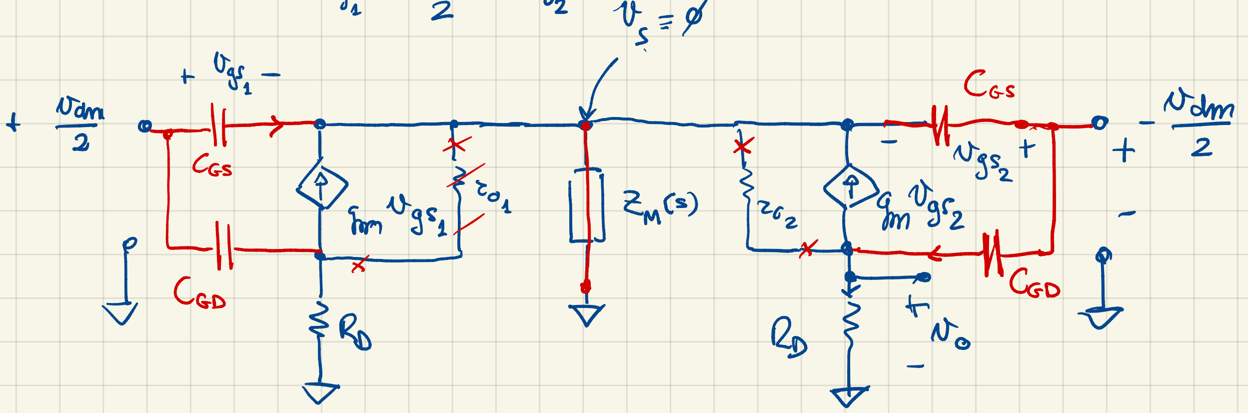
DM ANALYSIS

$v_{g_1} = \frac{v_{dm}}{2} = -v_{g_2}$



$g_{m_1} = g_{m_2} = g_m \qquad r_{o_1} = r_{o_2} = r_o$ NEGLIGIBLE

LET'S CALCULATE THE SOURCE VOLTAGE v_s

$$v_s = Z_M(s)\cdot\left(sC_{GS}\cdot v_{gs_1} + g_m v_{gs_1} + sC_{GS} v_{gs_2} + g_m v_{gs_2}\right) =$$

$$= Z_M(s)\cdot(sC_{GS}+g_m)\left(v_{gs_1}+v_{gs_2}\right) = -Z_M(s)\left(g_m + sC_{GS}\right)\cdot 2v_s$$

$$v_{gs_1} = \frac{v_{dm}}{2} - v_s \;; \quad v_{gs_2} = -\frac{v_{dm}}{2} - v_s \quad \Rightarrow \quad v_{gs_1}+v_{gs_2} = -2v_s$$

THE EQUATION FOR v_s IS HOMOGENUOUS $\Rightarrow$

$$v_s = -Z_M(s)\left(sC_{GS}+g_m\right)2v_s \iff v_s \equiv \emptyset \;!!$$

\# CONCLUSION: THE DM CIRCUIT IS COMMON SOURCE TYPE AND ITS GAIN DOES NOT DEPEND ON THE CURRENT MIRROR CHARACTERISTICS

LET'S NOW FIND THE DM GAIN

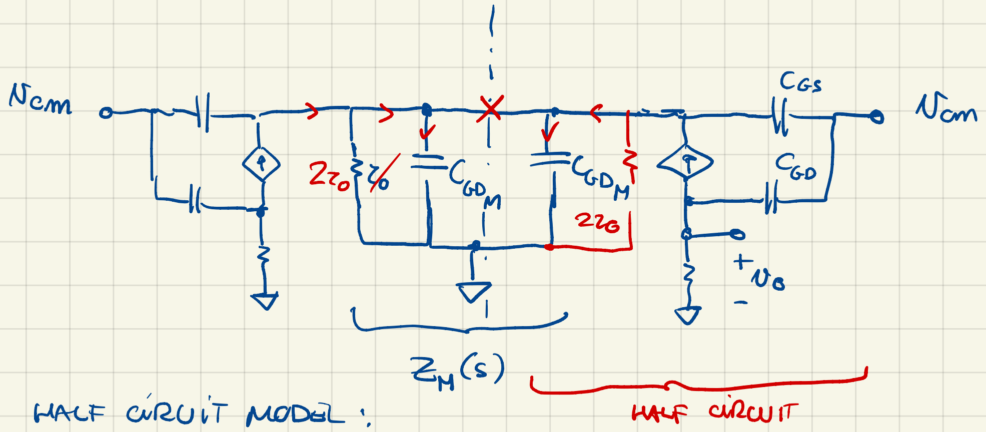
$$v_o = R_D\left[sC_{GD}\left(-\frac{v_{dm}}{2} - v_o\right) - g_m v_{gs_2}\right] = -R_D\left[sC_{GD}\left(+\frac{v_{dm}}{2}+v_o\right) - g_m\frac{v_{dm}}{2}\right]$$

$$v_o = \frac{v_{dm}}{2}\,\frac{g_m R_D - sC_{GD}R_D}{1+sC_{GD}R_D} = \frac{v_{dm}}{2}\cdot g_m R_D \cdot \frac{1 - s\frac{C_{GD}}{g_m}}{1+sC_{GD}R_D}$$

