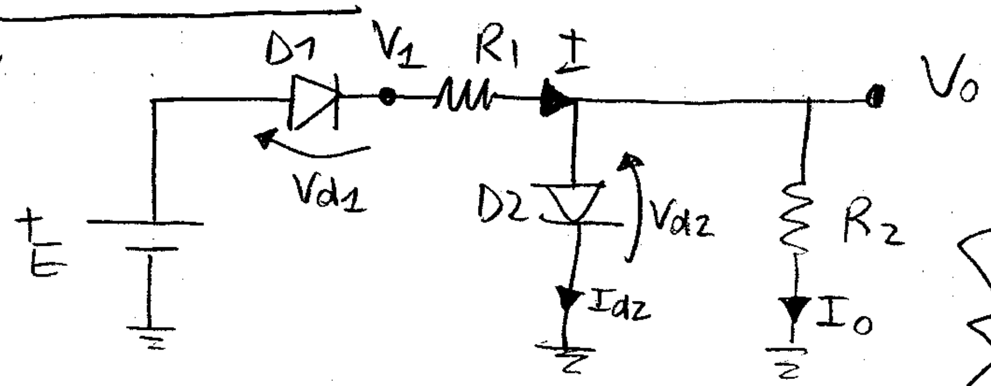
ES - DIODI



Dire : corrente va sempre da pot. + alti a pot. + bassi

$V_\gamma = 0.7V$ $R_1 = 9 k\Omega$
$R_2 = 1 k\Omega$

? Det V_0, I ? per : ① E = +5V
② E = +10V

① E=+5V IPOTESI SU DIODI.

D1 OFF ? Non sembra sensato.

• IP: { D1 POL. DIR
D2 OFF   Rifo disegno

D1 ON : è una batteria $V_{d1} = V_\gamma = 0.7V$

$$V_1 = E - V_{d1} = E - V_\gamma = 5 - 0.7 = 4.3V$$

D2 OFF : $I_0 = I$ → Vo : partitore

$$V_0 = V_1 \cdot \frac{R_2}{R_1 + R_2} = 4.3 \frac{1}{10} = 0.43V$$

$$I = \frac{V_1}{R_1 + R_2} = \frac{4.3}{10k} = 0.43 mA$$

• VERIFICA IPOTESI: $I_{d1} = I > 0$ Ok

!! Dire che verifica si fa su I_d x D ON e su V_d x D OFF

$V_{d2} = V_0 = 0.43 < V_\gamma$ Ok

• PROVO IP ERRATA : { D1 POL. DIR.
D2 POL. DIR   Rifo dis.

D1 è batteria : $V_{d1} = V_\gamma = 0.7$
D2 è batteria $V_{d2} = V_\gamma = 0.7$

$$V_0 = V_{d2} = V_\gamma = 0.7\ V$$

$$I = \frac{V_1 - V_0}{R_1} = \frac{4.3 - 0.7}{9k} = \frac{3.6}{9k} = 0.4\ mA$$

- VERIFICA IPOTESI :

$$I_{d1} = I = 0.4mA > 0 \quad OK$$

$$I_{d2} = I - I_0$$

$$I_0 = \frac{V_0}{R_2} = \frac{0.7}{1k} = 0.7\ mA$$

$$I_{d2} = I - I_0 = +0.4 - 0.7 = -0.3\ mA$$

$$I_{d2} < 0 \Longrightarrow \text{IP. ERRATA!!}$$

(2) $E = +10\ V$

- IP (ERRATA) : $\begin{cases} D1 \text{ POL. DIR} \\ D2 \text{ OFF} \end{cases}$ (come prima)

$$V_1 = E - V_\gamma = 10 - 0.7 = 9.3\ V$$

$$I_0 = I$$

$$V_0 = V_1 \cdot \frac{1}{10} = 0.93\ V$$

- VERIFICA : $V_{d2} = V_0 = 0.93V > V_d$ NO!

- NUOVA IP : $\begin{cases} D1 \text{ POL DIR} \\ D2 \text{ POL DIR} \end{cases}$

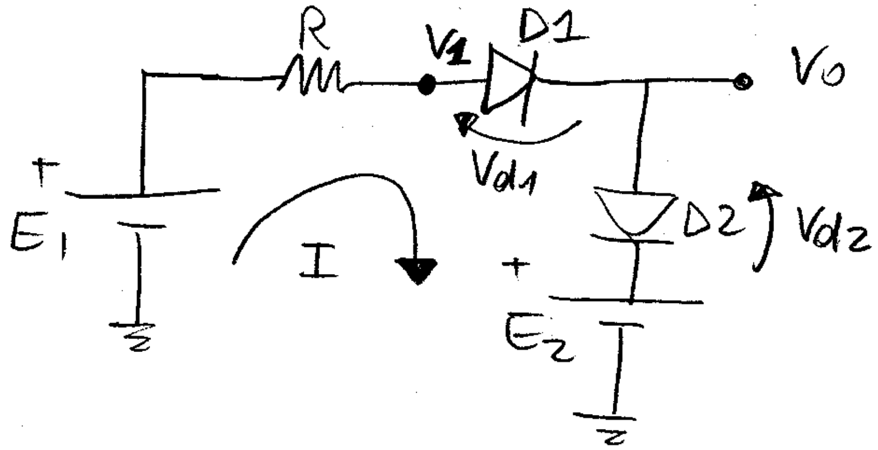
$$V_0 = V_{d2} = V_\gamma = 0.7\ V$$

$$I = \frac{V_1 - V_0}{R_1} = \frac{9.3 - 0.7}{9k} = \frac{8.6}{9k} = 0.95\ mA$$

- VERIFICA : OK $\begin{cases} I_{d1} = I > 0 \\ I_{d2} = I - I_0 = I - \frac{0.7}{1k} = 0.95 - 0.7 = +0.25m \end{cases}$

2C

• ES - DIODI (MOSTRA NO SOVRAPP. EFF)



$V_\gamma = 0.7$
$R = 1\ k\Omega$

? V0 ? se: ① $E_1 = +10\,V$; $E_2 = -2\,V$
② $E_1 = +10\,V$; $E_2 = 0\,V$
③ $E_1 = 0\,V$; $E_2 = -2\,V$

① • IP: { D1 POL. DIR. / D2 POL. DIR. (x verso corrente)

$\Rightarrow$ $V_{d1} = V_\gamma = 0.7\,V$
$V_{d2} = V_\gamma = 0.7\,V$

$V_0 = E_2 + V_{d2} = -2 + 0.7 = -1.3\,V$

• VERIFICA: SU I ($\bar{e}$ $I = I_{d1} = I_{d2}$)

$$I = \frac{E_1 - V_1}{R}$$

$V_1 = V_0 + V_{d1} = -1.3 + 0.7 = -0.6\,V$

$$I = \frac{10 - (-0.6)}{1k\Omega} = \frac{10.6}{1k} = +10.6\,mA$$ OK

② $E_1 = +10\,V$; $E_2 = 0\,V$ (Fare Dis)

• IP: { D1 POL DIR / D2 POL. DIR

$V_0 = 0 + V_{d2} = +0.7$

• VERIFICA: $I = \frac{E_1 - V_1}{R} = \frac{10 - 1.4}{1k} = +8.6\,mA$ OK

③ $E_1 = 0$; $E_2 = -2V$ (Fare dis)

- IP: $\begin{cases} D1 \text{ POL DIR} \\ D2 \text{ POL DIR} \end{cases}$

$$V_0 = E_2 + V_{d2} = -2 + 0.7 = -1.3\ V$$

- VERIFICA

$$I = \frac{0 - V_1}{R} = \frac{0 - (-0.6)}{R} = \frac{0.6}{R} = +0.6\ mA$$

OK

OSSERVAZIONE:

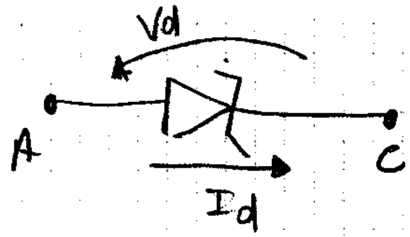
Notare che $V_0^{(1)} \neq V_0^{(2)} + V_0^{(3)}$

$$-1.3 \neq +0.7 - 1.3$$

Non vale principio di sovrapp. effetti!

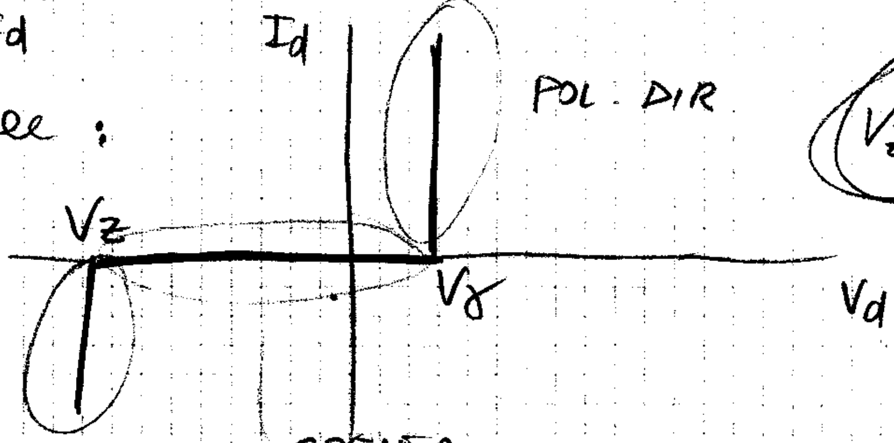
— o — o — o —

DIODO ZENER



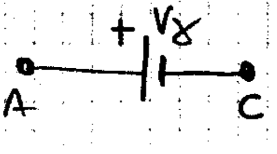
(stessa convenzione!)

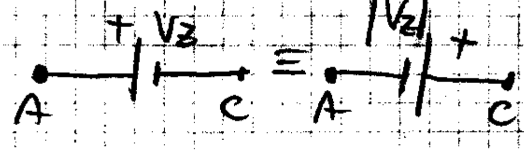
Ideale:

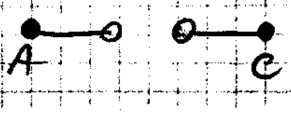


$V_Z < 0$!!

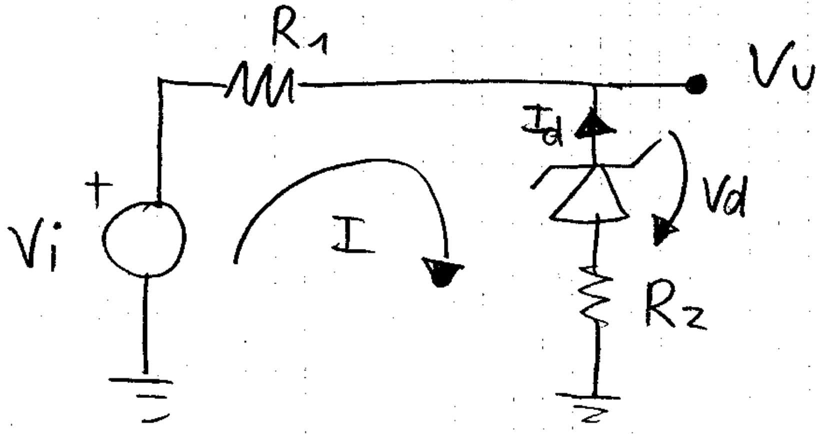
$I_d > 0$	$I_d < 0$	$V_Z < V_d < V_\gamma$
Batteria V_γ	Batteria $V_Z < 0$	Circ. ap.







