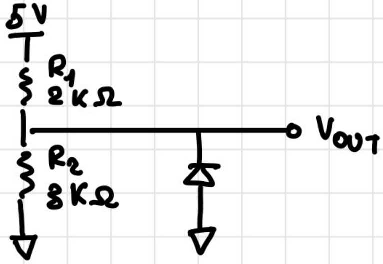
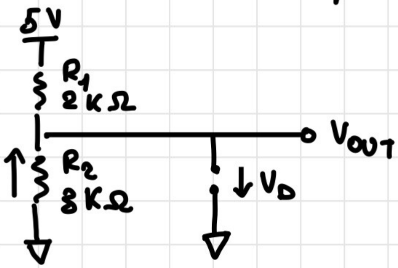
30/09/21

ESERCIZIO 1



$V_{OUT} = ?$

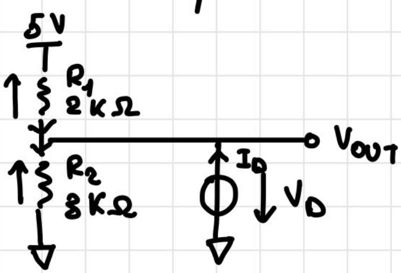
Ipotizziamo diodo spento e verifichiamo:



$$V_D = -V_{R_2} = -5 \cdot \frac{3\cancel{k\Omega}}{5\cancel{k\Omega}} = -3\,V$$

$$V_{OUT} = -V_D = 3\,V$$

Se avessimo ipotizzato diodo ACCESO avremmo ottenuto:



$I_D > 0$?

$V_{R_2} = -V_D = -0{,}7\,V$

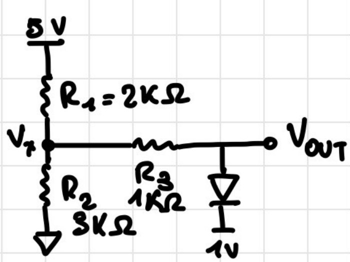
$I_{R_2} = -0{,}7V / 3k\Omega = -0{,}23\,mA$

$V_{R_1} = 5V - V_{R_2} = 5{,}7\,V$

$I_{R_1} = 5{,}7V / 2k\Omega = 2{,}85\,mA$

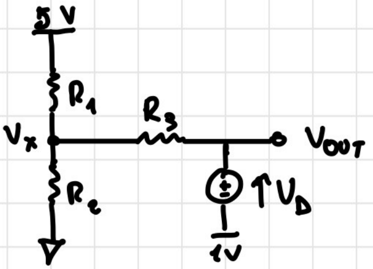
$I_D = -0{,}23 - 2{,}85 < 0$!! diodo i spento

ESERCIZIO 2

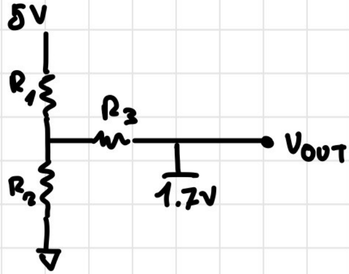


$V_{OUT} = ?$ $V_x = ?$

Ipotizziamo diodo acceso:



$\equiv$

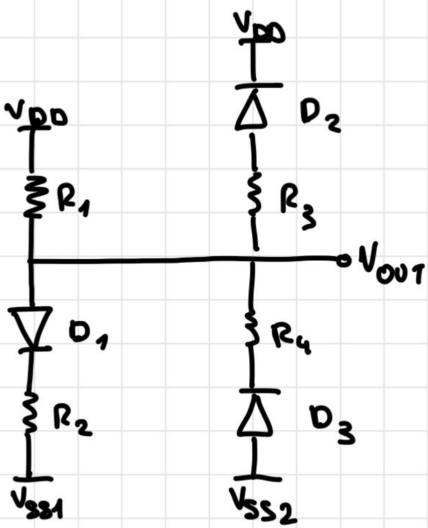


PSI... $\rightarrow$ $I_D = \cdots = 0.59\ mA$ $\rightarrow$ diodo acceso

$\rightarrow$ $V_{OUT} = \cdots = 1.7\ V$

$V_x = \ldots = 2,29\ V$

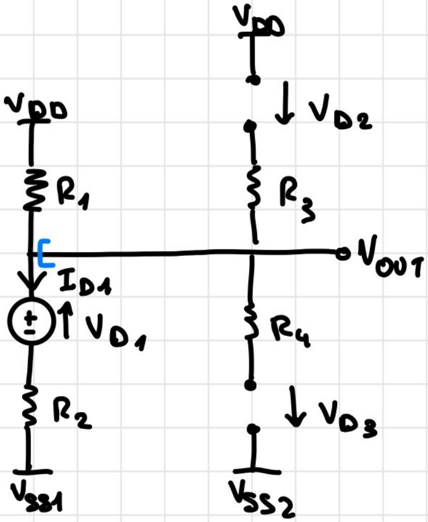
ESERCIZIO 3



$V_{DD} = 3\ V$
$V_{SS1} = -2\ V$
$V_{SS2} = -7\ V$
$R_1 = 1\ K\Omega$
$R_2 = 1,7\ K\Omega$
$R_3 = 4,3\ K\Omega$
$R_4 = 5\ K\Omega$

$V_{OUT} = ?$

Ipotizziamo D1 : acceso $\rightarrow$ $I_{D1} > 0$?
D2 : spento $\rightarrow$ $V_{D2} > 0$?
D3 : spento $\rightarrow$ $V_{D3} > 0$?



$V_{OUT} = V_{SS1} + V_{R2} + 0.7V$

$V_{R2} = I_D R_2$

$V_{R1} + 0.7V + V_{R2} = 5V$

↳ $V_{R1} + V_{R2} = 4,7V$

↳ $I_{D1} = 4,3V/(R_1+R_2) = 1,59\ mA$

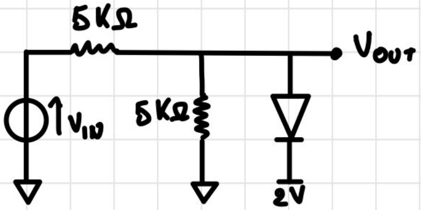
$\Rightarrow V_{OUT} = \dots = 1.4V$

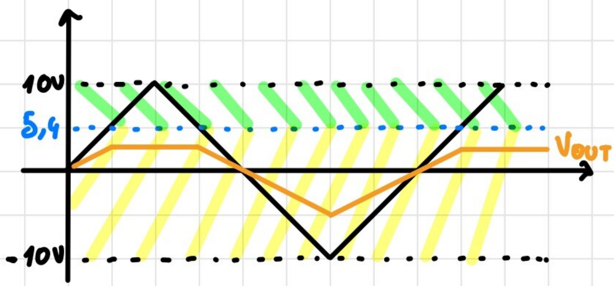
$V_{D2} = V_{OUT} - V_{DD} = \dots = -1.6V$

$V_{D2} = V_{SS2} - V_{OUT} = \dots = -8,4V$

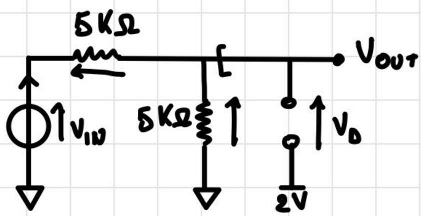
05/10/2021

ESERCIZIO 1





Ipotesi di diodo spento:



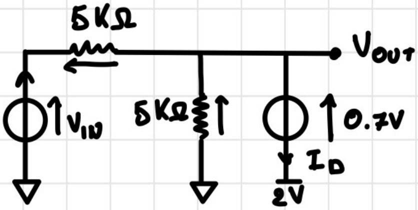
$V_{OUT} = V_{IN}/2$

$V_D = V_{OUT} - 2V = V_{IN}/2 - 2V$

$V_{IN} < (0,7V + 2V) \cdot 2 = 5,4$

$I_D = 0, \quad I_{R1} = I_{R2} = V_{IN}/10K\Omega$

Se consideriamo il diodo acceso:



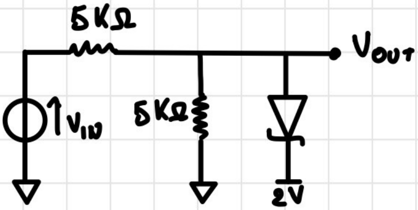
$V_{R_2} = 2{,}7V$ $I_{R2} = R_2 I_{R_2} = 0.54\ mA$

$V_{OUT} = 2{,}7V$

$I_{R_1} = V_{IN} - V_{R_2} / 5K\Omega = V_{IN} - 2{,}7 / 5K\Omega$

$I_D = I_{R_1} - I_{R_2} = \dots = V_{IN}/5K\Omega - 1.08\ mA$

Sostituiamo al diodo un diodo zener con $V_{BD} = -2V$ e ricalcoliamo i parametri

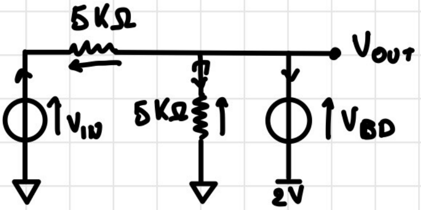


...

$0V < V_{IN} < 5{,}4\ V$

$\downarrow$

breakdown



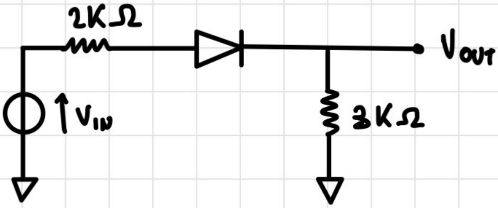
$V_{OUT} = V_{BD} + 2V = 0\ V$

$I_{R_2} = 0\ A$

$I_{R1} = V_{IN} / 5K\Omega$

$I_{D1} = I_{R1}$

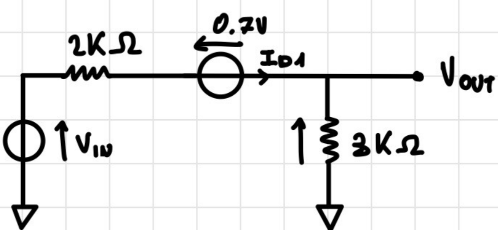
ESERCIZIO 2



$V_{IN} = 5V \cdot \sin(2\pi f t)$

$f = 1\ KHz$

Ipotizziamo diodo acceso:

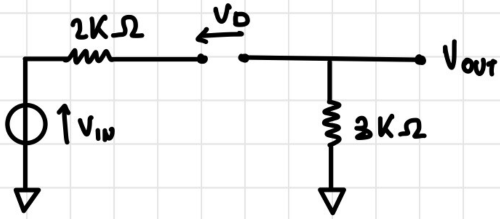


$I_{D1} = (V_{IN} - 0.7V) / 5K\Omega$

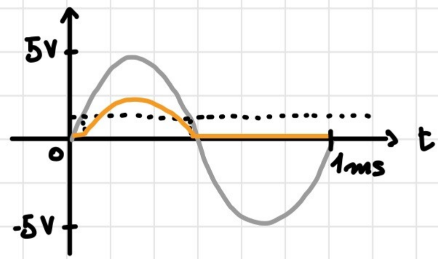
$I_{D1} > 0 \rightarrow \frac{V_{IN}}{\cancel{5K\Omega}} > \frac{0.7V}{\cancel{5K\Omega}}$

$V_{OUT} = \dots = 0{,}6V_{IN} - 0.42\ V$

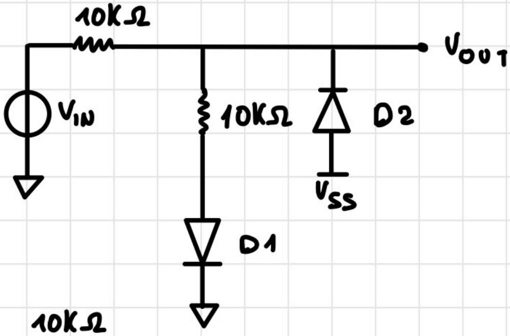
Se il diodo è spento:



$V_{OUT} = 0\,V$



ESERCIZIO 3

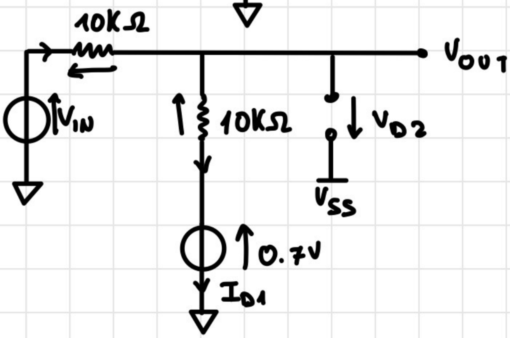


$V_{IN} = 5\,V \sin(2\pi\, 1KHz\, t)$

$V_{SS} = -2\,V$

IPOTESI: D2 spento

D1 acceso



$I_{D1} = \dfrac{V_{IN} - 0.7V}{20\,K\Omega}$

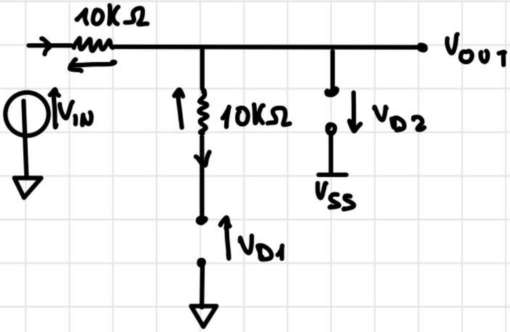
↳ $V_{IN} > 0.7$ per D_1 acceso

$$\begin{aligned} V_{D2} &= -2V - V_{OUT} \\ &= -2V - 0.7V - I_{D1} R_2 \\ &= -2{,}7V - \frac{V_{IN} - 0.7V}{2} \\ &= -2{,}35V - \frac{V_{IN}}{2} \end{aligned}$$

↳ $V_{IN} > 6{,}05\,V \quad \forall V_{IN}$

$\Rightarrow V_{IN} > 0.7V \Rightarrow \begin{cases} D_1 \text{ acceso} \\ D_2 \text{ spento} \end{cases} \rightarrow V_{OUT} = 0{,}35V + V_{IN}/2$

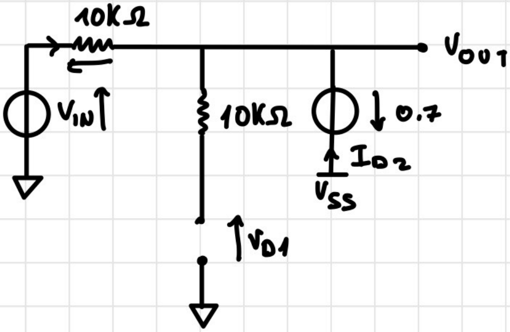
Se D_1 è spento, anche D2 rimarrà spento:



$$V_{D2} = -V_{D1} + V_{SS} = -V_{IN} - 2V$$
$$V_{D1} = V_{IN}$$

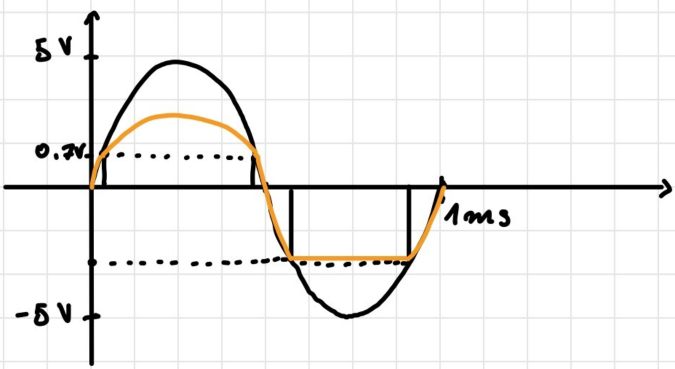
$$\begin{cases} V_{IN} < 0.7\,V \\ V_{IN} > -2,7\,V \end{cases} \rightarrow V_{OUT} = V_{IN}$$

Per $V_{IN} < -2,7\,V$ il diodo 2 si accende:



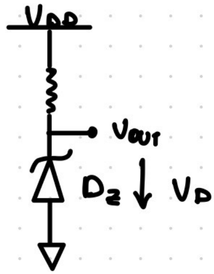
$$V_{OUT} = -2,7\,V$$
$$I_{D2} = -I_{R_1} = \frac{V_{IN} + 2,7V}{10K\Omega}$$
$$\hookrightarrow I_{D2} > 0A \checkmark$$

$$V_{D1} = -2,7\,V < 0.7V \checkmark$$



12/10/21

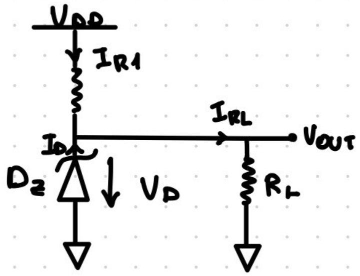
ESERCIZIO 1



$V_{DD} = 10V$
$R_1 = 1K\Omega$
$V_{BD} = -5,1V$

Hp: D_Z spento $V_D = 0 - V_{OUT} = 0 - V_{DD} = -10V < V_{BD}$
$\Rightarrow$ non è spento!
$\Rightarrow$ siamo in BD

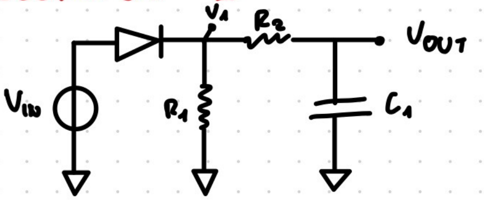
$V_{OUT} = -V_{BD} = 5,1V$



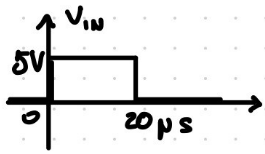
Affinché D_Z sia ancora in breakdown $I_D < 0$.

$I_D = I_{RL} - I_{R1} = \frac{5,1}{R_L} - \frac{10V - 5.1V}{1K\Omega} < 0$
$\Rightarrow R_L > 1,04 K\Omega$

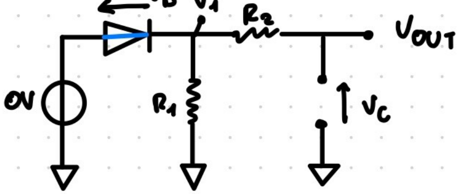
ESERCIZIO 2



$R_1 = R_2 = 10 K\Omega$
$C_1 = 1000 pF$



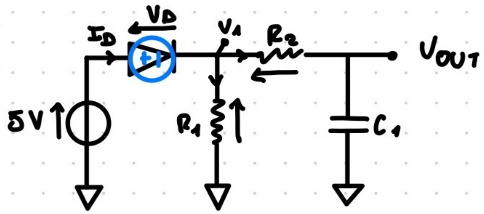
$t < 0s$



Hp: diodo spento $\to V_D = 0V$ ✓

$V_{OUT} = 0V$, $V_1 = 0V$
$V_C = 0V$, $i_C = 0V$

$\boxed{t=0}$



$V_C = 0\,V$ (continuità)
$\Rightarrow V_{OUT} = 0V$

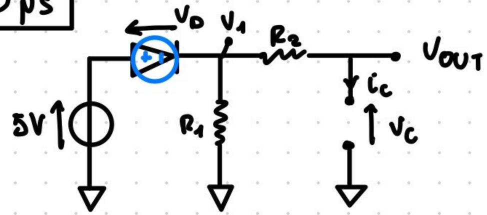
Hp: diodo acceso

$V_1 = V_{IN} - V_D = 4{,}3\,V$

$i_C = i_{R2} = \dfrac{4{,}3V}{10K\Omega} = 0{,}43\ mA$

$i_D = i_{R1} + i_{R2} = 0{,}86\ mA$

$\boxed{t = 20\,\mu s}$



$i_C = 0$

Hp: diodo acceso

$i_D = i_{R1} = \dfrac{V_1}{R_1} = \dfrac{5V - 0.7V}{R_1} = 0{,}43\ mA > 0$ ✓

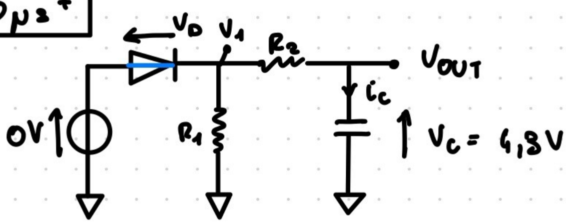
$V_1 = i_D \cdot 10\,K\Omega = 4{,}3V$

$V_{OUT} = V_1 = V_C = 4{,}3V$

$\tau = C \cdot R_{eq} = 1000\,nS = 1\,\mu S \rightarrow 5\tau < 20\,\mu S \Rightarrow$ il circuito è stazionario!

↘ spento diodo e gen.

$\boxed{t = 20\,\mu s^+}$



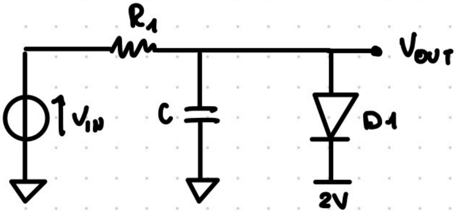
Hp: diodo spento: $V_D = -V_1 = -V_{OUT}\dfrac{R_1}{R_1+R_2} = \cdots = -2{,}15V < 0.7V$ ✓

$i_C = -\dfrac{+2{,}15}{10K\Omega} = 0{,}215\ mA$

$t = \infty s$ uguale a $t < 0s$ $\qquad \tau = C \cdot (R_1 + R_2) = 2\,\mu S$

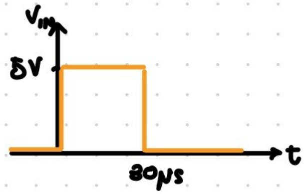
14/10/21

ESERCIZIO 1

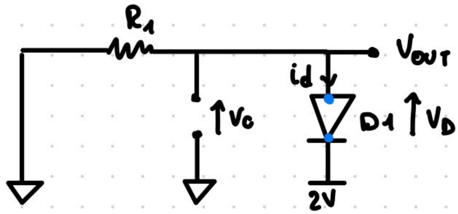


$R_1 = 7\,K\Omega$

$C_1 = 2\,nF$



$\boxed{t<0}$



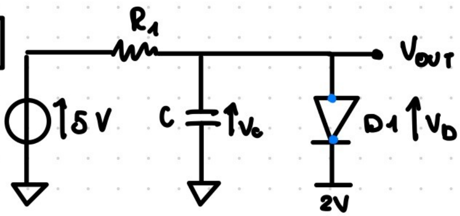
$V_D < 0.7V$?

