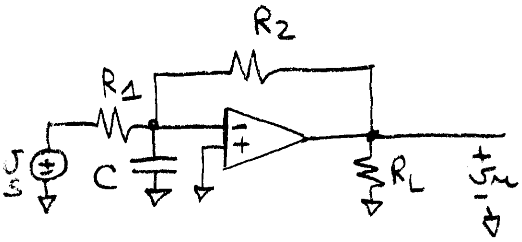
Esame di Elettronica - Corso di Laurea in Ingegneria delle Telecomunicazioni
12 gennaio 2005

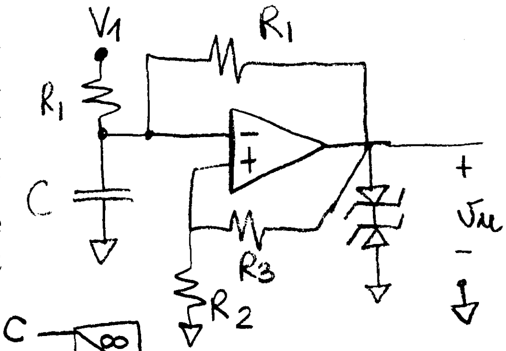
Parte A

1. Calcolare la funzione di trasferimento del circuito a lato. L'amplificatore ha resistenza di ingresso infinita, resistenza di uscita R_{out}=100 Ω, amplificazione di tensione A_v=2000, un polo di modulo 100 rad/s. Altri dati: R_1= R_2 = 1 kΩ, C=100 nF, R_L = 250 Ω.

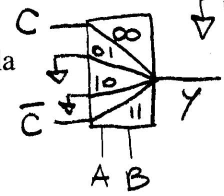


2. Realizzare un filtro passabanda con frequenza centrale 8 KHz e banda passante 400 Hz. Disegnare il circuito, calcolare la funzione di trasferimento e dimensionare i componenti, giustificando il procedimento.

3. Sia dato il circuito mostrato a lato. Calcolare l'andamento della forma d'onda all'uscita e agli ingressi dell'amplificatore operazionale, e rappresentarne l'andamento sullo stesso asse dei tempi, con precisione (in scala e quotando i punti). E' importante giustificare il procedimento. Supporre che l'operazionale sia ideale, R_1 = 1 kΩ, R_2 = 3 kΩ, R_3 = 12 kΩ, C = 100 nF, V_z = 10 V, V_1 = 5 V



4. Sia dato il circuito mostrato a lato. Disegnare e quotare la porta complessa CMOS che svolga stessa funzione logica.



Punteggio totale Parte A: 14

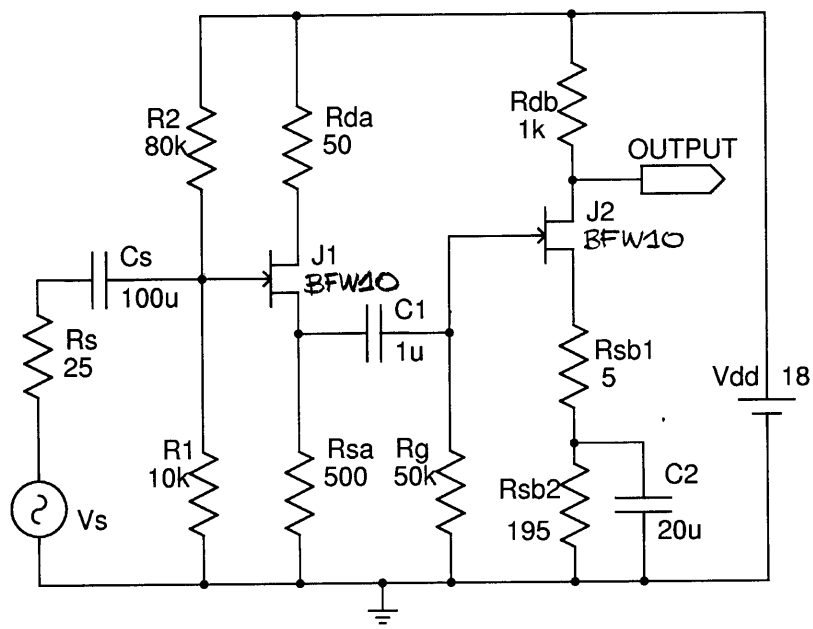
Parte B

Con riferimento al circuito mostrato a lato, calcolare:

- il punto di riposo dei due transistori J1 e J2 e i parametri del circuito di piccolo segnale.
- la funzione di trasferimento a centro banda.
- il limite superiore di banda
- il limite inferiore di banda.