• ES - DIODO ZENER



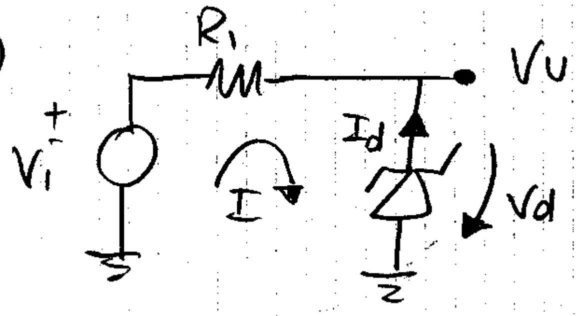
$V_\gamma = 0.7\ V$

$V_Z = -5\ V$

$R_1 = 1\ k\Omega$

? Det. caratteristiche di uscita V_U vs. V_i ; I vs. V_i ? per: ① $R_Z = 0$ ② $R_Z = 2k\Omega$

①



condizioni su $I = -I_d$ ⇒ si deduce stato del diodo

- $I > 0$ ($I_d < 0$) ⟺ D ZENER

$V_d = V_Z < 0$

$V_U = -V_d = -V_Z = +5\ V$

Per: $\begin{cases} I > 0 \\ I = \dfrac{V_i - V_U}{R} \end{cases} \rightarrow V_i > V_U = +5\ V$

- $I < 0$ ($I_d > 0$) ⟺ D POL. DIR

$V_d = V_\gamma = 0.7$

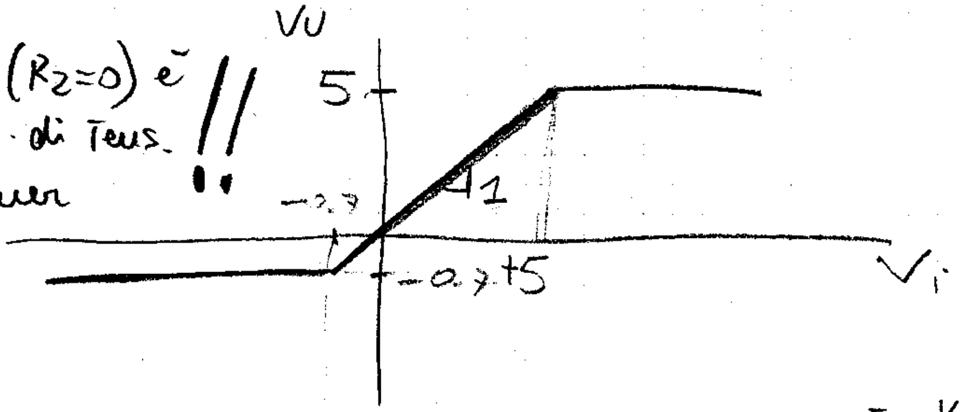
$V_U = -V_d = -0.7\ V$

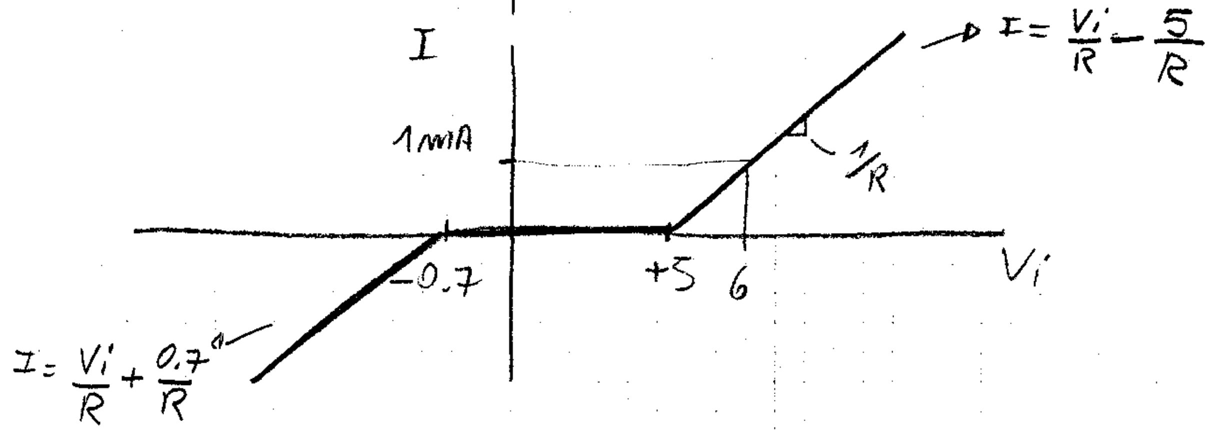
Per: $\begin{cases} I < 0 \\ I = \dfrac{V_i - V_U}{R} \end{cases} \rightarrow V_i < V_U = -0.7$

- $I = 0$ ($I_d = 0$) D OFF → $V_U = V_i$ (per V_i: restanti casi)

→ ! FARE VERIFICA su V_d!

!! Questo ($R_Z=0$) è un reg. di tens. con zener !!





(2) $R_Z = 2k\Omega$

Equaz. alla maglia:

$$V_i - IR_1 + V_d - IR_Z = 0$$

$$V_i + V_d - I(R_1+R_Z) = 0$$

$$I = \frac{V_i + V_d}{R_1 + R_Z}$$

Condizioni su $I = -I_d \Rightarrow$ si deduce stato del diodo

- $I > 0$ ($I_d < 0$) $\Leftrightarrow$ ZENER

$$V_d = V_Z = -5V$$

per $\begin{cases} I > 0 \\ I = \frac{V_i + V_d}{R_1 + R_Z} \end{cases} \Rightarrow V_i > -V_d = +5V$ (come prima!)

Legame $V_i - V_U$:

$$V_U = IR_Z - V_d = V_i \frac{R_Z}{R_1+R_Z} + V_d \frac{R_Z}{R_1+R_Z} - V_d =$$

$$= V_i \frac{R_Z}{R_1+R_Z} - V_d \frac{R_1}{R_1+R_Z} = \frac{2}{3} V_i + \frac{5}{3} \quad [V]$$

- $I<0$ $(I_d>0)$ $\Leftrightarrow$ D POL DIR

$V_d = V_\gamma = 0.7\ V$

per $\begin{cases} I<0 \\ I = \dfrac{V_i + V_d}{R_1+R_2} \end{cases} \Rightarrow V_i < -V_d = -0.7$

(! come prima !)

Legame V_i - V_u:

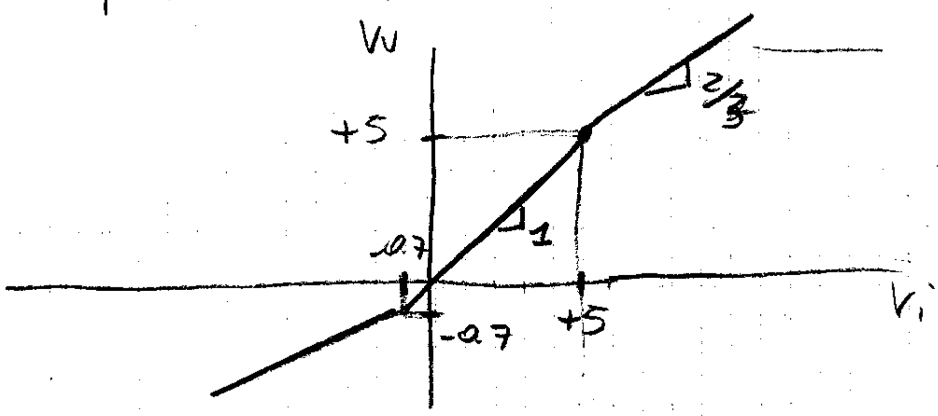
$V_U = I R_2 - V_d = V_i \dfrac{R_2}{R_1+R_2} - V_d \dfrac{R_1}{R_1+R_2} =$

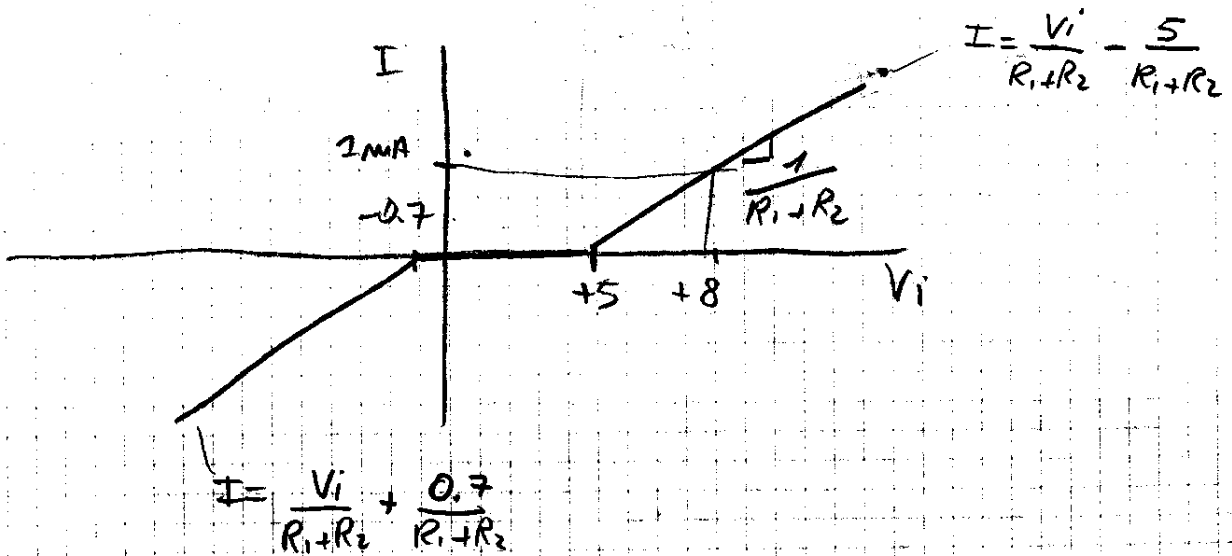
$= \dfrac{2}{3} V_i - \dfrac{0.7}{3}$

- $I=0$ $(I_d=0)$ D OFF

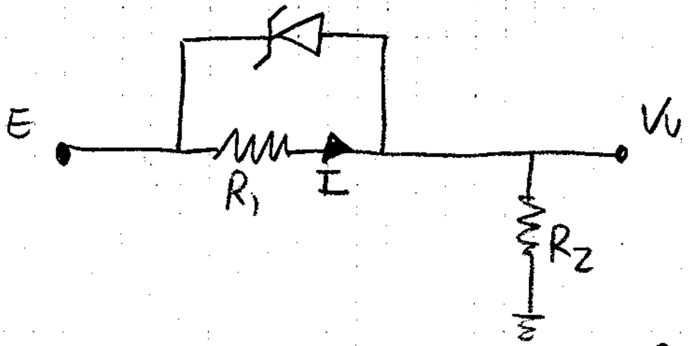
$V_U = V_i$ (fare VERIFICA)

per $-0.7 < V_i < 5$ [V]





