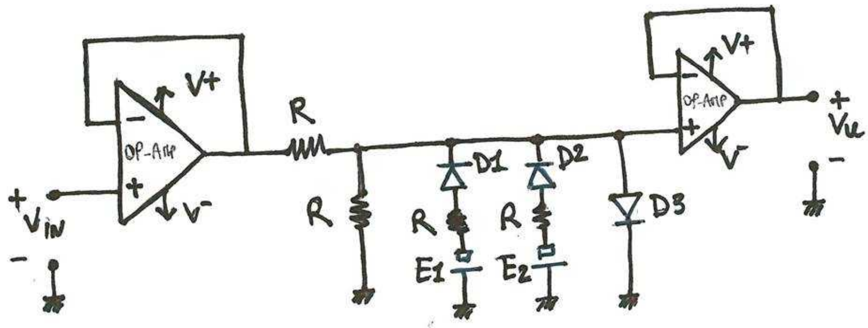
SCHEDA **A16_08**		Data: **14 Settembre 2016**
Cognome	Nome	Matricola

ESERCIZIO N°1

6 punti (4)

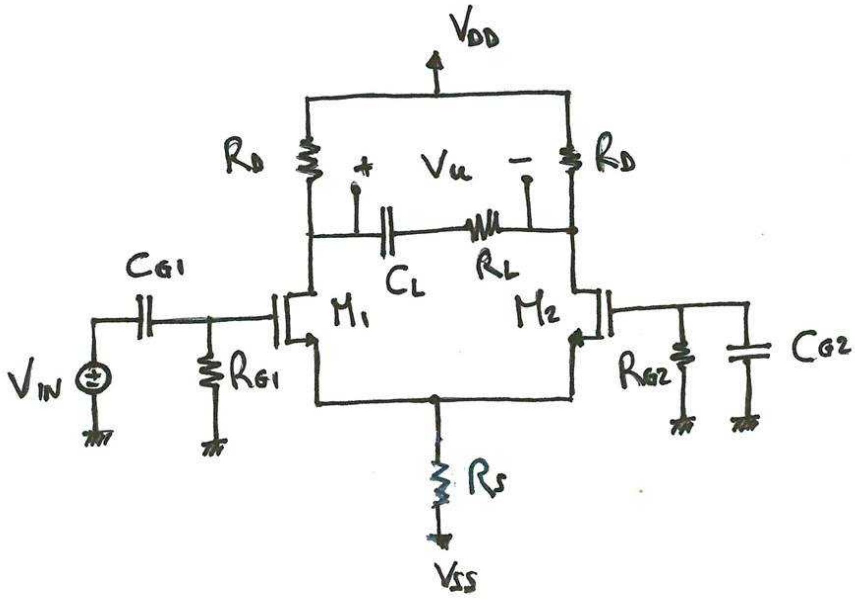
Con rifermento al circuito in figura, determinare e rappresentare la caratteristica statica ingresso/uscita per tensioni di ingresso comprese nell'intervallo [-10, 10] V. Per i diodi D1, D2 e D3 sia V_γ = 0 V, R = 6 kΩ, E_1 = 1 V, E_2 = 3 V. Si considerino gli amplificatori operazionali ideali.



ESERCIZIO N°2

7 punti (4)

Con riferimento al circuito in figura, determinare il punto di riposo dei transistor M1 e M2. Per entrambe i transistor si consideri V_T = 1 V, k = 0.444 mA/V^2. R_C = 5 kΩ, R_S = 2 kΩ, R_{G1} = R_{G2} = 850 kΩ, R_L = 5 kΩ, C_{G1} = C_{G2} = 240 nF, C_L = 33 nF, V_{DD} = 12 V, V_{SS} = - 12 V.



ESERCIZIO N°3

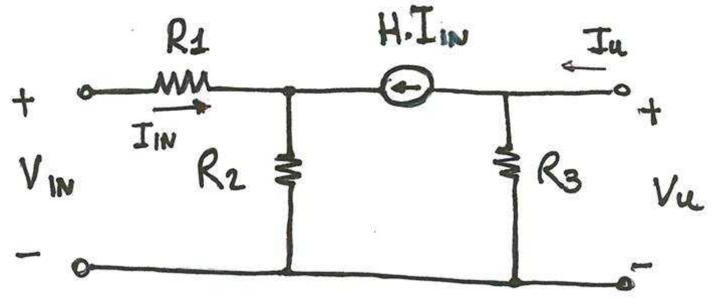
9 punti (4)

Nel circuito mostrato nell'esercizio precedente si ricavi il la funzione di trasferimento *Av(s)* = V_U/V_{IN}. Per entrambe i transistor M1 e M2 si considerino g_m = 3mS.

