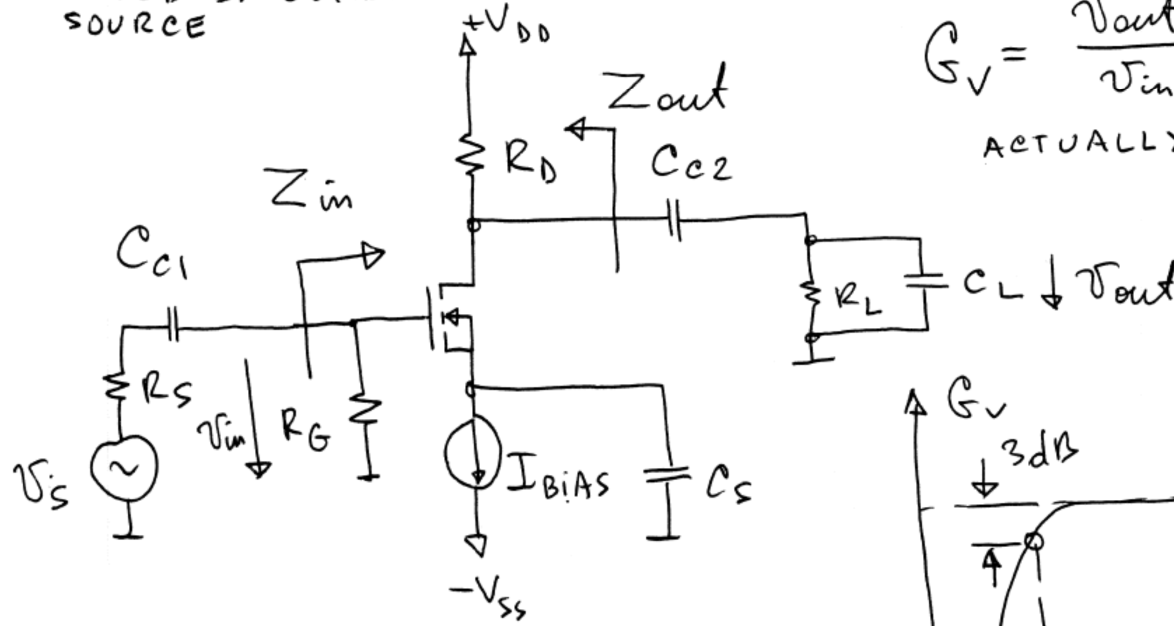
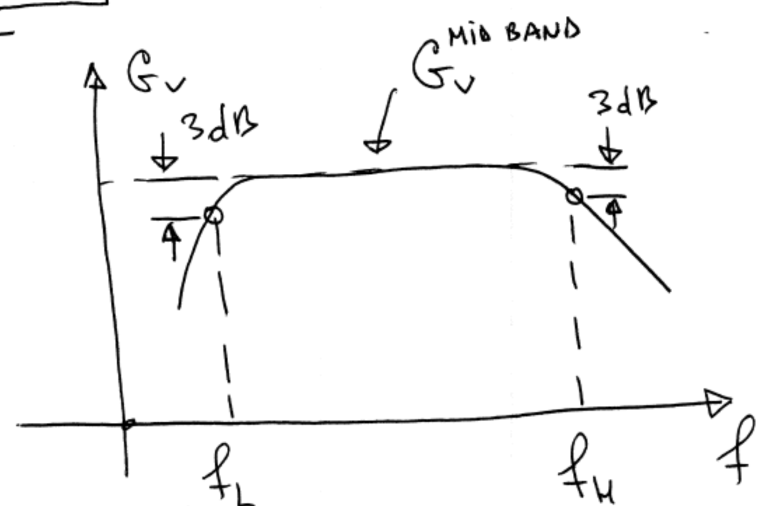
Frequency response of CS amplifier

CONSIDER CS AMP BIASED BY CURRENT SOURCE

$$G_V = \frac{v_{out}}{v_{in}} = ?$$

ACTUALLY $\rightarrow G_V(f)$



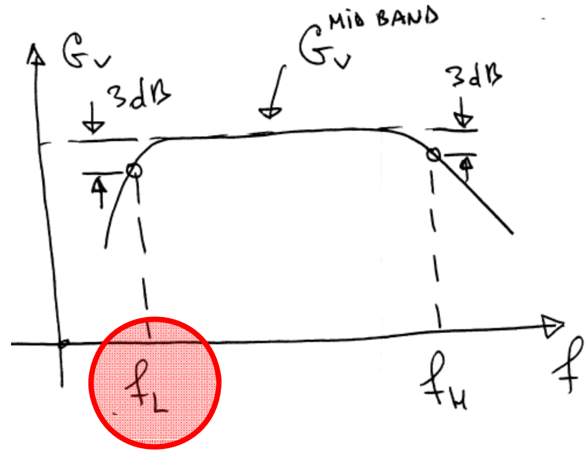


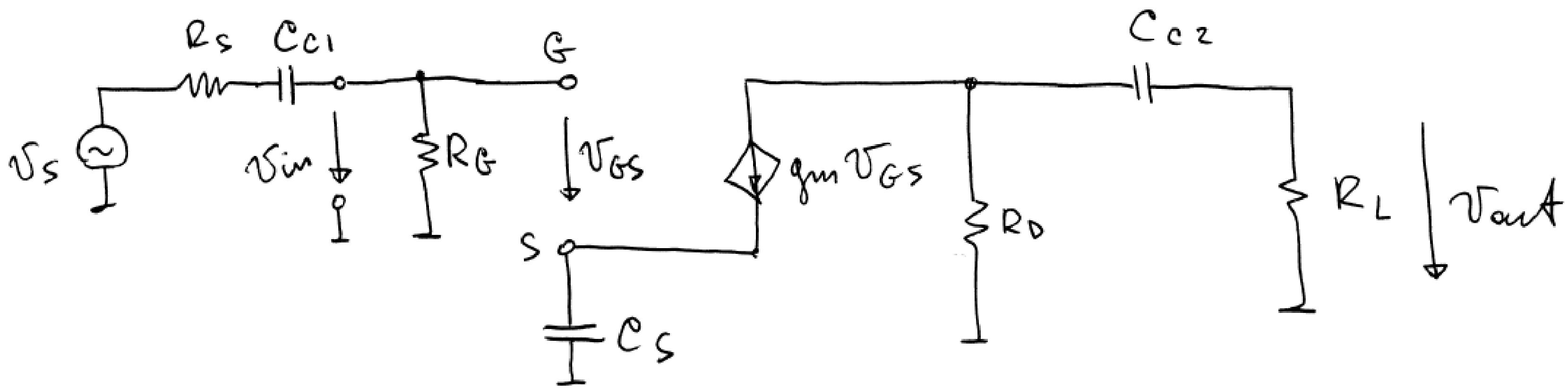
$$G_V^{MID.BAND} = \frac{R_{in}}{R_{in}+R_S} A_{VO} \frac{R_L}{R_L+R_{OUT}}$$