ES - DIODI (USO SOVRAPP. EFF. DOPO IP. SU DIODO)



$V_\gamma = 0.7$
$V_Z = -5V$
$R_1 = R_2 = 1k\Omega$

? Vu ; I ? per ① $E = +2V$ ② $E = -5V$ ③ $E = +10V$

① $E = +2V$

D OFF (E=+2V non basta a fare Zener)

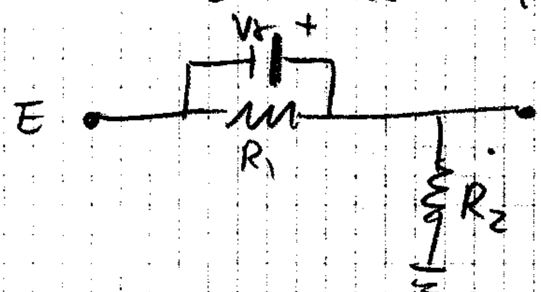
$$V_U = E \frac{R_2}{R_1 + R_2} = \frac{E}{2} = +1V$$

$$I = \frac{E}{R_1 + R_2} = +1 mA$$

<u>Verifica</u>: $V_d = V_U - E = 1 - 2 = -1V$ OK
$(-5 < V_d < 0.7)$

② $E = -5V$

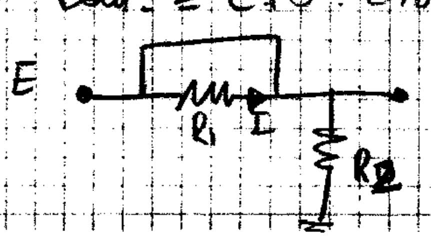
D POL. DIR. $(V_d = V_\gamma = +0.7)$



⇒ il circuito ORA è LINEARE

Uso <u>sovrapp. eff.</u>

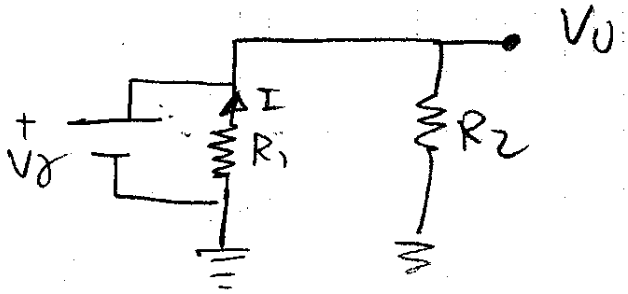
Ⓐ Batt. = CTO. CTO



$V_U^{(A)} = E = -5V$

$I^{(A)} = 0$

(B) E = cto cto



$V_U^{(B)} = V_\gamma = +0.7$

$I^{(B)} = \frac{0 - V_U}{R_1} = -0.7\ mA$

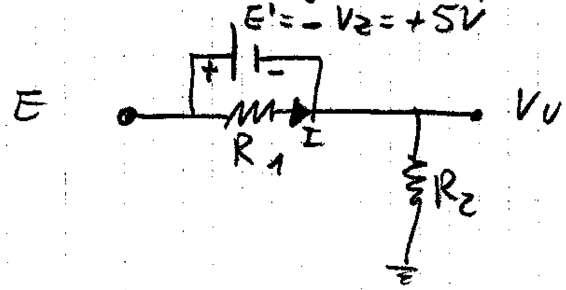
(TOT) $V_U = V_U^{(A)} + V_U^{(B)} = -5 + 0.7 = -4.3\ V$

$I = I^{(A)} + I^{(B)} = 0 - 0.7 = -0.7\ mA$

!! FARE VERIFICA !!

(3) $E = +10V$

D ZENER $(V_d = V_z = -5V)$



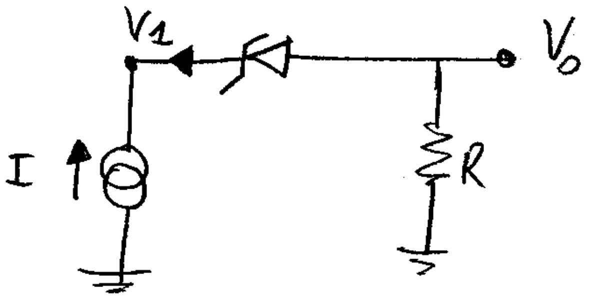
$V_U = E - E' = E - (-V_z) = +10 - 5 = +5\ V$

$I = \frac{E - V_U}{R_1} = \frac{10 - 5}{1k\Omega} = +5mA$

!! FARE VERIFICA !!

ES (SCRITTO © 22/11/96 n° 1)

(A)



$V_\gamma = 0.7\,V$

$V_Z = -5\,V$

$R = 1\,k\Omega$

? V_0 ? per
(1) $I = 0$
(2) $I = +1\,mA$
(3) $I = -1\,mA$

(1) $I_d = -I$

Dire che qui di corr. comando corr. nella maglia

- IP: D OFF

$V_0 = IR = 0\ V$

- VERIFICA: Non necessaria. (V_d è indet.)

V_1 = indet.

(2) $I = +1\,mA$

$I_d = -I = -1\,mA < 0 \Rightarrow$ D ZENER (verifico non nec.)

$V_0 = I \cdot R = +1\,V$

($V_1 = +6\,V$)

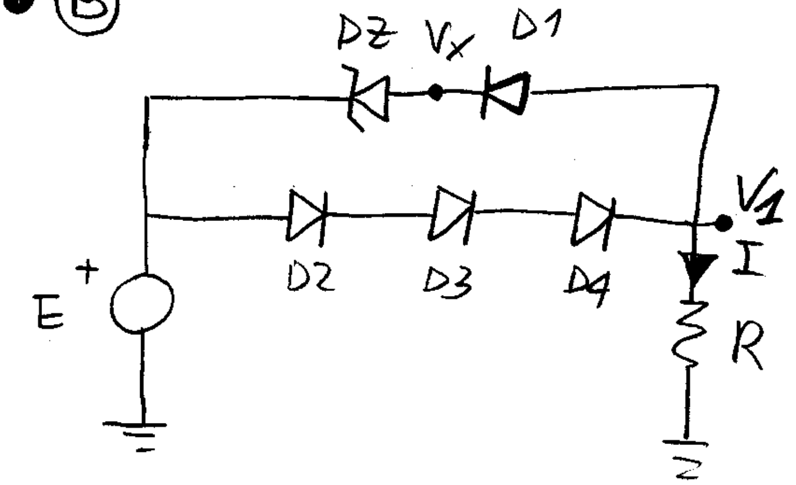
(3) $I = -1\,mA$.

$I_d = -I = +1\,mA > 0 \Rightarrow$ D POL. DIR

$V_0 = I \cdot R = -1\,V$

($V_1 = -1.7\,V$)

• (B)



$V_\gamma = 0.7\ V$

$V_Z = -5\ V$

$R = 10\ K\Omega$

? I ? per
(1) $E = +15\ V$
(2) $E = -15\ V$
(3) $E = 0\ V$

(1) $E = +15\ V$

Corr. può passare in D2, D3, D4
" non " " " DZ, (D1) – a causa di D1

• IP: D2, D3, D4 POL DR

D1 OFF (DZ non interessa)

$$V_1 = E - 3V_\gamma = 15 - 2.1 = +12.9\ V$$

$$I = \frac{V_1}{R} = +\frac{12.9}{10k} = +1.29\ mA$$

• VERIFICA:

D2, D3, D4 : $I > 0$ OK

D1 : $V_1 - E = -2.1\ V$

(In realtà Tens. V_x è indeterm. con diodi ideali)

(2) $E = -15\ V$

Corr. può passare in DZ, D1
" non " " " D2 ... D4

- IP: D_Z, D_1 POL. DIR
  $D_2 \dots D_4$ OFF

$$V_1 = E + 2V_\gamma = -15 + 1.4 = -13.6\,V$$

$$I = \frac{V_1}{R} = \frac{-13.6}{10k} = -1.36\,mA$$

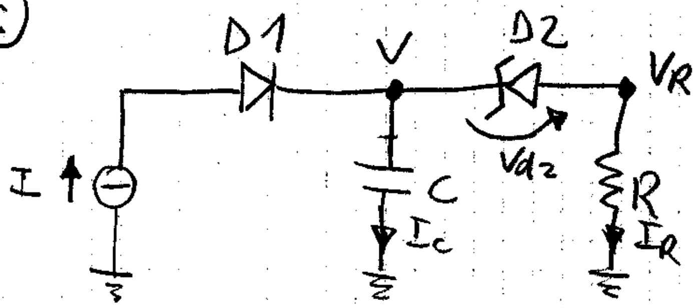
- VERIFICA:
  D_Z, D_1 . $I < 0$ OK
  $D_2, \dots D_4$: $E - V_1 = -1.4\,V$

③ $E = 0V$

Non può scorrere corrente nei diodi

- IP $D_Z, D_1 \dots D_4$ OFF
  $I = 0$ $(V_1 = 0)$

- Ⓒ



$V_\gamma = 0.7V$
$V_Z = -5\,V$
$C = 100\,nF$
$R = 10k\,\Omega$
$I = 1\,\mu A$

? ① Ciniz. scarico: Det. t. in cui $V = 5V$
· ② grafico di $V(t)$ vs. t

① D1 sempre ON $(I_{d1} = I > 0)$

$t < 0$: $V(t) = 0$ (DZ OFF) $(V_{dz} = 0)$

C si carica

$$I = C\frac{dV}{dt} \Rightarrow V(t) = \frac{1}{C}\int_0^t I\,d\theta = \frac{I}{C}\cdot t$$

25

$$\begin{cases} V(\bar{t}) = 5 \cdot V \\ \frac{I}{C}\bar{t} = 5 \qquad \bar{t} = 5 \cdot \frac{C}{I} = 5 \cdot \frac{10^{-7}}{10^{-6}} = 0.5\ s \end{cases}$$

② Finché $V < 5V$ D2 OFF

$t > \bar{t} = 0.5s$: D2 ZENER ($V_{d2} = V_z = -5V$)

$$I = I_C + I_R$$

$$V_R(t) = V(t) + V_{d2} = V(t) + V_z$$

$$I_R(t) = \frac{V_R(t)}{R} = \frac{V(t)}{R} + \frac{V_z}{R}$$

$$I_C(t) = I - I_R(t) = I - \frac{V(t)}{R} - \frac{V_z}{R}$$

Vale ancora: $I_C(t) = C\frac{dV(t)}{dt}$

$$C\frac{dV(t)}{dt} = I - \frac{V(t)}{R} - \frac{V_z}{R}$$

$$\tau\frac{dV(t)}{dt} + V(t) = RI - V_z \qquad \tau = RC$$

$$V(t) = \underbrace{V^* e^{-\frac{t-\bar{t}}{\tau}}}_{\text{sol. omog}} + \underbrace{RI - V_z}_{\text{sol. part. compl.}} \qquad t > \bar{t}$$