ESERCIZIO N°4

6 punti (4)

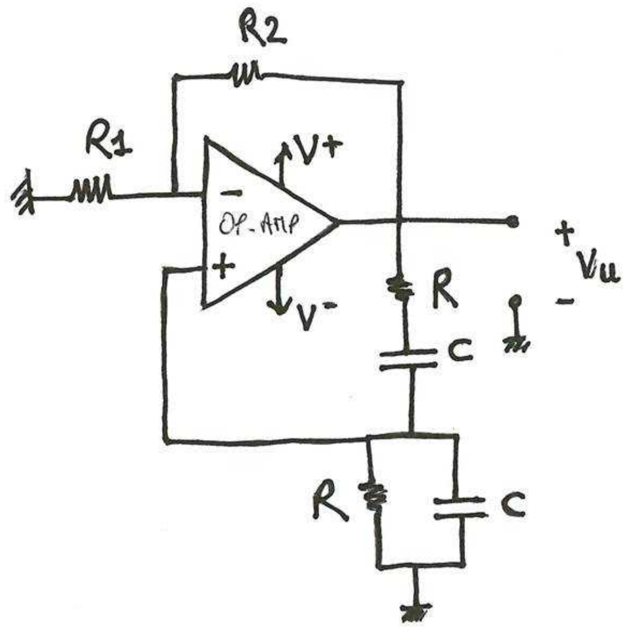
Determinare il modello equivalente a parametri *f* del circuito riportato in figura. R_1 = 20 kΩ, R_2 = 30 kΩ, R_3 = 50 kΩ ed H = 75.



ESERCIZIO N°5

5 punti (4)

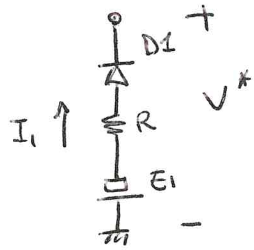
Ricavare il massimo sbilanciamento in uscita del circuito mostrato in figura. R_1 = 5 kΩ, R_2 = 9 kΩ, R = 15 kΩ e C = 240 nF. Si consideri l'amplificatore operazionale ideale a meno dei generatori di offset e sbilanciamento $|V_{io}|$ = 0.3 mV, I_B = 45 μA ed $|I_{io}|$ = 17 μA.



- Es. 1

  - Indicando con V^* la tensione tra l'ingresso non invertente dell'operazionale che fornisce la tensione V_u ed il terminale comune delle tensioni si osserva che:

1) $V^* = -V_{D1} - RI_1 - E_1$



$$I_1 = \frac{-V^* - V_{D1} - E_1}{R}$$

D1 conduce se: $I_1 > 0 \rightarrow -V^* - V_{D1} - E_1 > 0$

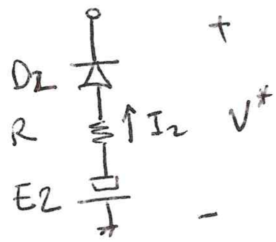
$$\downarrow$$

$$V^* < -V_{D1} - E_1$$

$$\downarrow$$

$\underline{V^* < -E_1}$ $(V\gamma = 0V)$

2) $V^* = -V_{D2} - RI_2 - E_2$



$$I_2 = \frac{-V^* - V_{D2} - E_2}{R}$$

D2 conduce se: $I_2 > 0 \rightarrow -V^* - V_{D2} - E_2 > 0$

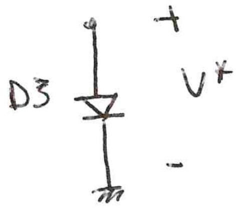
$$\downarrow$$

$$V^* < -V_{D2} - E_2$$

$$\downarrow$$

$\underline{V^* < -E_2}$ $(V\gamma = 0V)$

3) $V^* = V_{D3}$



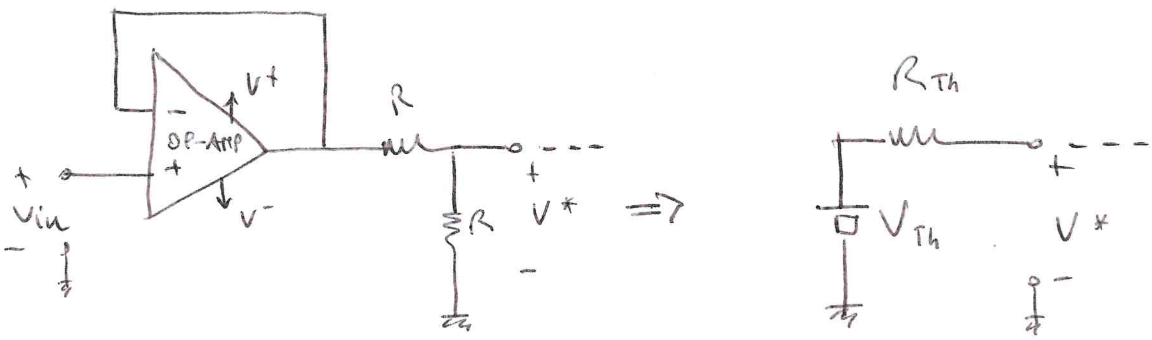
D3 conduce se:

$V_{D3} \geq 0 \rightarrow \underline{V^* \geq 0}$

- Il buffer in uscita fa in modo che $\forall\, V_{in}$ si abbia:

$$\underline{V_u = V^*}$$

- Effettuando l'equivalente di Thevenin del buffer in ingresso con il relativo partitore resistivo si ottiene:



$$R_{Th} = \frac{R}{2} \quad (\text{OP-AMP ideale})$$

$$V_{Th} = V_{in} \cdot \frac{R}{R+R} = \frac{V_{in}}{2}$$

- Tensione in ingresso positiva: $V_{in} \geq 0$

$$V_{in} \geq 0 \rightarrow V_{Th} \geq 0 \rightarrow V^* \geq 0$$

Quindi per quanto detto sopra D1 e D2 OFF, D3 ON per cui:

$$V^* = 0 \longrightarrow \boxed{V_u = 0} \qquad \underline{V_{in} \geq 0}$$

- Tensione in ingresso negativa: $V_{in} < 0$

$V_{in} < 0 \rightarrow V_{TH} < 0 \rightarrow V^*$ potenzialmente negativa

Quindi sicuramente D3 OFF, mentre D1 e D2 saranno ON/OFF a seconda del valore di V^*.