$R_{in} = R_G$; $R_{OUT} = (R_D \| r_o)$; $A_{VO} = -g_m(R_D \| r_o)$

Low frequency cutoff

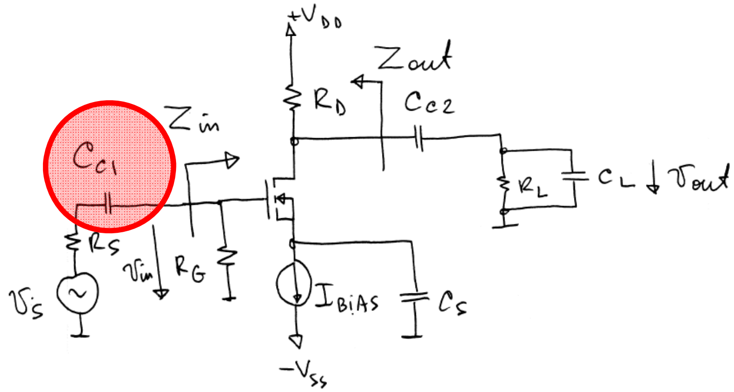
HPF action of coupling and bypass capacitors

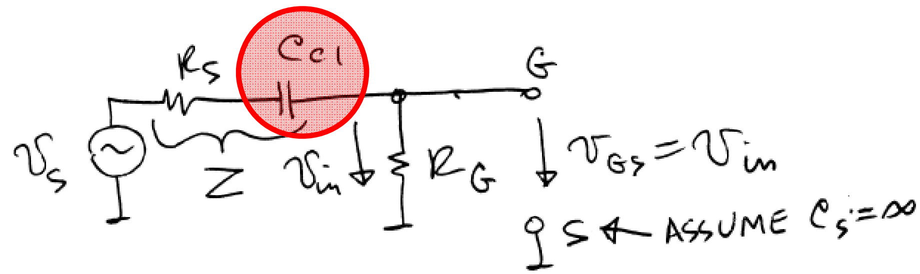




$$G_V(f) = \frac{v_{out}(f)}{v_s(f)} = \underbrace{\frac{v_{out}(f)}{v_{GS}(f)}}_{C_{C2}} \cdot \underbrace{\frac{v_{GS}(f)}{v_{in}(f)}}_{C_S} \cdot \underbrace{\frac{v_{in}(f)}{v_s(f)}}_{C_{C1}}$$

Effect of C_{C1}

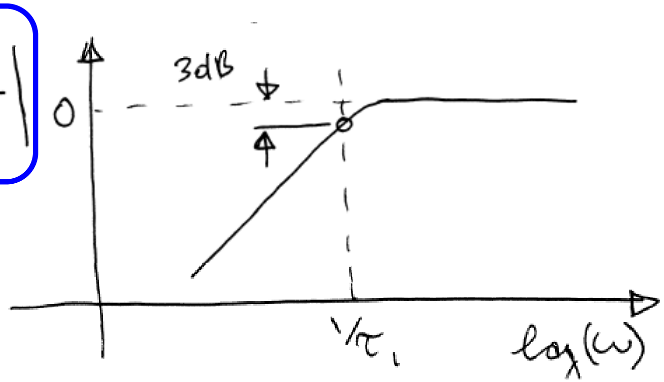




$$\frac{v_{in}}{v_s} = \frac{R_G}{R_G + Z} = \frac{R_G}{R_G + R_S + \frac{1}{j\omega C_{C1}}} = \frac{j\omega C_{C1} R_G}{1 + j\omega C_{C1}(R_G + R_S)} =$$

$$= \frac{R_G}{R_G + R_S} \cdot \frac{j\omega\left[(R_G+R_S)C_{C1}\right]}{1 + j\omega\left[(R_G+R_S)C_{C1}\right]} = \frac{R_G}{R_G+R_S} \cdot \boxed{\frac{j\omega\tau_1}{1+j\omega\tau_1}}$$

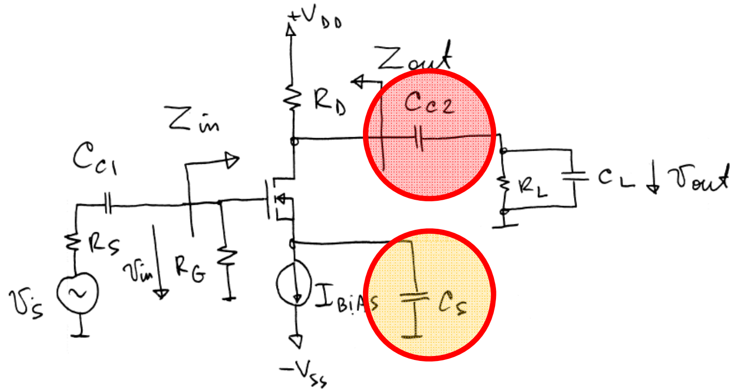
$$\boxed{20\log\left|\frac{j\omega\tau_1}{1+j\omega\tau_1}\right|}$$