$V_D = \cancel{V_{OUT}} - 2V = -2V < 0.7V$ ✓

$\downarrow$

$V_{OUT} = 0V = V_C$

$\boxed{t=0^+}$

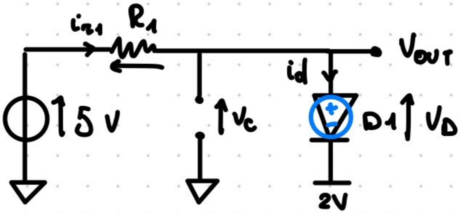


$V_{OUT} = V_C = 0V$

Diodo nella stessa situaz. di $t<0$

$\tau = R_1 \cdot C = 14\,\mu s$ con diodo spento!

$\boxed{t = 80\mu s^-}$ Supponendo regime:



$i_D > 0$?

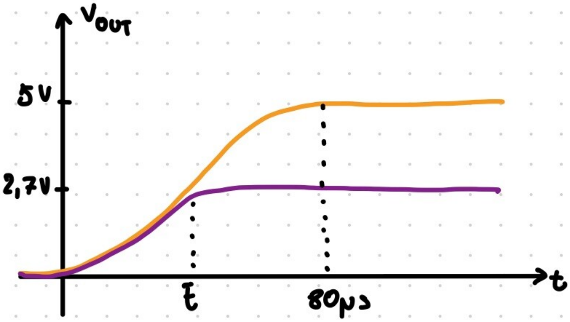
$i_D = i_{R1} = \dfrac{5V - V_{OUT}}{R_1} = \dfrac{5V - 2V + 0.7V}{7K\Omega}$

$= 0{,}33\,mA$ ✓

$V_{OUT} = V_C = 2{,}7\,V$

V_{OUT} tende ai 5V, come visto dall'analisi a regime forzando il diodo spento. Quindi il diodo si accenderà per

$V_D = V_{OUT} - 2V \geq 0.7V \rightarrow V_{OUT} \geq 2{,}7\,V$.



$V_{OUT} = 5V - 5V\, e^{-t/14\mu s}$

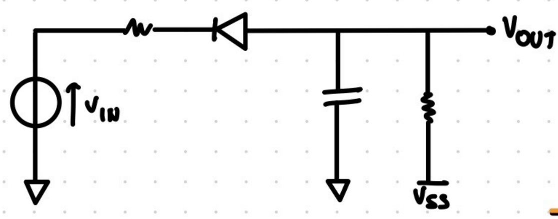
$V_{OUT}(\bar{t}) = 5V - 5V\, e^{-\bar{t}/14\mu s} = 2{,}7V$

$\rightarrow \cdots \rightarrow \bar{t} = \tau \cdot \ln(5V/2{,}3V)$

$= 10{,}87\ \mu s$

$t = 80\mu s^+$: $V_{OUT} = V_C = 2{,}7\ V$

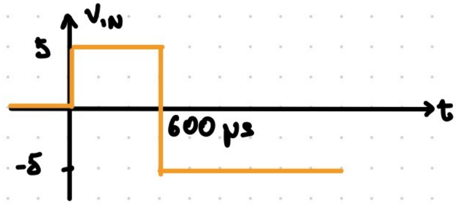
ESERCIZIO 2



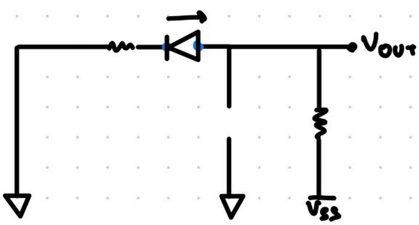
$V_{SS} = 1V$

$R_1 = 7K\Omega$ $R_2 = 2K\Omega$

$C = 70\ nF$



$\boxed{t < 0}$

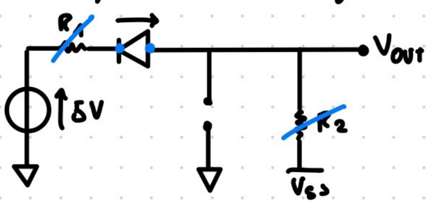


$V_D = -1V < 0.7V$ ✓

$V_{OUT} = V_C = -1V$

$\boxed{t = 0^+}$ $V_{OUT} = V_C = -1V$

$\boxed{t = T^-}$ Ipotizziamo regime:

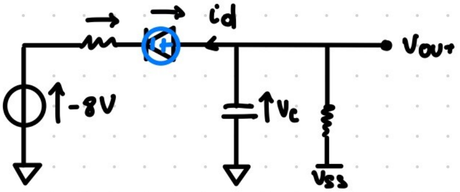


$V_D < 0.7V$?

$V_D = -1V - 5V = -6V$ ✓

$V_{OUT} = -1V = V_C$

$\boxed{t = T^+}$ $\quad V_{OUT} = -1V = V_C$

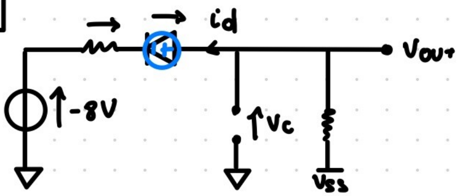


$I_D > 0$?

$V_{R1} = -1V - V_{IN} - 0.7 = 6{,}3\,V$

$I_{R1} = I_D = \cdots = 0{,}9\ mA$ ✓

$\boxed{t = +\infty}$



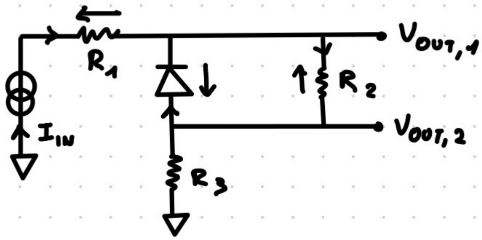
$I_D > 0$

$$I_D = \frac{(-8V + 0{,}7V + 1V)}{R_1 + R_2} = 0.7\ mA$$

$V_{OUT} = -1V + V_{R2} = \cdots = -2{,}4V$

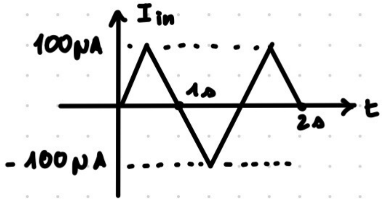
$$\tau = C \cdot \left(\frac{R_1 R_2}{R_1 + R_2}\right) = \cdots = 108{,}88\ \mu s$$

ESERCIZIO 3



$R_1 = 30\ K\Omega \quad R_2 = 20\ \Omega$

$R_3 = 50\ K\Omega$



1. Ipotizziamo D_1 acceso: $I_D > 0$?

$$I_{R_2} = I_{IN} - I_D = \frac{V_{R2}}{R_2} = \frac{0.7V}{20K\Omega} = 35\ \mu A$$

$I_D = I_{IN} - 35\mu A > 0$

$\rightarrow I_{IN} > 35\ \mu A$

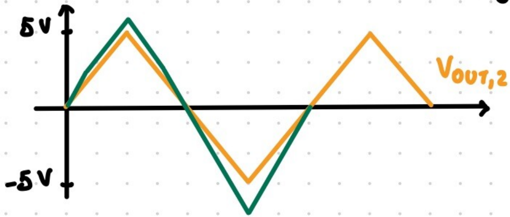
2. Nel caso di D_1 acceso: $V_{OUT,2} = I_{IN} \cdot R_3 = I_{in} \cdot 50\ K\Omega$

$V_{OUT,1} = V_{OUT,2} + 0{,}7V$

Nel caso di D_1 spento: $V_{OUT,2} = I_{IN} \cdot R_3 = I_{IN} \cdot 50\ K\Omega$

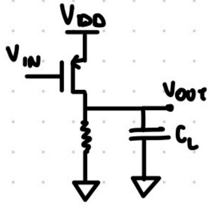
$V_{OUT,1} = V_{OUT,2} + I_{IN} \cdot R_2 = I_{IN}(R_2 + R_3)$

$= I_{IN} \cdot 70\ K\Omega$



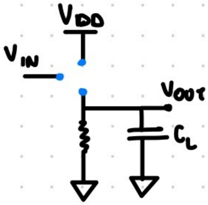
21/10/21

ESERCIZIO 1



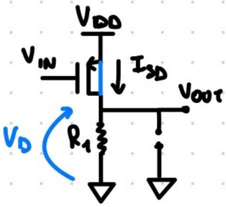
$R_1 = 1K\Omega$
$C_L = 1pF$
$V_{DD} = 3.3V$
$|V_{TP}| = 1V$
$K_P = 2\ mA/V^2$

$\boxed{V_{IN} = 3,3V}$



→ pMOS spento → $V_{OUT} = 0V$

$\boxed{V_{IN} = 0V}$



Supponiamo pMOS saturato:

$I_{SD} = |K_P|(V_{SG} - |V_{TP}|)^2 = \dots = 10,58\ mA$
$V_{OUT} = R_1 \cdot I_{SD} = 10,58V$ ✗ → uscita impossibile!
→ MOS ohmico

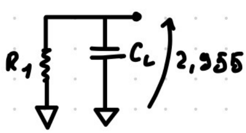
$$\begin{cases} I_{SD} = 2|K_P|\left[(V_{SG} - |V_{TP}|)\cdot V_{SD} - V_{SD}^2/2\right] \\ I_{SD} = V_D/R_1 \end{cases}$$

$\rightarrow V_D/1K\Omega = 2 \cdot 2\,mA/V^2 \cdot \left[2,3V\cdot(3,3 - V_D) - (3,3 - V_D)^2/2\right]$

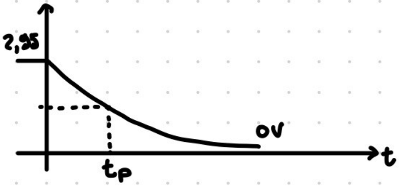
$\rightarrow \dots \rightarrow V_D = \begin{cases} -1,455\ V & ✗ \\ 2,955\ V \end{cases}$ V_{OUT} non può essere negativa

$\Rightarrow V_{OUT} = V_D = 2,955$ $\qquad V_{SD} = 0,345\,V < V_{SG} - |V_{TP}| = 2,3V$ ✓

Per $0 \xrightarrow{t=0} 1$, calcoliamo il tempo di commutazione:



→ $\tau = 1pF \cdot 1K\Omega = 1ns$



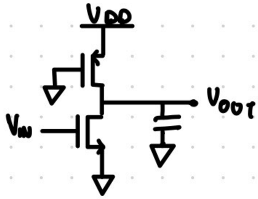
$V_{OUT} = 2,95 \cdot e^{-t/\tau}$
$\rightarrow 1,48 = 2,95\, e^{-t_P/t} \Rightarrow t_P = \dots = 0,69\ ns$

La potenza statica sarà:

$\boxed{V_{IN} = 3,3V}$ $I_{SD} = 0 \rightarrow P = 0W$

$\boxed{V_{IN} = 0V}$ $I_{SD} = 2,95A \rightarrow P = V_{DD} \cdot I_{SD} = 9,735\ mW$

ESERCIZIO 2



$|K_p| = \frac{1}{2} \mu_P C_{ox} \frac{W}{L} = 200\ \mu A/V^2$

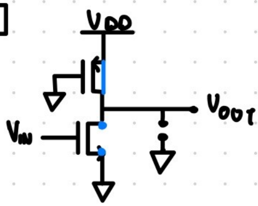
$K_n = \frac{1}{2} \mu_N C_{ox} \frac{W}{L} = 50\ \mu A/V^2$

$V_{tN} = |V_{tp}| = 1V$

$V_{DD} = 5V$

$C_L = 1pF$

$\boxed{V_{IN} = 0}$

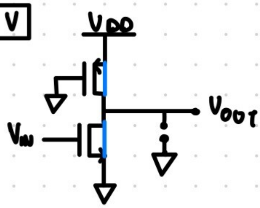


$V_{SG,P} = 5V > |V_{TP}| \rightarrow$ PMOS acceso

$V_{GS,N} = 0V < V_{tN} \rightarrow$ NMOS spento

poiché PMOS vede 2 CA, la $V_{SD,P} = 0$ e quindi $V_{OUT} = V_{DD} = 5V$

$\boxed{V_{IN} = 5V}$



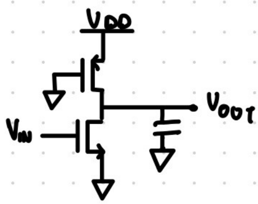
$V_{SG,P} = 5V > |V_{TP}| \rightarrow$ PMOS acceso

$V_{GS,N} = 5V > V_{TN} \rightarrow$ NMOS acceso

$V_{OUT} = 0V$ poiché è la tensione ai capi di un CC

26/10/21

ESERCIZIO 1



$|K_p| = \frac{1}{2} \mu_P C_{ox} \frac{W}{L} = 200\ \mu A/V^2$

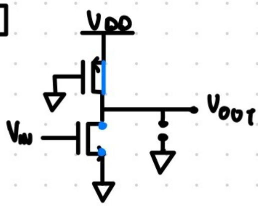
$K_n = \frac{1}{2} \mu_N C_{ox} \frac{W}{L} = 50\ \mu A/V^2$

$V_{tN} = |V_{tp}| = 1V$

$V_{DD} = 5V$

$C_L = 1pF$

$\boxed{V_{IN} = 0}$

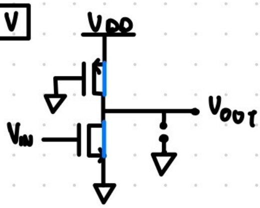


$V_{SG,P} = 5V > |V_{TP}| \rightarrow$ PMOS acceso

$V_{GS,N} = 0V < V_{tN} \rightarrow$ NMOS spento

poiché PMOS vede 2 CA, la $V_{SD,P} = 0$ e quindi $V_{OUT} = V_{DD} = 5V$

$\boxed{V_{IN} = 5V}$



$V_{SG,P} = 5V > |V_{TP}| \rightarrow$ PMOS acceso
$V_{GS,N} = 5V > V_{TN} \rightarrow$ NMOS acceso

$V_{OUT} = 0V$ poichè è la tensione ai capi di un cc

Dimensionare W/L del NMOS affinchè con $V_{IN} = 5V$ si abbia $V_{OUT} = 0{,}5V$.

$$V_{IN} = 5V \rightarrow \begin{cases} V_{G_N} = 5V \\ V_{S_N} = 0V \end{cases} \rightarrow V_{GS_N} = 5V > V_{TN} = 1V$$

$$V_{OUT} = 0{,}5V \rightarrow V_{DSN} = 0{,}5 < V_{GSN} - V_{TN} = 4V \rightarrow \text{OHMICO}$$
$$\rightarrow V_{SDP} = 4{,}5 > V_{SGP} - |V_{TP}| = 4V \rightarrow \text{SATURAZ.}$$

$$I_{SDP} = |K_P| (V_{SGP} - |V_{TP}|)^2 = \dots = 3{,}2 \text{ mA}$$

$$I_{DSN} = I_{SDP} = 2 K_N [(V_{GSN} - V_{TN}) V_{DSN} - V_{DS}^2/2]$$

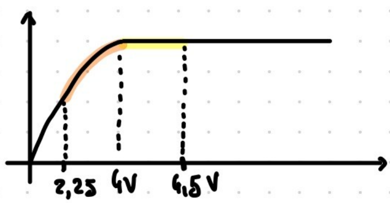
$\hookrightarrow K_N = \dots/\dots = 853{,}33 \ \mu A/V^2$

$\Rightarrow W/L = K_n/K'_n = \dots = 17$

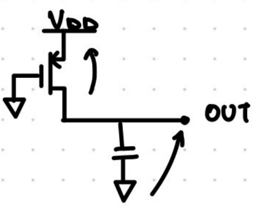
Nel caso in cui V_{IN} varia istantaneamente da 5V a 0V, calcolare il tempo di propagazione.

$V_{OUT}(V_{IN} = 5V) = 0.5V$

$V_{OUT}(V_{IN} = 0V) = 5V$

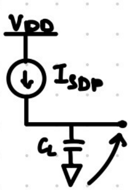


T_P è il tempo da $V_{OUT} = 0.5V$ a $V_{OUT} = 2{,}75V$.



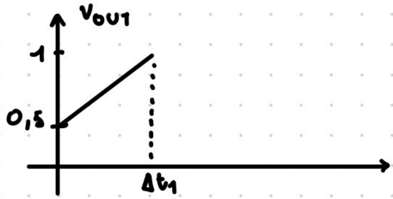
$V_{SDP}(0{,}5V) = 4{,}5V$
$V_{SDP}(2{,}75V) = 2{,}25V$

1) SATURAZIONE

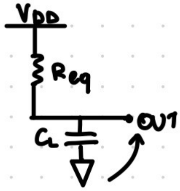


$I_C = C \cdot \frac{dV_C}{dt} \rightarrow I_{SDP} = C \frac{dV_C}{dt} \rightarrow$ deriv. costante

$\hookrightarrow \Delta t_1 = C_L \Delta V_{OUT} / I_{SDP} = \dots = 1{,}56$ ns

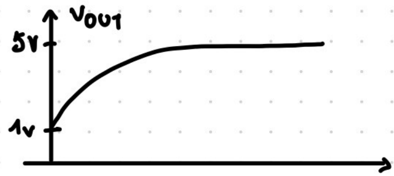


2) OHMICO



$R_{eq} = \dots = 1{,}25\ K\Omega$

$\tau = C_L R_{eq} = 12{,}5\ ns \rightarrow V_{OUT} = 4V\,(1 - e^{-t/\tau}) + 1V$



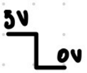
$\rightarrow\ 5V - 4V\,e^{-\Delta t_2/\tau} = 2{,}75\ V \rightarrow \dots \rightarrow \Delta t_2 = \dots = 7{,}19\ ns$

$\Rightarrow\ t_p = \dots = 8{,}75\ ns$

Calcolare la potenza statica dissipata.

$V_{IN} = 0V \rightarrow P = 0W$
$V_{IN} = 5V \rightarrow P = V_{DD} \cdot I_{SDP} = 16\ mW$

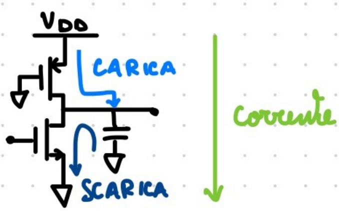
Calcolare la potenza dinamica data un'onda quadra con periodo 1ns e duty-cycle 50%.