Assunzioni semplificative:
- considerare J1 completamente resistivo.
- Considerare infinita la r_d dei due transistori

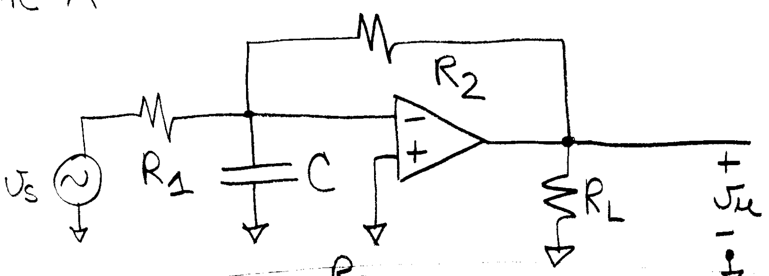
Estrarre graficamente il punto di riposo e i parametri di piccolo segnale

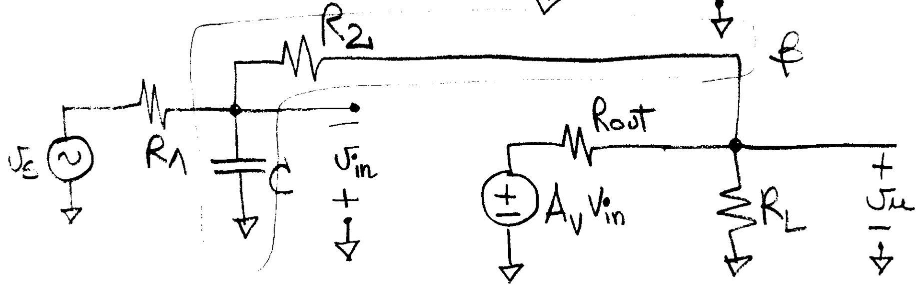


Punteggio totale Parte B: 14/30

Parte A

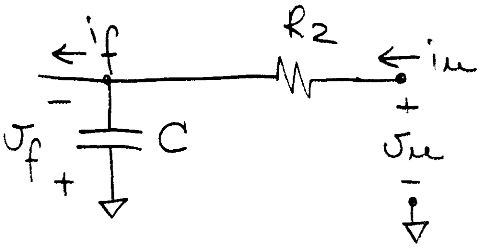
1.





Prelievo di tensione – Inserzione di corrente

Rete per il β



$$i_f = \beta v_u + \frac{v_f}{Z_{o\beta}}$$

$$i_u = \frac{v_u}{Z_{i\beta}} + ~~h~~ v_f$$

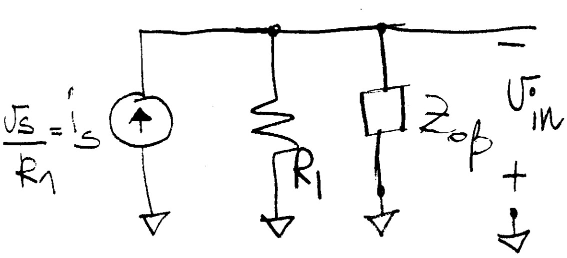
trascuro ~~K1~~

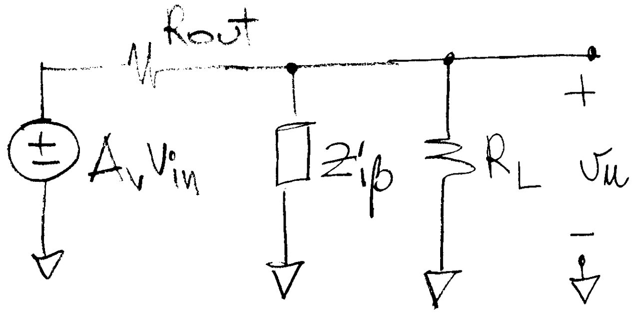
$$\beta \triangleq \left.\frac{i_f}{v_u}\right|_{v_f=0} = \frac{1}{R_2}$$

$$Z_{o\beta} \triangleq \left.\frac{v_f}{i_f}\right|_{v_u=0} = \frac{R_2}{R_2 C s + 1}$$

$$Z_{i\beta} \triangleq \left.\frac{v_u}{i_u}\right|_{v_f=0} = R_2$$

Rete per $A_e = \left.\frac{v_u}{i_s}\right|_{\beta=0}$





$$v_{in} = \frac{-Z_0\beta R_1}{Z_0\beta + R_1} i_s = \frac{-R_2 R_1}{R_1 + R_2 + R_1 R_2 C s} i_s$$