In particolare:

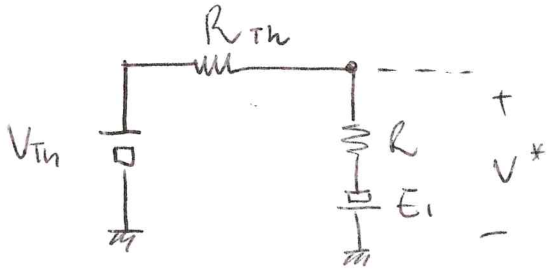
A) $\underline{-1V < V^* < 0} \rightarrow$ D1 e D2 OFF $\rightarrow V^* = V_{TH} = \frac{V_{in}}{2}$

Quindi:

$-1V < V^* < 0 \rightarrow \underline{-2V < V_{in} < 0} \rightarrow \boxed{V_u = \frac{V_{in}}{2}}$

B) $\underline{-3V < V^* \leq -1V} \rightarrow$ D1 ON e D2 OFF

Quindi:



$$V^* = V_{TH} \cdot \frac{R}{R+R_{TH}} - E_1 \cdot \frac{R_{TH}}{R+R_{TH}}$$

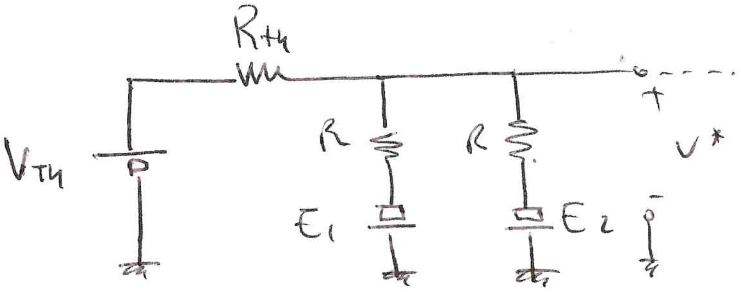
$$V^* = \frac{V_{IN}}{3} - \frac{E_1}{3} = \frac{V_{IN} - E_1}{3}$$

Quindi:

$-3V < V^* \leq -1V \rightarrow \underline{-8V < V_{in} \leq -2V} \rightarrow \boxed{V_u = \frac{V_{IN} - E_1}{3}}$

c) $\underline{V^* \leq -3V} \rightarrow$ D1 e D2 ON

Quindi:

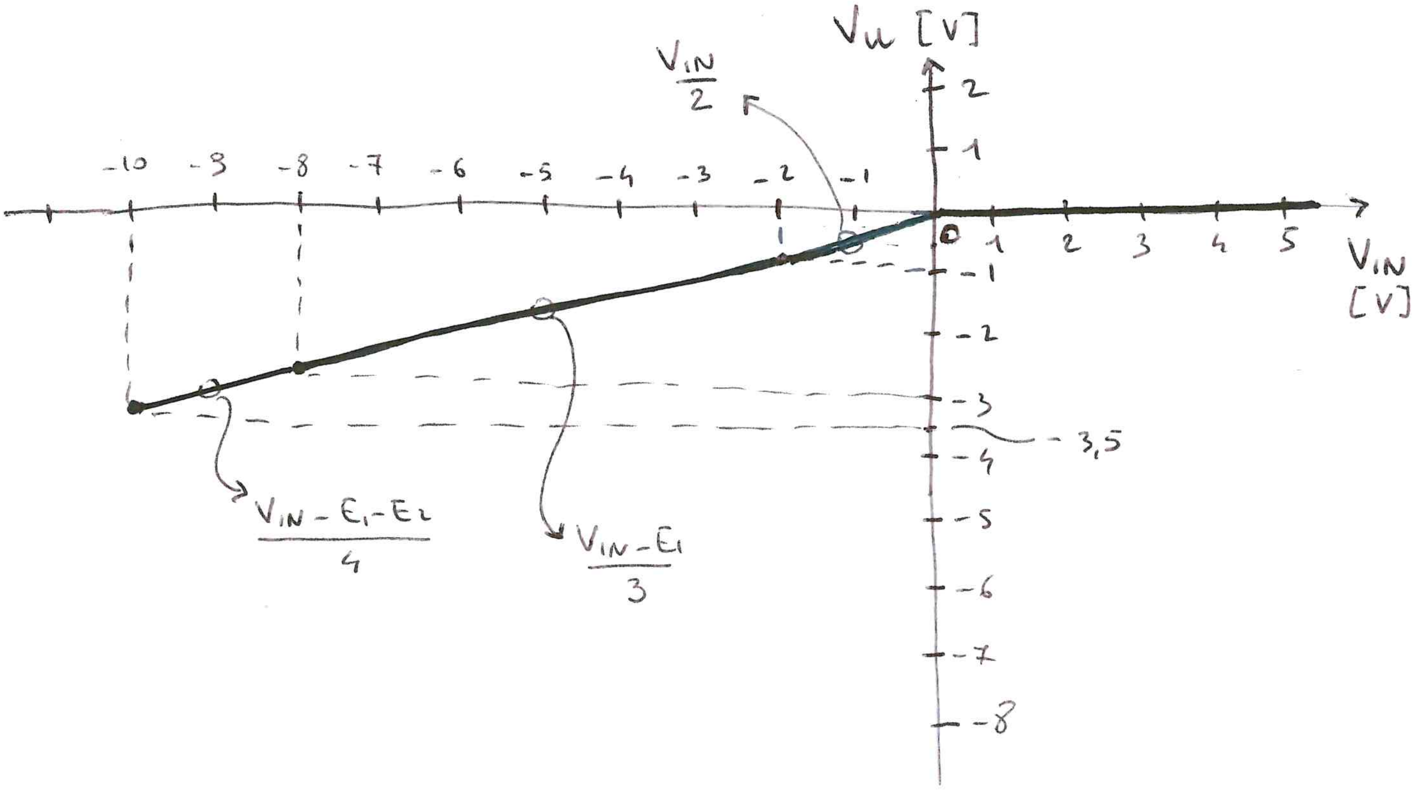


$$V^* = V_{TH} \cdot \frac{R/2}{R_{TH} + R/2} - E_1 \cdot \frac{R_{TH}//R}{R + R_{TH}//R} - E_2 \cdot \frac{R_{TH}//R}{R + R_{TH}//R}$$

$$V^* = \frac{V_{IN}}{4} - \frac{(E_1 + E_2)}{4}$$

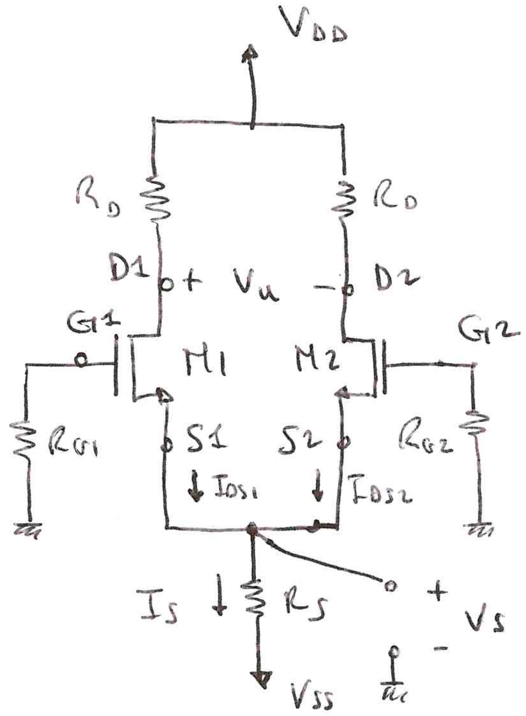
Quindi:

$$V^* \leq -3V \rightarrow \underline{V_{IN} \leq -8V} \rightarrow \boxed{V_u = \frac{V_{IN} - E_1 - E_2}{4}}$$



• Es. 2

• Circuito di polarizzazione:



• $V_{G1} = V_{G2} = 0$

$V_{S1} = V_{S2} = V_S \rightarrow V_{GS1} = V_{GS2} = -V_S$

• Ipotesi di lavoro: M1 ed M2 in saturazione

$$I_{DS1} = \frac{K}{2}(V_{GS1} - V_T)^2 = \frac{K}{2}(-V_S - V_T)^2$$

$$I_{DS2} = \frac{K}{2}(V_{GS2} - V_T)^2 = \frac{K}{2}(-V_S - V_T)^2$$

$$I_{DS1} = I_{DS2} = I_{DS}$$

$$I_{DS1} + I_{DS2} = I_S \rightarrow I_S = 2 I_{DS}$$

$$V_S = R_S I_S + V_{SS} = 2 R_S I_{DS} + V_{SS}$$

$$I_{DS} = \frac{V_S}{2R_S} - \frac{V_{SS}}{2R_S}$$

$$I_{DS} = \frac{K}{2}(V_{GS} - V_T)^2 = \frac{K}{2}(-V_S - V_T)^2$$

$$\frac{V_S}{\cancel{2}R_S} - \frac{V_{SS}}{\cancel{2}R_S} = \frac{K}{\cancel{2}} \cdot [V_S^2 + 2V_SV_T + V_T]^2$$

$$V_S^2 + \left[2V_T - \frac{1}{KR_S}\right] \cdot V_S + V_T^2 + \frac{V_{SS}}{KR_S} = 0$$

$$V_S^2 + \left[2 \cdot 1V - \frac{1}{0.444 \cdot 10^{-3} \frac{A}{V^2} \cdot 2 \cdot 10^3 \frac{V}{A}}\right] \cdot V_S + 1V^2 - \frac{12\,V}{0.444 \cdot 10^{-3} \frac{A}{V^2} \cdot 2 \cdot 10^3 \frac{V}{A}} = 0$$