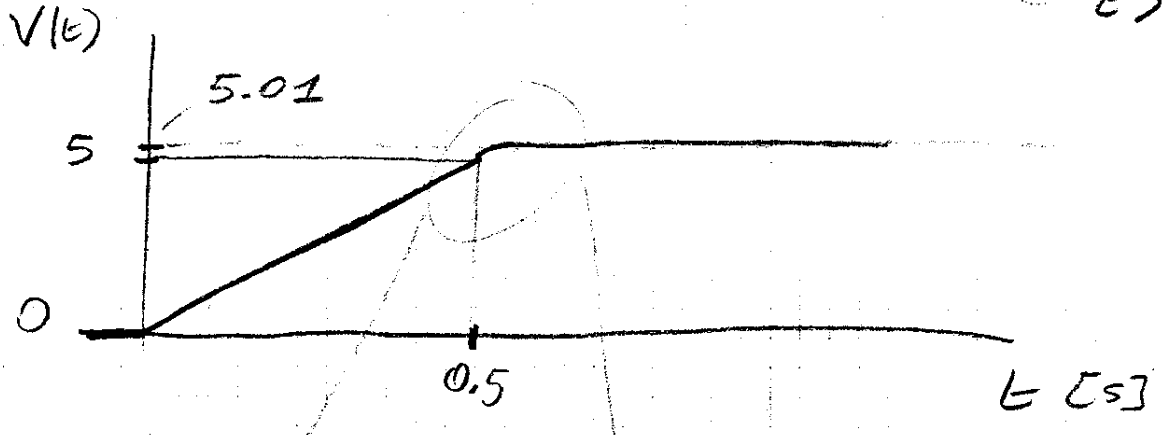
$$\begin{cases} V(\bar{t}) = +5V \\ V^* + RI - V_z = +5 \end{cases}$$

$$\rightarrow V^* = \cancel{5} + \cancel{V_z} - RI = -RI = -$$

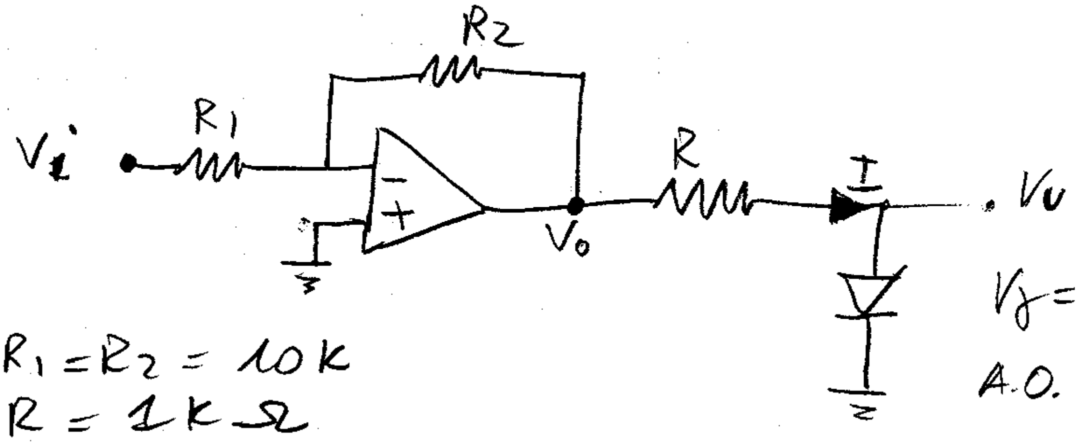
$$V(t) = RI\left(1 - e^{-\frac{t-\bar{t}}{\tau}}\right) - V_z$$

$$V(t) = \begin{cases} \frac{I}{C} \cdot t = 10\,t & 0 < t < \bar{t} = 0.5\text{ s} \\ RI\left(1 - e^{-\frac{t-\bar{t}}{\tau}}\right) - V_z = 10^{-2}\left(1 - e^{-\frac{t-\bar{t}}{\tau}}\right) + 5 & t > \bar{t} = 0.5\text{ s} \end{cases}$$

$\tau = RC = 10^4 \cdot 10^{-7} = 10^{-3}$ s



- ES - DIODI

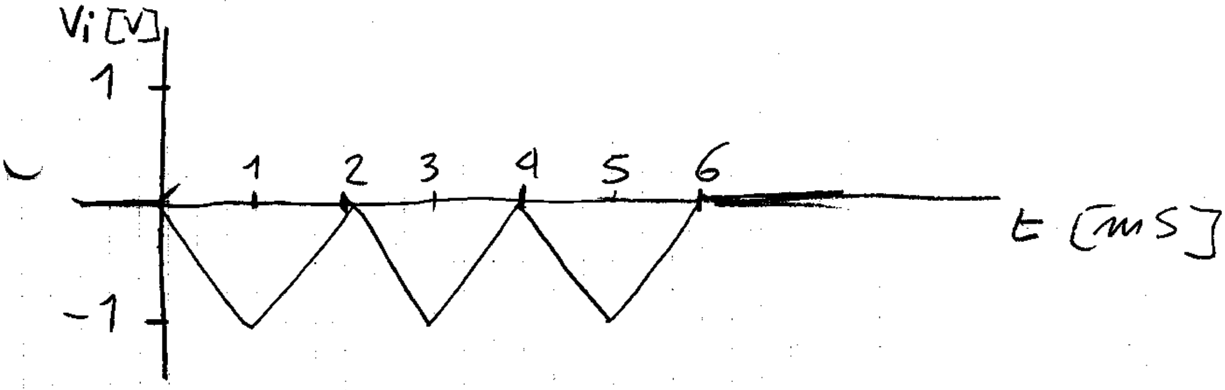


$V_\gamma = 0.5\,V$

A.O. ideale

$R_1 = R_2 = 10K$

$R = 1K\Omega$

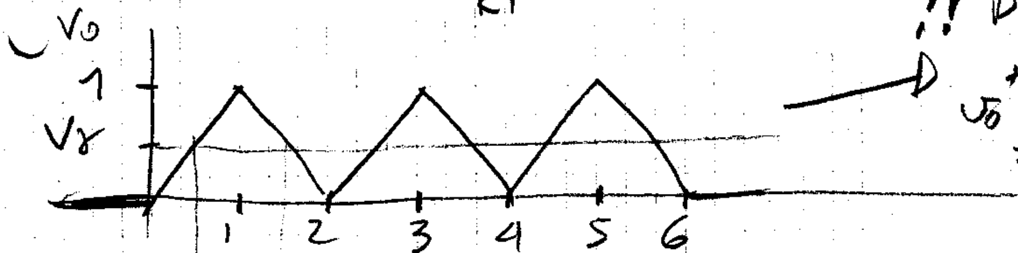


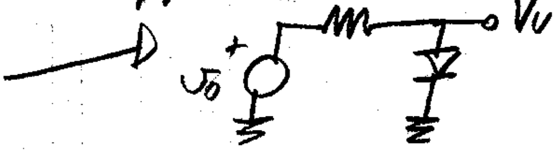
? andamento $I(t)$?

Determino prima V_0

$$V_0(t) = -\frac{R_2}{R_1} V_i(t) = -V_i(t)$$

!! Dis. circ. equiv. !!

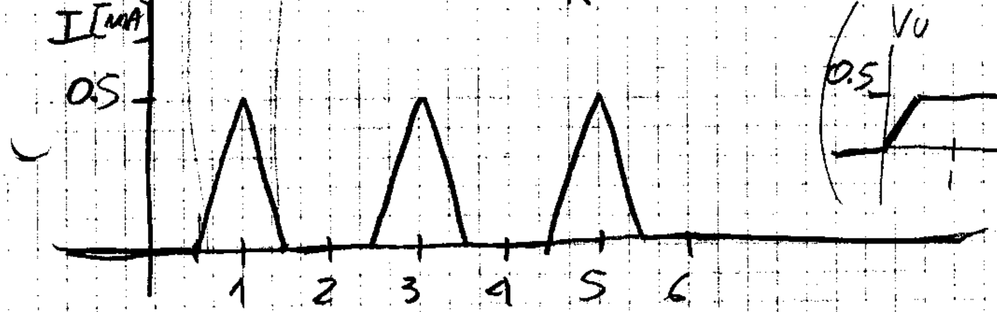


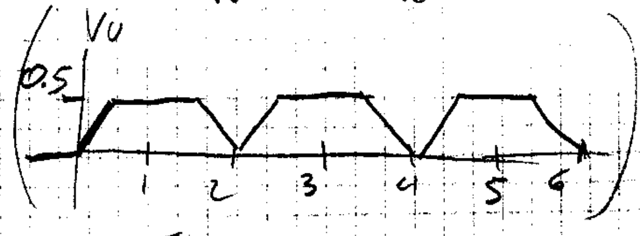


DIODO: ON se $V_0 > V_\gamma = 0.5\,V$

OFF se $V_0 < V_\gamma = 0.5\,V$ $(I = 0)$

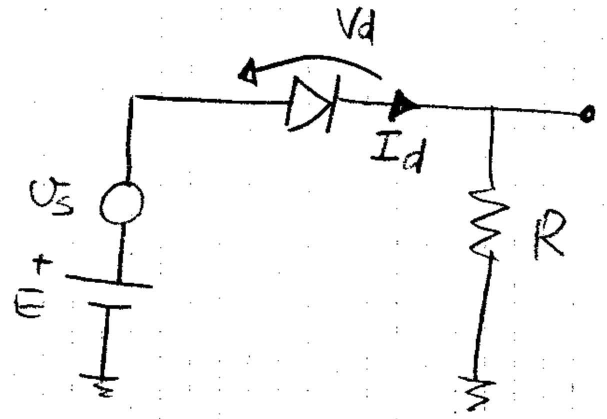
Diodo ON: $I = \frac{V_0 - V_\gamma}{R}$; $I_{MAX} = \frac{V_{0,MAX} - V_\gamma}{R} = \frac{0.5}{R} = 0.5\,mA$





DIODO REALE – MODELLO PER PICCOLI SEGNALI

- ES. di CIRCUITO:



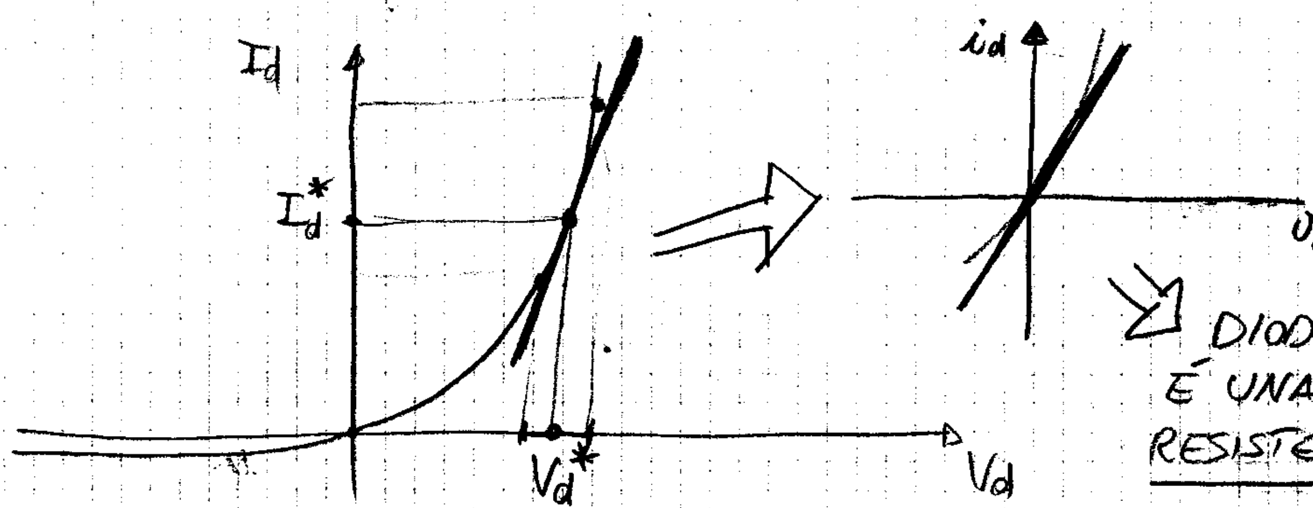
$v_U = V_U + v_u$

E : Batteria
v_S : Gen. piccolo segnale

DIODO REALE : $I_d = I_0 \left(e^{\frac{V_d}{V_T}} - 1 \right)$

- PUNTO di LAVORO : $v_S = 0$
  - TROVO I_d^* ; V_d^* ⇒ v_U
- PICCOLO SEGNALE : E è C.TO C.TO

? DIODO ? LO LINEARIZZO



⇒ DIODO È UNA RESISTENZA

$V_d = V_d^* + v_d$ con v_d piccolo segnale (decine di mV)

↳ $I_d = I_d^* + i_d$
└ piccolo seg.