V_{IN} : 

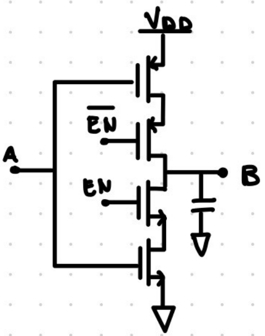
V_{OUT} : 

$E = \Delta Q \cdot V_{DD} = C_L \Delta V_{OUT} \cdot V_{DD}$

$\hookrightarrow P = \dfrac{E}{T} = \dots = 225\ \mu W$



ESERCIZIO 2



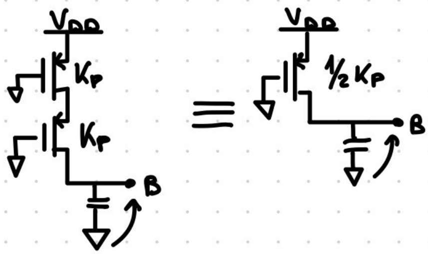
$K_P = 380\ \mu A/V^2$
$K_N = 380\ \mu A/V^2$

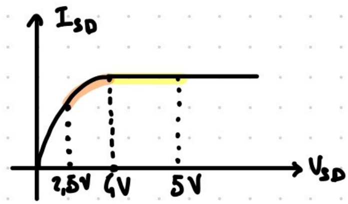
$V_{TN} = |V_{TP}| = 1V$
$V_{DD} = 5V$
$C_L = 4pF$

A	EN	B
0	0	HZ
0	1	$\bar{A}$
1	0	HZ
1	1	$\bar{A}$

Calcolare il tempo di propagazione con A=0 e EN = 0 → 1

A=0 ; EN=0 → B=HZ → supponiamo la capacità scarica
A=0 ; EN=1 → B=1 (non ci sarebbe nulla da calcolare sennò)





1) SATURAZIONE: $\Delta t_1 = C_L \Delta V_{OUT} / I_{SDP} = 1,31\ ns$
$I_{SDP} = |K_{eq}|(V_{SG} - |V_{TP}|)^2 = 3,04\ mA$

2) OHMICO: $R_{eq} = 4V / 3,04\ mA = 1,31\ K\Omega$
$\tau = C_L \cdot R_{eq} = 5,24\ ns$

$V_{OUT} = 5V - 4V e^{-t/\tau} \Rightarrow \dots \Rightarrow \Delta t_2 = \dots = 2,46\ ns$

$\Rightarrow t_p = 3,77\ ns$

Calcolare la potenza dinamica quando EN=1 e A è un'onda quadra con frequenza 400 KHz

→ come un'inverter: $E = C_L \Delta V_{OUT} V_{DD} = C_L V_{DD}^2$
$P = E \cdot f = C_L V_{DD}^2 f = 40\ \mu W$

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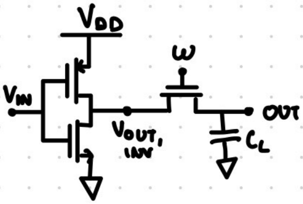
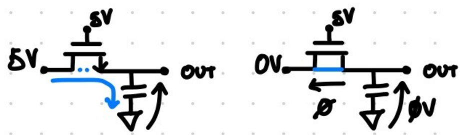
ESERCIZIO 1



$K_N = |K_P| = 1\ mA/V^2$
$V_{TN} = |V_{TP}| = 1V$
$V_{DD} = 5V$
$C_L = 1pF$

$\begin{cases} W=1 \\ V_{IN}=0 \end{cases} \rightarrow \begin{cases} V_{OUT,INV} = 5V \\ V_{OUT} = 5V - V_{TN} = 4V \end{cases}$

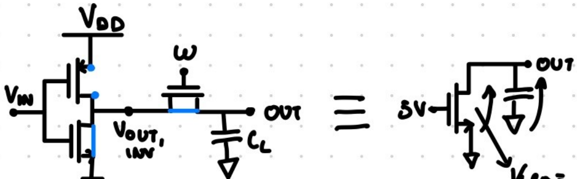


$\begin{cases} W=1 \\ V_{IN}=1 \end{cases} \rightarrow \begin{cases} V_{OUT,INV} = 0 \\ V_{OUT} = 0 \end{cases}$

Calcolare il tempo di propagazione con $W=1$ e $V_{IN} = 0 \rightarrow 1$

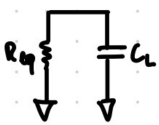
$V_{OUT} = 4V \rightarrow \emptyset V$ attraverso il condensatore

Con $V_{IN}=1$, $W=1$:



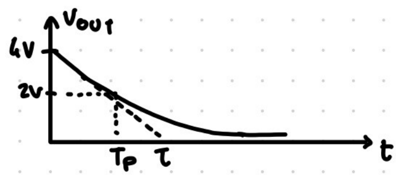
$K_{eq} = K_n/2 = 0,5\ mA/V^2$

$V_{DS} \equiv V_{OUT} \in [0; 4V] \Rightarrow$ tutto in regione ohmica



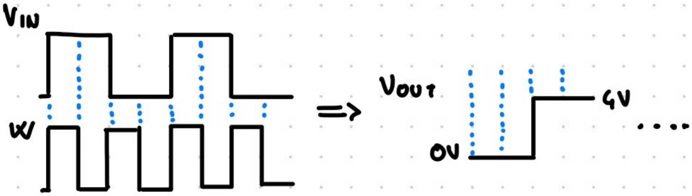
$R_{eq} = \frac{V_{GSN} - V_{TN}}{I_{DS,SAT}} = \frac{\cancel{4V}}{0,5 \frac{mA}{V^2} \cdot 4V^{\cancel{2}}} = 0,5\ K\Omega$

$\Rightarrow \tau = C_L \cdot R_{eq} = 0,5\ ns$



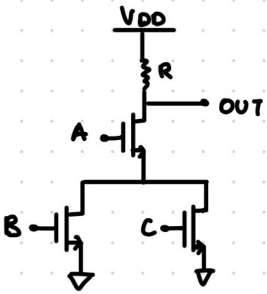
$V_{OUT} = 4V\ e^{-t/\tau} \Rightarrow \dots \Rightarrow T_P = 0,34\ ns$

Calcolare la potenza dinamica dissipata con V_{IN} e W onde quadre con frequenza $f_V = 1MHz$ e $f_W = 2MHz$ rispettivamente con duty cycle di 50%.



$$E = C_L \cdot \Delta V \cdot V_{DD} = 1pF \cdot 4V \cdot 5V = 20\ pJ \Rightarrow W = E \cdot f = 20pJ \cdot 1MHz = 20\mu W$$

ESERCIZIO 2



$K_N = 1 mA/V^2$
$V_{TN} = 1V$
$V_{DD} = 5V$
$R = 5K\Omega$

Determinare la funzione logica:

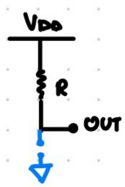
A	B	C	OUT
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

$$\overline{OUT} = \underbrace{A \wedge \overbrace{(B+C)}^{\text{PARALLELO}}}_{\text{SERIE}} \rightarrow \text{estratto dalla PDN}$$

$$\hookrightarrow OUT = \left(\overline{A \cdot (B+C)}\right)$$

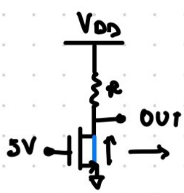
Calcolare V_{OUT} e la potenza statica quando $A=B=C=1$ e $A=B=C=0$.

$A=B=C=0$:



$\rightarrow V_{OUT} = V_{DD} \Rightarrow P_s = 0\ W$

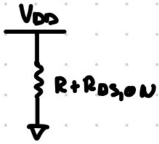
$A=B=C=1$:



$V_{GS} = 5V \rightarrow V_{GS} - V_{TN} = 4V$

$\longrightarrow K_{eq} = K_A \parallel (K_B + K_C) = 2/3\ K_N = 0{,}67\ mA/V^2$

Ipotizziamo regime ohmico:



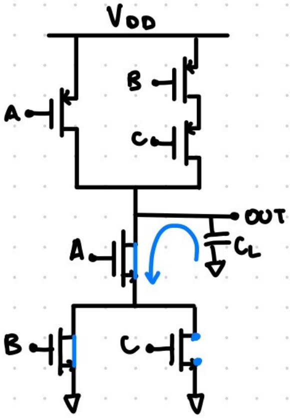
$R_{DS,ON} = 1/2K_{eq}(V_{GS}-V_T) = 0{,}19\,K\Omega$

$V_{OUT} = V_{DD}\dfrac{R_{DS,ON}}{R+R_{DS,ON}} = 0{,}18\,V$

$V_{DS} = V_{OUT} < V_{GS} - V_{TN} \Rightarrow$ ipotesi verificata

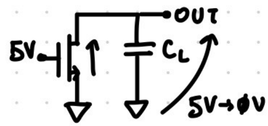
$P_S = V_{DD} \cdot I_{DS} = V_{DD} \cdot V_{DD}/R+R_{DS,ON} = \dots = 4{,}82\ mW$

Costruire la PUN a partire dalla PDN. Usando la PUN trovata, calcolare il tempo di propagazione di $ABC = 000 \to 110$ considerando $C_L = 10pF$



$ABC = 000 \to V_{OUT} = V_{DD}$
$ABC = 110 \to V_{OUT} = \emptyset V$

$\equiv$



$K_{eq} = K_A // K_B = K_N/2 = 0{,}5\ mA/V_2$
$V_{GS} - V_T = 4V$
$\hookrightarrow V_{DS} = V_{OUT} \in [0; 5V] \to$ misto

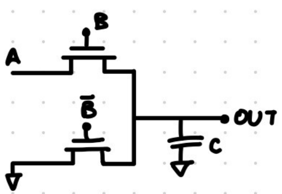
$$\Delta t_1 = \frac{C_L \cdot \Delta V_{OUT}}{I_{D,SAT}} = \frac{10pF \cdot 1V}{0.5mA/V^2 \cdot (4V)^2} = 1{,}25\ nS$$

$$R_{eq} = \frac{V_{GS}-V_{TN}}{I_{D,SAT}} = \frac{\cancel{4V}}{0{,}5mA/V^{\cancel{2}} \cdot (4V)^{\cancel{2}}} = 0{,}5\,K\Omega \to \tau = C_L \cdot R_{eq} = 5\,ns$$

$\hookrightarrow V_{OUT} = 4V\,e^{-\Delta t_2/\tau} = 2{,}5V \Rightarrow \dots \Rightarrow \Delta t_2 = 2.35\ ns$

$\Rightarrow T_P = 3{,}60\ ns$

ESERCIZIO 3



$K_N = 200\ mA/V^2$
$V_{TN} = 1V$
$V_{DD} = 3{,}3V$
$C = 0{,}2\,pF$

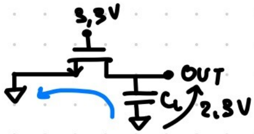
Determinare la tabella di verità della porta logica specificando i valori di V_{OUT}.

A	B	OUT	V_{DD}
0	0	0	0V
0	1	0	0V
1	0	0	0V
1	1	1	2,3V

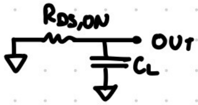
OUT = AB

Calcolare il tempo di propagazione in caso di AB = 11 → 10.

AB = 11 → $V_{OUT} = 2{,}3V$
AB = 10 → $V_{OUT} = 0V$ ⇒



$V_{GS} = 3{,}3\,V \Rightarrow V_{GS} - V_T = 2{,}3V$; $V_{DS} \in [2{,}3V, 0V] \Rightarrow$ sempre ohmico

↳ 

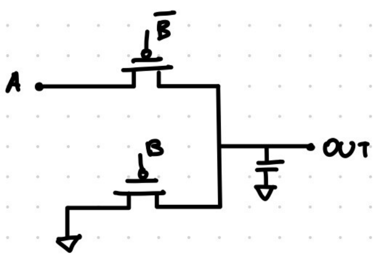
$R_{DS,ON} = V_{GS} - V_T / I_{D,SAT} = \dots = 2{,}17\,K\Omega$

$\tau = C_L \cdot R_{DS,ON} = 0{,}434$ ns

$\Rightarrow V_{OUT} = 2{,}3V \cdot e^{-t_P/\tau} = 1{,}15 \Rightarrow t_P = 0{,}3$ ns

02/11/21

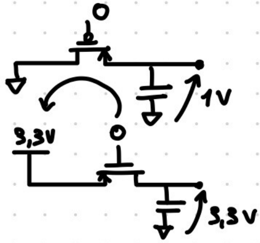
ESERCIZIO 1



$|K_P| = 200\ mA/V^2$
$|V_{TP}| = 1V$
$V_{DD} = 3{,}3\,V$
$C = 0{,}2\,pF$
$A, B \in \{0V; 3{,}3V\}$

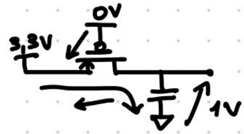
A	B	OUT	
0	0	0	1V
0	1	0	1V
1	0	0	1V
1	1	1	3,3V

→ AND



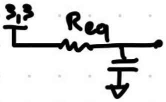
Calcolare il tempo di propagazione con AB = 01 → 11.

AB = 01 ⇒ $V_{OUT} = 1V$
AB = 11 ⇒ $V_{OUT} = 3{,}3V$ ⇒



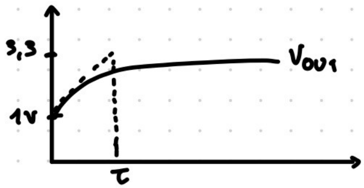
$V_{SG} = 3{,}3V \Rightarrow V_{SG} - |V_{TP}| = 2{,}3V$
$V_{SD} = 3{,}3V - V_{OUT}$

$\hookrightarrow V_{SD} \in [1{,}15V ; 2{,}3V] \Rightarrow$ sempre ohmico



$R_{eq} = \frac{\cancel{V_{SG} - |V_{TP}|}}{|K_P|(\cancel{V_{SG} - |V_{TP}|})} = \frac{1}{200\,mA/V^2 \cdot 2{,}3V} = 2{,}174\,K\Omega$

$\Rightarrow \tau = R \cdot C = 0{,}434\,ns$



$V_{OUT} = 2{,}3V\,(1 - e^{-t/\tau}) + 1V$

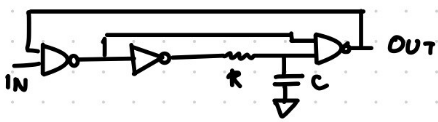
$= 3{,}3V - 2{,}3V\,e^{-t/\tau}$

$\Rightarrow \Delta t = \cdots = 0{,}3\,ns$

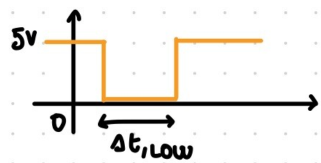
Con A=1 e B un'onda quadra con $T = 2\mu s$ e $D = 50\%$, calcolare la potenza dinamica.

$P = \frac{C \cdot \Delta V \cdot V_{DD}}{T} = \frac{0{,}2 \cdot 2{,}3 \cdot 3{,}3V}{2\mu s} =$

ESERCIZIO 2



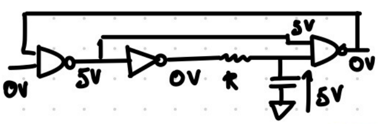
$R = 100\,K\Omega \quad C = 10\,nF$



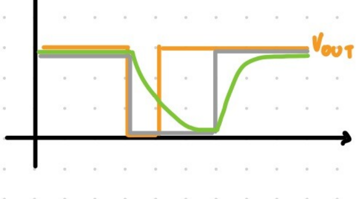
$V_{OUT} = ?$ con $\Delta T_{,LOW} = 1\,s$

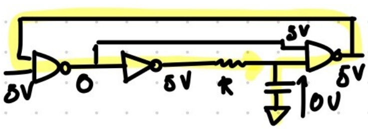
$\hookrightarrow V_{IN} = 5V \quad \cdots \quad OUT = 5V,\; V_C = 5V$

$\hookrightarrow V_{IN} = 5V \to 0V$



$\Rightarrow OUT = 0V, \quad \tau = RC = 1\,ms$



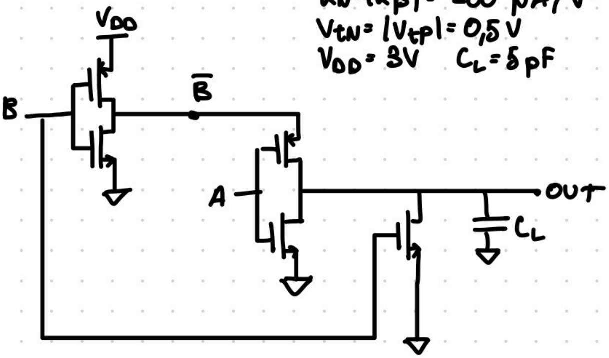


$\tau = RC = 1\,ms$

4/11/21

ESERCIZIO 1

$K_N = |K_P| = 200\ \mu A/V^2$
$V_{tN} = |V_{tP}| = 0{,}5\ V$
$V_{DD} = 3V \quad C_L = 5\ pF$



$B = 0 \rightarrow V_{OUT} = \overline{A}$

$B = 1 \rightarrow V_{OUT} = 0$

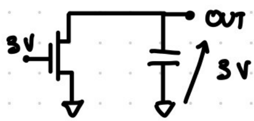
$\Downarrow$

A	B	
0	0	1
0	1	0
1	0	0
1	1	0

$\rightarrow$ NOR

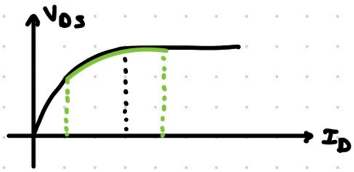
Calcolare il tempo di propagazione della transizione $AB = 00 \rightarrow 11$

$AB = 00 \rightarrow 11$
$\quad\ \ 3V \rightarrow 0V$



$K_{eq} = K_4 + K_5 = 2K_N = 400\ \mu A/V^2 \qquad V_{GS} - V_T = 2{,}5\ V$

$V_{DS} \in [2{,}5V ; 3]$

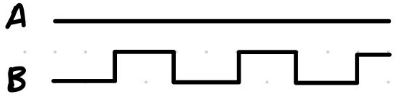


1) $t_1 = \dfrac{C\,\Delta V_{OUT}}{I_{D,SAT}} = \cdots = 1\ ns$

2) $\tau = C \cdot R_{eq} = C \cdot 1/K_{eq}(V_{GS} - V_{TN}) = 5\ ns \rightarrow \dots \rightarrow t_2 = \tau \ln \dfrac{2{,}5}{1{,}5} = 2{,}55\ ns$

$\Rightarrow t_p = 3{,}55\ ns$

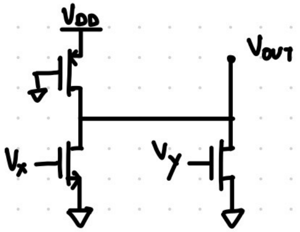
Calcolare la potenza dinamica dissipata con A=0 e B un'onda quadra con duty cycle 50% e f = 1MHz



$P = C_L \cdot \Delta V_{OUT} \cdot V_{DD} \cdot f = 5\ pF \cdot 3V \cdot 3V \cdot 1MHz$

$= 45\ \mu W$

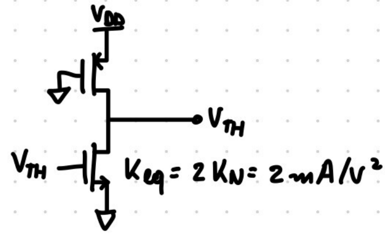
ESERCIZIO 2



$K_N = 1 mA/V^2$
$|K_p| = 50\ \mu A/V^2$
$V_{TP} = 1,2V$
$V_{TN} = 0,7V$
$V_{DD} = 3,33V$

Calcolare la soglia di commutazione.

$OUT = V_x = V_y = V_{TH}$



NMOS $\begin{cases} V_{GS} - V_{TN} = V_{TH} - 0,7V \\ V_{DS} = V_{TH} \end{cases}$ -> sempre saturato

PMOS $\begin{cases} V_{SG} - |V_{Tp}| = 3,3V - 1,2V = 2,1V \\ V_{SD} = 3,3V - V_{TH} \end{cases}$

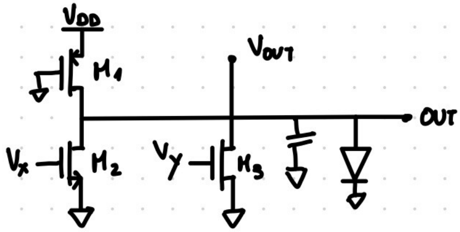
Ipotizziamo PMOS in saturazione e NMOS in saturazione

$I_{SD,SAT,P} = I_{SD,SAT,N} \Rightarrow I_{D,SAT,P} = |K_p|(V_{SG} - |V_{Tp}|)^2 = 220,5\ mA$

$I_{D,SAT,N} = K_{EQ}(V_{GS} - V_{TH})^2 = 2\ mA/V^2\ (V_{TH} - 0,7)^2$

$\Rightarrow V_{TH} = \sqrt{\frac{220,5\mu}{2m}} + 0,7 = 1,03V$

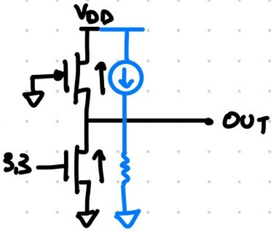
- $V_{TH} > V_{TN}$ ✓
- $V_{SD,P} \sim 2,27V > 2,1$ ✓



$C_L = 10pF$

Calcolare V_{OUT} con $V_x = V_y = 3,3V \to 0V$

$t = 0^-$: Ipotizziamo diodo spento:



Ipotizziamo il PMOS saturato e lo NMOS ohmico

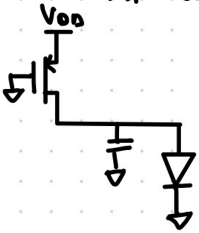
$I_{D,SAT,P} = \cdots = 220{,}5 \text{ mA}$

$R_{DS,ON} = 1/2K_{eq}(V_{GS} - V_{TN}) = 96\ \Omega$

$V_{OUT} = 220{,}5\ \mu A \cdot 96\ \Omega = 20 \text{ mV}$

- $V_D = V_{OUT} < 0{,}7\text{ V}$ ✓
- $V_{SD,P} = 3{,}3\text{ V} - 20\text{ mV} \sim 3{,}28\text{ V} > V_{SG} - |V_{TP}|$ ✓
- $V_{DS} = V_{OUT} < V_{GS} - V_{TN}$ ✓

$t \geq 0$: M_2 e M_3 spenti
M_1 acceso $\rightarrow V_{OUT} \sim 20\text{ mV} \rightarrow 3{,}3\text{ V}$



$V_{SG} - |V_{TP}| = 2{,}1\text{ V}$

$V_{SD} = 3{,}3 - V_{OUT} \Rightarrow V_{SD} \in [3{,}28;\ 2{,}6\text{V}] \Rightarrow$ SATURATO

$\bar{t} = \dfrac{C_1 \Delta V_{OUT}}{I_{D,SAT,P}} = \cdots = 30{,}8 \text{ ns}$

Calcolare la potenza statica con $V_x = 0\text{V}$ e V_y un'onda quadra con $f = 100\text{ KHz}$ e duty cycle 50% sia con diodo/capacità collegati che scollegati

C e D scollegati: $V_x V_y = 00 \rightarrow 01$

$3{,}3\text{V} \rightarrow 40\text{mV}$

↓

M_2 spento e M_1/M_3 accesi

$\Rightarrow V_{OUT} = I_{D,SAT,P} \cdot R_{DS,ON} = 40\text{mV}$

P statica (00) = 0 W

P statica (01) = $V_{DD} \cdot I_{D,SAT,P} = 727{,}65\ \mu W$

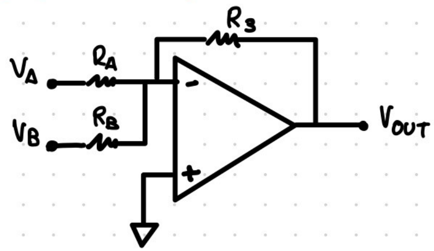
P statica_media = $727{,}65/2 = 363{,}825\ \mu W$

C e D connessi: $V_x V_y = 00 \rightarrow 01$
$0{,}7V \rightarrow 40mV$

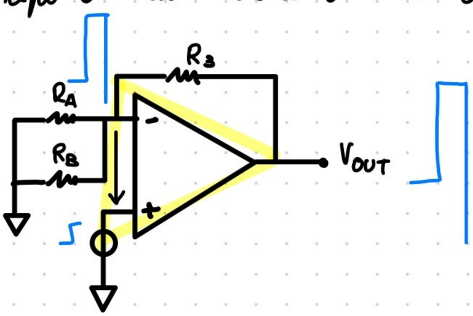
P statica (00) = 727,65 μW -> P statica_media = 723,65 μW
P statica (01) = 727,65 μW

11/11/21

ESERCIZIO 1

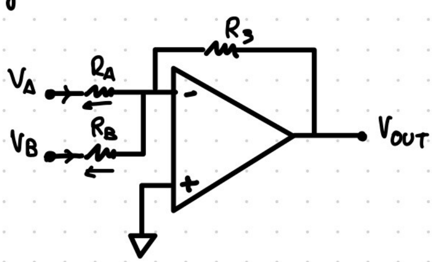


Che tipo di retroazione otteniamo?