$$\tau_1 = C_{C1}(R_G + R_S)$$

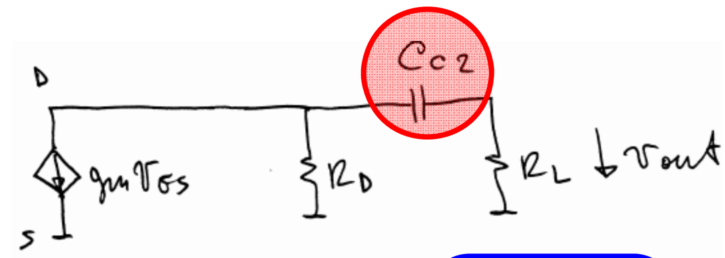
$$f_L \simeq \frac{1}{2\pi\tau_1}$$

Effect of C_S and C_{C2}



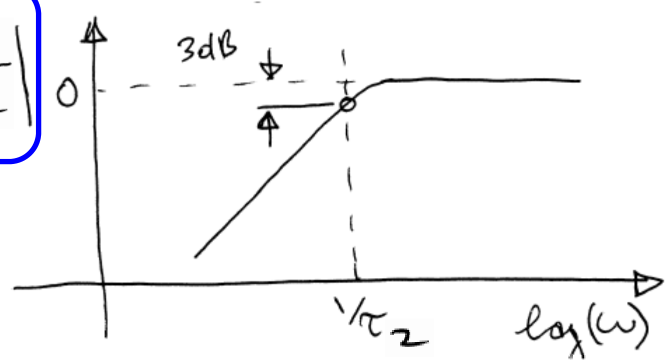
**In our labs we will use $R_G=\infty$ so no need in C_{C1}*

1. Effect of C_{C2}



$$\frac{v_{out}}{v_{GS}} = -\frac{g_m v_{GS}}{v_{GS}} \cdot \frac{R_D}{R_D+R_L+\frac{1}{j\omega C_{c2}}} \cdot R_L = -g_m (R_D \| R_L) \boxed{\underbrace{\frac{j\omega\tau_2}{1+j\omega\tau_2}}_{HPF}}$$

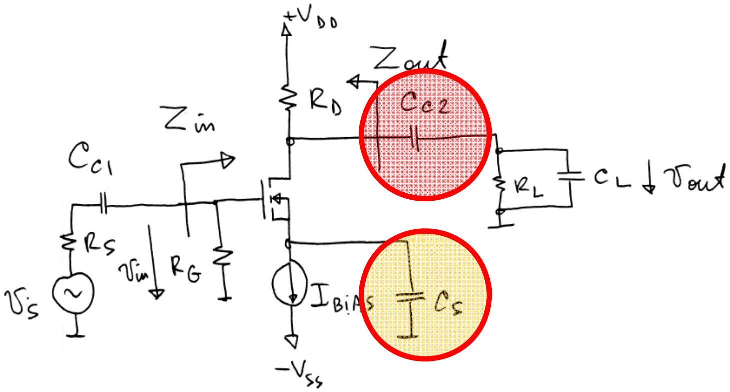
$$\boxed{20\log\left|\frac{j\omega\tau_2}{1+j\omega\tau_2}\right|}$$



$$\tau_2 = C_{c2}(R_D+R_L)$$

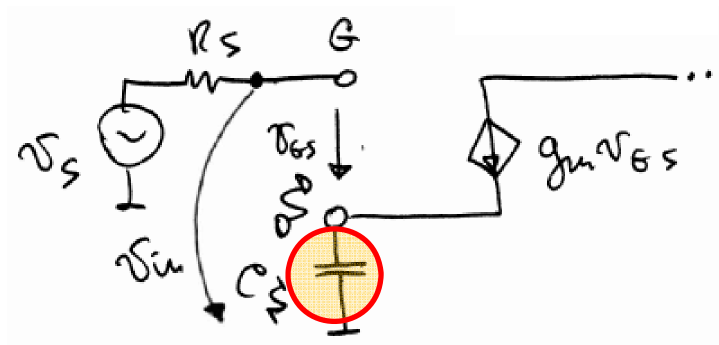
$$\left.\begin{array}{l} C_{c2} = 100nF \\ R_D + R_L = 10k\Omega \end{array}\right\} \tau_2 = 10^{-7}\cdot 10^{4} = 10^{-3}s \Rightarrow f_L = \frac{1}{2\pi 10^{-3}} \approx 160\ Hz$$

Effect of C_S and C_{C2}



In our labs we will use $R_G=\infty$ so no need in C_{C1}

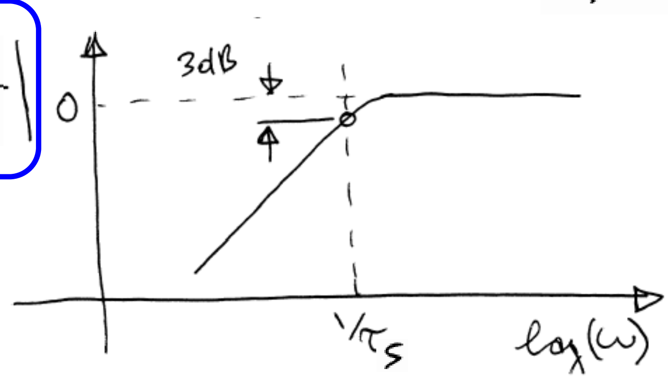
1. Effect of C_S



$$\frac{v_{GS}}{v_{in}} = \frac{v_{GS}}{v_{GS}+g_m v_{GS}\frac{1}{j\omega C_S}} = \boxed{\underbrace{\frac{j\omega\tau_S}{1+j\omega\tau_S}}_{HPF}}$$