$v_d = r_d \cdot i_d$? r_d ?

$$\frac{1}{r_d} = g_d = \left.\frac{\partial I_d}{\partial V_d}\right|_{V_d = V_d^*}$$

calcolo: $\frac{1}{r_d} = I_0 \cdot e^{\frac{V_d}{V_T}} \cdot \frac{1}{V_T} \Big|_{V_d = V_d^*}$

$$\frac{1}{r_d} = \frac{1}{V_T} \cdot I_0 \, e^{\frac{V_d^*}{V_T}}$$

- se $V_d^* \gtrsim 100\,mV \Rightarrow I_0 e^{\frac{V_d^*}{V_T}} \simeq I^*$

$$\frac{1}{r_d} = \frac{I_d^*}{V_T} \Rightarrow r_d = \frac{V_T}{I_d^*}$$

Es: $I_d^* = 1\,mA \rightarrow r_d = \frac{25\,mV}{1\,mA} = 25\,\Omega$ ↗ PICCOLA!

- se $V_d^* \lesssim -100\,mV \Rightarrow e^{\frac{V_d^*}{V_T}} \ll 1$

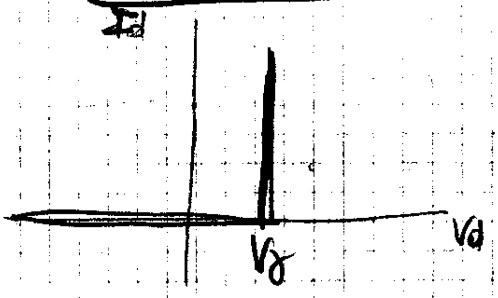
Es: $I_0 = 100\,pA = 10^{-10}\,A$

$V_d^* = -100\,mV$

$$r_d = \frac{V_T}{I_0 \, e^{\frac{V_d^*}{V_T}}} = \frac{25 \cdot 10^{-3}}{10^{-10} e^{-\frac{100}{25}}} = 13.6 \cdot 10^9\,\Omega = 13.6\,G\Omega \;!!$$

↗ GRANDE (la caratteristica è quasi orizzontale)

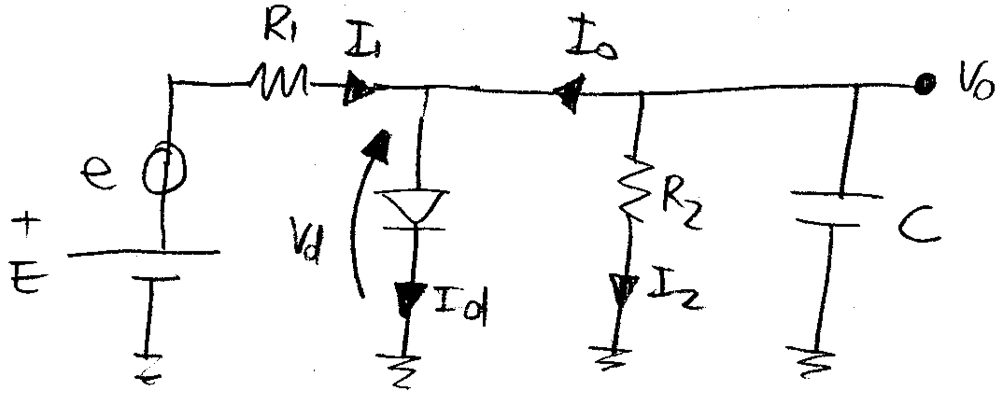
DIODO IDEALE:



ON: $r_d = 0$ (è c.to c.to)

OFF: $r_d = \infty$ (è circ. aperto)

• ES - DIODO (18/4/95 ES. 2)



$R_1 = R_2 = 1k\Omega$

$C = 1\mu F$

(A) $e=0$ DIODO ID ($V_\gamma = 0.7V$)

? I_o, V_o ? per (1) $E=+5V$ (2) $E=-5V$ (3) $E=0V$

(B) $I_d = I_s e^{V_d/V_t}$ (un po' diversa da reale)

$I_s = 1mA$

? Det uscita di piccolo segnale v_o ? per (1) $E=+5V$ (2) $E=-5V$ (3) $E=0V$

se $e = 10^{-3}\sin(50t)$ [V] [t] = s

(A)

(1) $E=+5V$

E = batteria (in continua) → C = circ. ap.

- IP: D POL. DIR.

$V_o = V_d = V_\gamma = +0.7V$

$I_o = -I_2 = -\frac{V_o}{R_2} = -\frac{0.7}{1k\Omega} = -0.7mA$

← ? VERIFICA ? $I_d > 0$?

! calcolare I_d, serve dopo (B) !

$I_d = I_1 + I_o$

$I_1 = \frac{E - V_o}{R_1} = \frac{5 - 0.7}{1k} = +4.3mA$

$I_d = 4.3 - 0.7 = +3.6mA$ OK

(2) $E = -5V$

IP : D OFF $(I_d = 0)$

$$I_0 = \frac{0 - E}{R_1 + R_2} = \frac{0 + 5}{2k\Omega} = +2.5\ mA$$

$$V_0 = \text{partitore} = E \cdot \frac{R_2}{R_1 + R_2} = -2.5\ V$$

? VERIFICA ? $V_d < 0.7\ V$?

$V_d = V_0 = -2.5\ V$ OK

(3) $E = 0V$

IP : D OFF

$I_0 = 0\ A$

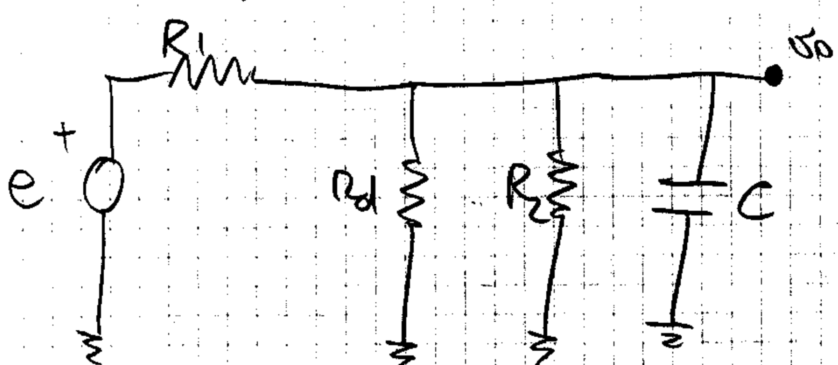
$V_0 = 0\ V$

? VERIFICA ? $V_d = V_0 = 0 < 0.7$ OK

(B)

DIODO ? COME PRIMA (Era modello idealizzato ma realistico)
SUPPONGO VALIDI I RISULTATI PRECEDENTI per I_d ; V_d –

Diodo è resistenza R_d



$$\frac{v_0}{e} = \frac{Z}{R_1 + Z} \qquad Z = \frac{1}{sC} // R_{eq} = \frac{R_{eq}}{1 + sR_{eq}C}$$

$$R_{eq} = r_d // R_2$$

$$F(s) = \frac{v_0}{e} = \frac{\frac{R_{eq}}{1+sR_{eq}C}}{R_1 + \frac{R_{eq}}{1+sR_{eq}C}} = \frac{R_{eq}}{R_1 + R_{eq} + sR_1R_{eq}C} =$$

$$= \frac{R_{eq}}{R_1 + R_{eq}} \cdot \frac{1}{1 + s\frac{R_1R_{eq}}{R_1+R_{eq}}C} = K \cdot \frac{1}{1+s\tau}$$

? r_d ?

$$\frac{1}{r_d} = \frac{\partial I_d}{\partial V_d} = \frac{I_S}{V_T} \cdot e^{V_d/V_t}$$

ESPR. BUONA PER DIODO **OFF**

$$r_d = \frac{V_T}{I_S \; e^{V_d/V_t}} = \frac{V_T}{I_d}$$

ESPR. BUONA PER DIODO **ON**

(1) $E = +5\,V$ D ON ($I_d = +3.6\,mA$)

$$r_d = \frac{25\,mV}{3.6\,mA} = 6.9\,\Omega$$

$$R_{eq} \simeq r_d$$

$$F(s) = \frac{r_d}{R_1 + r_d} \cdot \frac{1}{1 + s\frac{R_1 r_d}{R_1 + r_d}C} = K \cdot \frac{1}{1+s\cdot\tau}$$

PASSO BASSO

$K = 6.8 \cdot 10^{-3}$

$\tau \simeq r_d \cdot C = 6.8 \cdot 10^{-6} = 6.8 \cdot 10^{-6}\,s$

$\omega_c = 1.4 \cdot 10^5\,r/s$

$\omega = 50\,r/s \qquad \omega \ll \omega_c$

$v_0 = 6.8 \cdot 10^{-6} \sin(50t)$ [V] ($\varphi = 0$)

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(2) $E = -5\ V$ <u>D OFF</u>

$V_d = -2.5\ V$

$$r_d = \frac{V_T}{I_S\, e^{V_d/V_T}} = \frac{25 \cdot 10^{-3}}{10^{-9} \cdot e^{-\frac{2.500}{25}}} = 2.68 \cdot 10^{43}\ \Omega$$

$r_d = \infty$!!