$$V_S^2 + 0.874V \cdot V_S - 12{,}636\,V^2 = 0$$

$$V_S = \frac{-0.874\,V \pm \sqrt{(0.874V)^2 + 4 \cdot 12{,}636V^2}}{2}$$

$$V_S = \begin{cases} \underline{-4{,}019\,V} & \underline{\text{ok}} \\ 3.145\,V & \text{(Non ammissibile dovendo essere } V_{GS} > V_T\text{)} \end{cases}$$

$$V_{GS1} = V_{GS2} = -V_S = 4.019V > V_T \quad \underline{\text{ok}}$$

$$I_{DS1} = I_{DS2} = \frac{K}{2}(V_{GS} - V_T)^2 = \underline{2{,}023\ mA}$$

$$V_{D1} = V_{D2} = V_{DD} - R_D \cdot I_{DS} = 12V - 5 \cdot 10^3\,\Omega \cdot 2.023 \cdot 10^{-3}A =$$

$$= 1.885\ V$$

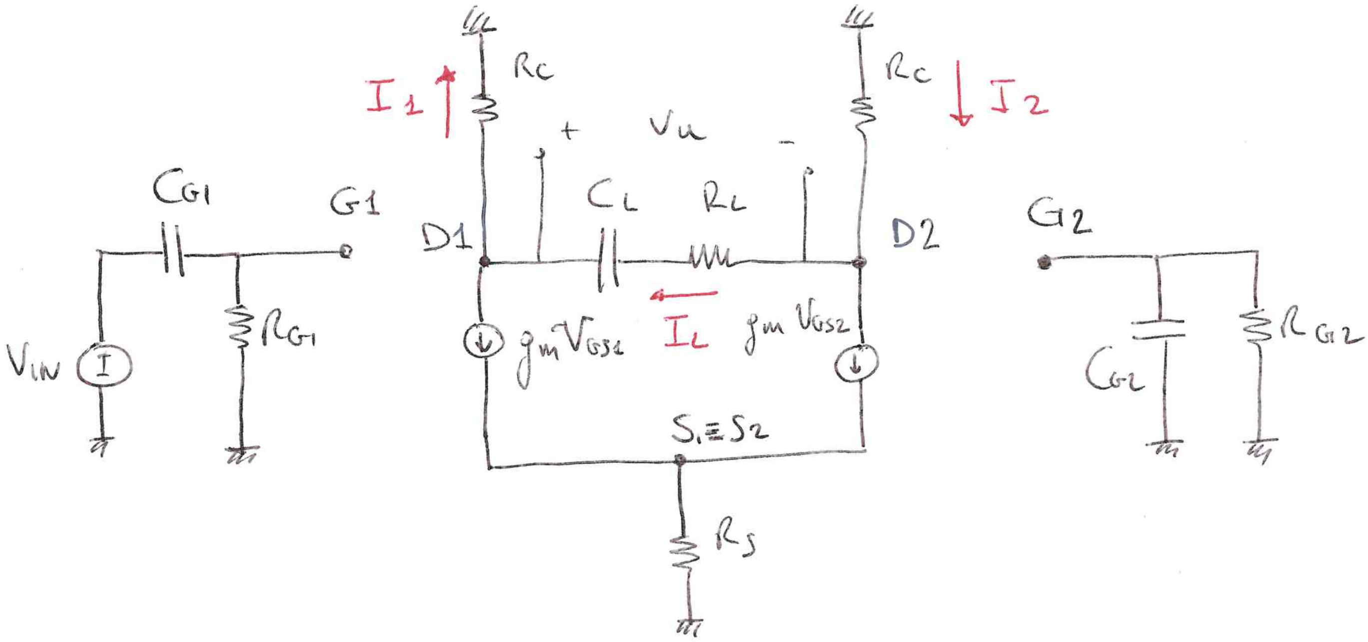
$$V_{DS1} = V_{DS2} = V_D - V_S = 1.885V - (-4.019V) =$$

$$\underline{V_{DS} = 5{,}904} > V_{GS} - V_T = 3.019V \quad \underline{\text{ok}}$$

$$\underline{V_u = V_{D1} - V_{D2} = 0V}$$

Es 3

- Circuito per il piccolo segnale:



- $$V_{G1} = \frac{R_{G1}}{R_{G1} + \frac{1}{C_{G1} s}} \cdot V_{IN} = \frac{R_{G1} \cdot C_{G1} \cdot s}{R_{G1} \cdot C_{G1} \cdot s + 1} \cdot V_{IN}$$