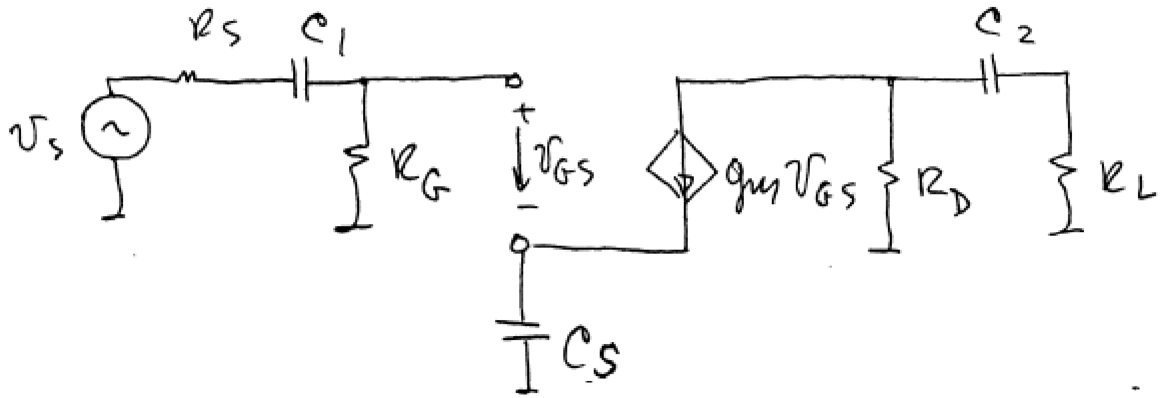
$$\tau_S = C_S/g_m$$

$$\boxed{20\log\left|\frac{j\omega\tau_S}{1+j\omega\tau_S}\right|}$$



(*) $1/g_m \simeq 1/1\frac{mA}{V} \simeq 1k\Omega$

Open circuit time constants method

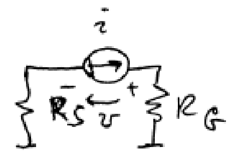


$$f_{CO} \approx \frac{1}{2\cdot\pi\cdot\tau_\Sigma}$$

$$\tau_\Sigma = \sum_{i=1}^{N}\left(C_i\cdot R_i\right)$$

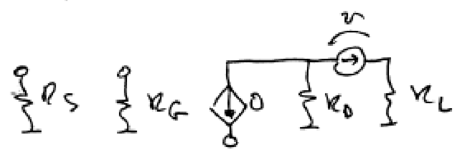
$v_S = 0$ & $C_{j\neq i} = 0$ & look for R_i

1. $\tau_1 = C_1\cdot R_1 \Rightarrow \underline{R_1 = R_S + R_G}$

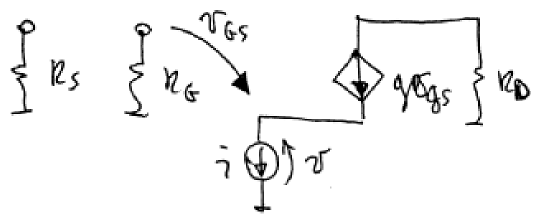


$v = R_G\cdot i - (-i\cdot R_S)$

2. $\tau_2 = C_2\cdot R_2 \Rightarrow \underline{R_2 = R_D + R_L}$



3. $\tau_S = C_S\cdot R_S \Rightarrow$

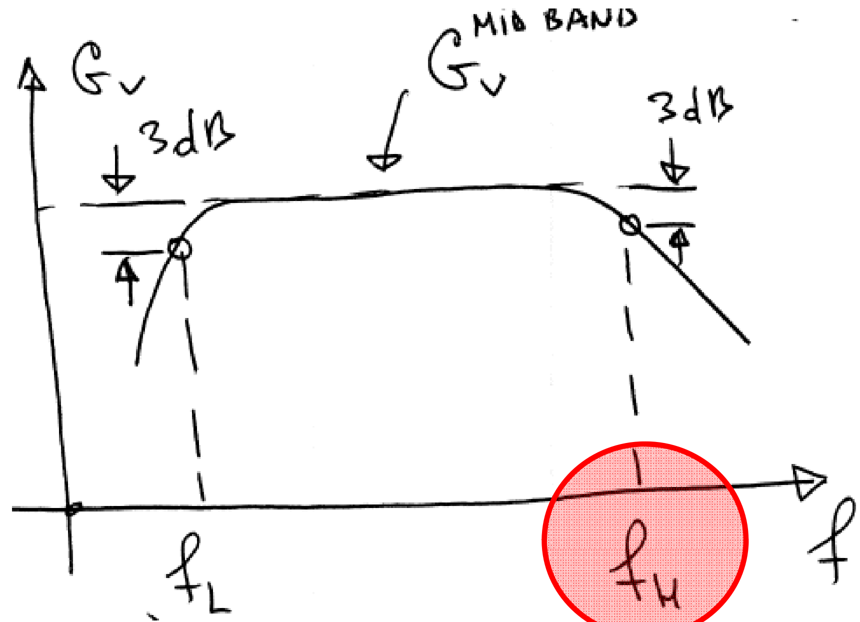


$i = g_m v_{gs}$

$v = v_{gs}$

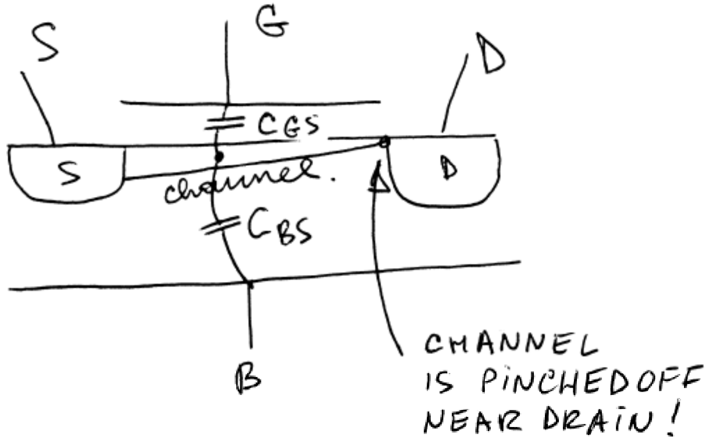
Hence $\underline{R_S = \frac{v}{i} = 1/g_m}$