=> V_{OUT} si assesta quando $\varepsilon = V_+ - V_- = \emptyset V$

Determinare la tensione di uscita V_{OUT} in funzione dei due ingressi V_A e V_B e della somma



$\varepsilon = 0$ poiché OPAMP ideale => $V^+ = V^-$

$i_A = V_A / R_A$

$i_B = V_B / R_B$

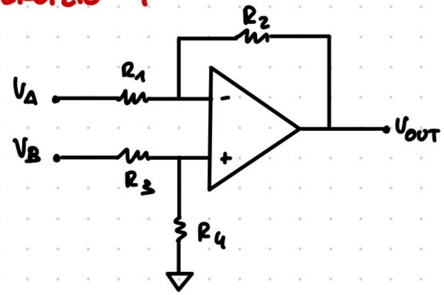
=> $i_3 = i_A + i_B$

$$\Longrightarrow V_{OUT} = -R_3 i_3 = R_3\left(-\frac{V_A}{R_A} - \frac{V_B}{R_B}\right) = R_3 \frac{-R_B V_A - R_A V_A}{R_A R_B}$$

Se $R_A = R_B$ otteniamo che $V_{OUT} = (V_A + V_B)\left(-\frac{R_3}{R}\right)$

12/11/21

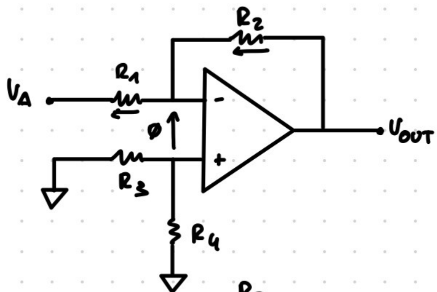
ESERCIZIO 1



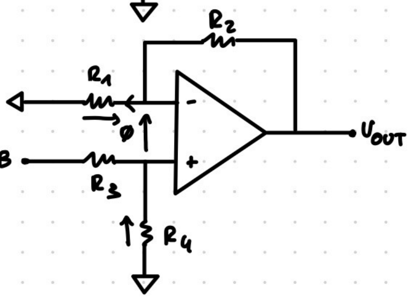
Hp: OPAMP ideali

Determinare Vout in funzione di V_A e di V_B

Applichiamo la sovrapposizione degli effetti:



$$V_{OUT}\big|_{V_A} = -V_{R2} = -R_2 \cdot (V_{R1}/R_1) =$$
$$= -\frac{R_2}{R_1} V_A$$

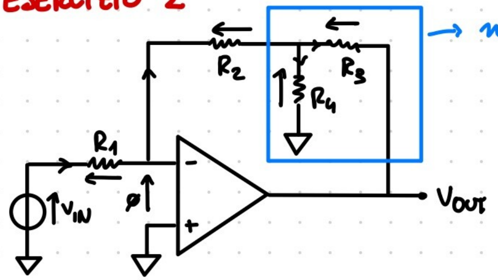


$$V^- = V^+ = V_B \frac{R_4}{R_3+R_4} = V_{R1}$$
$$V_{R_2} = V_B \frac{R_4}{R_3+R_4} \frac{R_2}{R_1}$$
$$\Rightarrow V_{OUT} = V_B \frac{R_4}{R_4+R_3}\left(1+\frac{R_2}{R_1}\right)$$

$$\Rightarrow V_{OUT} = -V_A \frac{R_2}{R_1} + V_B \frac{R_4}{R_4+R_3}\left(1+\frac{R_2}{R_3}\right)$$

Per legare Vout a $V_B - V_A$ basta porre $\frac{R_2}{R_1} = \frac{R_4}{R_4+R_3}\left(1+\frac{R_2}{R_3}\right)$

ESERCIZIO 2



→ non è un semplice partitore

$$G_{ID} = \frac{V_{OUT}}{V_{IN}} = ?$$

$$i_{R1} = \frac{V_{IN}}{R_1} \qquad V_{R2} = \frac{V_{IN}}{R_1} R_2 \qquad V_{R4} = -V_{R2}$$

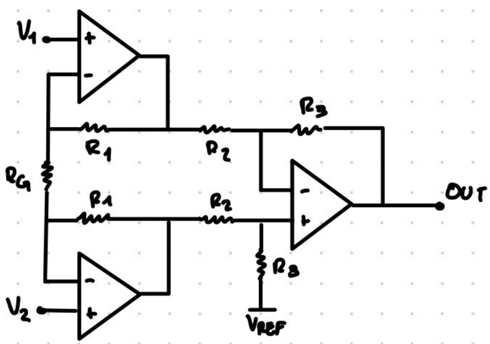
$$i_{R4} = V_{R4}/R_4 = -\frac{V_{IN}}{R_1}\frac{R_2}{R_4}$$

$$i_{R3} = i_{R2} - i_{R3} = \dots = \frac{V_{IN}}{R_1} + \frac{V_{IN}}{R_1}\frac{R_2}{R_4} \Rightarrow V_{OUT} = V_x - V_{R3} = -V_{IN}\frac{R_2}{R_1} - \frac{V_{IN}}{R_1}\left(1 + \frac{R_2}{R_4}\right)R_3$$

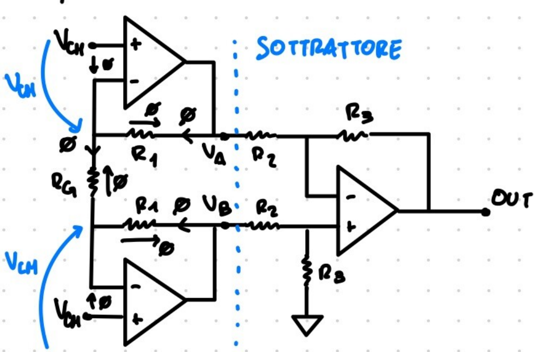
$$= -\frac{V_{IN}}{R_1}\left(R_2 + R_3 + \frac{R_2 R_3}{R_4}\right)$$

15/11/21

ESERCIZIO 1 INSTRUMENTATION AMPLIFIER



Imponendo $V_{REF} = 0V$ e $V_1 = V_2 = V_{CM}$, determinare il guadagno totale.

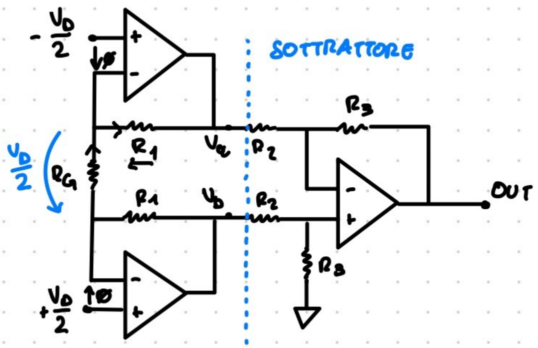


$$V_{OUT} = (V_B - V_a)\frac{R_3}{R_2}$$

$$V_a = V_b = V_{CM} \Rightarrow V_{OUT} = 0$$

$$G_{ID} = 0$$

Considerando $V_{REF} = 0V$ e $V_1 = -\frac{V_D}{2}$, $V_2 = +\frac{V_D}{2}$ determinare il guadagno ideale $G_{ID} = V_{OUT}/V_D$



$$i_{R_G} = V_D/R_G$$

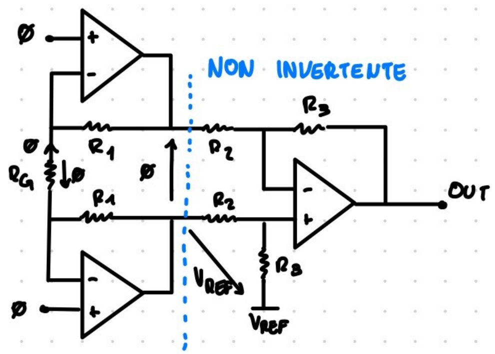
$$V_a = -\frac{V_D}{2} - \left(\frac{V_D}{R_G} R_1\right)$$

$$V_b = \frac{V_D}{2} + \frac{V_D}{R_G} R_1$$

$$\Rightarrow V_{OUT} = (V_b - V_a)\frac{R_3}{R_2} = \cdots = V_d\left(1 + \frac{2R_1}{R_G}\right)\frac{R_3}{R_2}$$

$$\Rightarrow G_{ID} = \left(1 + \frac{2R_1}{R_G}\right)\frac{R_3}{R_2}$$

Considerando $V_1 = V_2 = 0V$, determinare il guadagno $G_{ID} = V_{OUT}/V_{REF}$



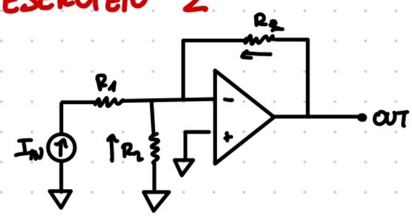
$$V^+ = V_{REF}\frac{R_2}{R_2+R_3} = V^-$$

$$V_{OUT} = V^-\left(1 + \frac{R_3}{R_2}\right) = V_{REF}\frac{R_2}{R_2+R_3}\left(1 + \frac{R_3}{R_2}\right)$$

$$= V_{REF}\left(\cancel{\frac{R_2}{R_2+R_3}} + \cancel{\frac{R_3}{R_2+R_3}}\right) = V_{REF}$$

$$\Rightarrow G_{ID} = 1$$

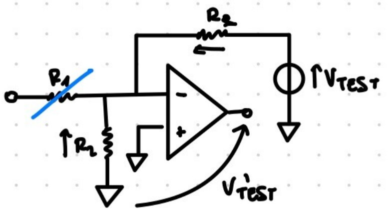
ESERCIZIO 2



Calcolare il trasferimento ideale $T_{ID} = V_{OUT}/I_{IN}$

$$V_{OUT} = \cancel{V_{R_2}} - V_{R_3} = -V_{R_3} = -R_3 I_{IN} \Rightarrow T_{ID} = -R_3$$

Calcolare il guadagno d'anello:

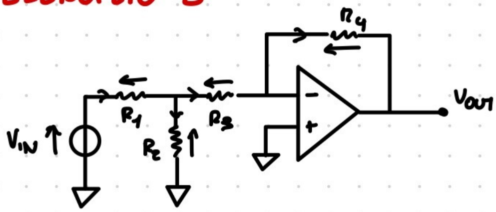


$$V^- = V_{TEST}\,\frac{R_2}{R_2+R_3}$$

$$V'_{TEST} = -V^- A_d = -V_{TEST}\,\frac{R_2}{R_2+R_3}\,A_d$$

$$\hookrightarrow G_{LOOP} = -\frac{R_2}{R_2+R_3}\,A_d$$

ESERCIZIO 3



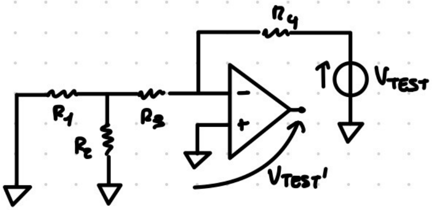
$R_1 = R_2 = R_3 = 1\,K\Omega$ $\quad$ $A_d = 10^5$
$R_4 = 12\,K\Omega$

Calcolare il G_{REALE}.

$$V_{OUT} = -V_{IN}\,\frac{R_2/\!/R_3}{R_2/\!/R_3+R_1} - V_{IN}\,\frac{(R_2/\!/R_3)R_4}{(R_2/\!/R_3+R_1)R_3}$$

$$= -V_{IN}\,\frac{R_2/\!/R_3}{R_2/\!/R_3+R_1}\left(1+\frac{R_4}{R_3}\right)$$

$$\Rightarrow G_{ID} = -\frac{R_2/\!/R_3}{R_2/\!/R_3+R_1}\left(1+\frac{R_4}{R_3}\right) = \dots = -4$$



$$V_{TEST}' = -A_d V^-$$

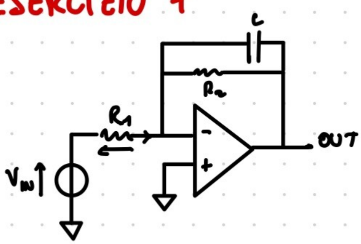
$$= -A_d\left(V_{TEST}\,\frac{R_1/\!/R_2+R_3}{R_1/\!/R_1+R_3+R_4}\right)$$

$$\Rightarrow G_{LOOP} = -A_d\,\frac{R_1/\!/R_2+R_3}{R_1/\!/R_1+R_3+R_4} = -11\,111$$

$$\Rightarrow G_{REALE} = {}^{-4}/_{1+\,1/-11\,111} = -3{,}9996$$

16/11/21

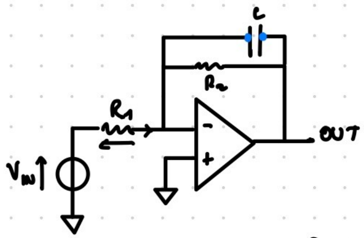
ESERCIZIO 1

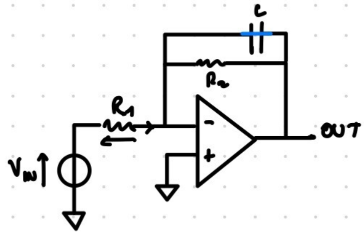


$R_1 = 5\,K\Omega$ $\quad$ $A_0 = 4000$
$R_2 = 100\,K\Omega$ $\quad$ GBWP $= 320\,KHz$
$C = 1.6\,nF$

Calcolare i $G_{ID}(s)$ e i relativi diagrammi di modulo e fase

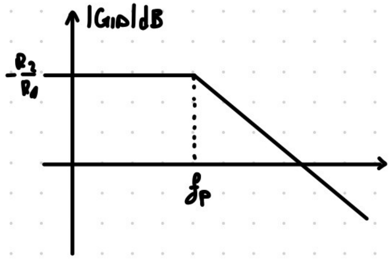
$V^+ = V^- = 0V \Rightarrow V_{R1} = V_{IN} \quad i_{R1} = V_{IN}/R$





per $s \to 0$ $\quad G_{ID}(s) = -R_2/R_1$

per $s \to +\infty$ $\quad G_{ID}(s) = 0$



$$V_{OUT}(s) = -\frac{V_{IN}}{R_1}\left(\frac{1}{sC} \cdot R_2\right)$$

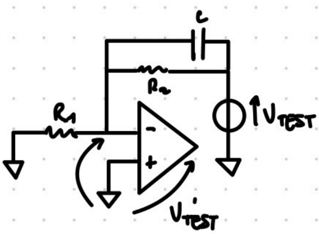
$\rightarrow$ Z CONDENSATORE

$$\Rightarrow G_{ID}(s) = -\frac{R_2}{R_1}\frac{1}{1+sCR_2}$$

$$\Rightarrow f_P = \frac{1}{2\pi CR_2} = 1KHz$$

Calcolare $|G_{REALE}|$ e farne il diagramma di Bode.

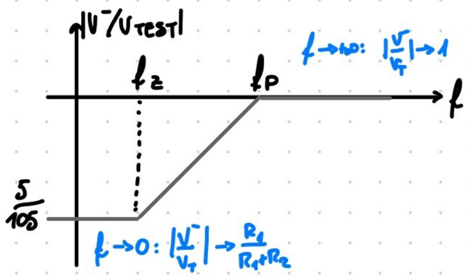
$|G_{LOOP}|$:



$$G_{LOOP}(s) = \frac{V^-}{V_{TEST}} \cdot \underbrace{\frac{V_{TEST}'}{V^-}}_{-A_d(s)}$$

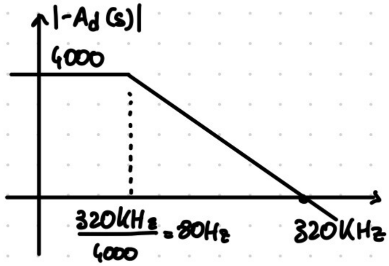
$$\frac{V^-}{V_{TEST}} = \frac{R_1}{R_1 + R_2 /\!/ 1/sC} = \frac{R_1}{R_1 + \frac{R_2 \, 1/sC}{R_2 + 1/sC}} = \frac{R_1(R_2 + 1/sC)}{R_1R_2 + \frac{R_1}{sC} + \frac{R_2}{sC}} = \frac{R_1R_2 + R_1/sC}{R_1R_2 + \frac{R_1+R_2}{sC}}$$

$$= \frac{R_1R_2sC + R_1}{R_1R_2sC + R_1 + R_2} = \frac{R_1}{R_1+R_2}\frac{1 + R_2sC}{1 + R_1/\!/R_2 \, sC}$$

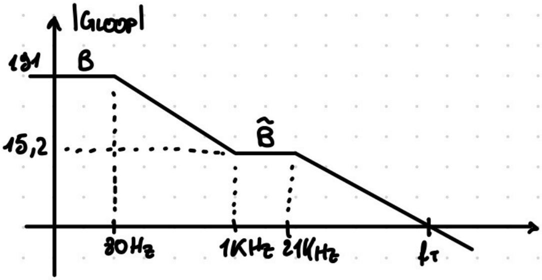


$$f_P = \frac{1}{2\pi R_1/\!/R_2 C} \cong 21 KHz$$

$$\frac{5}{105} \cdot f_z^{-1} = f_P^{-1} \rightarrow f_z = f_P \frac{105}{5} = 1KHz$$



$$\Longrightarrow G_{LOOP} = -\frac{R_1}{R_1+R_2}\,\frac{1+R_2 sC}{1+R_1/\!/R_2 sC}\cdot\frac{4000}{1+s\tau_0}$$



$$B = \frac{4000\cdot 5}{105} \cong 191$$

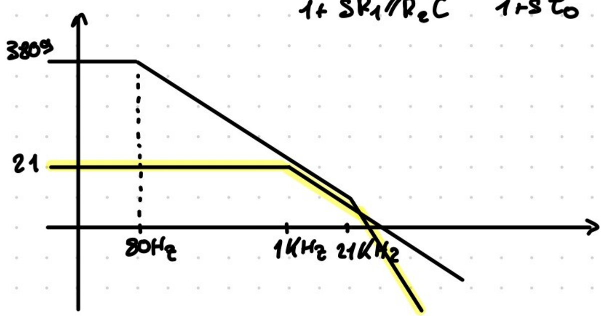
$$\tilde{B} = \frac{191\cdot 80Hz}{1KHz} = 15,2$$

$$f_T = 21KHz\cdot 15,2 \cong 319\,KHz$$

$|G_{OPEN}|$:

$$G_{OPEN} = 191\,\frac{\cancel{1+sR_2C}}{1+sR_1/\!/R_2C}\,\frac{1}{1+s\tau_0}\cdot 21\cdot\frac{1}{\cancel{1+sR_2C}}$$

$$= 3809\,\frac{1}{1+sR_1/\!/R_2C}\cdot\frac{1}{1+s\tau_0}$$

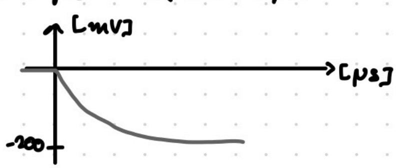


Dato un gradino di tensione 0V → 1 mV, tracciamo il grafico di V_{OUT}.

$$G_{ID}(s) = -\left(\frac{R_3}{R_1}\right)\frac{1}{1+sCR_2} = -20\cdot\frac{1}{1+s\cdot 160\mu s} = \frac{V_{OUT}(s)}{V_{IN}(s)}$$

$$\Rightarrow V_{OUT} = \frac{10mV}{s}\cdot\frac{-20}{1+s\cdot 160\mu s} = \frac{-200\,mV}{s(1+s\,160\mu s)}$$

↳ ANTITRASFORMANDO →

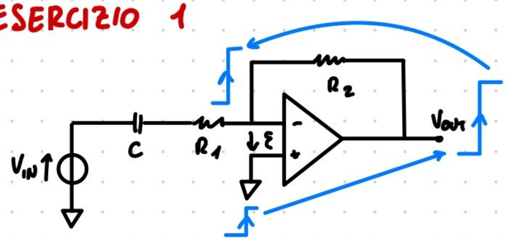


Valutare la stabilità del circuito

$$\phi_m = 180° - \arctg\left(\frac{f_T}{f_0}\right) - \arctg\left(\frac{f_T}{f_P}\right) + \arctg\left(\frac{f_T}{f_Z}\right) = 180° - 90° - 90° + 90°$$
$$= 90° > 45° \checkmark$$

18/11/21

ESERCIZIO 1



$R_1 = 1 K\Omega$
$R_2 = 10 K\Omega$
$C = 10 nF$
$A_0 = 10^4$
$f_0 = 100 Hz$
$GBWP = 1 MHz$

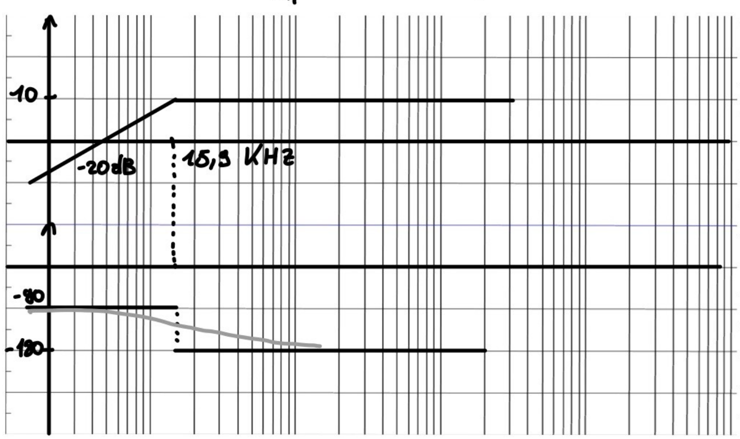
Calcolare G_{ID} e disegnarne il diagramma di Bode.

Poiché se alziamo V^+ il circuito reagisce alzando V^- per rendere $V^+ = V^-$ si mantiene $\varepsilon = 0 \Rightarrow$ retroazione negativa.