$R_{eq} = R_2$

$K = \frac{1}{2}$

$\tau = \frac{R_1}{2} C = 5 \cdot 10^2 \cdot 10^{-6} = 5 \cdot 10^{-4}\ s$

$\omega_c = 2 \cdot 10^3\ r/s = 2000\ r/s$

$\omega \ll \omega_c$

$v_0 = 0.5 \cdot 10^{-3} \sin(50 \cdot t)$

(3) $E = 0\ V$ <u>D OFF</u>

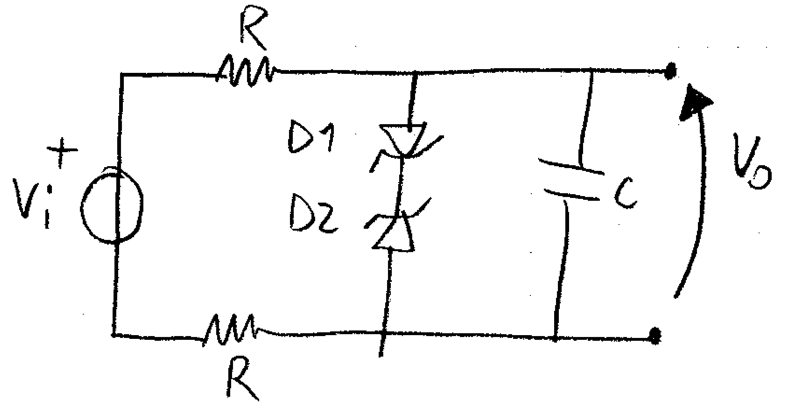
$V_d = 0$ (a rigore, per il modello $I_d > 0$)

$$r_d = \frac{V_T}{I_S\, e^{V_d/V_T}} = \frac{25 \cdot 10^{-3}}{10^{-9} \cdot 1} = 25 \cdot 10^{6}\ \Omega = 25\ M\Omega$$

$R_{eq} = R_2$

v_0 come punto (2)

• ES - DIODI (SCRITTO 26/9/97 ES 2)



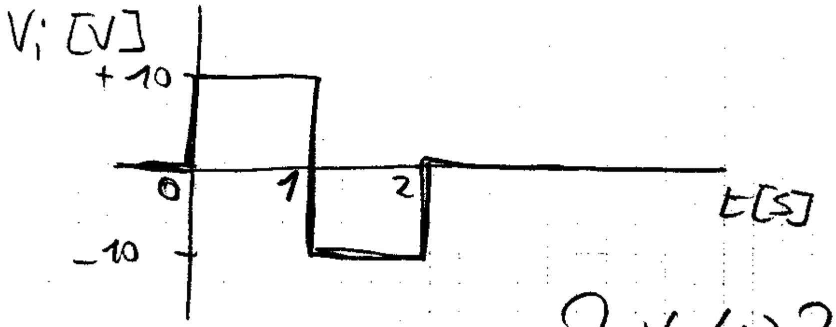
$R = 5\,k\Omega$

$C = 10\,\mu F$

$V_{\gamma 1} = V_{\gamma 2} = 0\,V$

$V_{z1} = -5\,V$

$V_{z2} = -7\,V$



? $V_0(t)$?

SOLUZ : PRIMA <u>SENZA DIODI</u>

$\omega \to 0 \quad V_0 = V_i$

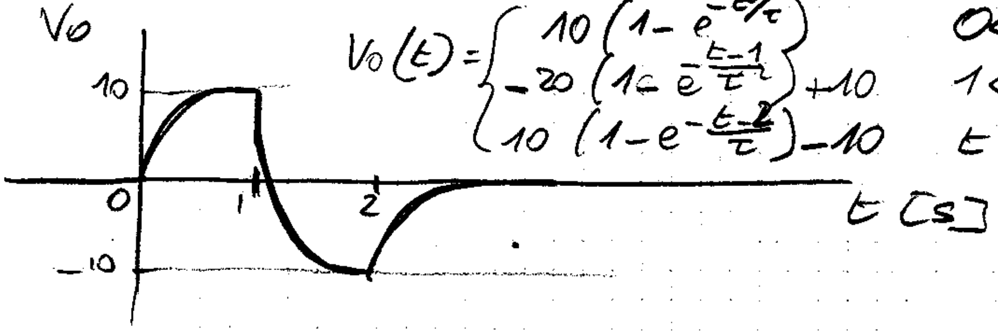
$\omega \to \infty \quad V_0 = 0$

Passa basso

$$\frac{V_0}{V_i} = \frac{1}{1 + s\tau}$$

$$\tau = (R+R)\,C = 10^4 \cdot 10^{-5} = 0.1\,s$$

$$V_0(t) = \begin{cases} 10\left(1 - e^{-t/\tau}\right) & 0 < t < 1\,s \\ -20\left(1 - e^{-\frac{t-1}{\tau}}\right) + 10 & 1 < t < 2 \\ 10\left(1 - e^{-\frac{t-2}{\tau}}\right) - 10 & t > 2 \end{cases}$$



- DIODI : 2 CASI "ON"

- D1 POL DIR + D2 ZENER → $V_0 = +7\,V$
- D1 ZENER + D2 POL DIR → $V_0 = -5\,V$

⇒ L'uscita V_0 è limitata a +7 e -5 V

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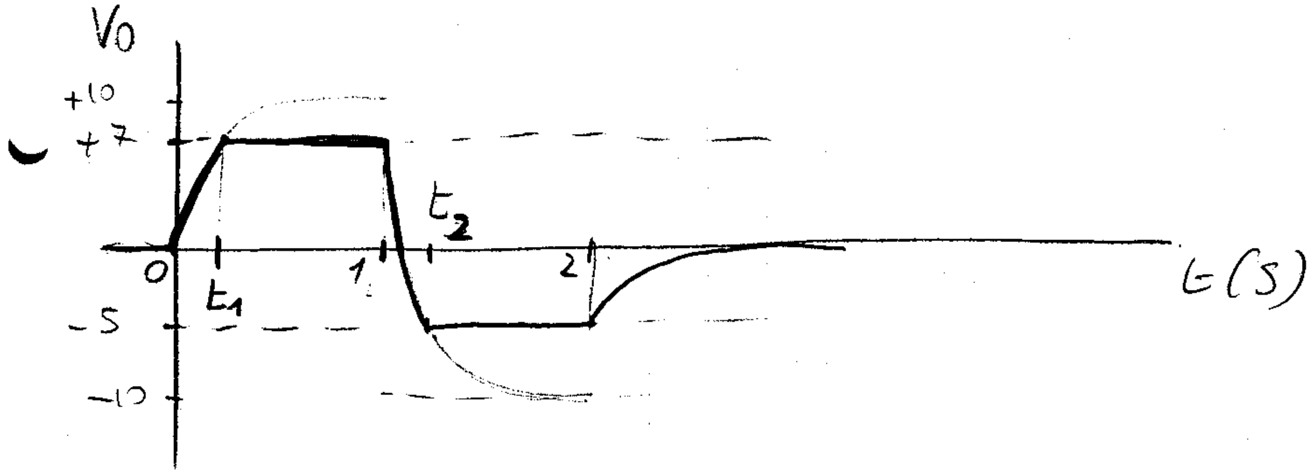


$0 < t < t_1 \qquad V_0(t) = 10\left(1 - e^{-t/\tau}\right)$ ✓

$t_1 < t < 1 \qquad V_0(t) = -V_{Z2} = +7\,V$ ✓

$1 < t < t_2 \qquad V_0(t) = (-10-7)\left(1 - e^{-\frac{t-1}{\tau}}\right) + 7 =$

$= -17\left(1 - e^{-\frac{t-1}{\tau}}\right) + 7 =$

$= -10 + 17\, e^{-\frac{t-1}{\tau}}$ ✓

$t_2 < t < 2s \qquad V_0(t) = -V_{Z1} = +5\,V$

$t > 2s \qquad V_0(t) = (0-(-5))\left(1 - e^{-\frac{t-2}{\tau}}\right) - 5 =$

$= +5\left(1 - e^{-\frac{t-2}{\tau}}\right) - 5 =$

$= -5\, e^{-\frac{t-2}{\tau}}$ ✓

- calcolo istanti temporali

$V_0(t_1) = +7\,V$

$10\left(1 - e^{-t_1/\tau}\right) = +7$

$1 - e^{-t_1/\tau} = \frac{7}{10}$

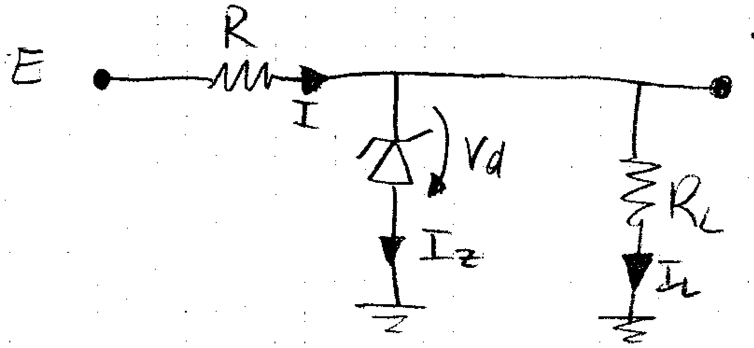
$e^{-\frac{t_1}{\tau}} = \frac{3}{10}$

$-\frac{t_1}{\tau} = \ln\frac{3}{10}$

$t_1 = -\tau \ln\frac{3}{10} = +0.1 \cdot 1.2 = +0.12\ s$

• ES (SCRITTO © 24/11/95)

(A)



$E = +15\,V$
$R = 1\,k\Omega$
$V_\gamma = 0.7\,V$
$V_Z = -6\,V$

? I, I_z, V ? per
(1) $R_L = 0$
(2) $R_L \to \infty$
(3) $R_L = 1\,k\Omega$
(4) $R_L = 250\,\Omega$

(1) $R_L = 0$ (Forze Dis)

IP : D OFF (perché $V_d = -V = 0$)

$V = 0$
$I_z = 0$

$$I = \frac{E}{R} = \frac{15}{1k\Omega} = +15\,mA$$

(2) $R_L \to \infty$ (Forze Dis)

IP: D ZENER

$V_d = V_Z = -6\,V$

$V = -V_d = -V_Z = +6\,V$

$$I = I_Z = \frac{E-V}{R} = \frac{15-6}{10^3} = +9\,mA$$

? verifico ? $I_d = -I_Z < 0$ <u>OK</u>

(3) $R_L = 1\,k\Omega$

IP : D OFF (Non si sa se è + simile a (1) o (2))

$I_z = 0$

$V = E \cdot \frac{R_L}{R+R_L} = 15 \cdot \frac{1}{2} = +7.5\,V$

? VERIFICA ? $V_d = -V = -7.5\,V < V_z$!!

↳ IP ERRATA !