High frequency cutoff



High frequency cutoff

Intrinsic part in saturation

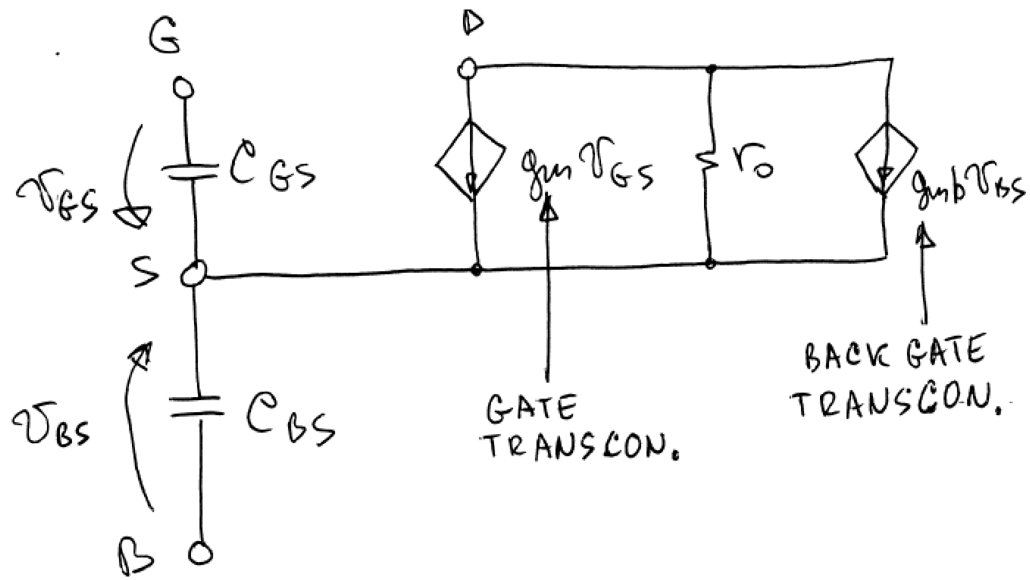


$$C_{GS} = \frac{2}{3} C'_{ox} \cdot W \cdot L \quad ; \; C'_{ox} = \frac{\varepsilon \varepsilon_{ox}}{t_{ox}}$$

$$C_{BS} = \frac{2}{3} C_B$$

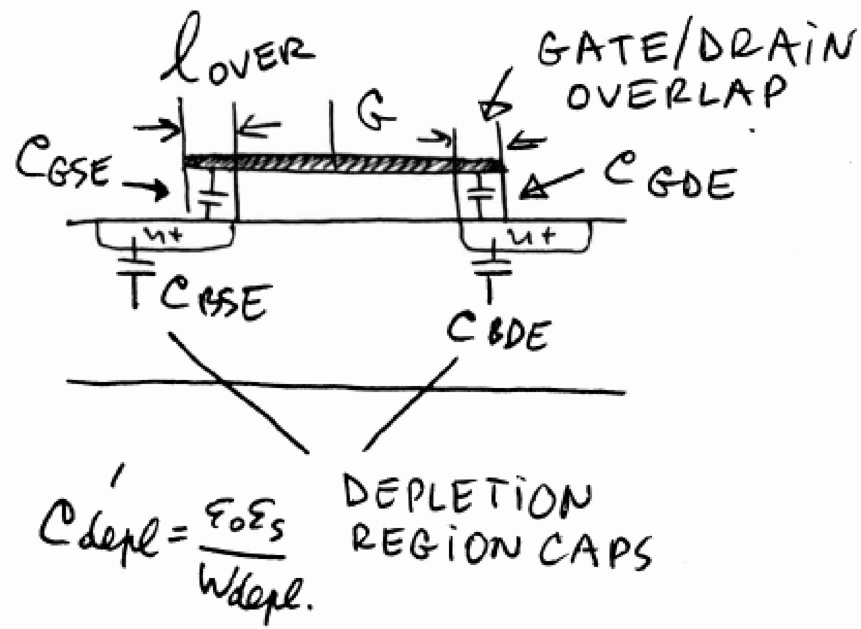
BODY EFFECT!

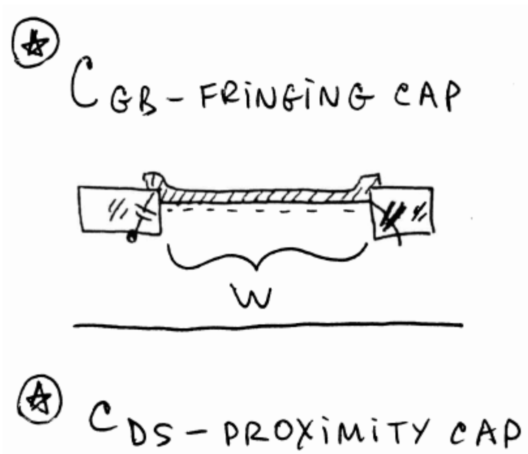
$\underbrace{C_{GS} \,\&\, C_{BS}}_{\text{PRINCIPAL CAPS OF FET}}$