- $V_{G2} = 0\,V$

- $V_{S1} = V_{S2} = V_S$

- $V_{GS1} = V_{G1} - V_S \quad , \quad V_{GS2} = V_{G2} - V_S = -V_S$

- $$V_S = R_S \cdot [g_m V_{GS1} + g_m V_{GS2}] = R_S [g_m V_{G1} - 2 g_m V_S]$$

$$V_S [1 + 2 g_m R_S] = g_m R_S \cdot V_{G1}$$

$$V_S = \frac{g_m R_S}{1 + 2 g_m R_S} \cdot V_{G1}$$

- Nodo D1: $I_1 + g_m V_{GS1} = I_L$

$$I_1 = I_L - g_m V_{GS1}$$

- Nodo D2: $I_2 = I_L + g_m V_{GS2}$

- Equazione alla maglia di uscita:

$$R_D \cdot I_2 + R_D \cdot I_1 - V_u = 0$$

$$V_u = R_D [I_1 + I_2] =$$
$$= R_D [I_L - g_m V_{GS1} + I_L + g_m V_{GS2}] =$$
$$= R_D [2 I_L - g_m V_{G1} + \cancel{g_m V_S} - \cancel{g_m V_S}] =$$
$$= 2 R_D I_L - R_D g_m V_{G1}$$

- $I_L = -\dfrac{V_u}{R_L + \dfrac{1}{C_L \cdot s}} = -\dfrac{C_L \cdot s}{1 + R_L C_L \cdot s} \cdot V_u$

Quindi:

$$V_u = -2 R_D \cdot \frac{C_L s}{1 + R_L C_L s} \cdot V_u - R_D g_m V_{G1}$$

$$V_u \left[1 + \frac{2 R_D C_L \cdot s}{1 + R_L \cdot C_L \cdot s} \right] = - R_D g_m V_{G1}$$

$$V_u \left[\frac{1 + R_L C_L \cdot s + 2 R_D C_L \cdot s}{1 + R_L C_L \cdot s} \right] = - R_D g_m V_{G1}$$

$$V_u = - \frac{g_m R_D \cdot (1 + R_L C_L \cdot s)}{1 + (R_L + 2 R_D) \cdot C_L \cdot s} \cdot V_{G1}$$

In conclusione:

$$V_u = - \frac{g_m R_D \cdot R_{G1} \cdot C_{G1} \cdot s \cdot (1 + R_L C_L \cdot s)}{(1 + R_{G1} \cdot C_{G1} \cdot s) \cdot [1 + (R_L + 2R_D) \cdot C_L \cdot s]} V_{IN}$$

$$A_v(s) = \frac{V_u}{V_{in}} = - \frac{g_m R_D R_{G1} C_{G1} \cdot s\,(1 + R_L C_L \cdot s)}{(1 + R_{G1} \cdot C_{G1} \cdot s)[1 + (R_L + 2R_D) \cdot C_L \cdot s]}$$

$$A_v(s) = - \frac{g_m R_D R_L \cdot s \cdot \left(\frac{1}{R_L C_L} + s \right)}{(R_L + 2R_D) \cdot \left[\frac{1}{R_{G1} C_{G1}} + s \right] \cdot \left[\frac{1}{(R_L + 2R_D) C_L} + s \right]}$$

$$\boxed{A_v(s) = \frac{A_{v\infty} \cdot s \cdot (\omega_0 + s)}{(\omega_{p1} + s) \cdot (\omega_{p2} + s)}}$$

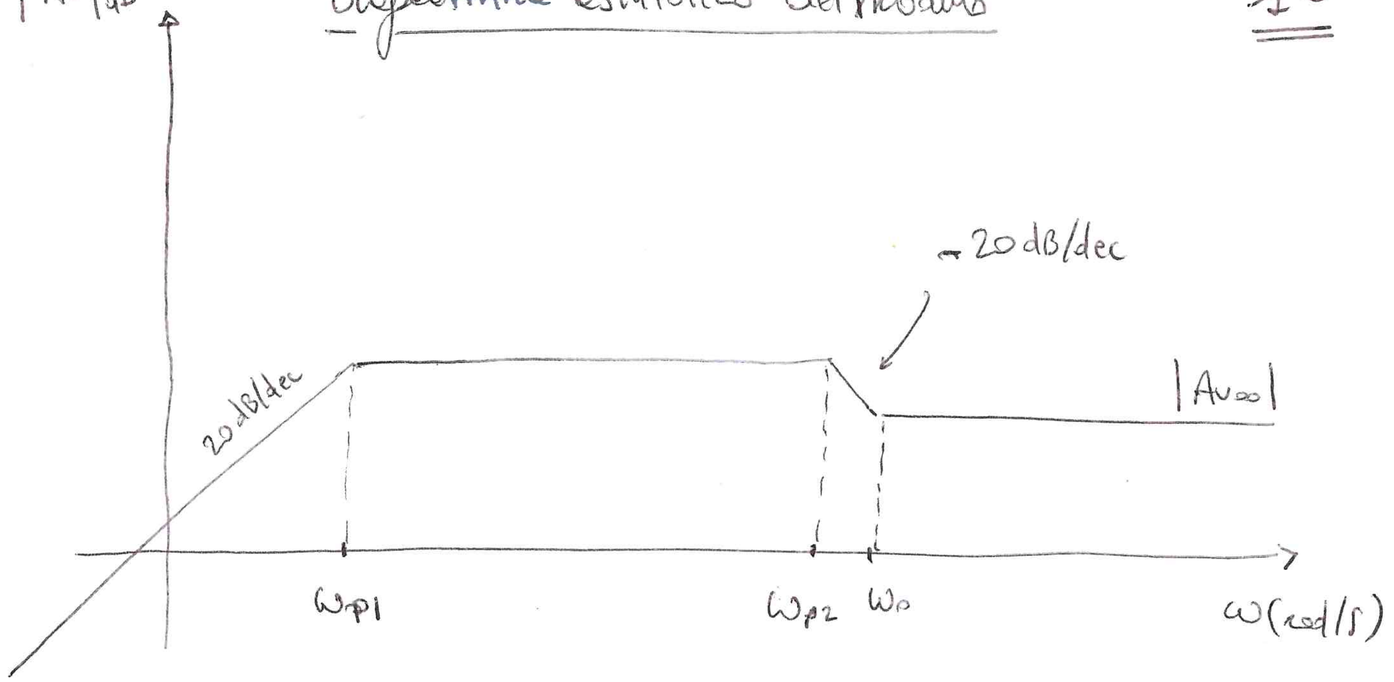
$$A_{v\infty} = - \frac{g_m R_D R_L}{R_L + 2R_D} = - \frac{3 \cdot 10^{-3} S \cdot 5 \cdot 10^3 \cdot 5 \cdot 10^3 \Omega^2}{5 \cdot 10^3 + 10 \cdot 10^3} = -5$$