$$v_u = \frac{(A_v v_{in}) R_2 /\!/ R_L}{R_{out} + R_2 /\!/ R_L}$$

$$A_e = \left.\frac{v_u}{i_s}\right|_{\beta=0} = \frac{-R_2 R_1}{R_1 + R_2 + R_1 R_2 C s} \cdot \frac{R_2 /\!/ R_L}{R_{out} + R_2 /\!/ R_L} \cdot \frac{A_{v\varnothing}}{1 + s/\omega_p}$$

$$A_F = \frac{A_e}{1 - \beta A_e} = \frac{-R_2 R_1 (R_2 /\!/ R_L) A_{v\varnothing} \,/\, (R_{out} + R_2 /\!/ R_L)}{(R_1 + R_2 + R_1 R_2 C s)\left(1 + \frac{s}{\omega_p}\right) + \frac{R_1 (R_2 /\!/ R_L) A_{v\varnothing}}{R_{out} + R_2 /\!/ R_L}}$$

$$A_{F\varnothing} = \left.A_F\right|_{s=0} = \frac{\frac{-R_2 (R_2 /\!/ R_L) R_1}{R_{out} + R_2 /\!/ R_L} A_{v\varnothing}}{R_1 + R_2 + \frac{(R_2 /\!/ R_L) A_{v\varnothing} R_1}{R_{out} + R_2 /\!/ R_L}} \simeq -1000\,\Omega$$

$$\left.A_{F\varnothing} = \frac{v_u}{i_s}\right|$$

ci sono due poli che sono le radici del denominatore

$$\frac{R_1 R_2 C}{\omega_p} s^2 + s\left[R_1 R_2 C + \frac{(R_1 + R_2)}{\omega_p}\right] + R_1 + R_2 + \frac{R_1 (R_2 /\!/ R_L)}{R_{out} + R_2 /\!/ R_L} A_{v0} = 0$$

$$\frac{10^3 \cdot 10^3 \cdot 100 \cdot 10^{-9}}{100} s^2 + s\left[10^3 \cdot 10^3 \cdot 100 \cdot 10^{-9} + \frac{2000}{100}\right] + 2000 + \frac{1000\,(200)}{200 + 200} \cdot 2000 = 0$$

$$10^{-3} s^2 + 20.1\, s + 1.33 \cdot 10^6 = 0$$

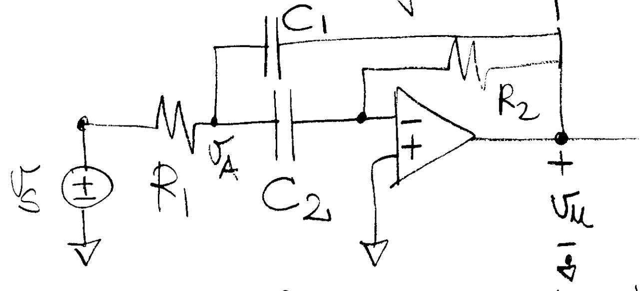
$$s_{p1}, s_{p2} = \frac{-20.1 \pm \sqrt{(20.1)^2 - 4 \cdot 10^{-3} \cdot 1.33 \cdot 10^{6}}}{2 \cdot 10^{-3}} = \frac{-20.1 \pm j\,70.11}{2 \cdot 10^{-3}} = 10.1 \pm j35.1 \text{ Krad/s}$$

$$A_F = \frac{A_{F0}}{\left(1 - \frac{s}{|s_{p1}|}\right)\left(1 - \frac{s}{|s_{p2}|}\right)}$$

---

2)

Realizziamo un filtro passabanda con un filtro di Delyannis



calcoliamo la fdt supponendo l'A.O. ideale, usando il metodo dei nodi

$$v_A\left[\frac{1}{R_1} + C_2 s + C_1 s\right] - \frac{v_S}{R_1} - C_1 s\, v_u = 0$$

$$v_A C_2 s = -\frac{v_u}{R_2} \qquad v_A = \frac{-v_u}{R_2 C_2 s}$$

$$\frac{-v_u}{R_2 C_2 s}\left[1 + R_1(C_1 + C_2)s\right] - v_S - R_1 C_1 s\, v_u = 0$$

$$v_u\left[1 + R_1(C_1 + C_2)s + R_1 R_2 C_1 C_2 s^2\right] = -v_S R_2 C_2 s$$

$$\frac{v_u}{v_S} = \frac{-R_2 C_2 s}{1 + R_1(C_1 + C_2)s + R_1 R_2 C_1 C_2 s^2}$$

frequenza centrale 8KHz $\rightarrow \frac{1}{R_1 R_2 C_1 C_2} = \omega_0^2 = (2\pi \cdot 8000)^2$

