At $f = f_T$, $|A_{is}| = 1$

$$1 = \frac{g_m}{2\pi f_T (C_{gs} + C_{gd})}$$

$$f_T = \frac{g_m}{2\pi (C_{gs} + C_{gd})} \quad \rightarrow (6)$$

Miller capacitance (CM)



For b/w $P_1 < P_2$

$\frac{V_{gs} - V_{ds}}{\frac{1}{j\omega C_{gd}}}$

Node P_1, at KCL.

$$I_i = \frac{V_{gs} - V_{ds}}{\frac{1}{j\omega C_{gd}}} + \frac{V_{gs}}{\frac{1}{j\omega C_{gs}}}$$

$$= (V_{gs} - V_{ds} + V_{gs})\, j\omega C_{gd} + V_{gs}\, j\omega C_{gs}$$

$$= V_{gs}\, j\omega C_{gd} - V_{ds}\, j\omega C_{gd} + V_{gs}\, j\omega C_{gs}$$

$$I_i = j\omega V_{gs}(C_{gd} + C_{gs}) - j\omega C_{gd} V_{ds} \quad \hookrightarrow (7)$$

Node P_2, KCL

$$\frac{V_{gs} - V_{ds}}{\frac{1}{j\omega C_{gd}}} = g_m V_{gs} + \frac{V_{ds}}{R_L}$$

$$j\omega C_{gd}(V_{gs} - V_{ds}) = g_m V_{gs} + \frac{V_{ds}}{R_L}$$

$$g_m V_{gs} + \frac{V_{ds}}{R_L} + j\omega C_{gd}(V_{ds} - V_{gs})$$

$$g_m V_{gs} R_L + V_{ds} + j\omega C_{gd} R_L (V_{ds} - V_{gs})$$

$$g_m V_{gs} R_L + V_{ds} + j\omega C_{gd} R_L V_{ds} - j\omega C_{gd} R_L V_{gs}$$

$$(g_m - j\omega C_{gd}) V_{gs} R_L + V_{ds}(1 + j\omega C_{gd} R_L)$$

$$V_{ds} = \frac{(j\omega C_{gd} - g_m) R_L V_{gs}}{1 + j\omega C_{gd} R_L} \rightarrow (8)$$

Sub (8) in (7)

$$I_i = j\omega V_{gs}(C_{gs} + C_{gd}) - j\omega C_{gd}\left[\frac{(j\omega C_{gd} - g_m)R_L V_{gs}}{1 + j\omega C_{gd} R_L}\right]$$

$$= j\omega V_{gs}[C_{gs} + C_{gd}] + \left[\frac{\omega^2 C_{gd}^2 R_L V_{gs}}{1 + j\omega C_{gd} R_L}\right] + j\omega \frac{C_{gd} g_m R_L V_{gs}}{1 + j\omega C_{gd} R_L}$$

C_{gd} small ⇒ neglect

$$I_i = j\omega V_{gs}[C_{gs} + C_{gd}] + \frac{j\omega C_{gd} g_m R_L V_{gs}}{1 + j\omega C_{gd} R_L}$$

$1 \gg \omega C_{gd} R_L j\omega$ (order of 10^{12})

$$I_i = j\omega V_{gs} C_{gs} + j\omega V_{gs} C_{gd} + \frac{j\omega C_{gd} g_m R_L V_{gs}}{1}$$

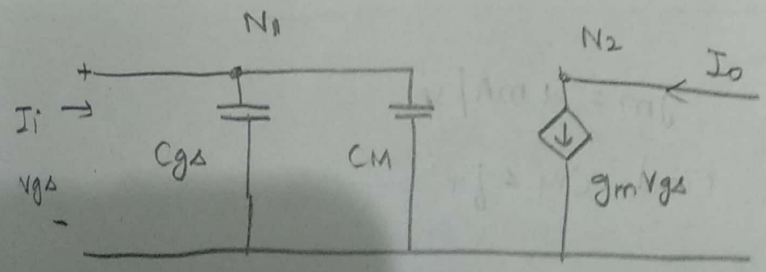
$$I_i = j\omega V_{gs} C_{gs} + j\omega V_{gs} C_{gd} [1 + g_m R_L]$$

$$I_i = j\omega V_{gs} [C_{gs} + C_M]$$

where $$\boxed{C_M = C_{gd}[1 + g_m R_L]} \rightarrow (9)$$

$(1 + A_V)$

Ais & f_T with C_M:



KCL at node N_1,

$$I_i = \frac{V_{gs}}{\frac{1}{j\omega (C_{gs} + C_M)}} \Rightarrow$$

$$I_i = j\omega V_{gs} (C_{gs} + C_M) \rightarrow (10)$$

KCL at N_2,

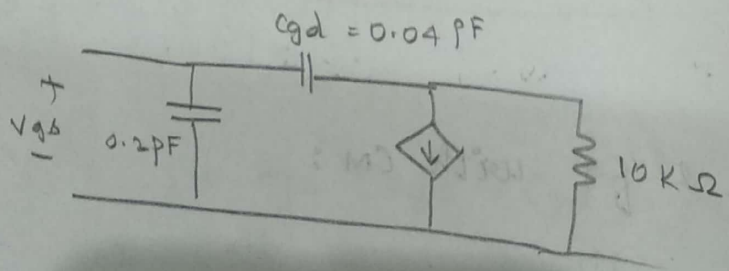
$$I_o = g_m V_{gs} \rightarrow (11)$$

$$\frac{I_o}{I_i} = \frac{g_m V_{gs}}{j\omega V_{gs}(C_{gs}+C_M)} \Rightarrow A_{is} =$$

$$|A_{is}| = \frac{g_m}{\omega(C_{gs}+C_M)} \rightarrow (12)$$

$$f_T = \frac{g_m}{2\pi[C_{gs}+C_M]} \rightarrow (13)$$

(1)



$g_m = 1\,mA/V$

Find $C_M < f_T$

$$C_M = C_{gd}[1 + g_m R_L]$$

$$= 0.04 \times 10^{-12}[1 + 10^{-3} \times 10 \times$$

$$= 0.04 \times 10^{-12}[1+10]$$

$$= 0.04 \times 11 \times 10^{-12} = 0.44\,pF$$

$$f_T = \frac{g_m}{2\pi [C_{gs} + C_M]}$$

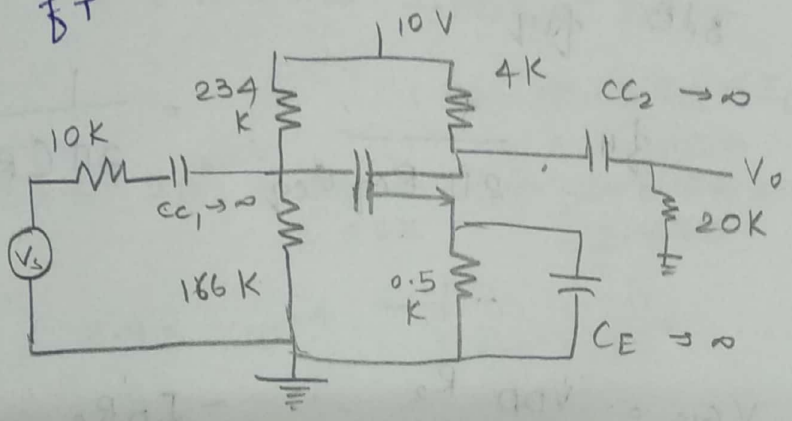
$$= \frac{1 \times 10^{-3}}{2 \times 3.14 [0.2 + 0.44] \times 10^{-12}}$$

$$= \frac{1 \times 10^{-3}}{4.019 \times 10^{-12}}$$

$$f_T = 0.248 \times 10^{9}$$

f_T = 248 MHz.