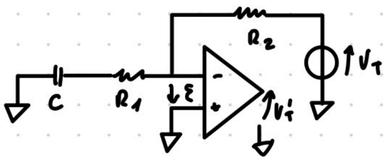
$$I_{IN}(s) = \frac{V_{IN}}{1/sC + R_1} \qquad V_{OUT}(s) = -I_{IN} R_2 \Rightarrow G_{ID} = \frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{1/sC + R_1}$$
$$= \frac{-sCR_2}{1 + sCR_1}$$

$@ f = 0 \Rightarrow G_{ID} = 0 \quad (s=0)$ $\qquad f_P = 1/2\pi C R_1 = 15{,}9 \ KHz$

$@ f = +\infty \Rightarrow G_{ID} = -\frac{R_2}{R_1} = -10$ $\qquad f_Z = 0$



Determinare G_{LOOP} e rappresenta il diagramma di Bode del modulo.

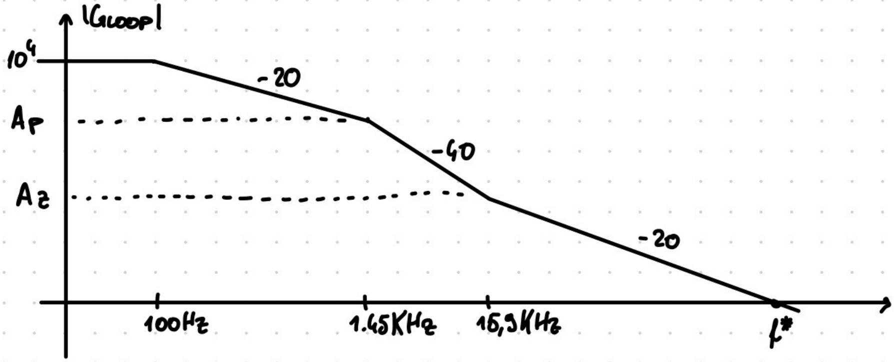


$$G_{LOOP}(s) = T_P(s)(-A(s))$$

$$T_P(s) = \frac{V^-}{V_T'} = \frac{\frac{1}{sC} + R_1}{\frac{1}{sC} + R_1 + R_2} = \frac{1 + sCR_1}{1 + sC(R_1+R_2)}$$

$@ f=0 \rightarrow T_P(s) = 1$ $\quad$ $@ f \rightarrow +\infty \rightarrow T_P(s) = \frac{R_1}{R_1+R_2} = \frac{1}{11}$

$f_P = \dots = 1{,}45 \text{ KHz}$ $\quad$ $f_Z = 15{,}9 \text{ KHz}$



$10^4 f_0 = A_P f_P \rightarrow A_P = \dots = 689{,}6$

$A_P f_P^2 = A_Z f_Z^2 \rightarrow A_Z = \dots = 5{,}7$

$\Rightarrow f^* = A_Z f_Z = 90{,}63 \text{ KHz}$

Stabilire la stabilità del circuito:

$$\phi_m = 180 - \text{arctg}\left(\frac{f^*}{f_0}\right) - \text{arctg}\left(\frac{f^*}{f_P}\right) + \text{arctg}\left(\frac{f^*}{f_Z}\right) = 0° + 80° = 80° \checkmark$$

Calcolare G_{REALE} e disegnarne il diagramma del modulo.

$$G_{REALE} = \frac{G_{ID}}{1 - 1/G_{LOOP}}$$

$\rightarrow |G_{LOOP}| \gg 1 \rightarrow G_{REALE} \simeq G_{ID}$

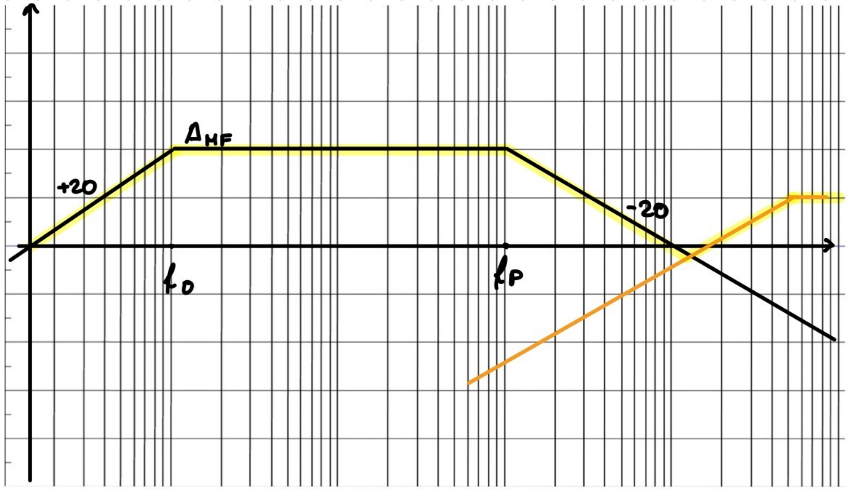
$\rightarrow |G_{LOOP}| \ll 1 \rightarrow G_{OPEN} = -G_{LOOP} G_{ID}$

$$\rightarrow G_{OPEN} = -\left(\frac{-A_0}{1+s\tau_0}\right)\left(\frac{\cancel{1+sCR_1}}{1+sC(R_1+R_2)}\right)\left(\frac{-sCR_2}{\cancel{1+sCR_1}}\right)$$

$$= -\frac{A_0\, sCR_2}{(1+s\tau_0)(1+sC(R_1+R_2))}$$

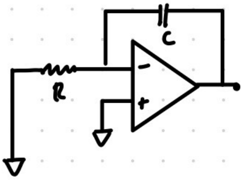
$$A_M = \frac{A_0}{\cancel{1+}\cancel{s}\tau_0} \frac{\cancel{s}CR_2}{1+\cancel{sC(R_1+R_2)}} = 100$$

↳ dopo zero $\quad$ ↳ prima del polo



22/11/21

ESERCIZIO 1 INTEGRATORE IDEALE

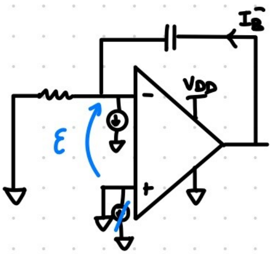


$$\frac{V_{OUT}(s)}{V_{IN}(s)} = \frac{1/sC}{R} = -\frac{1}{sRC}$$

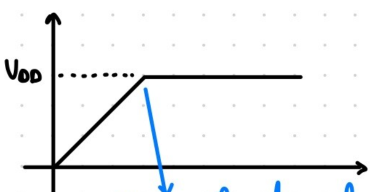
$$\Longrightarrow V_{OUT} = \underbrace{V_{IN}\left(-\frac{1}{sRC}\right)}_{} = -\frac{1}{CR}\int_0^t V_{IN}(t)\,dt$$

nel dominio di Laplace, moltiplicare per 1/s equivale ad integrare.

Calcolare l'effetto delle correnti di bias considerando l'alimentazione



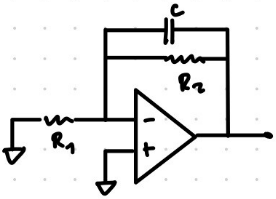
$$V_{OUT} = I_B^-/C \cdot t$$



Una volta che satura, la corrente va in R, rompendo la retroazione poiché non riesce a mantenere E=0.

Per limitare questo problema possiamo:

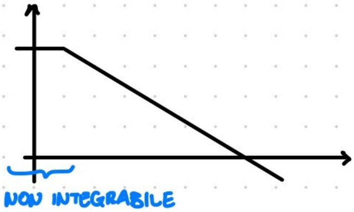
- aggiungere una resistenza in parallelo a C



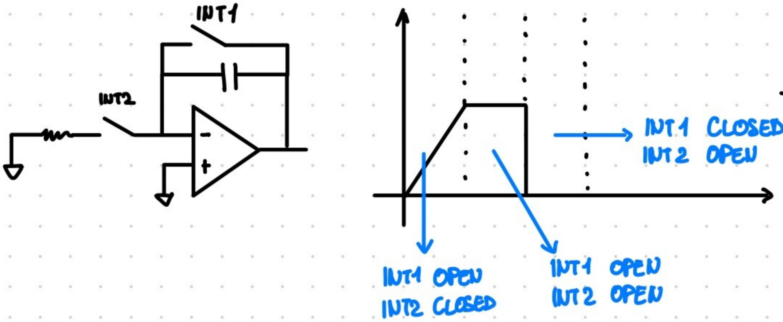
$V_{OUT}|_{I_B^-} = I_B^- R_2 \Rightarrow$ corrente limitata

$\hookrightarrow G_{ID} = -\dfrac{R_1}{R_2} \cdot \dfrac{1}{1+sCR_2}$

integratore reale



- usare degli interruttori per scaricare periodicamente la capacità

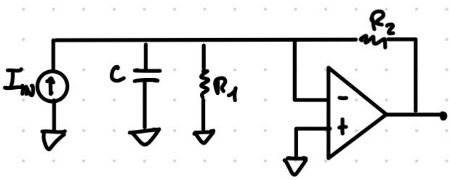


$\rightarrow V_{OUT} = \dfrac{V_{IN}}{RC} \Delta t$

Abbiamo realizzato un convertitore tempo-ampiezza.

23/11/21

ESERCIZIO 1

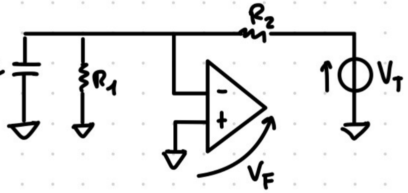


$R_1 = 500\ \Omega$ $\quad$ $A_0 = 10^5$
$R_2 = 5\ K\Omega$ $\quad$ $GBWP = 100\ MHz$
$C_1 = 100\ pF$

Calcolare il trasferimento ideale $T_{ID}(s) = V_{OUT}/I_{IN}$.

$V^+ = V^- = 0V \qquad V_{R2} = I_{IN} R_2 \qquad V_{OUT} = -I_{IN} R_2 \Rightarrow T_{ID}(s) = -R_2 = -5K\Omega$

Valutare la stabilità del circuito.



$$G_{LOOP}(s) = \frac{V_F}{V_T} = -A(s)\,\frac{V^-}{V_T} =$$

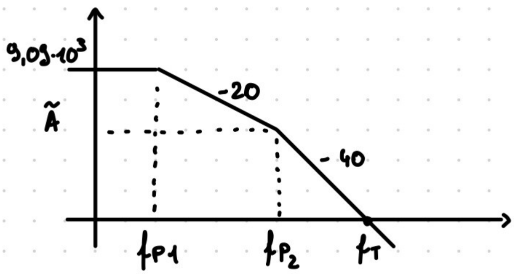
$$= -A(s)\,\frac{1/sC \,//\, R_1}{1/sC \,//\, R_1 + R_2}$$

$$= \cdots = -\frac{A_0}{1+s\tau_0}\,\frac{R_1}{(R_1+R_2)(1+sC\,R_1//R_2)}$$

$$|G_{LOOP}(0)| = A_0\left(R_1/R_1+R_2\right) = \cdots = 9{,}09\cdot 10^3$$

$$f_{P1} = f_0 = GBWP/A_0 = 1\,KHz$$

$$f_{P2} = 1/2\pi C\,R_1//R_2 = 3{,}5\ MHz$$



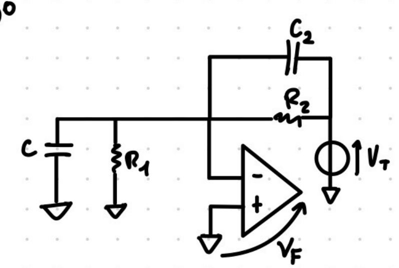
$$\tilde{A} = A_0 f_0 / f_T = 2{,}60$$

$$f_T = \sqrt{\tilde{A} f_{P2}^2} = 5{,}64\ MHz$$

$$\phi_m = 180° - \text{arctg}\left(\frac{f_T}{f_{P1}}\right) - \text{arctg}\left(\frac{f_T}{f_{P}}\right) =$$

$$= 31{,}82° \quad \times$$

Si colleghi C_2 in parallelo a R_2. Dimensionare C_2 per avere $\phi_m = 90°$

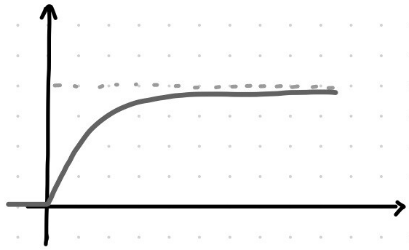


$$G_{LOOP}(s) = -A(s)\,\frac{R_1 // \frac{1}{sC}}{R_1 // \frac{1}{sC} + R_2 // \frac{1}{sC}}$$

$$= \frac{A_0}{1+s\tau_0}\left(\frac{R_1}{R_1+R_2}\right)\left(\frac{1+sC_2R_2}{1+s(C_1+C_2)(R_1//R_2)}\right)$$

poniamo $f_{P2} = f_z \Rightarrow C_2R_2 = (C_1+C_2)(R_1//R_2) \rightarrow C_2 = C_1\frac{R_1}{R_2} = \cdots = 10\,pF$

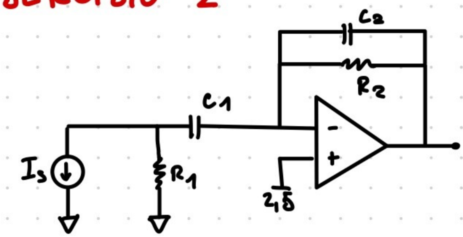
Disegnare su un grafico quotato la tensione di uscita V_{OUT} in risposta ad un gradino di ampiezza $-1\,mA$.



$T_{ID}(s) = -5\ K\Omega$

$\tau = C_2 R_2 = 50\ ns$

ESERCIZIO 2



$R_1 = 1M\Omega$ $\quad f_0 = 10Hz$

$R_2 = 10M\Omega$ $\quad GBWP = 1MHz$

$C_1 = 100\ nF$

$C_2 = 1pF$

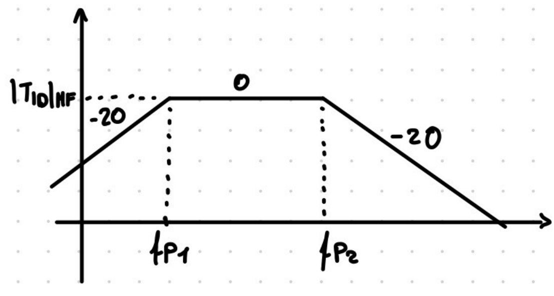
$I_S = 100\ nA\ \sin(2\pi\ 100KHz\ t)$

Determinare il trasferimento ideale $T_{ID}(s) = \frac{V_O}{I_S}$ e tracciare su un grafico quotato il diagramma di Bode del modulo.

spegniamo il potenziale a massa:

$V_+ = V_- = \varnothing\ V \qquad I_{IN} = I_S \frac{R_1}{R_1 + 1/sC_1} \rightarrow V_{OUT} = I_{IN}\left(R_2 \parallel \frac{1}{sC_2}\right)$

$\Rightarrow T_{ID}(s) = \left(\frac{sC_1R_1}{1 + sC_1R_1}\right)\left(\frac{R_2}{1 + sC_2R_2}\right)$



$f_{P1} = \frac{1}{2\pi C_1 R_1} = 1,6 Hz$

$f_{P2} = \frac{1}{2\pi C_2 R_2} = 15,9\ KHz$

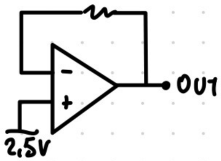
$|T_{ID}|_{HF} = \left|\frac{\cancel{sC_1R_1}R_2}{\cancel{sC_1R_1}\cdot 1}\right| = R_2$

Determinare la tensione $V_O(t)$ e rappresentarla. Calcolare il minimo slew rate per non distorcere.

$V_{OUT}|_{I_S} = 100\ nA\ |T_{ID}|\ \sin(2\pi\ 1KHz\ t + \Delta T_{ID}) =$

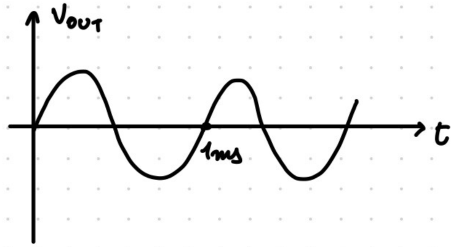
$$= 100\,nA \cdot (10\,M\Omega)\,\sin\left(2\pi\,1\,KHz\,t + \cancel{(90° - 90° - 0)}\right)$$

$$= 1V\,\sin(2\pi\,1KHz\,t)$$



$\rightarrow\ V_{OUT}|_{GND} = 2,5\,V$

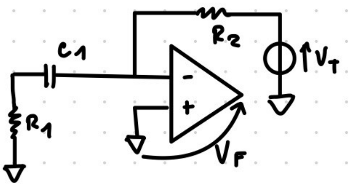
$$\Rightarrow\ V_{OUT} = 2,5V + 1V\,\sin(2\pi\,1KHz\,t)$$



$$\frac{dV_{OUT}}{dt} = 1V\cos(2\pi\,1KHz\,t)\cdot 2\pi\,1KHz$$

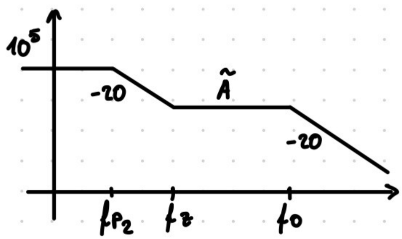
$$\Rightarrow\ SR_{MIN} = 1V \cdot 2\pi \cdot 1KHz = 6,28\ V/\mu s$$

Trascurando C_2, valutare la stabilità



$$G_{LOOP}(s) = -A(s)\frac{V_-}{V_+} = -A(s)\frac{1/sC_1 + R_1}{1/sC_1 + R_1 + R_2}$$

$$= -\frac{A_0}{1+s\tau_0}\ \frac{1+sC_1R_1}{1+sC_1(R_1+R_2)}$$



$$|G_{LOOP}(0)| = 10^5$$

$$f_Z = 1/2\pi C_1R_1 = 1,6\,Hz$$

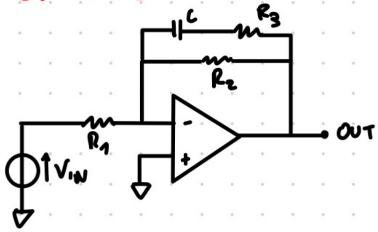
$$f_{P2} = 1/2\pi C_1(R_1+R_2) = 0,14\,Hz$$

$$\tilde{A} = 10^5 f_{P2}/f_Z = 8750$$

$$f_T = \tilde{A} f_{P1} = 87,5\,KHz$$

$$\phi_M = 180° - \mathrm{arctg}\left(\frac{f_T}{f_{P2}}\right) + \mathrm{arctg}\left(\frac{f_T}{f_Z}\right) - \mathrm{arctg}\left(\frac{f_T}{f_0}\right) = \dots = 90° \ \checkmark$$

ESERCIZIO 3



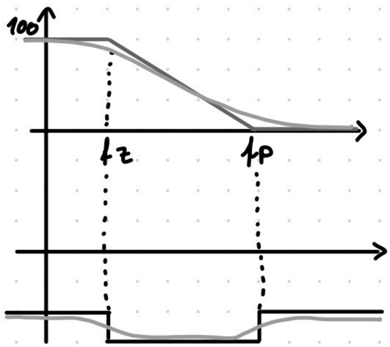
$R_1 = 10\ K\Omega$
$R_2 = 1\ M\Omega$
$R_3 = 10\ K\Omega$

$C = 1{,}6\ nF$

Disegnare i diagrammi di Bode di modulo e fase di $G_{ID}(s)$

$$V_- = V_+ = 0V \rightarrow V_{OUT} = -\frac{V_{IN}}{V_{R_1}}(R_2) // \left(\frac{1}{sC}+R_3\right)$$

$$\Rightarrow G_{ID}(s) = -\frac{R_2}{R_1}\left(\frac{1+sCR_3}{1+sC(R_2+R_3)}\right) \rightarrow \begin{array}{l} G_{ID}(0) = \dots = -100 \\ G_{ID}(+\infty) = \dots = \frac{-R_2 // R_3}{R_1} = -1 \end{array}$$



$$f_z = 1/2\pi C_3 = 9{,}95\ KHz$$

$$f_p = 1/2\pi C(R_1+R_2) = 98{,}5\ KHz$$

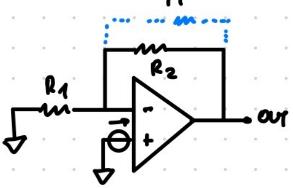
Trovare l'espressione di V_{OUT} con

$$V_{IN} = 1mV \sin(2\pi\ 5Hz\ t) + 5mV \sin(2\pi\ 100Hz\ t) + 20mV \sin(2\pi\ 1MHz\ t)$$

$$V_{OUT} = (1mV \cdot 100)\sin(2\pi 5Hz\,t - 180^\circ) +$$
$$\left(5mV \cdot \frac{100}{\sqrt{2}}\right)\sin(2\pi\ 100Hz\,t - 225^\circ) +$$
$$(20mV \cdot 1)\ \sin(2\pi\ 1MHz - 180^\circ)$$

40dB-3dB; i 3dB sono dovuti all'approssimazione

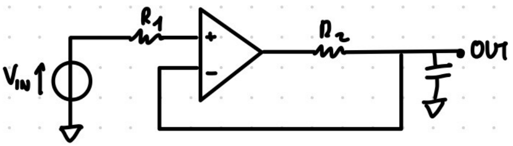
Valutare l'effetto di una tensione di offset di $\pm 100\ \mu V$



$$V_{OUT}|_{V_{OS}} = V_{OS}\left(1+\frac{R_1}{R_2}\right) = \pm 10{,}1\ mV$$

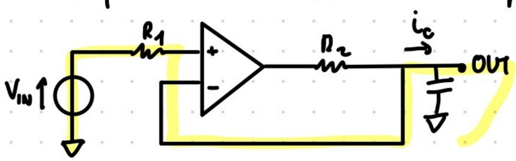
25/11/21

ESERCIZIO 1



$R_1 = 1K\Omega$
$R_2 = 100\Omega$
$C = 1nF$

Sia V_{IN} una sinusoide con ampiezza 1V e frequenza tra 10 Hz e 10 KHz, qual è la I_{OUT} minima per non distorcere



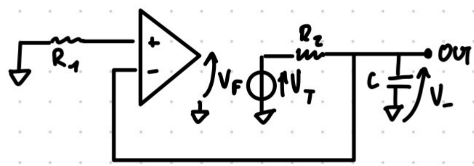
$V_{OUT} = V_{IN}$

$I_{OUT,OPAMP} = i_C = C \frac{dV_c}{dt}$

$$I_{OUT,OPAMP}\Big|_{MIN} = C \frac{dV_c}{dt}\Big|_{MAX} = C \cdot A\, 2\pi f_{MAX} = 62,83 \text{ mA}$$

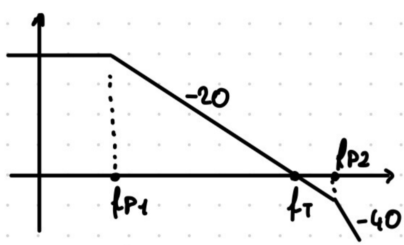
Sia GBWP = 1 MHz, calcolare il massimo slew rate per non distorcere. Considerare G_{REALE}

<u>G_{LOOP}:</u>



$$G_{LOOP} = \frac{V_F}{V_T} = -A(s)\frac{V_-}{V_T}$$
$$= -A(s)\frac{1/sC}{1/sC + R_2}$$
$$\Rightarrow G_{LOOP} = -\frac{A_0}{1+s\tau_0}\frac{1}{1+sCR_2}$$

$f_{P1} = f_0 \qquad f_{P2} = 1/2\pi CR2 = 1,6 \text{ MHz}$



$f_T = 1MHz$

↳ $|G_{LOOP}| > 1$ per $f < 1MHz$

↳ $G_{REALE} = G_{ID}$ per $f < 1MHz$

G_{OPEN} non bisogna calcolarlo perchè il circuito non supererà 10 KHz

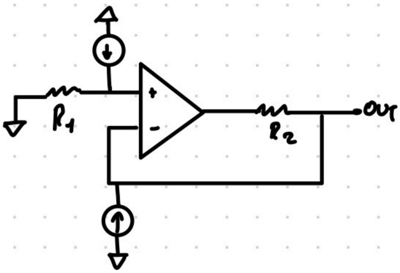
$$V_{OUT} = V_{IN}$$

$$V_{OUT,OPAMP} = V_{OUT} + V_{R2} = V_{IN} + R_2 C \frac{dV_{IN}}{dt}$$

$$\frac{dV_{OUT,OPAMP}}{dt} = \frac{dV_{IN}}{dt} + \underbrace{R_2 C \frac{d^2 V_{IN}}{dt^2}}_{\text{TRASCURIAMO}} \rightarrow SR_{MIN} = \left.\frac{dV_{IN}}{dt}\right|_{MAX} = 1V\, 2\pi f_{MAX} = 62{,}8\ V/ms$$

Qual è l'effetto delle correnti di bias sul circuito?