banda passante 400 Hz $\Rightarrow Q = 20$

$$R_1(C_1 + C_2) = \frac{1}{\omega_0 Q} = \frac{1}{2\pi \cdot 8000 \cdot 20}$$

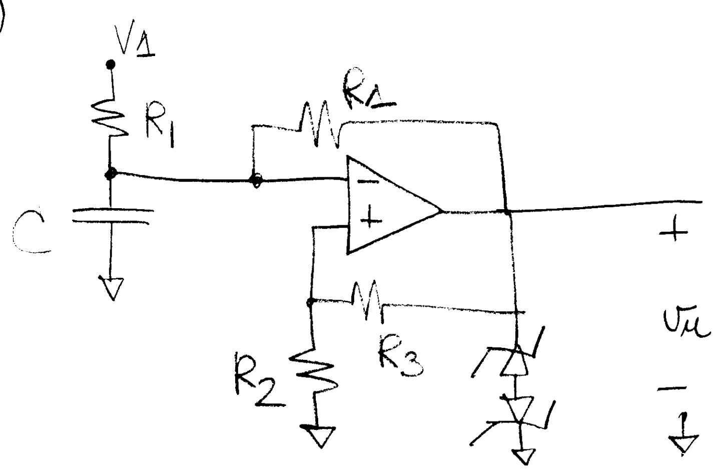
poniamo $C_1 = C_2 = 100\,nF = C$

$$R_1 = \frac{1}{2C\left(2\pi \cdot 8000 \cdot 20\right)} = 4.98\,\Omega$$

$$R_2 = \frac{1}{R_1 C^2 \omega_0^2} = 7961.8\,\Omega$$

---

(3)

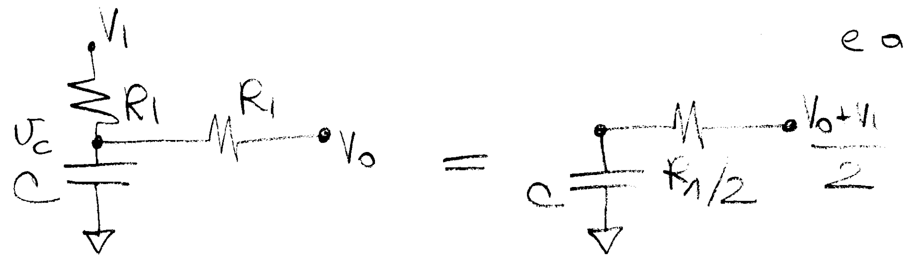


$V_0 = V_Z + V_\gamma = 10.7V$

poniamo che per $t=0$ la capacità sia scarica e $v_u = +V_0$.

La capacità comincia a caricarsi con costante di tempo $\tau = \frac{R_1 C}{2} = 0.5 \cdot 10^{-4}\,s$

e asintoto $\frac{V_0 + V_1}{2} = 7.85V$



la commutazione si ha quando $v_c = \frac{R_2}{R_2 + R_3} \cdot v_0 = 0.2 \cdot 10.7 = 2.14V$

all'istante t_1 dato da

$$v_c(t_1) = \left[\frac{V_0 + V_1}{2}\right]\left[1 - e^{-\frac{t_1}{\tau}}\right] = \frac{V_0}{5}$$

$$+\frac{V_0 + V_1}{2} e^{-t_1/\tau} = +\frac{3}{10}V_0 + \frac{V_1}{2}$$

$$t_1 = \tau \ln\left(\frac{V_0 + V_1}{\frac{3}{5}V_0 + V_1}\right) = 15.9\,\mu s$$

Scarica - costante di tempo τ, asintoto $\frac{V_1 - V_0}{2} = -2{,}85\,V = V_A$

$$v_C(t_2) = -\frac{V_0}{5} = \frac{V_0}{5} + \left[V_A - \frac{V_0}{5} \right]\left(1 - e^{-(t_2-t_1)/\tau}\right)$$

$$V_A + \frac{V_0}{5} = e^{-\frac{t_2-t_1}{\tau}} \left[V_A - \frac{V_0}{5} \right]$$