(2)

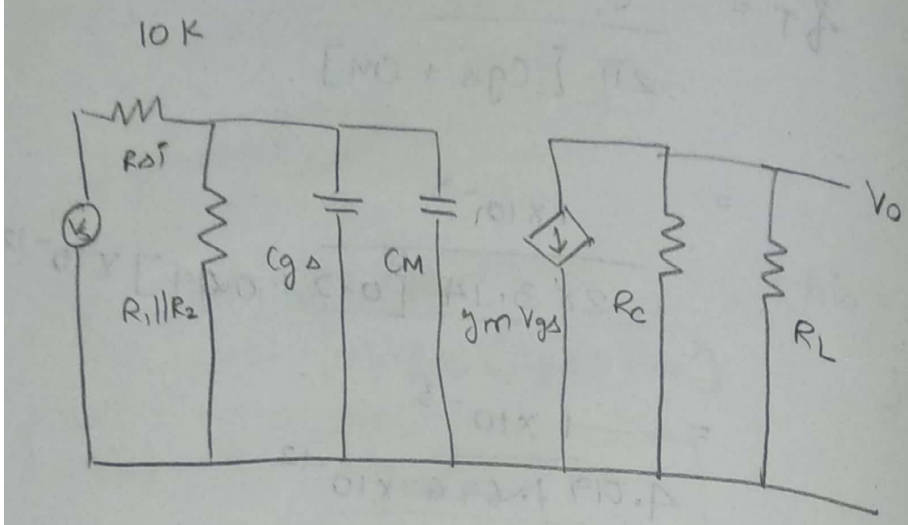


$V_{TN} = 2V$ $K_n = 0.5\ mA/V^2$ $\lambda = 0$

$C_{gs} = 1\ pF$ $C_{gd} = 0.1\ pF$

⇒ Find C_M ⇒ 3 dB frequency

⇒ f_T



$$C_M = C_{gd}\,[1 + g_m (R_c \| R_L)]$$

3dB freq

$$f_H = \frac{1}{2\pi R_{eq} C_{eq}} = \frac{1}{2\pi (R_{Si} \| R_1 \| R_2)\,(C_{gs} + C_M)}$$

$$V_{GS} = \frac{V_{DD} R_2}{R_1 + R_2} - I_D R_S$$

$$V_{GS} = \frac{10 \times 166 \times 10^3}{(234 + 166) \times 10^3} - I_D R_S$$

$$V_{GS} I_D = \frac{1660}{400} - I_D\,(0.5K)$$

$$= 4.15 - 0.5K\, I_D$$

$I_D = k_n (V_{GS} - V_{TN})^2$

$= 0.5 \times 10^{-3} (4.15 - 109k\, I_D - 2\Omega)^2$

$= 0.5 \times 10^{-3} [2.15 - 0.5 k I_D]^2$

$I_D = 0.5 \times 10^{-3} \times [4.6225 + 0.25 \times 10^6 I_D^2 - 2.15 k\, I_D]$

$I_D = 2.31125 \times 10^{-3} + 0.125 \times 10^4 I_D^2 - 1.075 I_D$

$0 = 2.31125 \times 10^{-3} + 0.125 \times 10^4 I_D^2 - 1.075 I_D - I_D$

$0.125 \times 10^4 I_D^2 - 2.075 I_D + 2.31125 \times 10^{-3} = 0$

$I_D = 2.93 \times 10^{-4}$, 1.56×10^{-4}

$I_D = 0.29$ mA , 0.156 mA

$V_{ds} = I_D R_S$

$= 0.29 \times 10^{-3} \times 10 \times 10^3$ $\quad 0.15 \times 10$

$= 2.9$ $\quad = 1.5$

$I_D = 1.2\ mA$

$g_m = 2\sqrt{K_n I_D}$

$= 2\sqrt{0.5 \times 10^{-3} \times 1.2 \times 10^{-3}}$

$= 2\sqrt{0.6 \times 10^{-6}}$

$= 2 \times 0.774 \times 10^{-3}$

$g_m = 1.549 \times 10^{-3}$

$C_M = 0.6\ pF \qquad f_T = 152\ MHz$

$3dB \qquad f_H = 10.9\ GHz$

15/10/18 **Active Loads Unit-5**

- Enhancement load
- Depletion load
- Current source load
- Resistive load

NMOS Amplifier with enhance ment lo