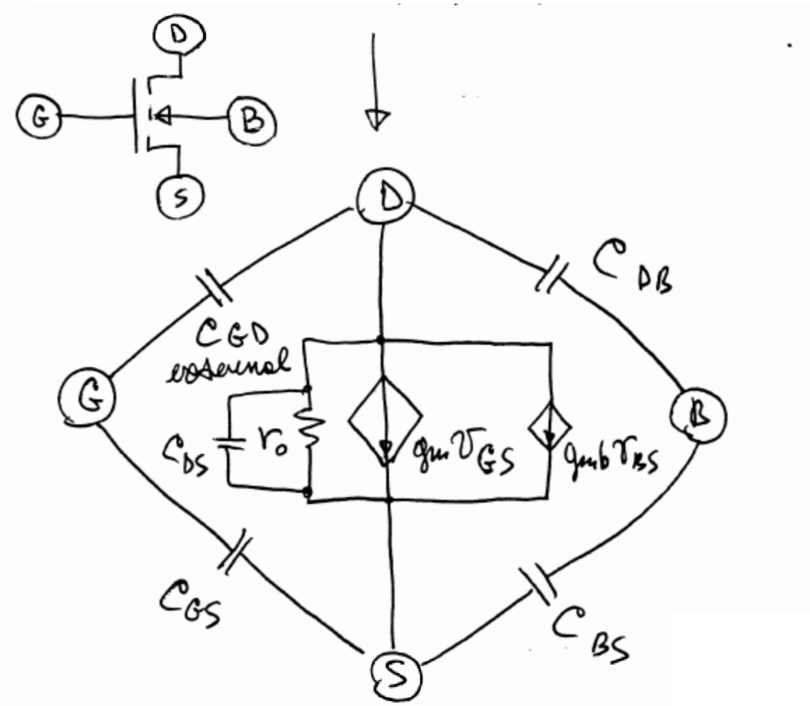
High frequency cutoff

Extrinsic part

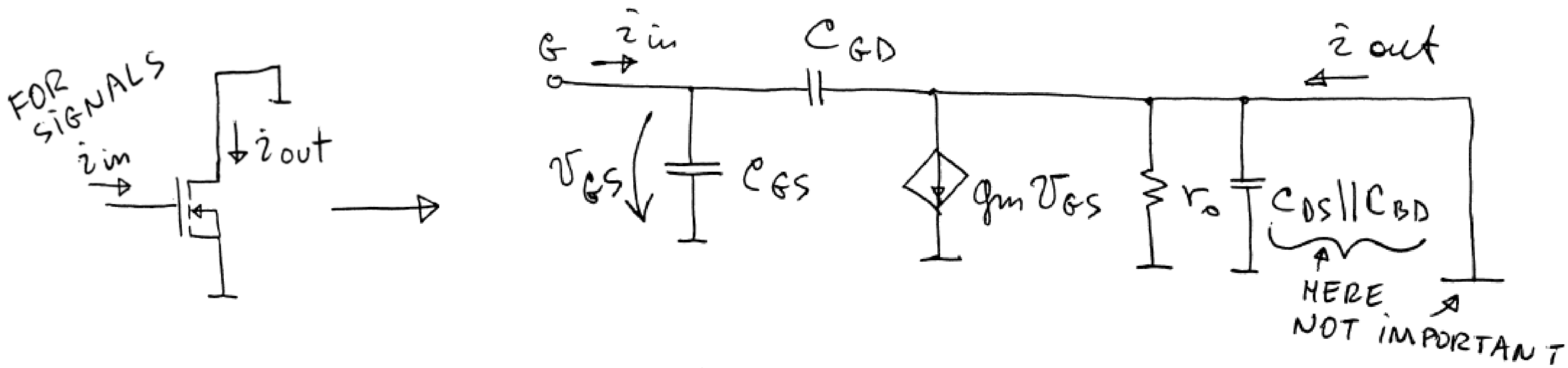




External (parasitic) and internal (principal) contributions to MOSFET capacitances are in parallel so in saturation:



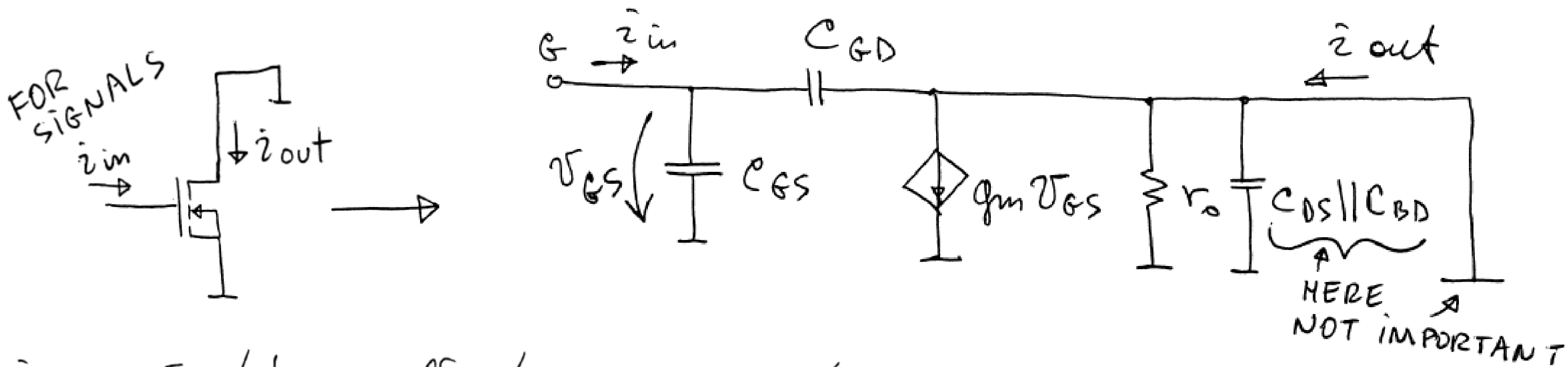
Short circuit current gain



$$C_{GS} = \underbrace{\frac{2}{3} C'_{ox} \cdot W \cdot L}_{\text{INTERNAL}} + \underbrace{C'_{ox} \cdot W \cdot l_{over}}_{\text{EXTERNAL}}$$

$$C_{GD} = C'_{ox} \cdot W \cdot l_{over}$$

Short circuit current gain



$$i_{in} = v_{GS} \Big/ \frac{1}{j\omega C_{GS}} + v_{GS} \Big/ \frac{1}{j\omega C_{GD}} = j\omega\, v_{GS}(C_{GS} + C_{GD})$$

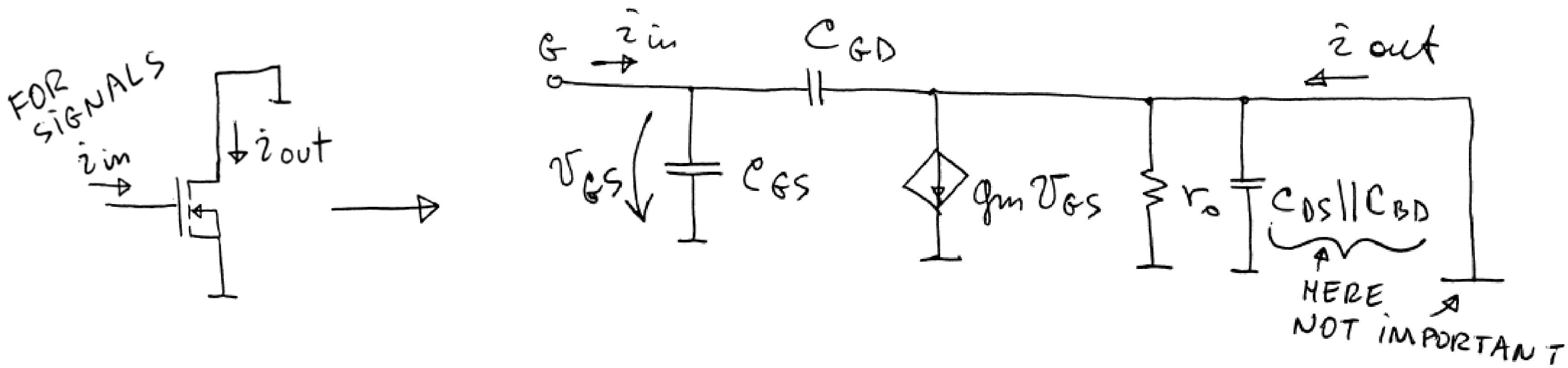
$$i_{out} = g_m v_{GS} - j\omega\, C_{GD} \cdot v_{GS}$$