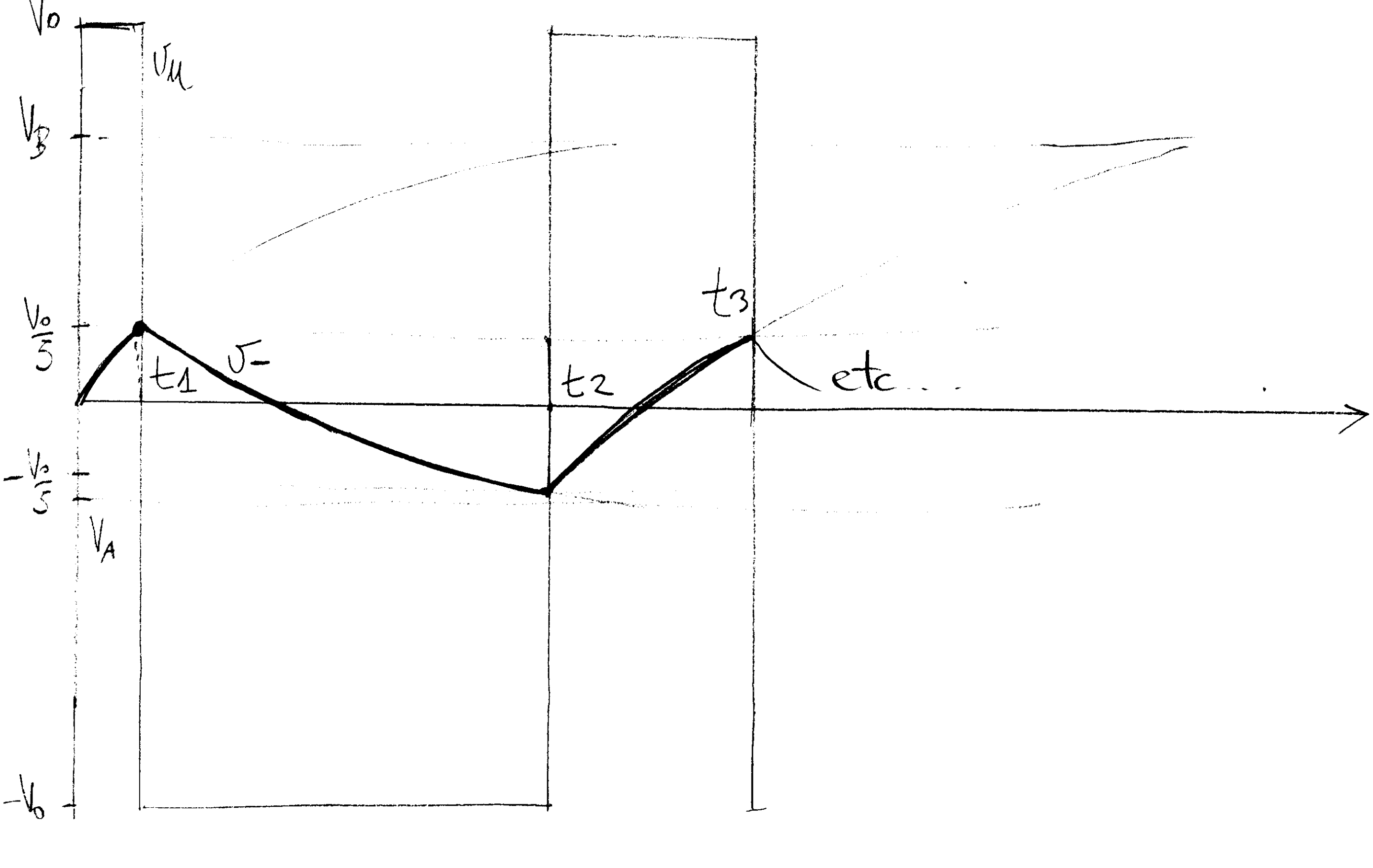
$$t_2 - t_1 = \tau \ln\left[\frac{V_A - V_0/5}{V_A + V_0/5}\right] = 0{,}5 \cdot 10^{-4} \ln\left[\frac{-2{,}85 - 2.14}{-2{,}85 + 2{,}14}\right] = 97{,}5\,\mu s$$

Carica - costante di tempo τ, asintoto $V_B = \frac{V_0 + V_1}{2} = 7{,}85\,V$

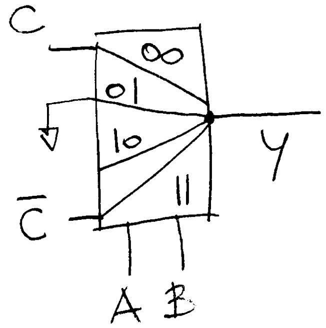
$$v_C(t_3) = \frac{V_0}{5} = -\frac{V_0}{5} + \left(V_B + \frac{V_0}{5}\right)\left(1 - e^{-(t_3-t_2)/\tau}\right)$$

$$V_B - \frac{V_0}{5} = \left(V_B + \frac{V_0}{5}\right) e^{-(t_3-t_2)/\tau}$$

$$t_3 = \tau \ln\left[\frac{V_B + V_0/5}{V_B - V_0/5}\right] = 0{,}5 \cdot 10^{-4} \ln\left[\frac{7.85 + 2{,}14}{7{,}85 - 2{,}14}\right] = 28\,\mu s$$