$$\omega_0 = \frac{1}{R_L C_L} = \frac{1}{5 \cdot 10^3 \Omega \cdot 33 \cdot 10^{-6} F} \cong 6{,}06 \text{ Krad/s}$$

$$\omega_{p1} = \frac{1}{R_{G1} \cdot C_{G1}} = \frac{1}{850 \cdot 10^3 \Omega \cdot 240 \cdot 10^{-6} F} \simeq 4{,}90 \text{ rad/s}$$

$$\omega_{p2} = \frac{1}{(R_L + 2R_D) \cdot C_L} = \frac{1}{15 \cdot 10^3 \Omega \cdot 33 \cdot 10^{-9} F} \cong 2{,}02 \text{ Krad/s}$$

Diagramma esintotico del modulo



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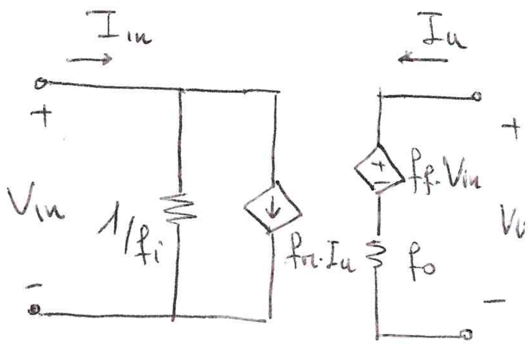
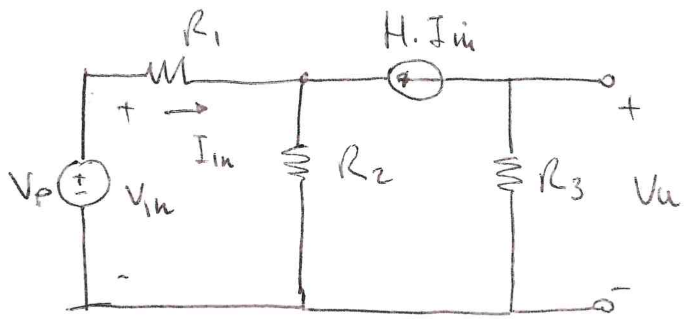
• Es. 4

$$\begin{cases} V_u = f_f \cdot V_{in} + f_o \cdot I_u \\ I_{in} = f_i \cdot V_{in} + f_r \cdot I_u \end{cases}$$



• Calcolo dei parametri f_f ed f_i $(I_u = 0)$

$$f_f = \left.\frac{V_u}{V_{in}}\right|_{I_u=0}$$



$$V_u = -R_3 \cdot H \cdot I_{in}$$

$$-V_p + R_1 I_{in} + R_2(1+H) I_{in} = 0$$

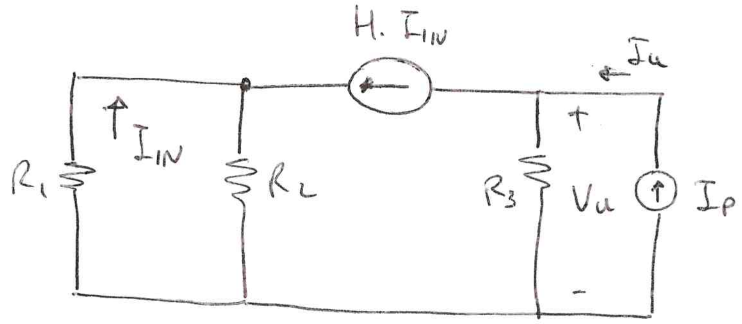
$$I_{in} = +\frac{V_p}{R_1 + R_2(1+H)} \longrightarrow V_u = -\frac{R_3 H}{R_1 + R_2(1+H)} \cdot V_p$$

$$\boxed{f_f} = -\frac{R_3 \cdot H}{R_1 + R_2(1+H)} = -\frac{50\,k\Omega \cdot 75}{20\,k\Omega + 30\,k\Omega(76)} \simeq \boxed{-1{,}63}$$

$$\boxed{f_i} = \frac{I_{in}}{V_{in}}\Big|_{I_u=0} = \frac{1}{R_1 + R_2(1+H)} \cong \boxed{0.435\,\mu S}$$