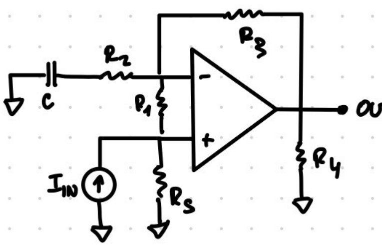
$I_B = 3\ nA$ (uscenti)



$$\left.\begin{array}{l} V_{OUT} = I_B R_1 = 3\ \mu V \\ V_{OUT,OPAMP} = 3\ \mu V \end{array}\right\} I_B^+$$

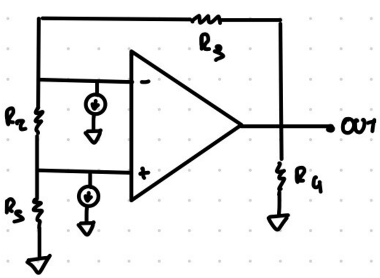
$$\left.\begin{array}{l} V_{OUT} = 0V \\ V_{OUT,OPAMP} = -I_B R_2 = -3\ \mu V \end{array}\right\} I_B^-$$

ESERCIZIO 2



$R_1 = R_5 = 100\ K\Omega$
$R_2 = 1 K\Omega$
$R_3 = 10\ K\Omega$
$R_4 = 20\ K\Omega$
$C = 1 nF$

Determinare l'effetto delle correnti di bias entranti $I_B = 1 \mu A$

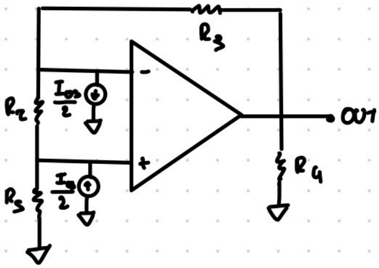


$V_+ = -I_B R_5 = -100\ mV$

$V_- = V_+$

$V_{OUT} = V_- + V_{R3} = V_- + I_B \cdot R_3 = -90\ mV$

Valutare l'effetto sull'uscita della corrente di offset $I_{os} = 100\,nA$



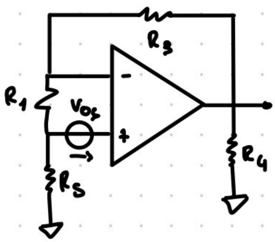
$V_+ = \frac{I_{os}}{2} R_5 = 50\,nA\,(100\,K\Omega) = 5\,mV$

$V_- = V_+ = 5\,mV$

$V_{OUT} = V_- + V_{R3} = V_- + \frac{I_o}{2} R_3 = 5,5\,mV$

$\Rightarrow \pm 5,5\,mV$

Valutare l'effetto della tensione di offset $V_{os} = \pm 1\,mV$



$V_{R1} = V_{os}$

$I_{R1} = V_{os}/R_1$

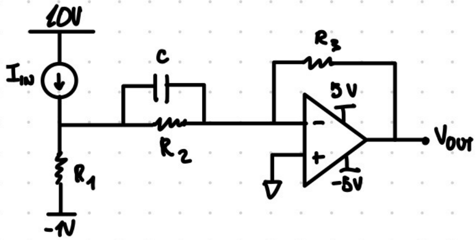
$V_{R5} = I_{R1} R_5$

$V_{R3} = I_{R1} R_3$

$V_{OUT} = V_{R5} + V_{R1} + V_{R3} \overset{!}{=} V_{os}\left(1 + \frac{R_5+R_3}{R_1}\right) = \pm 2,1\,mV$

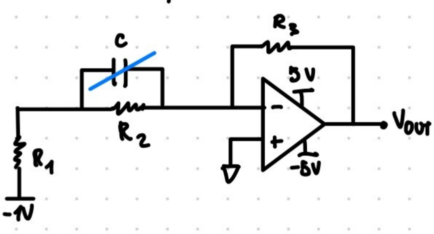
30/11/21

ESERCIZIO 1



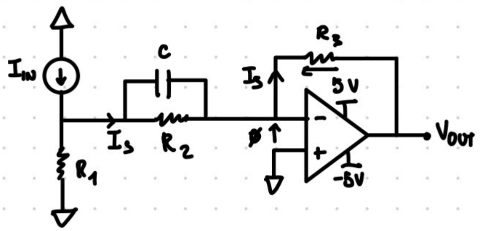
$R_1 = 1,5\,K\Omega$
$R_2 = 4,5\,K\Omega$
$R_3 = 18\,K\Omega$
$C = 17,5\,nF$

Calcolare V_{OUT} quando $I_{IN} = 0$



$V_{OUT} = +1V \frac{R_3}{R_1+R_2} = 3V$

Tracciare $V_{OUT}(t)$ in risposta a $I_{IN}(t) = 400\,\mu A \sin(2\pi\, 80\,KHz\, t)$



$$I_S = I_{IN} \frac{R_1}{R_1 + R_2 // \frac{1}{SC}}$$

$$V_{OUT} = -R_3\, I_S$$

$$\Longrightarrow\quad T_{ID} = \frac{V_{OUT}}{I_{IN}} = \cdots = -\frac{R_1 R_3}{R_1 + R_2} \cdot \frac{1 + SCR_2}{1 + SC\, R_1 // R_2}$$

$$f_z = 1/2\pi C R_2 = 2{,}02\ KHz \qquad T(0) = -\frac{R_1 R_3}{R_1 + R_2} = -4{,}5\ K\Omega$$

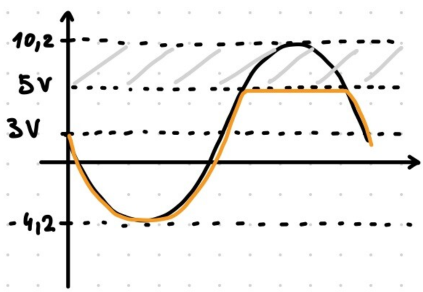
$$f_P = 1/2\pi C R_1 // R_2 = 8{,}08\ KHz \qquad T(\infty) = -R_3 = -18\ K\Omega$$

+1 decade rispetto a f_P

$$V_{OUT}|_{I_{IN}} = 400\,\mu A\, |T_{ID}| \cdot \sin(2\pi\, 80\,KHz\, t + \measuredangle T_{ID})$$

$$= 400\,\mu A \cdot 18\,K\Omega \cdot \sin(2\pi\, 80\,KHz\, t - 180°) = 7{,}2\,V \sin(2\pi\, 80KHz\, t - 180°)$$

$$\rightarrow V_{OUT} = \cancel{V_{OUT}|_{10V}} + V_{OUT}|_{-1V} + V_{OUT}|_{I_{IN}} = 3V + \cdots$$

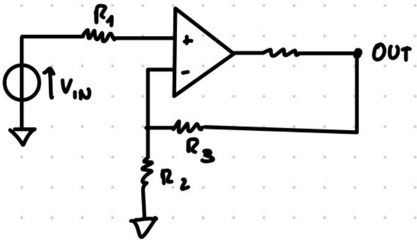


Sia un segnale con banda $[0; 100\,KHz]$ e ampiezza $[50; 250]\,\mu A$. Qual è lo slew rate minimo per non distorcere.

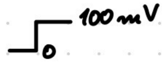
$$SR_{MIN} = \left.\frac{dV_{OUT}}{dt}\right|_{MAX} = A_{MAX} \cdot 2\pi f_{MAX} = 250\,\mu A \cdot |T_{MAX}| \cdot 2\pi\, 100\,KHz$$

$$= 250\,\mu A \cdot 18\,K\Omega \cdot 2\pi \cdot 100\,KHz = 2{,}83\ V/\mu s$$

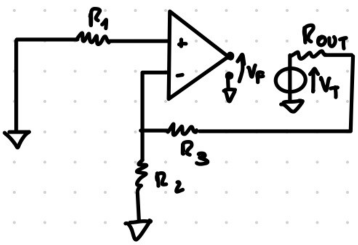
ESERCIZIO 2



$R_1 = 50\ K\Omega$
$R_2 = 2\ K\Omega$
$R_3 = 18\ K\Omega$
$R_{OUT} = 1\ K\Omega$

$V_{IN}(t) =$ 

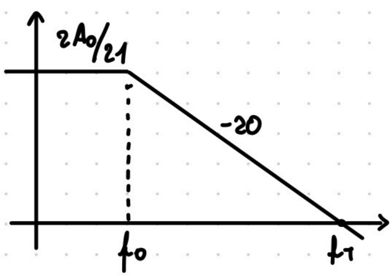
Considerando l'OPAMP a singolo polo con GBWP = 42 MHz, quanto vale V_{OUT}?



$$G_{ID} = 1 + \frac{R_3}{R_2} = 10$$

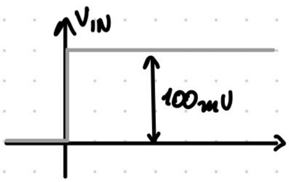
$$G_{LOOP} = \frac{V_F}{V_T} = -A(s)\frac{V_-}{V_T} = -\frac{A_0}{1+s\tau_0}\,\frac{R_2}{R_2+R_3+R_{OUT}}$$

$$= -\frac{A_0}{1+s\tau_0}\,\frac{2\cancel{K\Omega}}{21\cancel{K\Omega}}$$

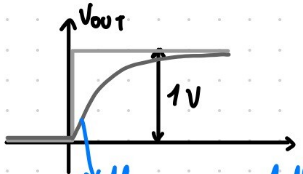


$$A_0 \frac{2}{21} f_0 = f_T$$

$$\frac{2}{21}\,GBWP = f_T \rightarrow f_T = 4\ MHz$$



$\rightarrow$



abbiamo un filtro passa basso, perciò passano solo le basse frequenze

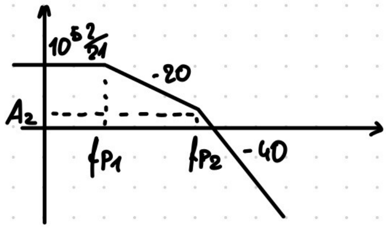
$$V_{OUT} = 1V\left(1 - e^{-t/\tau}\right) \qquad \tau = \frac{1}{2\pi f_T} = 39{,}79\ ns$$

Discutere la stabilità del circuito

$$\phi_M = 180° - \text{arctg}\left(\underbrace{\frac{f_T}{f_0}}_{\text{non possiamo ottenerlo}}\right) \geq 90° \quad ✓$$

Considerare un OPAMP con due poli $f_{P1} = 420\ Hz$ e $f_{P2} = 4\ MHz$ e $A_0 = 10^5$.

$$G_{LOOP} = -A(s)\frac{2}{21}$$



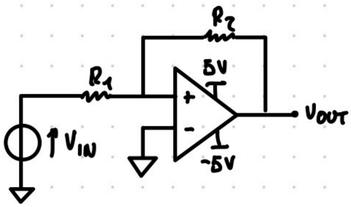
$$10^5\frac{2}{21}\ 420Hz = A_2\ 4MHz$$

$\hookrightarrow A_2 \simeq 1$

$\Rightarrow f_T \simeq f_{P2} = 4MHz$

$$\rightarrow \phi_M = 180° - \text{arctg}\left(\frac{f_T}{f_{P1}}\right) - \text{arctg}\left(\frac{\cancel{f_T}}{\cancel{f_{P2}}}\right) = 45° \ ✓$$

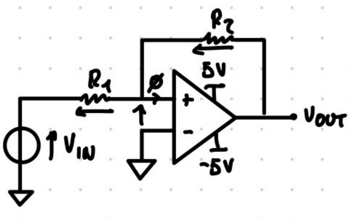
ESERCIZIO 3



$R_1 = R_2 = 5\ K\Omega$

Calcolare la caratteristica V_{OUT}/V_{IN}

La retroazione è positiva: $\varepsilon > 0 \rightarrow V_{OUT} \rightarrow +\infty \}\ V_{OUT} \rightarrow 5V$
$\varepsilon < 0 \rightarrow V_{OUT} \rightarrow -\infty \}\ V_{OUT} \rightarrow -5V$



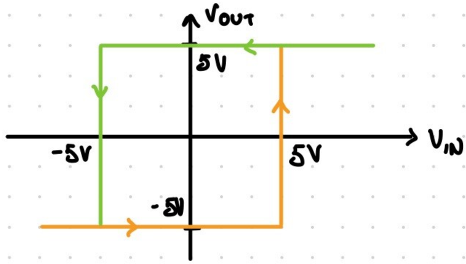
$V_- = 0V$

$$I_{R_1} = I_{R_2} = \frac{V_{IN} - V_+}{R_1} = \frac{V_+ - V_{OUT}}{R_2}$$

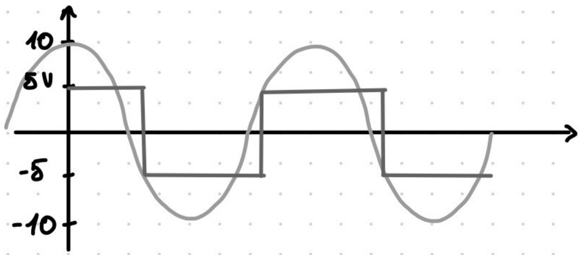
$$\rightarrow V_+ = \frac{V_{IN} + V_{OUT}}{2}$$

$V_{OUT} = 5V$ $\begin{cases} V_- = 0V \\ V_+ = V_{IN} + 5V/2 \end{cases}$ $\rightarrow \varepsilon < 0 \Rightarrow$ commuto a $\frac{V_{IN} + 5V}{2} < 0V \rightarrow V_{IN} < -5V$

$V_{OUT} = -5V$ $\begin{cases} V_- = 0V \\ V_+ = V_{IN} - 5V/2 \end{cases}$ $\rightarrow \varepsilon > 0 \Rightarrow$ commuto a $\frac{V_{IN} - 5V}{2} > 0V \rightarrow V_{IN} > +5V$



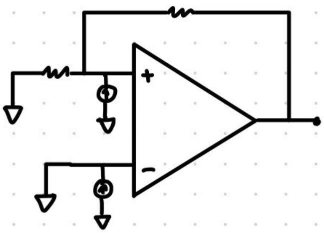
Si consideri V_{IN} una sinusoide di ampiezza 10V, valor medio 0V e frequenza 1KHz, disegnare la risposta.



$f = 1KHz$

$DC = 50\%$

Calcolare il contributo delle correnti di bias considerandole uscenti con $I_B = 100\ nA$



$V_+ = I_{B+}\ R_1 // R_2 = \dots = 250\ \mu V$

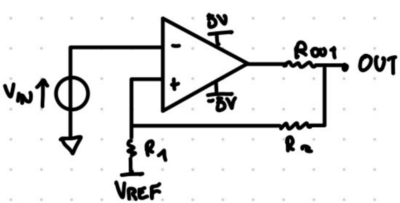
$V_+ = \frac{V_{IN} + V_{OUT}}{2} + 250\ \mu V$

$V_{OUT} = 5V \rightarrow \varepsilon < 0 \rightarrow$ commuta a $V_{IN} < -5V - 500\ \mu V$

$V_{OUT} = -5V \rightarrow \varepsilon > 0 \rightarrow$ commuta a $V_{IN} > 5V - 500\ \mu V$

2/12/21

ESERCIZIO 1



$R_1 = R_2 = 5\ K\Omega$

$R_{OUT} = 100\ K\Omega$

Supponendo $V_{REF} = 0V$, tracciare la caratteristica $V_{OUT} - V_{IN}$.

RETROAZIONE POSITIVA: $\begin{cases} \varepsilon > 0 \rightarrow V_{OUT,OPAMP} = 5V \\ \varepsilon < 0 \rightarrow V_{OUT,OPAMP} = -5V \end{cases}$

$$V_{OUT} = V_{OUT,OPAMP}\left(\frac{R_1+R_2}{R_1+R_2+R_{OUT}}\right) = \pm 4{,}95\ V$$

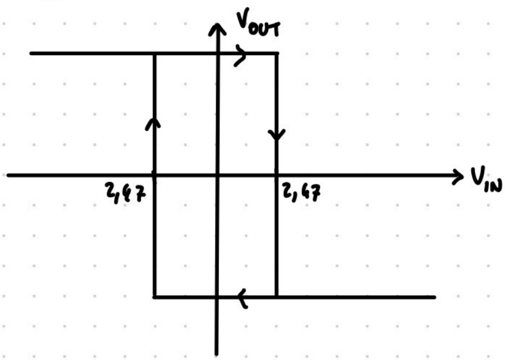
$$V_- = V_{IN} \quad V_+ = V_{OUT,OPAMP}\left(\frac{R_1}{R_1+R_2+R_{OUT}}\right) = \pm 2{,}47V$$

con $\underline{V_{OUT} = -4{,}95V}$, per commutare dobbiamo ottenere $\varepsilon > 0$

$\Rightarrow V_+ > V_- \rightarrow V_{IN} < -2{,}47V$

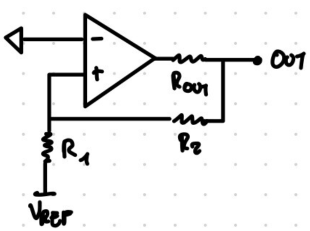
con $V_{OUT} = 4{,}95V$, per commutare dobbiamo ottenere $\varepsilon < 0$

$\Rightarrow V_+ < V_- \rightarrow V_{IN} > 2{,}47V$



Sia $V_{REF} = 2V$, ridisegnare la caratteristica

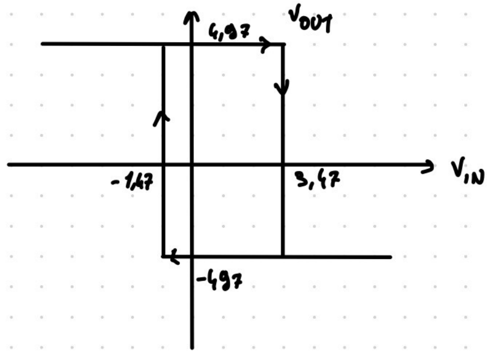
Applichiamo PSE:



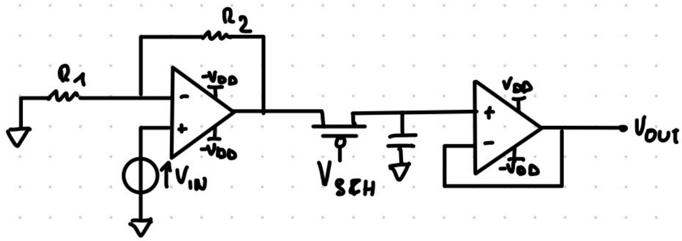
$$V_+|_{V_{REF}} = V_{REF}\left(\frac{R_1+R_{OUT}}{R_1+R_2+R_{OUT}}\right) = 1V$$

$$V_{OUT}|_{V_{REF}} = V_{REF}\left(\frac{R_{OUT}}{R_1+R_2+R_{OUT}}\right) = 0{,}02V$$

$\Rightarrow V_+ = \pm 2{,}47V + 1V = \begin{matrix} 3{,}47V \\ -1{,}47V \end{matrix}$ $\qquad V_{OUT} = \pm 4{,}97V + 0{,}02 = \begin{matrix} 4{,}97V \\ -4{,}93V \end{matrix}$



ESERCIZIO 2



$R_1 = 1K\Omega$
$V_{DD} = 5V$
$C = 1nF$
$V_{TP} = -1V$
$|K_p| = 1mA/V^2$
$V_{IN} \in [-100\,mV; 100\,mV]$

Calcolare R_2 affinchè la dinamica dello stadio amplificante sia sfruttata completamente.