Negligible

$$A_{IO} = \frac{i_{out}}{i_{in}} = \frac{g_m}{j\omega\,(C_{GS} + C_{GD})} - \boxed{\cancel{\frac{1}{1 + C_{GS}/C_{GD}}}}$$

$$\left| A_{IO}(f) \right| = \frac{g_m}{2\pi f \cdot (C_{GS} + C_{GD})}$$

Unity gain frequency



$$|A_{IO}(f)| = \frac{g_m}{2\pi f\cdot(C_{GS}+C_{GD})}$$

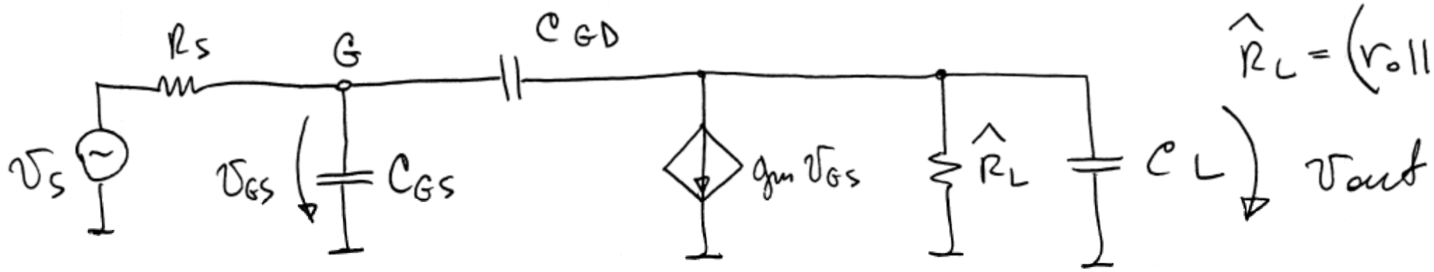
$$|A_{IO}(f_T)| = 1$$

$$f_T = \frac{g_m}{2\pi(C_{GS}+C_{GD})}$$

$$f_T = \frac{\frac{\cancel{W}}{L}\mu \cancel{C'_{ox}}(V_{GS}-V_T)}{2\pi(\cancel{W}\cdot L\cdot \cancel{C'_{ox}}\cdot\frac{2}{3}+2\cancel{W}\cdot\cancel{C'_{ox}}\cdot l_{over})} = \underbrace{\frac{\mu\cdot\frac{V_{GS}-V_T}{L}}{L}}_{v/L \,=\, 1/\tau_{S\to D}} \cdot \frac{1}{2\pi\left(\frac{2}{3}+\frac{l_{over}}{L}\right)}$$

Time of flight from source to drain

CS amp with load

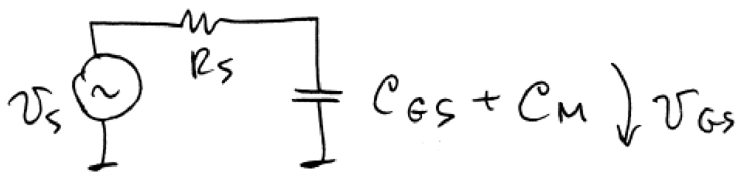


$$\hat{R}_L = (r_o \| R_D \| R_L)$$

1. Effect of C_{GS} and C_{GD}

Miller cap

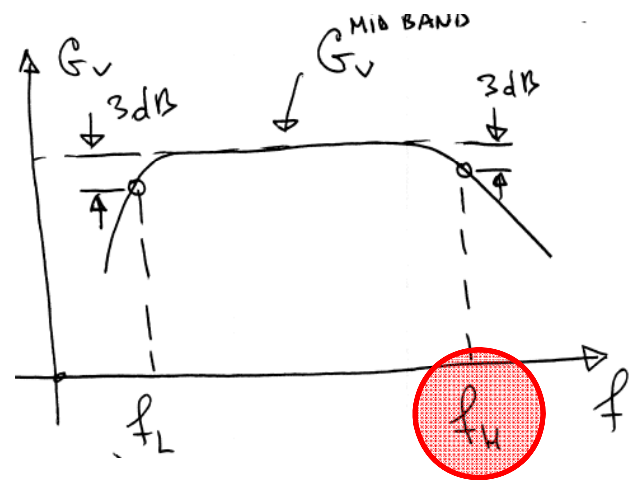
$$C_M = (1 + g_m \hat{R}_L) C_{GD}$$



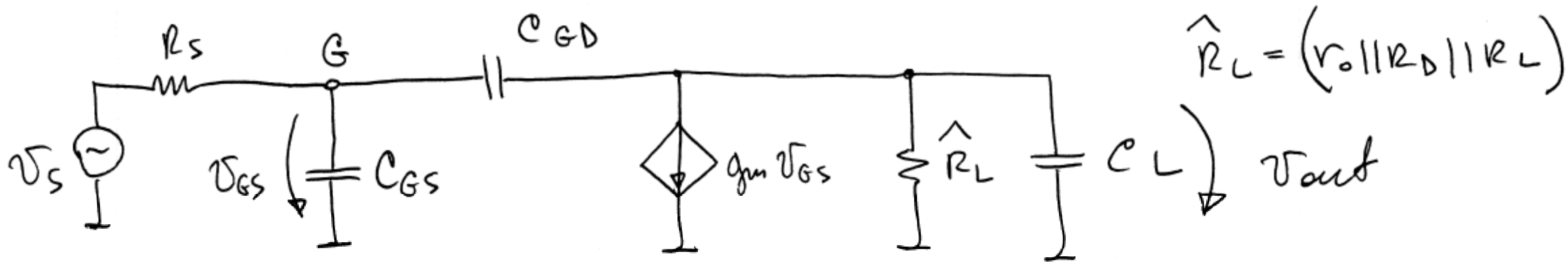
$$\frac{v_{GS}}{v_s} = \frac{1}{1 + j\omega\tau_M}$$