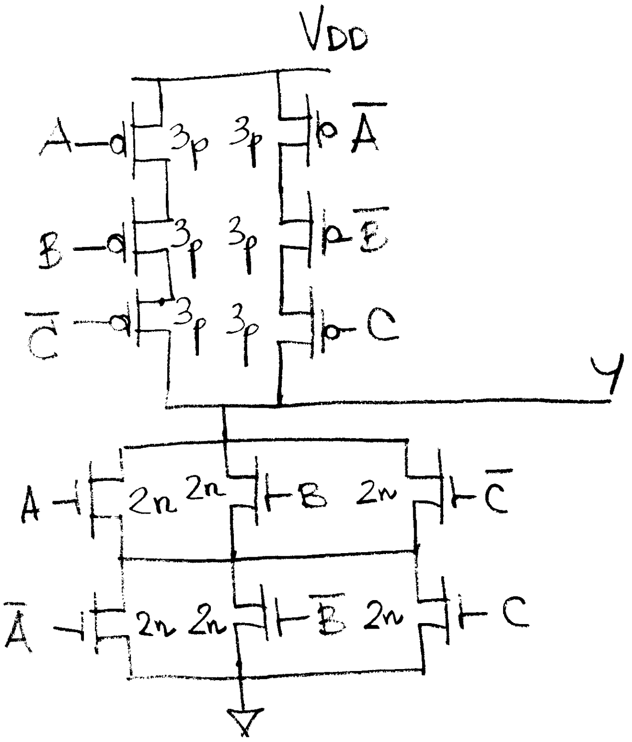


④

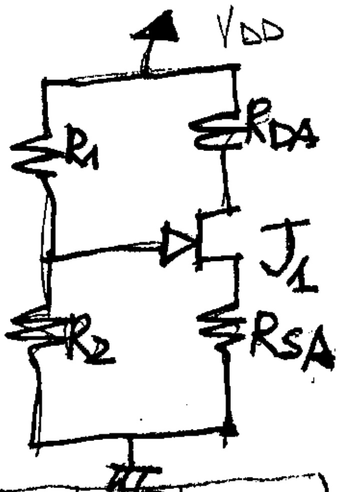


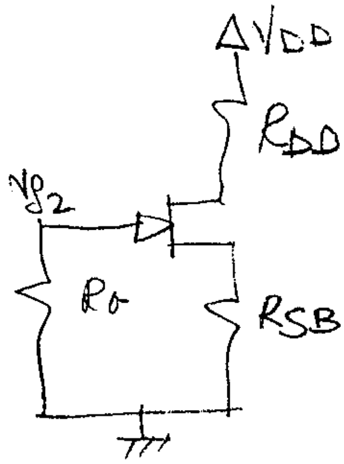
$Y = \bar{A}\bar{B}C + AB\bar{C}$

C \ AB	00	01	11	10
0	0	0	1	0
1	1	0	0	0



Polarizzazione





$V_{DD} = 18V$

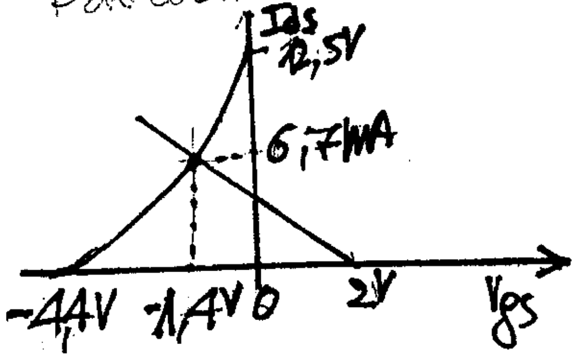
Punto di Riposo

Retta di carico: J1

$$V_{gs1} = \frac{V_{DD}\, R_2}{R_1+R_2} - R_{SA}\, I_{dsA}$$

2 V

Dalle caratteristiche:

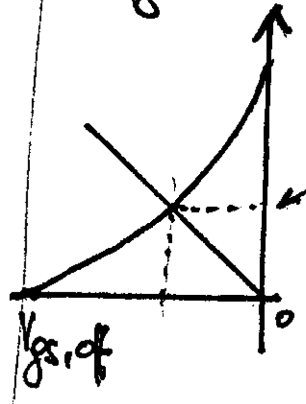


$I_{ds} \cong 6{,}7mA$

Retta di carico J2

$V_{g2} = 0$

$$V_{gs2} = -R_{SB}\, I_{dsB}$$



I due JFET lavorano praticamente nello stesso punto di riposo

Transconduttanza

$$g_{m1} = \frac{\Delta I}{\Delta V_{gs}} \cong \frac{11{,}5mA}{3{,}4V} \cong 3.6\ mS = g_{m2}$$