IP: D ZENER

$V = -V_d = -V_z = +6\,V$

$I = \frac{E-V}{R} = \frac{15-6}{10^3} = +9\,mA$

$I_z = I - I_L$

$I_L = \frac{V}{R_L} = \frac{6}{10^3} = +6\,mA$

$I_z = 9 - 6 = +3\,mA$

? VERIF ? $I_d = -I_z = -3\,mA < 0$ <u>OK</u>

④ $R_L = 250\,\Omega$

IP: D OFF

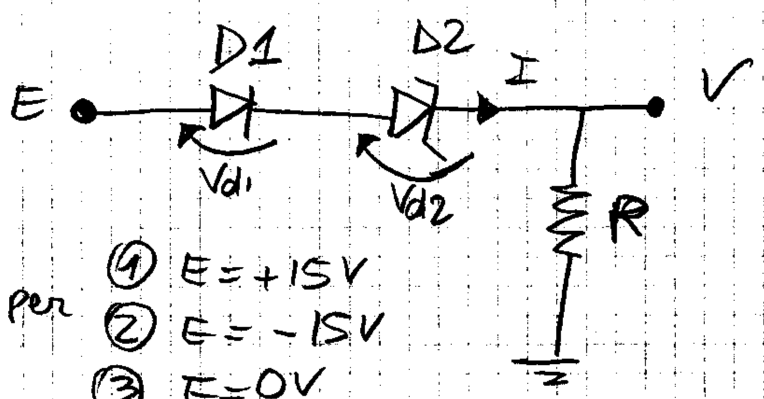
$V = E \frac{R_L}{R+R_L} = E \frac{250}{1250} = E \cdot \frac{1}{5} = +3\,V$

$I_z = 0$

$I = \frac{E}{R+R_L} = \frac{15}{1250} = +12\,mA$

? VERIF ? $V_d = -V = -3\,V$ <u>OK</u>

Ⓑ



$R = 1\,k\Omega$

$V_\gamma = 0.7\,V$

$V_z = -6\,V$

? I ? per
① $E = +15\,V$
② $E = -15\,V$
③ $E = 0\,V$

① $E = +15\,V$

IP: D1 POL DIR
D2 POL DIR

$V_{d1} = V_{d2} = V_\gamma = +0.7\,V$

$V = E - V_{d1} - V_{d2} = E - 2V_\gamma = 15 - 1.4 = +13.6$

$I = \frac{V}{R} = \frac{13.6}{10^3} = 13.6\,mA > 0$ **OK**

② $E = -15\,V$

IP: (D2 potrebbe essere ZENER. Ma D1 non può. Quindi:)
D1, D2 OFF

$V = 0$

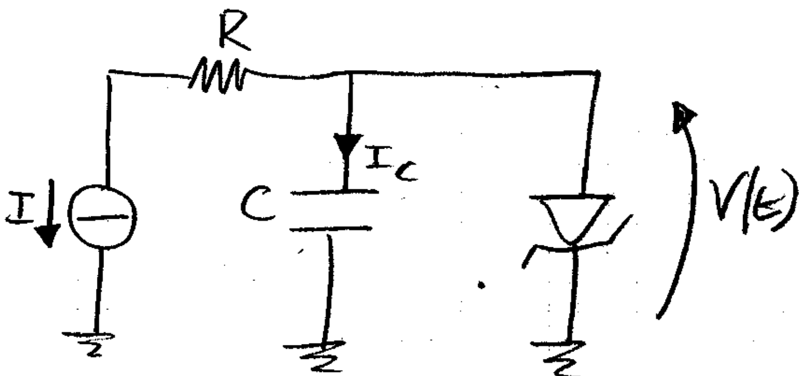
$I = \frac{V}{R} = 0$ OK

③ $E = 0\,V$

D1, D2 OFF

$I = 0$

Ⓒ



$I = +10\,\mu A$
$C = 10\,mF$
$R = 1\,k\Omega$
$V_\gamma = 0.7\,V$
$V_z = -6\,V$

t=0 : C scarico ? V(t) ?

$t = 0$: $V(0) = 0 \rightarrow$ D OFF

C si carica a corr. cost.

$I_C = C\frac{dV(t)}{dt}$ $\quad I_C = -I$

$t>0$: $V(t) = -\frac{I}{C}\int_0^t dt' + V(0) = -\frac{I}{C}\cdot t =$

$= -\frac{10^{-5}}{10^{-8}}\, t = -10^{3}\, t$

? Quando $V(t) = V_Z$?

per $t = \bar{t}$ $\quad V(\bar{t}) = V_Z = -6V$

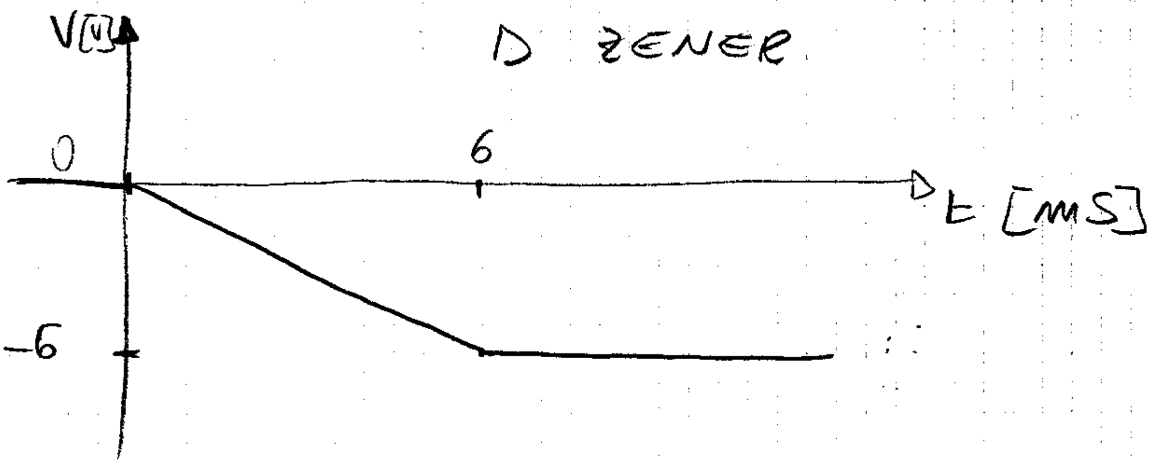
$-\frac{I}{C}\,\bar{t} = V_Z$

$\bar{t} = -\frac{C}{I}V_Z = -\frac{10^{-8}}{10^{-5}}\cdot(-6) =$

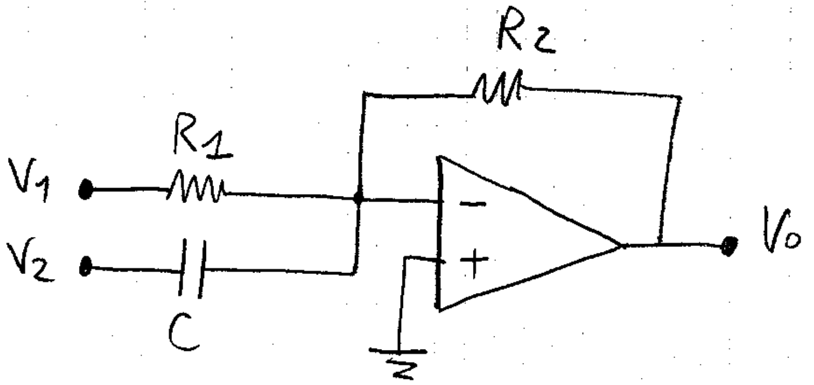
$= 6\cdot 10^{-3}\, s = 6\, ms$

per $t > \bar{t}$: $V(t) = V_Z = -6\,V$

D ZENER



• ES (SCRITTO © 15/11/94)



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

① Per $V_1 = V_2 = V_i$, $A \to \infty$, det $F(S) = \frac{V_0(S)}{V_i(S)}$
Bode, Risp. gradino unitario (+1 V)

② $V_2 = 0$; $A \to \infty$, det $F_1(S) = \frac{V_0}{V_1}$

③ $V_2 = 0$; $A = 100$; det. $F_1' = \frac{V_0}{V_1}$

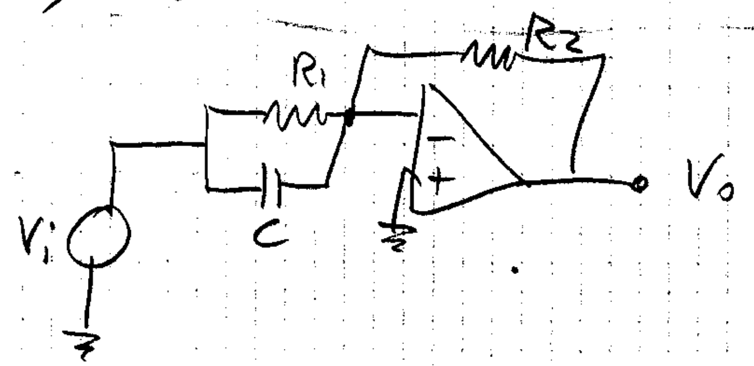
④ Det. Z_{IN} in casi ①, ②

⑤ Caso ①: Det. risp. a grad. unitario (1V) se AO ha liv. di sat. $L^+ = +10V$, $L^- = -10V$

⑥ Caso ①: Det $V_0(t)$ per $V_i(t) = 0.02 \sin 10^5 t$ [V]

FARE ANALISI PRELIMINARE !! $\omega \to 0$; $\omega \to \infty$ **!!**

①

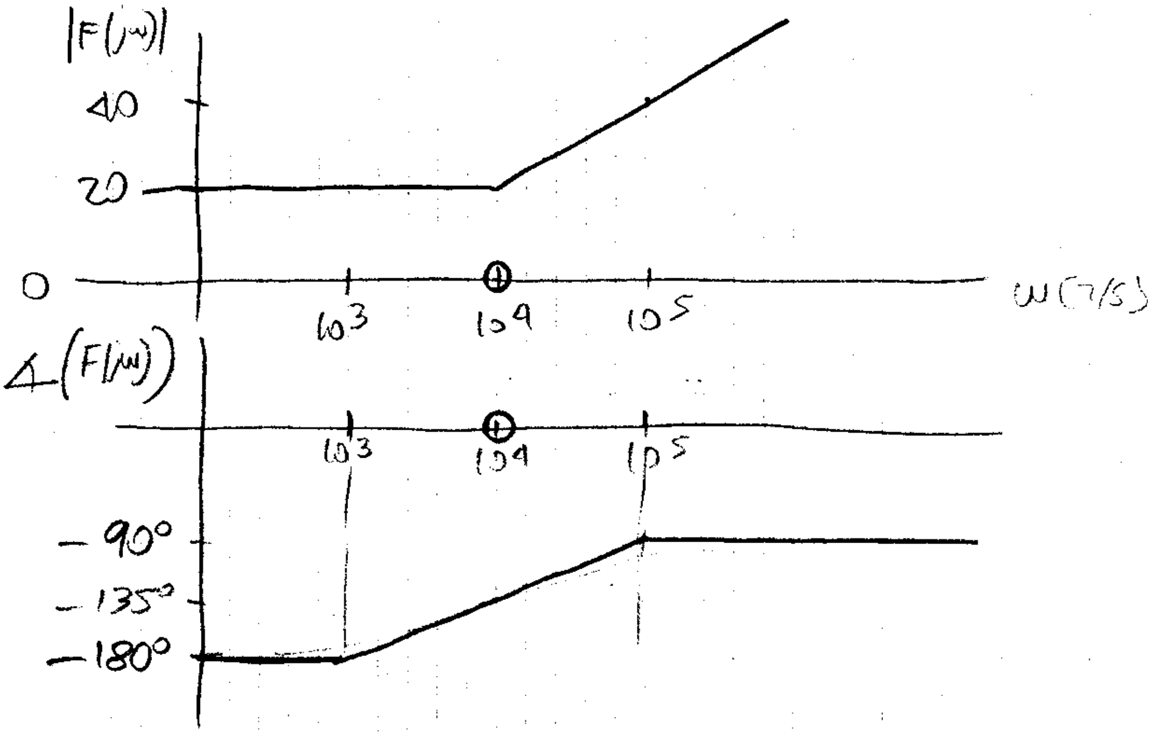


$F(S) = -\frac{R_2}{Z}$; $Z = R_1 // \frac{1}{SC} = \frac{R_1}{1 + SCR_1}$

$F(s) = -\frac{R_2}{R_1} \cdot (1 + SCR_1) = -10 \cdot (1 + S \cdot 10^{-4})$

zero: $z = -10^4$ r/s

$\omega_z = 10^4$ r/s



Risp. al grad.: $v_i(t) = 1 \cdot sca(t)$

$$V_o(s) = F(s) \cdot V_i(s)$$

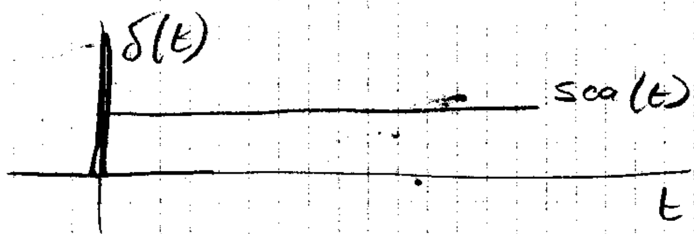
$$V_o(s) = -10\,(1 + sCR_1) \cdot V_i(s) =$$