$$\tau_M = R_s (C_{GS} + C_M)$$

$$f_H \simeq \frac{1}{2\pi\tau_M}$$

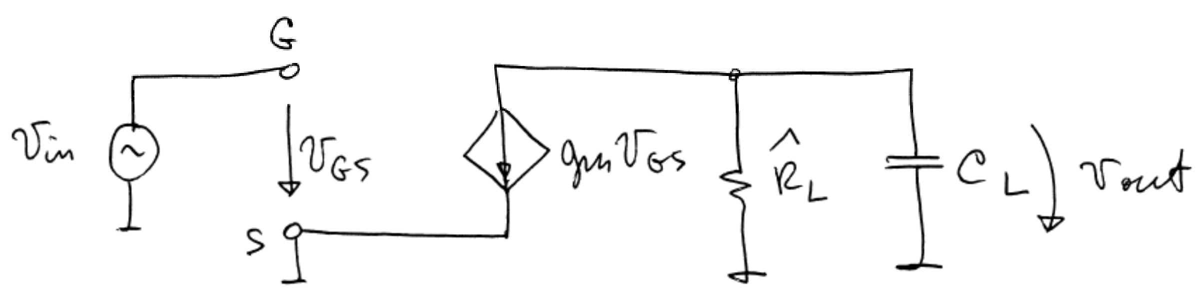


CS amp with load

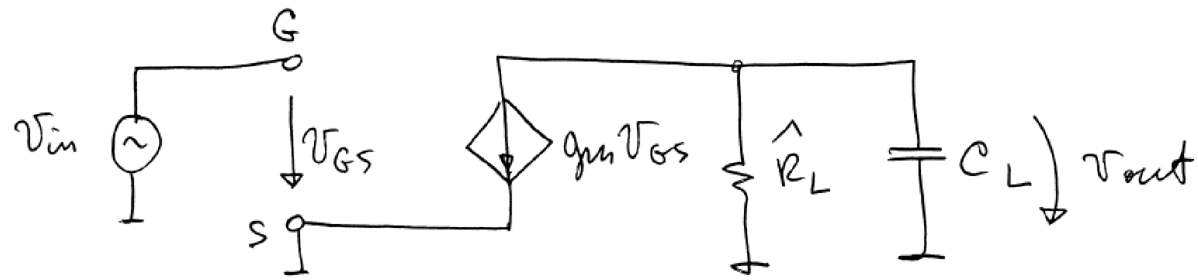


1. Effect of C_L

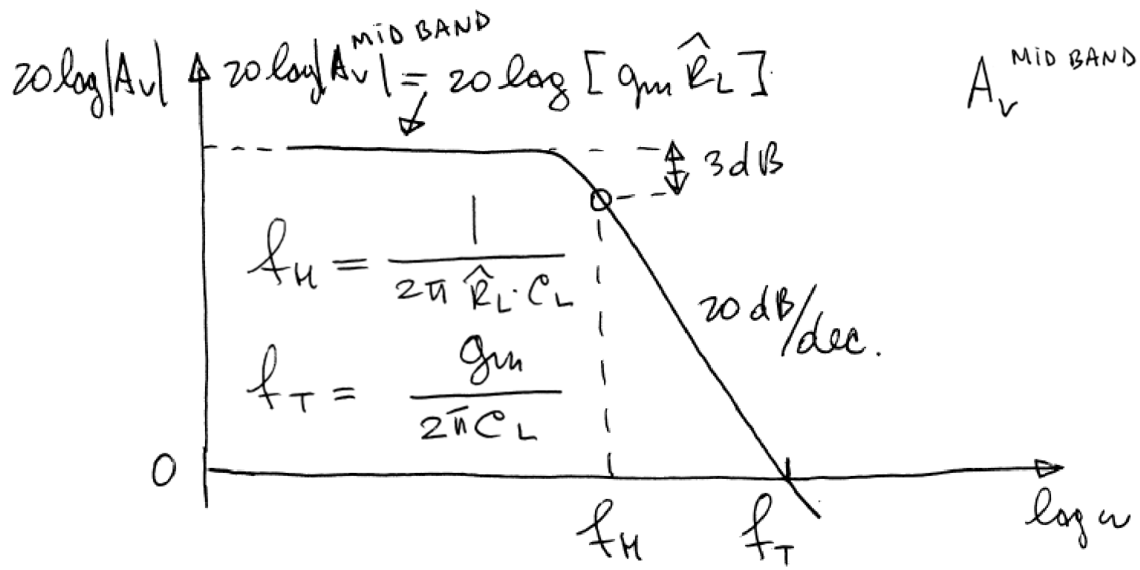
Either assume that role of C_{GS} and C_{GD} is not important or measure V_{GS} directly and treat it as a input signal.



CS amp with capacitive load



$$A_v(f) = -g_m\,(\hat{R}_L \,\|\, C_L) = \frac{-g_m \hat{R}_L}{1 + j\omega[\hat{R}_L \cdot C_L]}$$



$$A_v^{\text{MID BAND}} \times f_H = f_T = \underline{\underline{\text{Gain}\cdot\text{BW}}}$$

$g_m = 1\,\frac{mA}{V}$

$C_L = 20\,pF$

then $f_T \simeq 8\,MHz$

for $A_v^{m.b} \simeq 10\,\frac{V}{V}$

then $f_H \simeq 800\,kHz$!