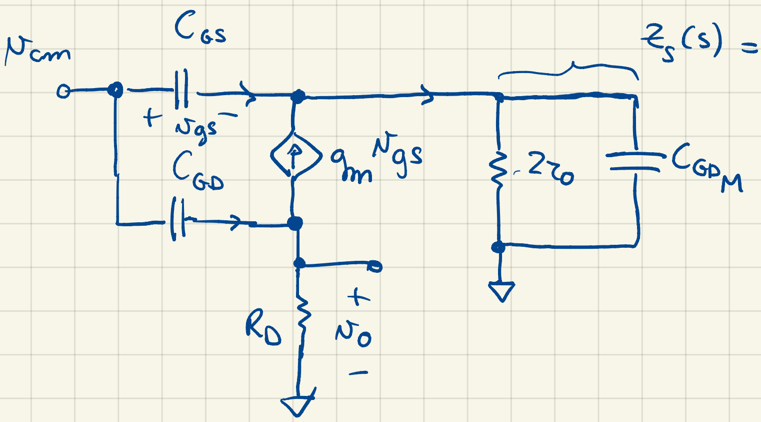
$$A_{dm} \triangleq \frac{v_o}{v_{dm}} = \frac{g_m R_D}{2}\cdot\frac{1 - s\frac{C_{GD}}{g_m}}{1+sC_{GD}R_D}$$ ← HIGH FREQUENCY ZERO

$$\lim_{s\to+\infty} A_{dm}(s) = -\frac{1}{2}$$ (OBVIOUS FROM CIRCUIT INSPECTION!)

CM ANALYSIS → WE USE THE HALF-CIRCUIT MODEL $v_{g_1} = v_{g_2} = v_{cm}$



HALF CIRCUIT MODEL:



$$Z_s(s) = \frac{2r_0}{1 + s\,2r_0 C_{GD_M}}$$

WE CAN SIMPLIFY THIS CIRCUIT USING **MILLER'S THEOREM**

$$Y = sC_{GD}$$

$$Y_1 = Y(1 - G)$$

$$Y_2 = Y\left(1 - \frac{1}{G}\right)$$

$$G = A_{21} = \frac{v_0}{v_{cm}} \quad \text{IN OUR CASE}$$

G IS APPROXIMATELY KNOWN IF WE CONSIDER ITS **MIDBAND VALUE.**

$$G_{MB} = \frac{v_0}{v_{cm}} \doteq -\frac{g_m R_D}{1 + g_m 2 r_0} \cong -\frac{R_D}{2r_0}$$

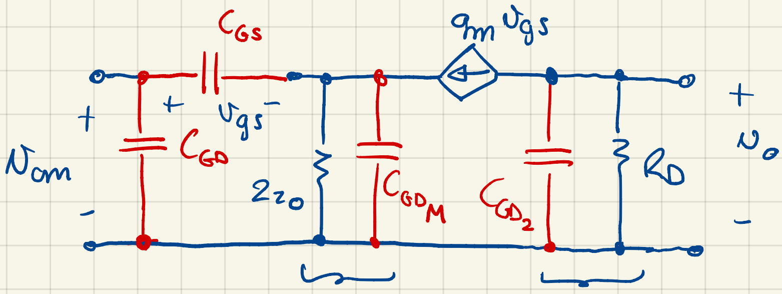
(1: NEGLIGIBLE)

VERY SMALL GAIN $\propto 10^{-2}$

AS A RESULT $Y_1 \cong Y = sC_{GD}$

$$Y_2 \cong sC_{GD} \cdot \underbrace{\left(1 + \frac{2r_0}{R_D}\right)}_{C_{GD_2}} \cong 10^2 C_{GD}$$