Capacità:

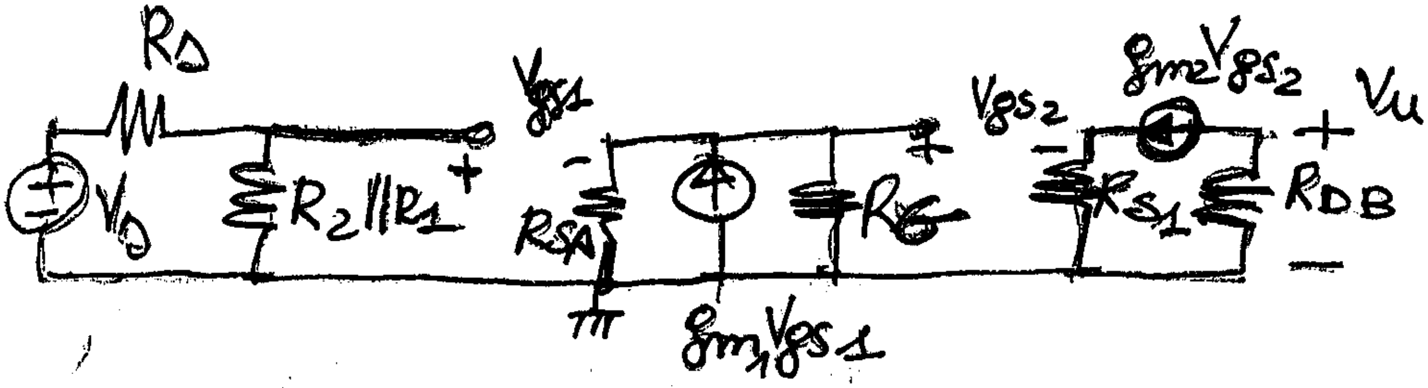
dal manuale:

$C_{iss} = C_{gs} + C_{gd} = 4pF$

$|C_{rss}| = C_{gd} = 0{,}6pF$

quindi: $C_{gs} = 3{,}4pF$

Amplificazione a Centro Banda



$$V_{g1} = \frac{R_2 || R_1}{R_S + R_2 || R_1} \cdot V_S$$

$$V_{gs1} = V_{g1} - R_{SA} || R_G \, g_{m1} V_{gs1}$$

$$\downarrow$$

$$V_{gs1} = \frac{V_{g1}}{1 + R_{SA} || R_G \, g_{m1}}$$

$$V_{gs2} = V_{g1} - R_{S1} \, g_{m2} V_{gs2}$$

$$\downarrow$$

$$V_{gs2} = \frac{V_{S1}}{1 + R_{S1} g_{m2}}$$

$$V_{S1} = \frac{g_{m1} R_{SA} || R_G}{1 + R_{SA} || R_G \cdot g_{m1}} \cdot V_{g1}$$

$$V_u = -R_{DB} \cdot g_{m2} V_{gs2}$$

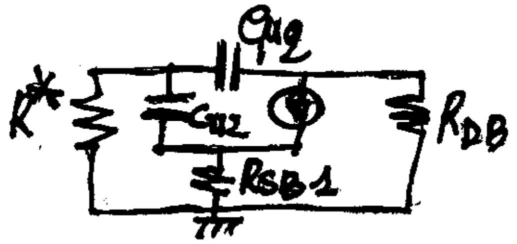
$$\downarrow$$

$$A_{CB} = \underbrace{\frac{-(R_{DB} g_{m2})}{(1 + R_{S1} g_{m2})}}_{3.57} \cdot \underbrace{\frac{g_{m1} R_{SA} || R_G}{1 + (R_{SA} || R_G) g_{m1}}}_{0.64} \cdot \underbrace{\frac{R_2 || R_1}{R_S + R_2 || R_1}}_{0.99} = -2.26$$