$V_{OUT} \in [-5V; 5V]$ e $V_{IN} \in [-100\,mV; +100\,mV]$

$G_{TOT} = G_1 G_2 = 1 + \left(\frac{R_2}{R_1}\right) \cdot 1 = \frac{5V}{100mV} = 50$

$\hookrightarrow \frac{R_2}{R_1} = 49 \rightarrow R_2 = 49\,K\Omega$

Considerando $R_2 = 24\,K\Omega$, scegliere V_{SAMPLE} e V_{HOLD} che garantiscono il corretto funzionamento.

<u>SAMPLE:</u> PMOS ON $\rightarrow V_{SG} > |V_T| \rightarrow V_S - V_G > 1V$
$\Rightarrow V_S - V_{SAMPLE} > 1V \Rightarrow V_{SAMPLE} < V_S - 1V$

poichè sfruttiamo metà dinamica, $V_{OUT} \in [-2{,}5V; 2{,}5V]$

$\Rightarrow V_{SAMPLE} < -2{,}5V - 1V = -3{,}5V$

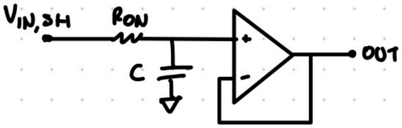
<u>HOLD:</u> PMOS OFF $\rightarrow V_{SG} < |V_T| \rightarrow V_S - V_G < 1V$
$\Rightarrow V_{HOLD} > V_S - 1V > 2{,}5V - 1V = 1{,}5V$

Determinare la tensione di comando da applicare allo S&H per avere una resistenza in ingresso di 50 Ω

$$R_{SD,ON} = \frac{1}{2|K_p|(V_{SG}-|V_{Tp}|)} < 50\,\Omega \rightarrow V_{SG} > 1V + \frac{1}{2\cdot 1mA/V^2 \cdot 50\,\Omega} = 11V$$

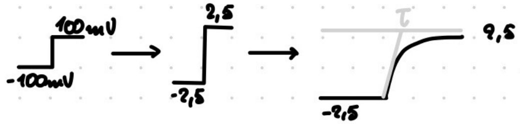
$$V_S - V_{SAMPLE} > 11V \rightarrow \quad V_{SAMPLE} < V_S - 11V = -13{,}5\,V$$

Considerando $R_{ON} = 50\,\Omega$, determinare il minimo SR del secondo OPAMP compatibile col circuito.



$V_{IN,SH} \in [-2{,}5V; 2{,}5V]$

Non conosciamo la forma di V_{IN}, supponiamo il caso pessimo: gradino

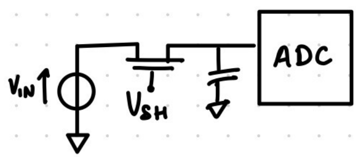


$\Rightarrow \tau = CR_{ON} = 50ns$

$$SR_{MIN} = \left.\frac{dV_{OUT}}{dt}\right|_{MAX} = \left.\frac{dV_C}{dt}\right|_{MAX} = \frac{\Delta V_C}{\tau} = \frac{5V}{50ns} = 100\,V/\mu s$$

9/12/21

ESERCIZIO 1



$C_H = 30\,nF$

$V_T = 1V$

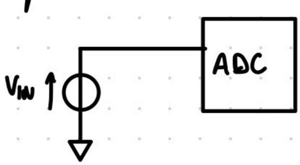
$C_{PAR} = 0{,}1\,pF$

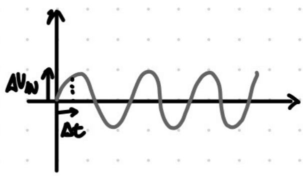
$V_{IN} = A\sin(2\pi f_{IN} t)$

$A \in [10mV; 100mV]$

$f_{IN} \in [10KHz; 100KHz]$

Qual è il T_{CAMP} affinché si abbia $\varepsilon_{MAX} = \frac{1}{1000}V_{IN}$ di errore SENZA sample & hold





$$\Delta V_{IN} = \frac{dV_{IN}}{dt}\Delta t = \varepsilon$$

$\Delta t \downarrow T_{CAMP}$

$$\Longrightarrow \varepsilon = A\cos(2\pi f_{IN} t)\, 2\pi f_{IN} t\, T_{COMP} \rightarrow E_{MAX} = A\, 2\pi f_{IN} t\, T_{comp}$$

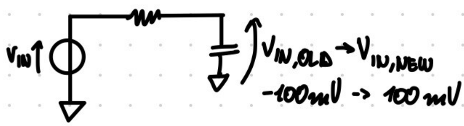
$$\rightarrow T_{COMP} \leq \frac{1}{1000\, 2\pi f_{IN}} \xrightarrow[\text{PESSIMO}]{\text{CASO}} T_{COMP} \leq 1{,}6\ ns$$

Considerando $T_{HOLD} = 1\,\mu s$, calcolare $T_{SAMPLE,MAX}$ compatibile con il circuito

$$T_{SAMPLE} + T_{HOLD} = \underbrace{T_{CAMP} \leq \frac{T_{IN}}{2}}_{\text{Th. Shannon}} \Longrightarrow T_{SAMPLE} \leq \frac{T_{IN}}{2} - T_{HOLD} = \frac{1}{2 f_{IN}} - T_{HOLD}$$

$$\xrightarrow[\text{PESSIMO}]{\text{CASO}} T_{SAMPLE} \leq 4\,\mu s$$

Considerare $R_{ON} = 10\,\Omega$, calcolare la corrente massima in ingresso



$$\Delta V_{CH} = 200\,mV$$

$$I_{MAX} = C_H \cdot \frac{dV_{CH}}{dt} = C_H \frac{\Delta V_{CH}}{\tau} = \frac{\Delta V_{CH}}{R_{ON}} = 20\,mA$$

Determinare V_{SAMPLE} e V_{HOLD} compatibili con la dinamica del circuito

SAMPLE → NMOS ON → $V_{GS} > V_T = 1V$

$V_G - V_S > 1V \rightarrow V_{SAMPLE} - V_{IN} > 1V \rightarrow V_{SAMPLE} > V_{IN} + 1V \rightarrow 1{,}1\,V$

HOLD → NMOS OFF → $V_{GS} < V_T = 1V$

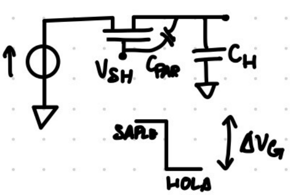
$V_G - V_S < 1V \rightarrow V_{SAMPLE} - V_{IN}\ \ 1V \rightarrow V_{SAMPLE} < V_{IN} + 1V \rightarrow 0{,}9\,V$

Si consideri $V_{SAMPLE} = 3V$, si calcoli la K_n affinché si abbia $R_{ON} \sim 10\,\Omega$

$$R_{ON} = \frac{1}{2K_N(V_{GS} - V_T)} \leq 10\,\Omega \Longrightarrow K_N \geq \frac{1}{2\,10\Omega\,(V_{SAMPLE} - V_{IN} - V_T)} =$$

$$= \frac{1}{2 \cdot 10\Omega\,(3V - 0{,}1V - 1V)} = 26{,}3\ mA/V^2$$

Considerando $V_{SAMPLE} = 3V$, determinare la V_{HOLD} l'errore massimo rispetto al segnale sia $E_{MAX} = \frac{1}{1000}\,IN$ nel passaggio tra sample e hold

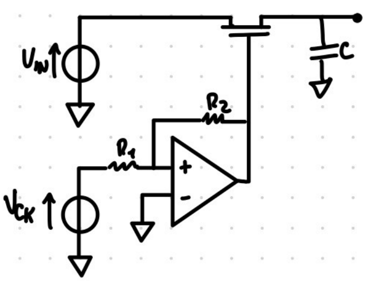


$$\Delta V_{CH} = \Delta V_G \left(\frac{1/sC_H}{1/sC_H + 1/sC_{PAR}}\right) = \Delta V_G \left(\frac{C_{PAR}}{C_{PAR} + C_H}\right)$$

$$\rightarrow \Delta V_{CH} = \Delta V_G \cdot \frac{C_{PAR}}{C_{PAR} + C_H} \leq \frac{1}{1000} A \rightarrow \Delta V_G \leq 3V$$

$\rightarrow V_{HOLD} \cong 0V$

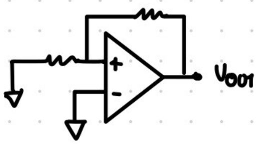
ESERCIZIO 2



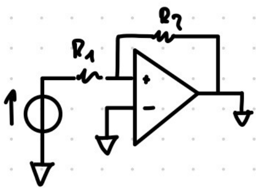
$R_1 = 10\,K\Omega$
$R_2 = 30\,K\Omega$
$V_{OUT,OPAMP} \in [-10; 10]V$
$V_T = 1{,}4V$
$K = 5\ mA/V^2$
$V_{CK} = 4V\cos(2\pi\ 1000MHz\ t)$

Calcolare T_{SAMPLE} e T_{HOLD}

L'OPAMP è retroazionato positivamente: $\varepsilon > 0$ $V_{OUT,OPAMP} = 10V$
$\varepsilon < 0$ $V_{OUT,OPAMP} = -10V$
$V_- = \emptyset V$



$$V^+|_{V_{OUT}} = V_{OUT}\frac{R_1}{R_1+R_2}$$

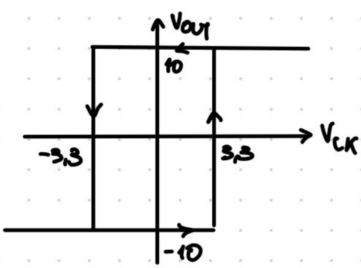


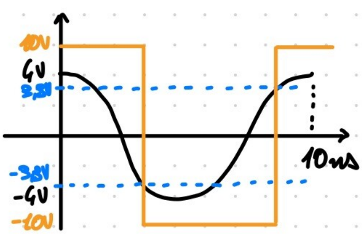
$$V^+|_{V_{CK}} = V_{CK}\frac{R_2}{R_1+R_2}$$

$$V^+ = V_{OUT}\frac{R_1}{R_1+R_2} + V_{CK}\frac{R_2}{R_1+R_2} = \pm\frac{10V}{4} + \frac{3}{4}V_{CK}$$

$\underline{V_{OUT,OPAMP} = -10V,\ \varepsilon < 0}$ $\rightarrow$ per $V_{OUT} = +10V$ $\quad \frac{10V}{4} + \frac{3}{4}V_{CK} > 0 \rightarrow V_{CK} > 3{,}3V$

$\underline{V_{OUT,OPAMP} = 10V,\ \varepsilon > 0}$ $\rightarrow$ per $V_{OUT} = -10V$ $\quad -\frac{10V}{4} + \frac{3}{4}V_{CK} < 0 \rightarrow V_{CK} < -3{,}3V$





$\hookrightarrow$ ONDA QUADRA $DC = 50\%$ e $T = 10\ ns$

$\hookrightarrow$ $T_S = T_H = 5\ ns$

Calcolare il valore massimo e minimo di V_{IN} compatibili con il S&H

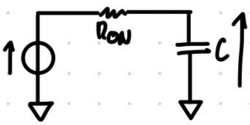
SAMPLE → NMOS ON → $V_{GS} > V_T$

$V_G - V_S > V_T \rightarrow V_{SAMPLE} - V_{IN} < V_T \rightarrow V_{IN} < V_{SAMPLE} - V_T$
$\rightarrow 8{,}6V$

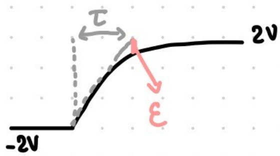
HOLD → NMOS OFF → $V_{GS} < V_T$

$V_G - V_S < V_T \rightarrow V_{HOLD} - V_{IN} > V_T \rightarrow V_{IN} > V_{HOLD} - V_T$
$\rightarrow -11{,}4V$

Se $V_{IN} \in [-2,2]V$ stimare il valore massimo di C_{MAX}. Si consideri $\varepsilon_{MAX} = \frac{1}{2000} V_{IN}$



$V_C = 2V - 4Ve^{-t/\tau}$



$$\varepsilon = 2V - (2V - 4Ve^{-T_S/\tau}) \le \frac{1}{2000} 2V$$

$$\hookrightarrow \tau \le \frac{T_S}{\ln(4V/1mV)} = R_{ON} C$$

$$R_{ON} = \frac{1}{2K_N(V_{GS} - V_T)} = \frac{1}{2 \cdot 5mA/V^2 (10V - 2V - 1V)} = 15{,}15\,\Omega \rightarrow C \le \frac{\tau}{R_{ON}} = 59{,}8\,pF$$

Calcolare $R_{2,MIN}$ che permette al segnale del S&H di avere la forma richiesta

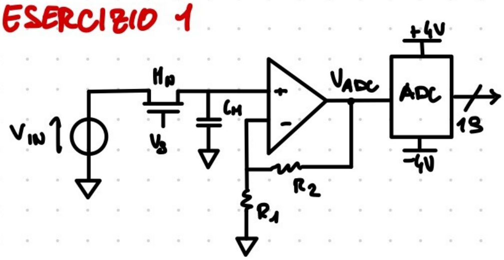
$$\begin{cases} V^- = 0 \\ V^+ = V_{OUT} \frac{R_1}{R_1 + R_2} + V_{CK} \frac{R_2}{R_1 + R_2} \end{cases}$$

$$V^+ = V^- \rightarrow \dots \rightarrow \underbrace{V_{CK} = \mp 10V \left(\frac{R_1}{R_2}\right) \le 4V}_{\text{Deve sempre commutare prima dei 4V}}$$

$$\Rightarrow R_2 \ge 25K\Omega$$

14/12/21

ESERCIZIO 1



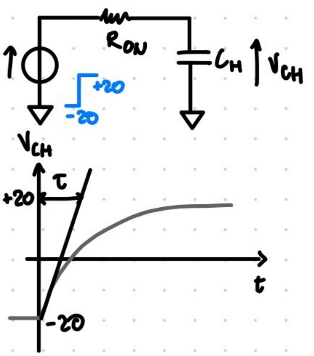
$R_1 = 1K\Omega$
$R_2 = 9K\Omega$
$C_H = 10nF$

Qual è il LSB dell'ADC visto all'ingresso dell'OPAMP

$$LSB = FSR/2^{13} = V_H - V_m/2^{13} = 4V+4V/2^{13} \simeq 976,5\ \mu V$$

$$LSB_{IN} = LSB/G = 976,5\ \mu V / 1 + 9k\Omega/1k\Omega = 97,6\ \mu V$$

Supponendo $-20\ mV < V_{IN} < 20\ mV$ e $R_{ON} = 100\ \Omega$, calcolare T_{SAMPLE} minimo compatibile



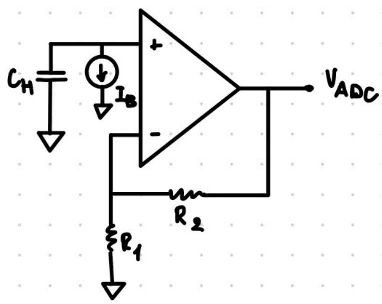
$$V_{CH} = 20\ mV - 40\ mV\ e^{-t/\tau}$$

$$\varepsilon = 20\ mV - V_{CH}(t = T_S) =$$

$$\stackrel{!}{=} 40\ mV\ e^{-T_S/\tau} \leq LSB_{IN} = 97,6\ \mu V$$

$$\Rightarrow T_S \geq \cdots = 6\ \mu s$$

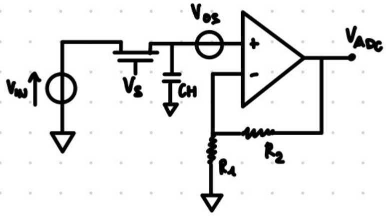
Determinare la massima T_{HOLD} se l'OPAMP possiede $I_B = 2\ nA$



$$\Delta V_{CH} = \frac{I_B}{V_{CH}} T_H \leq LSB_{IN}$$

$$\Rightarrow T_H \leq \cdots = 488\ \mu s$$

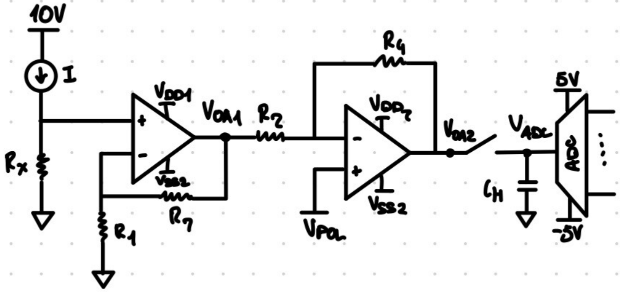
Qual è l'errore causato da una $V_{os} = 100\ \mu V$?



$$\varepsilon|_{V_{os}} = V_{os} = \pm 100\ \mu V$$

$$\varepsilon|_{V_{os}} = \frac{V_{os}}{LSB} = \frac{100}{97,6} \simeq 1 \cdot LSB$$

ESERCIZIO 2



$R_1 = 2\,K\Omega$
$R_2 = 49\,K\Omega$
$R_3 = 5\,K\Omega$
$R_4 = 20\,K\Omega$
$I = 100\,\mu A$
$V_{POL} = 1\,V$

Calcolare il numero di bit dell'ADC sapendo che $\Delta R_x = 0{,}1\,\Omega$

$$V_{ADC}|_I = I R_x \left(1 + R_2/R_1\right)\left(-R_4/R_3\right)$$
$$V_{ADC}|_{V_{POL}} = V_{POL}\left(1 + \frac{R_4}{R_3}\right)$$
$$\Rightarrow V_{ADC} = \cdots = 100\,\mu A\, R_x (-100) + 5V$$

$$\Delta R_x \to \Delta V_{ADC} = -1\,mV \implies LSB = FSR/2^n \leq 1\,mV \Rightarrow n \geq \log_2 10.000 \simeq 13{,}29$$
$$\to n = 14$$

Calcolare il massimo valore di R_x misurabile.

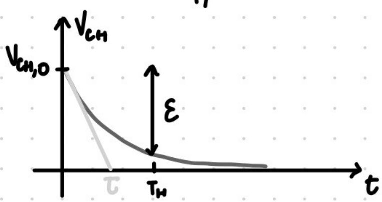
$$-5V < V_{ADC} < 5V \implies V_{ADC} = -10\,mA \cdot R_x + 5V \geq -5V \Rightarrow R_x \leq \cdots = 1\,K\Omega$$

Determinare le tensione di alimentazione degli operazionali affinché il circuito funzioni correttamente. Si considerino gli OPAMP R2R.

$$V_{OA1} = I R_x \left(1 + R_2/R_1\right) = 2{,}5\,mA \cdot R_x \to V_{OA1} \in [0;\, 2{,}5]\,V \to V_{SS1} = 0V,\ V_{DD1} = 2{,}5V$$

$$V_{OA2} = 5V - 10\,mA \cdot R_x \to V_{OA2} \in [-5;\, +5]\,V \to V_{SS2} = -5V,\ V_{DD2} = 5V$$

Sia la resistenza in ingresso dell'ADC $100K\Omega \leq R_{ADC} \leq 1M\Omega$. Quanto deve valere C_H affinché $\varepsilon < 1\,LSB$ con $T_H = 10\,\mu s$



PESSIMO: $V_{CH} = 5V e^{-t/\tau}$

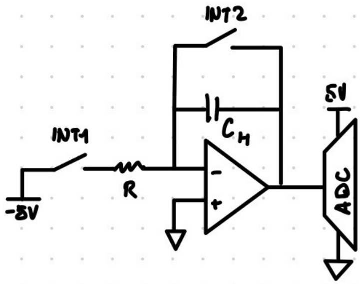
$$\varepsilon = 5V - 5V e^{-T_H/\tau} \leq 1 \cdot LSB = \frac{FSR}{2^{14}}$$

⋮

$$e^{-T_H/\tau} \le 1-2^{-13} \rightarrow \tau \ge \frac{T_H}{\log_2\left(1-2^{-13}\right)} = 81{,}9 \text{ ms}$$

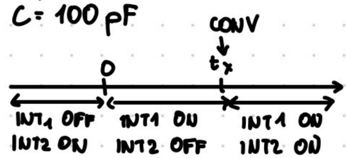
$$R_{ADC} C_H \ge 81{,}9 \text{ ms} \rightarrow C_H \ge \frac{\overset{81{,}9\text{ ms}}{\tau_{MIN}}}{\underset{100\text{K}\Omega}{R_{ADC}}} = 819 \text{ nF}$$

ESERCIZIO 3



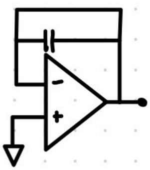
$R_1 = 1\text{K}\Omega$

$C = 100 \text{ pF}$



Supponendo $t_x = 50$ ns, calcolare $V_{OUT}(t)$ tra 0 e 60 ns

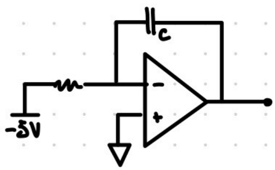
$t < 0$ s:



$V_{OUT} = 0V$

$V_C = 0V$

$t \in [0; t_x]$ s:



$$I_C = \frac{5V}{R} = 5 \text{ mA}$$

$$\overset{!}{=} C \frac{dV_C}{dt}$$

$$\Longrightarrow \frac{dV_C}{dt} = \frac{I_C}{C} = 50 \text{ V}/\mu s$$

$$\Longrightarrow V_C(t) = 50 \text{ V}/\mu s \cdot t$$

$$\Longrightarrow V_{OUT}(t) = 50 \text{ V}/\mu s \cdot t$$

$t > t_x$: V_C costante $\Longrightarrow$ V_{OUT} costante

$$V_{OUT}(t_x) = 50 \text{ V}/\mu s \cdot 50 \text{ ns} = 2{,}5 \text{ V}$$

Calcolare il massimo t_x compatibile con la dinamica in ingresso.