$$\stackrel{!}{=} -10\,V_i(s) - 10 \cdot CR_1 \cdot s \cdot V_i(s)$$

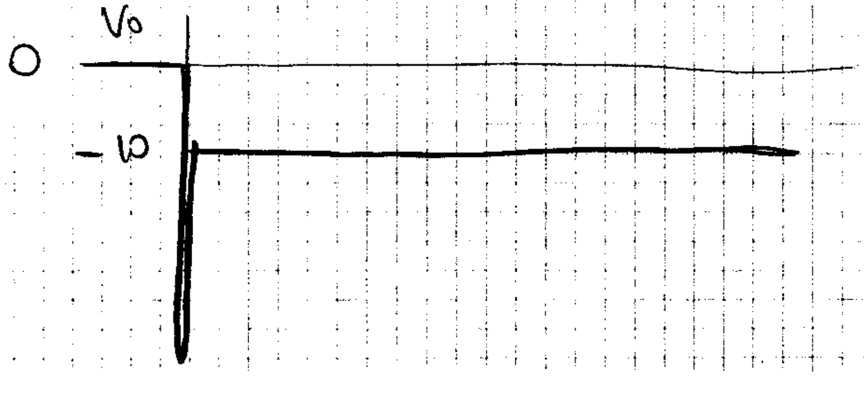
$$\Updownarrow$$

$$V_o(t) = -10\,V_i(t) - 10 \cdot CR_1 \cdot \frac{d}{dt} v_i(t)$$

$$\frac{d}{dt} v_i(t) = \frac{d}{dt}\left[sca(t)\right] = \delta(t)$$ — dim: $\left[\frac{V}{s}\right]$!!



$$V_o(t) = -10\,sca(t) - 10\,CR_1 \cdot \delta(t) \qquad [V]$$



Verifico: Teor. val. iniz. e finale:

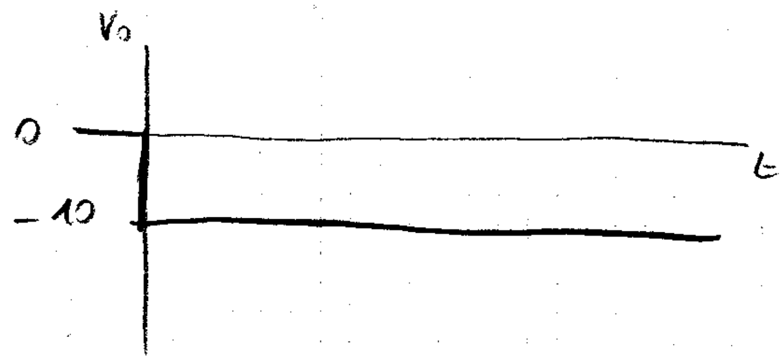
$$\lim_{t \to 0^+} V_0(t) = \lim_{s \to +\infty} s \cdot V_0(s) = \lim_{s \to +\infty} s \cdot (-10)(1+sCR_1)\frac{1}{s}$$

$$= \lim_{s \to \infty} (-10 - 10sCR_1) = -\infty \quad [V]$$

$$\lim_{t \to +\infty} V_0(t) = \lim_{s \to 0^+} s\, V_0(s) = \lim_{s \to 0^+} (-10 - 10sCR_1) = -10 [V]$$

Ok

(5) $L^+ = +10V$
$L^- = -10V$



(6) $V_i(t) = \bar{V} \sin \omega_s t \qquad \bar{V} = 0.02 \; V$
$\omega_s = 10^5 \; r/s$

$V_0(t) = V^* \sin(\omega_s t + \varphi)$

$|F(j\omega_s)| = \frac{V^*}{\bar{V}} \qquad V^* = \bar{V} \cdot |F(j\omega_s)| = 0.02 \cdot 10^2 = 2 [V]$

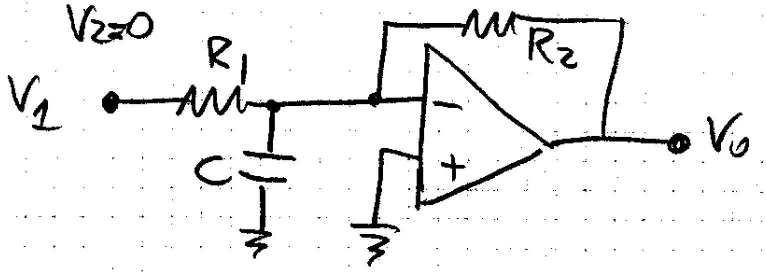
$\varphi \simeq -90°$ (approx)

esatto: $\varphi = -180° + \arctan \frac{\omega_s}{\omega_z} = -180° + \arctan \frac{10^5}{10^4} =$

$= -180° + 84.28° = -95.71° = -1.66$ rad

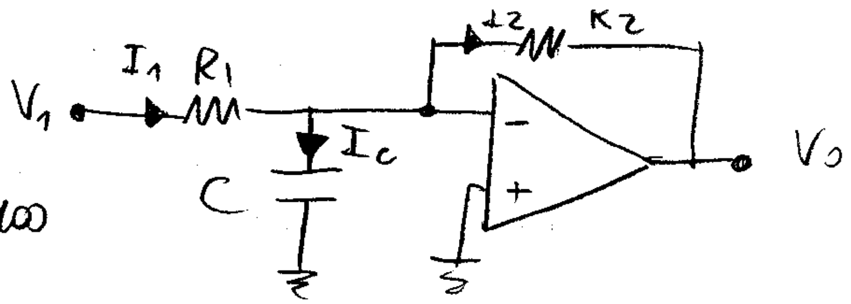
$V_0(t) = 2 \sin(10^5 t - 1.66)$ rad!!!

(2) $V_2 = 0$



$V^- = V^+ = 0V \rightarrow$ è Inv: $\frac{V_0}{V_i} = -\frac{R_2}{R_1} = -10$

③



$A = 100$

$A \neq \infty \; ; \quad V^+ \neq V^-$

$$V_0 = A(V^+ - V^-)$$

$$V^+ = 0 \longrightarrow V_0 = -AV^- \longleftrightarrow V^- = -\frac{V_0}{A}$$

$$\begin{cases} V_0 = V^- - I_2 R_2 \\ V_0 = -AV^- \end{cases}$$ ricavo V^-:

$$-AV^- = V^- - I_2 R_2$$

$$V^- = \frac{I_2 R_2}{A+1}$$

$$I_1 = I_C + I_2$$

$$I_1 = \frac{V_1 - V^-}{R_1} = \frac{V_1}{R_1} - I_2 \cdot \frac{R_2}{R_1(A+1)}$$

$$I_C = \frac{V^-}{1/sC} = I_2 \frac{sCR_2}{A+1}$$

Ricavo I_2:

$$\frac{V_1}{R_1} - I_2 \frac{R_2}{R_1(A+1)} = I_2 \frac{sCR_2}{(A+1)} + I_2$$

$$I_2 \left(1 + \frac{sCR_2}{A+1} + \frac{R_2}{R_1(A+1)}\right) = \frac{V_1}{R_1}$$

$$I_2 = V_1 \cdot \frac{1}{R_1} \cdot \frac{R_1(A+1)}{R_1(A+1) + sCR_1R_2 + R_2}$$

Espr. per V_0:

$$V_0 = V^- - I_2 R_2 = I_2 \frac{R_2}{A+1} - I_2 R_2 =$$

$$= I_2 R_2 \left(\frac{1}{A+1} - 1\right) = -I_2 R_2 \frac{A}{A+1}$$

$$F_1'(S) = \frac{V_0}{V_1} = -R_2 \frac{A}{\cancel{A+1}} \cdot \frac{\cancel{A+1}}{R_1(A+1) + SCR_1R_2 + R_2} =$$

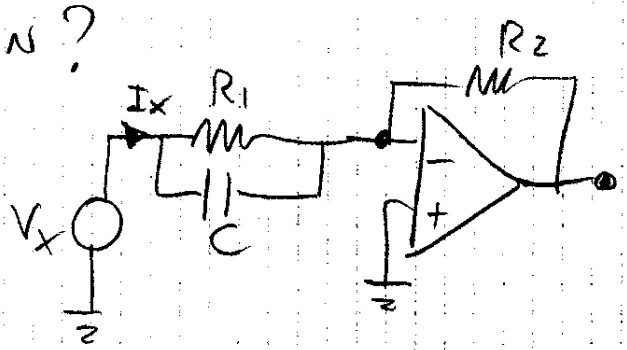
$$= -\frac{AR_2}{R_1(A+1) + R_2 + SCR_1R_2} =$$

$$= -\frac{AR_2}{R_1(A+1)+R_2} \cdot \frac{1}{1 + SC \cdot \frac{R_1R_2}{R_1(A+1)+R_2}}$$

? verifica ?: $A \to \infty \to -\frac{R_2}{R_1}$ OK

④ Z_{IN} ?

1)

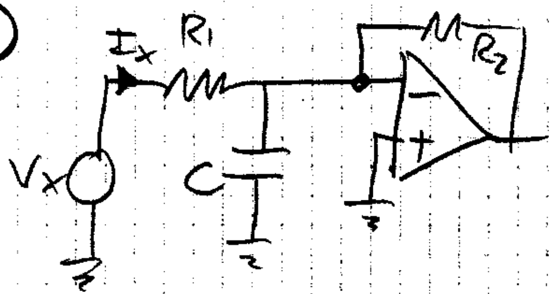


$$Z_{IN} = \frac{V_x}{I_x}$$

$$I_x = \frac{V_x - V^-}{R_1 // \frac{1}{SC}} = \frac{V_x}{R_1 // \frac{1}{SC}}$$

$$Z_{IN} = R_1 // \frac{1}{SC} = \frac{R_1}{1 + SCR_1}$$

2)



$$Z_{IN} = R_1$$