$$3.57 \times 0.64 \times 0.99$$

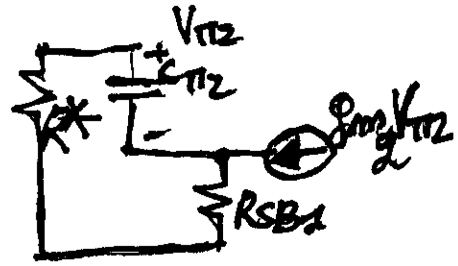
Limite superiore di banda

Resistenze viste dalle capacità di JFET2



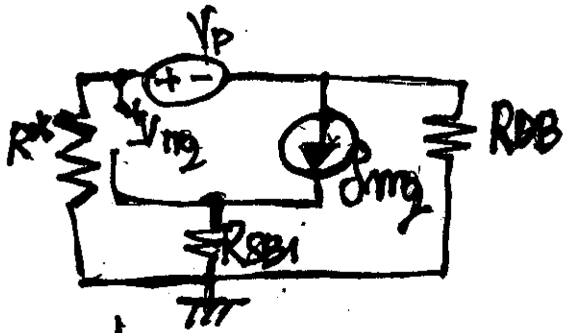
$$R^* = R_{SA} \| R_G \| g_{m_1}^{-1}$$

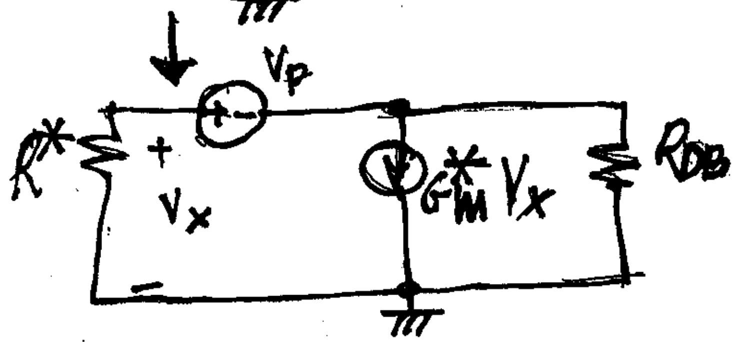
$R_{VC\pi 2}$:



$$R_{VC\pi_2} = \frac{R^* + R_{SB1}}{1 + R_{SB1} g_{m_2}} \cong 180\,\Omega$$

$R_{VC\mu 2}$:





$$V_{\pi 2} = V_x - R_{SB1} g_m V_{\pi}$$

$$V_{\pi 2} = \frac{V_x}{1 + g_m R_{SB1}}$$

$$G_m^* = \frac{g_{m2}}{1 + g_{m_2} R_{SB1}}$$

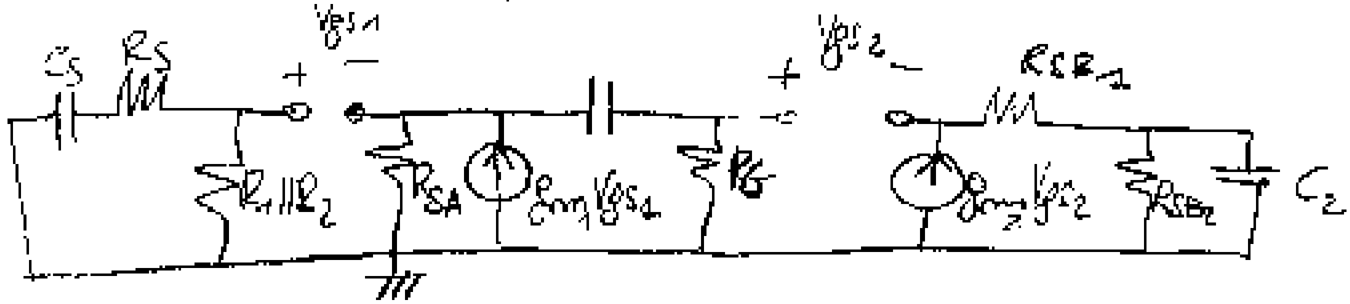
pertanto:

$$R_{VC\mu_2} = R^* + R_{DB} + R_{DB} \cdot R^* G_m^*$$

$$= R_{SA} \| R_G \| g_{m_1}^{-1} + R_{DB} + \frac{g_m (R_G \| R_{SA} \| g_m^{-1}) R_{DB}}{1 + g_m R_{SB1}} = 1807\,\Omega$$

Si trascurano i contributi di J1

pertanto
$$f_H = \frac{1}{2\pi (R_{VC\pi 2} C_{\pi 2} + R_{VC\mu 2} C_{\mu 2})} \cong 56\ \text{MHz}$$



Si trovano:

$$R_{VCS} = R_S + R_1 \| R_2 \cong 8{,}9\ K\Omega$$

$$R_{VC2} = R_{SB2} \,\|\, \left(R_{SB1} + \frac{1}{g_{m2}} \right) \cong 115\ \Omega$$

$$R_{VC1} = R_{SA} \,\|\, \frac{1}{g_{m1}} + R_G \cong 50{,}2\ K\Omega$$

Quindi:

$$f_L = \frac{1}{2\pi} \left[\frac{1}{R_{VCS} \cdot C_S} + \frac{1}{R_{VC2} \cdot C_2} + \frac{1}{R_{VC1} \cdot C_1} \right]$$

$$\cong 69\ Hz$$