- Calcolo dei parametri f_o ed f_r ($V_{in} = 0$):

$$f_o = \frac{V_u}{I_u}\Big|_{V_{in}=0}$$



$$R_1 \cdot I_{IN} + R_2 I_{IN}(1+H) = 0 \rightarrow I_{IN} = 0$$

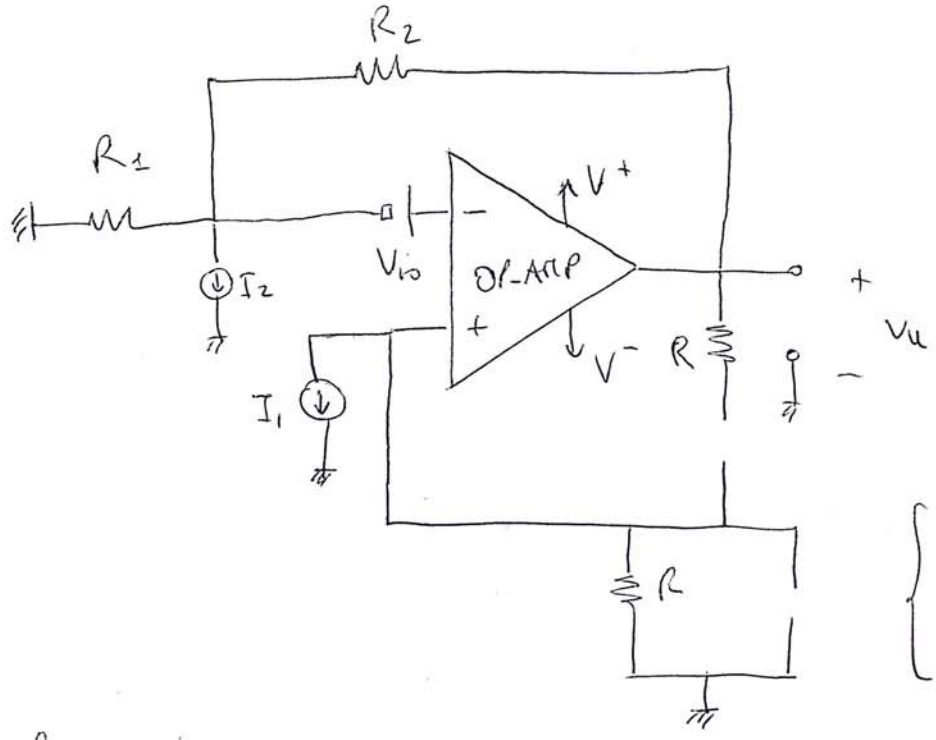
$$V_u = R_3 \cdot I_p$$

$$\boxed{f_o} = \frac{R_3 I_p}{I_p} = R_3 = \boxed{50\,k\Omega}$$

$$\boxed{f_r} = \frac{I_{in}}{I_u}\Big|_{V_{in}=0} = \boxed{0}$$

- Es 5

- I generatori di offset e di polarizzazione si considerano costanti per cui per $f=0$ i condensatori sono rami aperti:



$$\begin{cases} I_1 = I_B + \dfrac{I_{io}}{2} \\ I_2 = I_B - \dfrac{I_{io}}{2} \end{cases}$$

- Applicando il PSE:

I_1) $V^+ = -R \cdot I_1 = V^-$ C.C.V.

$$V_u\big|_{I_1} = -\left(1+\frac{R_2}{R_1}\right) \cdot R I_1$$

I_2) $V^+ = V^- = 0\ V$ ed I_2 scorre solo in R_2 C.C.V.

$$V_u\big|_{I_2} = R_2 \cdot I_2$$

V_{io})

$$V_u\big|_{V_{io}} = -\left(1+\frac{R_2}{R_1}\right) V_{io}$$

- Quindi:

$$V_u = -\left(1+\frac{R_2}{R_1}\right) \cdot R \cdot I_1 + R_2 I_2 - \left(1+\frac{R_2}{R_1}\right) V_{io}$$

$$V_u = \left[R_2 - \left(1+\frac{R_2}{R_1}\right) \cdot R\right] I_B - \left[R_2 + \left(1+\frac{R_2}{R_1}\right) \cdot R\right] \frac{I_{io}}{2} - \left(1+\frac{R_2}{R_1}\right) V_{io}$$

$$V_u = -33\,K\Omega \cdot I_B - \frac{51\,K\Omega}{2} \cdot I_{io} - 2{,}8 \cdot V_{io}$$

$I_B = 45\,\mu A \quad I_{io} = \pm 17\,\mu A \quad V_{io} = \pm 0.3\,mV$

Il caso peggiore si ha per $I_{ib} = +17\mu A$ e

$V_{io} = 0.3\ mV$:

$$V_u\big|_{max} = -33K\Omega\ 45\mu A - \frac{51K\Omega}{2} \cdot 17\mu A - 2.8 \cdot 0.3\, mV$$

$$V_u\big|_{max} = -1485\ mV - 433.5\ mV - 0.84\ mV$$

$$\boxed{V_u\big|_{max} \cong -1.92\ V}$$

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