$$V_{OUT} \le 5V \rightarrow 50 \text{ V}/\mu s \cdot t_{x,MAX} \le 5V \rightarrow t_{x,max} \le 100 \text{ ns}$$

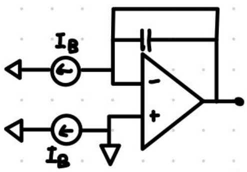
Scegliere il numero di bit dell'ADC affinché la risoluzione sia 50 ps.

$$\Delta V_{ADC} = \Delta V_{OUT} = 50\ V/\mu s \cdot \Delta t_x = \dots = 2,5\ mV$$

$$LSB_{ADC} \le 2,5\ mV$$
$$\frac{FSR}{2^n} \le 2,5\ mV$$
$$\frac{5V}{2^n} \le 2,5\ mV \rightarrow n \ge \log_2\left(\frac{5V}{2,5mV}\right) = 10,96 \Rightarrow n = 11$$

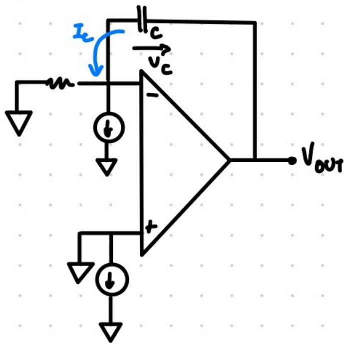
Calcolare l'effetto sul codice dell'ADC di una corrente di bias $I_B = 100\ pA$ entrante con $t_x = 50\ ns$

<u>$t < 0\,s$:</u>



$V_{OUT} = 0V \rightarrow V_C = 0V$

<u>$t \in [0; t_x]\,s$:</u>

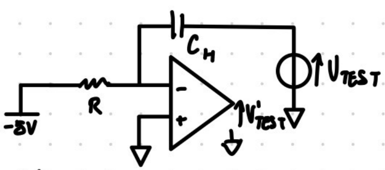


$$V_{OUT}|_{I_B} = \frac{I_c}{C} t = \frac{100pA}{100pF} = 1V/\mu s\ t$$
$$V_{OUT}(t_x)|_{I_B} = 50\ mV$$

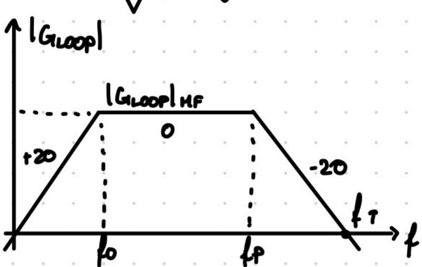
$$LSB = \frac{FSR}{2^{11}} = \frac{5V}{2^{11}} = 2,44\ mV$$

$\rightarrow \varepsilon = 20,5\ LSB$

Calcolare il margine di fase con INT1 chiuso e INT2 aperto, $f_0 = 10Hz$ e $GBWP = 100\ Hz$



$$G_{LOOP} = -A(s) \cdot \frac{V^-}{V_T} = -\frac{A_0}{1+s\tau_0} \cdot \frac{R}{R+\frac{1}{sC}}$$
$$= -\frac{A_0}{1+s\tau_0} \frac{sCR}{1+sCR}$$



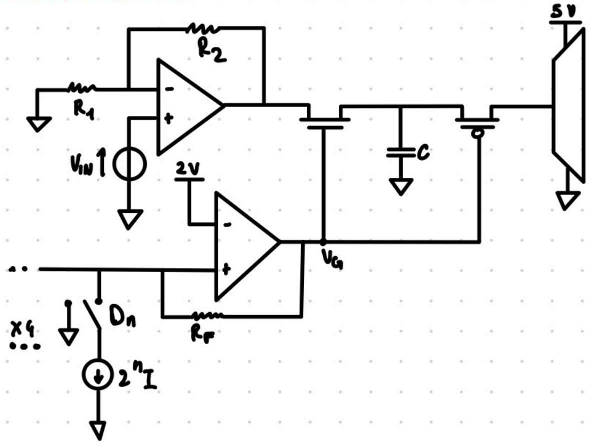
$$|G_{LOOP}|_{HF} = \frac{A_0}{\cancel{s}\tau_0} \cdot \frac{\cancel{s}CR}{1} = A_0 \frac{f_0}{f_P} = \frac{GBWP}{\cancel{f_0}} \frac{\cancel{f_0}}{f_P}$$
$$= \frac{GBWP}{f_P}$$

$$f_T = f_P |G_{LOOP}|_{HF} = GBWP = 100\ MHz$$

$$\phi = 180° - \arctg\left(\frac{f_T}{f_0}\right) - \arctg\left(\frac{f_T}{f_P}\right) + \arctg\left(\frac{f_T}{f_Z}\right)$$
$$= 180° - 90° - 90° + 90° = 90°$$

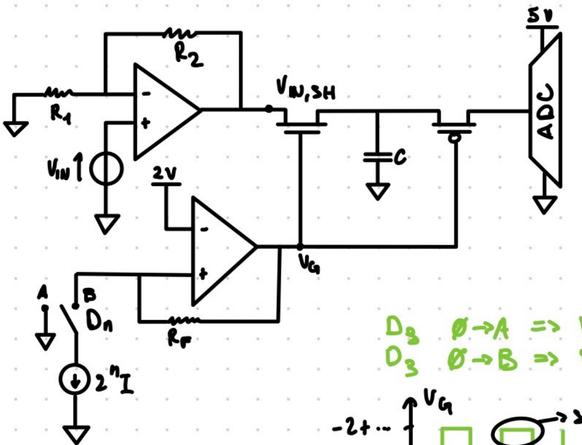
16/12/21

ESERCIZIO 1



$I = 250\ nA$
$C_{PAR} = 200\ pF$
$|V_T| = 1\ V$
$n_{bit} = 13$
$C = 5\ nF$
$R_1 = 1K\Omega$
$R_2 = 24\ \Omega$

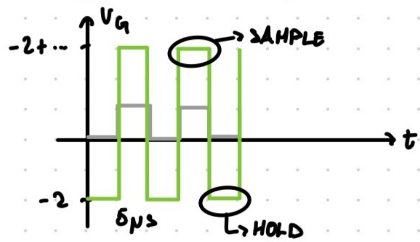
Si consideri $D_0 = D_1 = D_2 = \emptyset$ e D_3 che oscilla secondo un onda quadra di $f = 100\ KHz$ e $DC = 50\%$, calcolare la $R_{ON,MAX}$ tale che $\varepsilon < 1\ LSB$



$$V_{IN,SH} = V_{IN}\left(1 + \frac{R_2}{R_1}\right) = 25\ V_{IN}$$

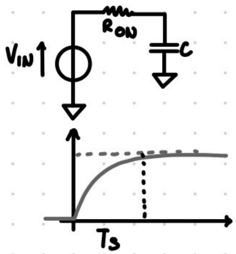
IPOTIZZIAMO $V_{IN} = 5V$

$D_3\ \ \emptyset \to A \Rightarrow V_G = -2V$
$D_3\ \ \emptyset \to B \Rightarrow V_G = -2V + 8IR_F = -2V + 2nA\,R_F$



$\Rightarrow T_S = T_H = 5\ \mu s$

$LSB = FSR/2^{13} = \cdots = 0{,}61\ mV$



$V_C(t) = 5V - 5V e^{-t/\tau}$

$\Rightarrow \varepsilon = 5V - V_C(T_S) = \cancel{5V - 5V} + 5V e^{-T_S/\tau}$

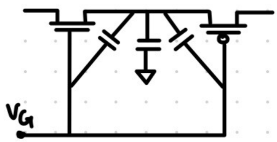
$\Rightarrow \cdots \Rightarrow \tau \leq 0{,}55\ ms$

$R_{ON} \leq 110\ \Omega$

Considerando $V_{G,MAX} = 8V$, quanto deve valere R_F?

$V_{G,MAX} = -2V + 2mA \cdot R_F \Rightarrow R_F = 5\ K\Omega$

Calcolare l'errore dovuto a charge injection. È minore di 2LSB?



$\varepsilon = \Delta V_G \dfrac{2C_{PAR}}{C + 2C_{PAR}} \simeq \dfrac{2C_{PAR}}{C} \simeq 0{,}8\ mV \simeq 1{,}3\ LSB$

Dimensionare K_{NMOS} per avere $R_{ON} < 100\ \Omega$

$R_{ON} = \dfrac{1}{2K_N(V_{GS} - V_{TN})} < 100\ \Omega \Rightarrow K_N > 2{,}5\ mA/V^2$

$V_{GS} = V_G - V_S = 8V - V_{IN,SH} \xrightarrow{W.C.} 8V - 5V = 3V$

fase di sample

Considerando $A_0 = 10^5$ e $V_{IN} \in [0, 100]\ mV$, calcolare l'errore statico max

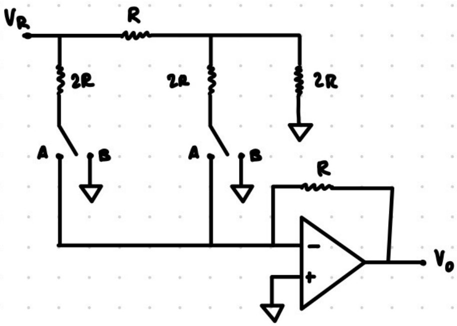
$V_{IN,SH,ID} = V_{IN} \cdot \underbrace{25}_{G_{IDEALE}}$, $V_{IN,SH} = V_{IN} \cdot G_{REALE} \simeq V_{IN} \cdot 25\,(1 - 25 \cdot 10^{-5})$

$G_{REALE} = \dfrac{G_{IDEALE}}{1 - 1/G_{LOOP}} = \cdots \simeq 25\,(1 - 25 \cdot 10^{-5})$

$G_{LOOP}(0) = -A_0 \dfrac{V^-}{V_T} = -A_0 \dfrac{R_1}{R_1 + R_2} = -\dfrac{10^5}{25}$

$\Rightarrow \varepsilon = V_{IN,SH} - V_{IN,SH,ID} = \cdots \simeq 1\ LSB$

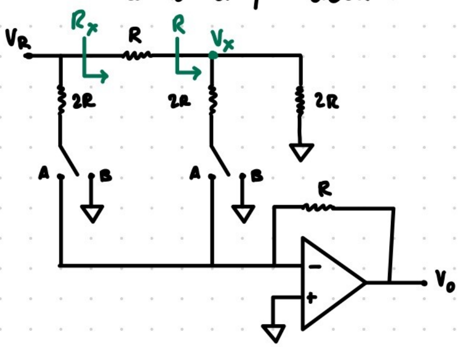
ESERCIZIO 2



$R = 5\,K\Omega$
$V_R = -10\,K\Omega$

Quanto vale V_o? Qual è la funzione del circuito?

$V_+ = V_- = \varnothing V$



$R_x = 2R$
$V_x = V_R/2$

$$I_R = \left(\frac{V_R}{2R}\right)\cdot D1 + \frac{V_R/2}{2R} D0$$

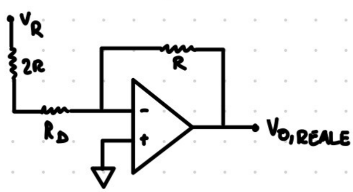
$$V_O = -I_R R$$
$$= -\frac{V_R}{2}\left(D_1 + D_0/2\right)$$

Il circuito è un DAC R-2R

Supponendo che gli interruttori deviatori sono degli nmos con $K = 1\,mA/V^2$, $V_{OD} = 4V$, quanto vale R_D? E l'errore dati $D_0 = 0$, $D_1 = 1$?

$$R_{DS,ON} = \frac{1}{2K_N \underbrace{(V_{GS} - V_T)}_{V_{OD}}} \rightarrow R_D = 125\,\Omega$$

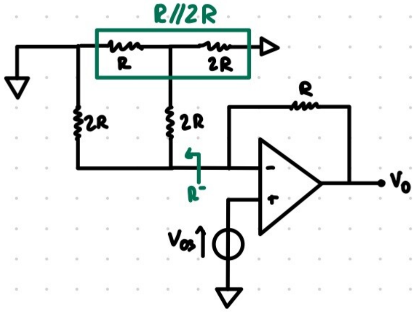
$$V_{O,IDEALE} = -\frac{V_R}{2}\left(D_0 + \frac{D_1}{2}\right) = 5V$$



$$V_{O,REALE} = V_R\left(-\frac{R}{2R + R_D}\right) = \dots = 4,938V$$

$$\Rightarrow E = V_{O,REALE} - V_{O,IDEALE} = -0,062\,V$$

Calcolare l'errore introdotto da $V_{OS} = \pm 10mV$ con $D_0 = D_1 = 1$.



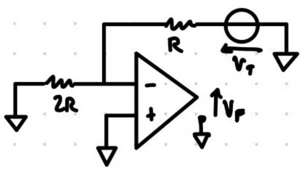
$$V_0 = V_{OS}\left(1 - \frac{R}{R_-}\right) = \dots = \pm 18{,}75 \text{ mV}$$

$$R^- = (R/\!/2R + 2R)/\!/2R \overset{!}{=} 2R/\!/\left(2R + \frac{2}{3}R\right) = 2R/\!/\frac{8}{3}R = \frac{8}{7}R$$

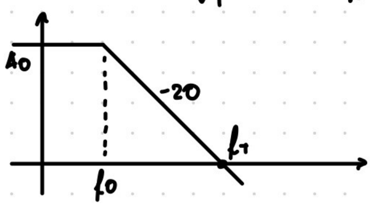
Considerando $A_0 = 100$ dB e GBWP $= 1$ MHz, come si comporta V_0 durante $00 \to 01$?

$D_0 = 0, D_0 = 0 \to V_0 = \emptyset V$
$D_0 = 0, D_0 = 1 \to V_0 = -V_R/2 = 5V$

$G_{ID} = V_0/V_R = 5V/-10V = -1/2\ V$,



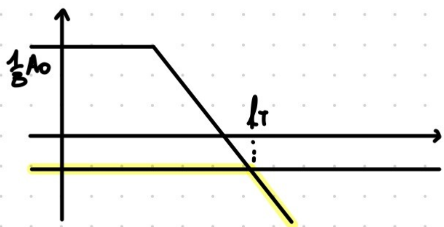
$$G_{LOOP} = -A(s)\frac{V_-}{V_T} = -A(s)\frac{2R}{R+2R} = -\frac{A_0}{1+s\tau_0}\cdot\frac{2}{3}$$



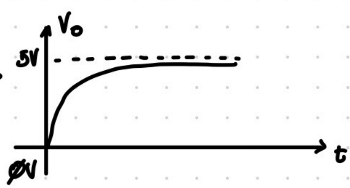
$$f_T = A_0\frac{2}{3}f_0 = GBWP\cdot\frac{2}{3} \overset{!}{=} 0{,}67 \text{ MHz}$$

$$G_{OPEN} = -G_{ID}\cdot G_{LOOP} = \dots = -\frac{A_0}{1+s\tau_0}\cdot\frac{1}{3}$$

$$G_{REALE} = \begin{cases} G_{ID} & f < f_T \\ \frac{A_0}{1+s\tau_0}\cdot\frac{1}{3} & f > f_T \end{cases}$$



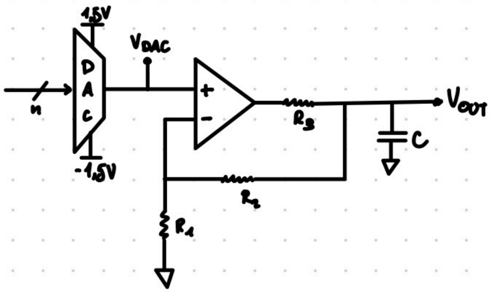
$\Rightarrow$



$$\tau = \frac{1}{2\pi f_T} \simeq 0{,}24\ \mu s$$

17/12/21

ESERCIZIO 1



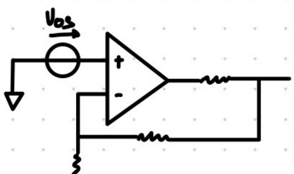
$R_1 = 10\ K\Omega$
$R_2 = 30\ K\Omega$
$R_3 = 20\ K\Omega$
$C = 25\ nF$

Considerando una risoluzione di 1V e $\Delta V \leq 1/1000\ A_P$, qual è il n_{bit} minimo?

$$\Delta V_{DAC} < \frac{1}{1000} V = 1mV$$

$$LSB = FSR/2^{n_{bit}} \rightarrow n_{bit} \geq \log_2(3V/1mV) \geq 11{,}55 \Rightarrow n_{bit} = 12$$

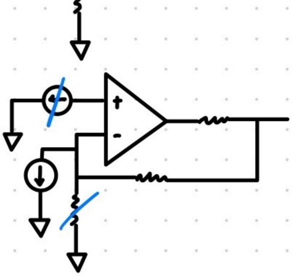
Considerando una $V_{OS} = \pm 0{,}4\ mV$ e $I_B = 20\ nA$ entrante, qual è il massimo numero di bit affinché l'LSB in uscita sia maggiore del contributo delle non idealità.



$$V_0|_{V_{os}} = V_{os}(1 + R_1/R_2) = \dots = \pm 1{,}6\ mV$$

$$V_0|_{I_B} = I_B R_2 = \dots = 0{,}6\ mV$$

$$V_0|_{V_{os}+I_B} = \pm 1{,}6\ mV + 0{,}6\ mV = \begin{cases} 2{,}2\ mV \ \text{(pessimo)} \\ -1\ mV \end{cases}$$



$$LSB_{OUT} = LSB_{DAC}(1 + R_1/R_2) = 4 \cdot LSB_{DAC} \geq 2{,}2\ mV$$

$$\rightarrow \dots \rightarrow n \leq 12{,}41 \Rightarrow n = 12$$

Si assuma ora $A(s) = A_0 = 10^4$. Qual è l'errore massimo

$G_{ID} = 4$

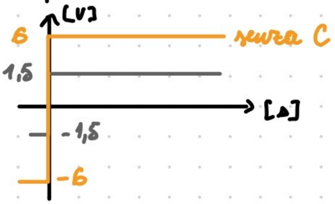
$$G_{LOOP} = -A(s)\,\frac{V_-}{V_T} = A_0 \cdot \frac{R_1}{R_1+R_2+R_3} = \dots = -\frac{10^4}{6} \Rightarrow G_{REALE} = \frac{G_{ID}}{1-\frac{1}{G_{LOOP}}} = \dots$$

$$= 4\,(1-6\cdot10^{-4})$$

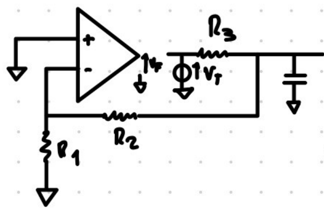
$$\varepsilon = V_{DAC}\,(G_{REALE}-G_{ID}) = V_{DAC}\,(\cancel{4} - 4\cdot 6\cdot 10^{-4} + \cancel{4})$$

$\hookrightarrow \varepsilon_{MAX} = \pm\, 3{,}6\ mV$

All'istante $t = 0\,s$ il DAC passa dal valore minimo a quello massimo. In quale istante di tempo $V_{OUT} = \emptyset V$?



Se consideriamo C, varia G_{LOOP}:

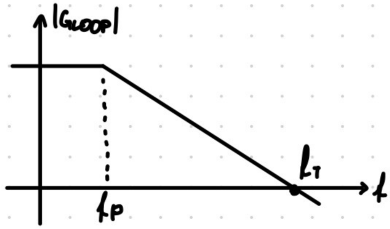


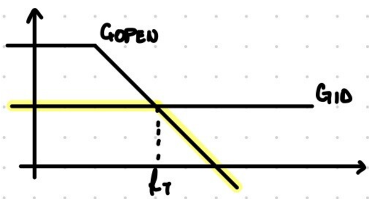
$$-A_0 \cdot \frac{(R_1+R_2)\,//\,1/sC}{(R_1+R_2)\,//\,1/sC + R_3} \cdot \frac{R_1}{R_1+R_2} =$$

$$= -A_0\,\frac{R_1}{R_1+R_2+R_3}\,\frac{1}{1+sC(R_1+R_2)//R_3}$$

$\hookrightarrow f_P = \dots = 482{,}53\ Hz$

$$G_{OPEN} = -G_{ID}\cdot G_{LOOP} = \dots = -\frac{2}{3}\cdot 10^4\,\frac{1}{1+s\tau_P}$$





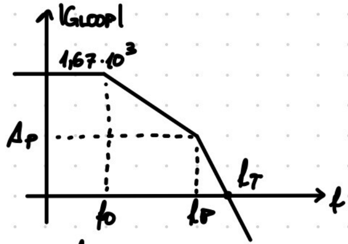
$\Rightarrow V_{OUT}$ esponenziale con $\tau = 1/2\pi f_T$

$$V_C = -6V + 12V e^{-t/\tau} \Rightarrow \dots \Rightarrow t^* = 137{,}9\ \mu s$$

Considerando $A(s)$ con un polo e $A_0 = 10^4$, $GBWP = 1MHz$ discutere la stabilità.

$$G_{LOOP} = -\frac{A_0}{1+s\tau_0}\cdot\frac{R_1}{R_1+R_2+R_3}\cdot\frac{1}{1+sC(R_1+R_2)//R_3}$$

$$f_0 = \frac{GBWP}{A_0} = 100\ MHz$$



$$A_P f_P = \frac{1,67 \cdot 10^3 \cdot 100\ Hz}{482,53\ Hz} = 346,2$$

$$f_T = \sqrt{A_P f_P^2} = 8,97\ KHz$$

$$\phi_M = 180 - \mathrm{arctg}\left(\frac{f_T}{f_0}\right) - \mathrm{arctg}\left(f_T / f_P\right) \simeq 180 - 90° - 90° = 0°$$ AS. STABILE