NOW WE CAN **RE-DRAW THE CIRCUIT**



$$Z_D(s) = \frac{R_D}{1 + sC_{GD_2}R_D}$$

FROM CIRCUIT INSPECTION WE EXPECT TWO POLES AND A ZERO

$$A_{cm} = \frac{v_0}{v_{cm}} = ?$$

$$\begin{cases} v_o = -Z_D(s) \cdot g_m v_{gs} \\ v_{gs} = v_{cm} - Z_s(s) \cdot \left(sC_{GS} v_{gs} + g_m v_{gs} \right) \end{cases}$$

$$\begin{cases} v_{gs} = \dfrac{v_{cm}}{1 + Z_s(s)\left(sC_{GS} + g_m\right)} \\ v_o = -v_{cm} \cdot \dfrac{g_m Z_D(s)}{1 + (g_m + sC_{GS}) Z_s(s)} \end{cases}$$

$$A_{cm} = \frac{v_o}{v_{cm}} = -\frac{\dfrac{g_m R_D}{1 + sC_{GD2} R_D}}{1 + (g_m + sC_{GS}) \cdot \dfrac{2r_o}{1 + s2r_o C_{GDM}}} = -\frac{g_m R_D \left(1 + s2r_o C_{GDM}\right)}{(1 + sC_{GD_2} R_D)\left[\underbrace{1 + 2g_m r_o}_{} + s2r_o(C_{GD_M} + C_{GS})\right]}$$

$1/\omega_{p_1}$

$$A_{cm} \triangleq \frac{v_c}{v_{cm}} = -\underbrace{\frac{g_m R_D}{1 + 2g_m r_o}}_{G_{MB}} \cdot \frac{1 + 2r_o C_{GDM} s}{(1 + sC_{GD_2} R_D)\left[1 + s\dfrac{2r_o(C_{GDM} + C_{GS})}{1 + 2r_o g_m}\right]}$$

$1/\omega_{p_1}$ MIDBAND FREQUENCY

$1/\omega_{p_2}$ → RELATIVELY HIGH FREQUENCY

$$\omega_z = \frac{1}{2r_o C_{GDM}}$$

VERY LOW FREQUENCY $\alpha\ 10^3$ Hz

THIS ZERO LIMITS THE CMRR $= \dfrac{A_{dm}}{A_{cm}}$ BANDWIDTH !

REMARK : WE HAVE FOUND THESE RESULTS USING MILLER'S THEOREM. ARE THEY MEANINGFUL?

THEY ARE AS LONG AS $A_{cm} \cong G_{MB}$, WHICH MEANS UP TO THE ZERO FREQUENCY.

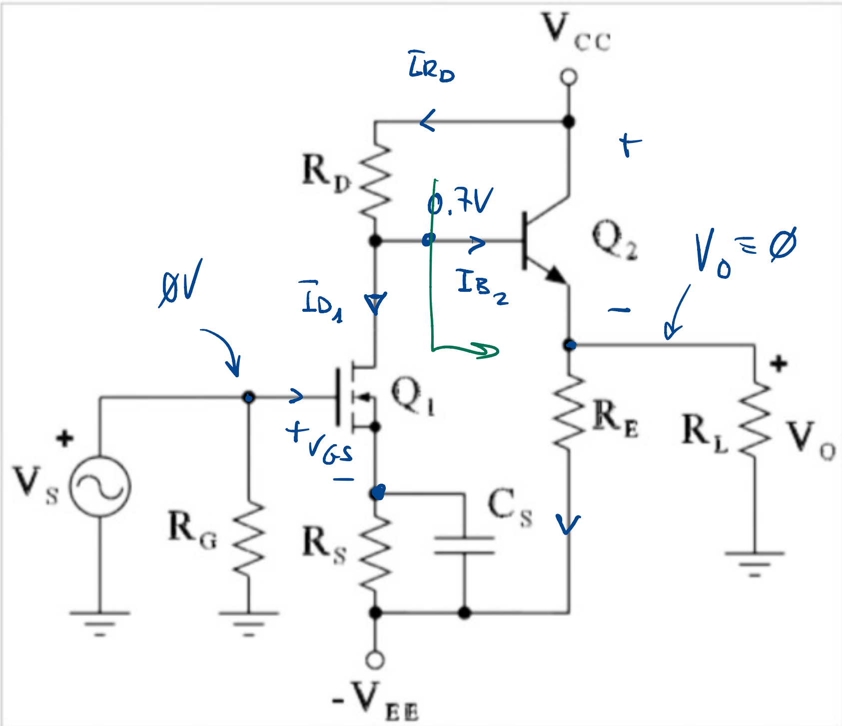
EXERCISE 1

Consider the amplifier in the figure below, whose papramenters are (@ T = 25°C):
$V_{CC} = V_{EE}$=30V, R_G=500kΩ, R_D=15kΩ, R_E=5kΩ, R_L=7.5kΩ

MOSFET: V_T = 8 V, $I_{DSS} = V_T^2 kW/L$ = 8 mA, $r_d = \infty$. $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_T}\right)^2$
BJT: V_{BE} = 0.7 V, β_F = 150, β_0 = 200, $r_o = \infty$.

Determine:

1) I_{CQ}, I_{DQ} and R_S so that V_o= 0 V.
2) Voltage gain at low frequency, $A_{v1}=v_o/v_s$ considering C_S open.
3) Voltage gain (mid frequency) $A_{v2}=v_o/v_s$ considerando C_S shorted.
4) Low frequency cut-off f_L due to C_S=100µF.
5) Draw the Bode asymptotic diagram of $A_v(f)$.



BIAS POINT ANALYSIS

$V_o \equiv 0V \Rightarrow V_{R_E} = V_{EE}$ $\quad I_{E_2} = \frac{V_{EE}}{R_E} = 6mA \Rightarrow I_{C_2}, I_{B_2}$

$V_{CE_2} = V_{CC} = 30\,V \Rightarrow$ F.A.R. ✓

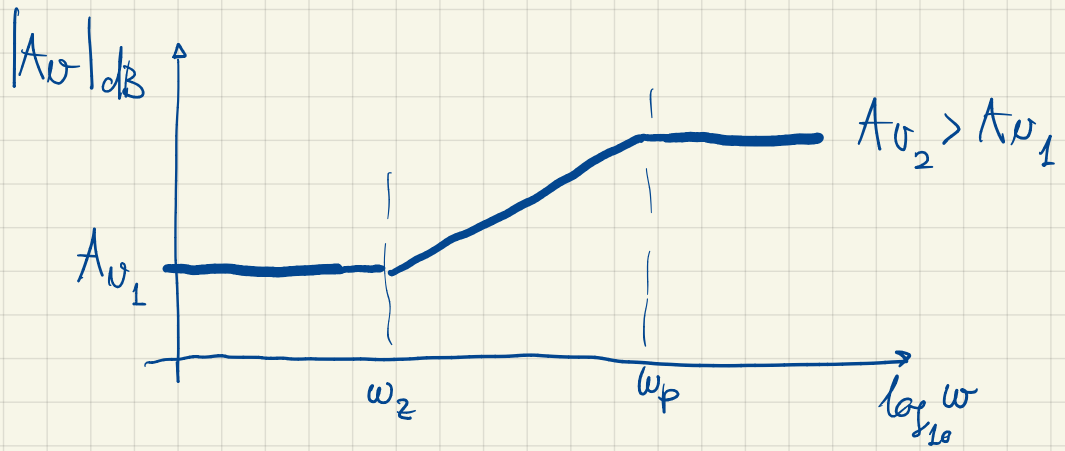
$I_{D_1} = I_{R_D} - I_{B_2} = \frac{V_{CC} - V_{BE}}{R_D} - I_{B_2} \cong 2mA \Rightarrow V_{GS_1} > V_t$

$V_{R_S} = V_{GS} - V_{EE}$ $\quad I_{R_S} = I_{D_1} \Rightarrow R_S = \frac{V_{R_S}}{I_{D_1}}$

$$A_{v_1} = \frac{v_o}{v_s} = - \frac{g_{m_1} R_D // R_{in_2}}{1 + g_{m_1} R_S} \cdot \underbrace{\frac{(\beta_0+1) R_E // R_L}{r_{\pi_2} + (\beta_0+1) R_E // R_L}}_{R_{in_2}}$$ $C_S =$ "OPEN"

$$R_{in_2} = r_{\pi_2} + R_E // R_L (\beta_0 + 1)$$

$$A_{v_2} = - g_{m_1} R_D // R_{in_2} \cdot \frac{(\beta_0+1) R_E // R_L}{R_{in_2}}$$ $C_S =$ "SHORT"



$$\omega_p = \frac{1}{R_{C_S} C_S} \quad , \quad R_{C_i} = R_S // \frac{1}{g_{m_1}}$$

EXERCISE 2

Consider the amplifier in the figure, whose parameters @ T= 25°C are the following:

V_{CC}=36V; R_5=10k▯

Q1: β_{F1}=100 ;β_{01}=200, I_{C1}=-0.4mA; V_{CE1}=-16V, V_{BE}=-0.7V (r_o=∞)
Q2: β_{F2}=100 ;β_{02}=200, I_{C2}=2mA; V_{CE2}=18V, V_{BE}=0.7V (r_o=∞)

Determine:

1) Resistances R_1, R_2, R_3, R_4.
2) A_V= v_o/v_S (considering C_1 e C_2 shorted and C_X open).
3) Resistance R_{in} indicated in the figure (as per point 2).
4) Resistenza R_{out} indicated in the figure (as per point 2).
5) High frequency cut-off f_H considering only C_X (C_X=20pF).