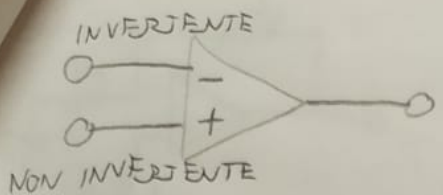
AMPLIFICATORE OPERAZIONALE



$$V_o = A(V^+ - V^-) \quad [\text{AD ANELLO APERTO}]$$

IDEALITÀ:

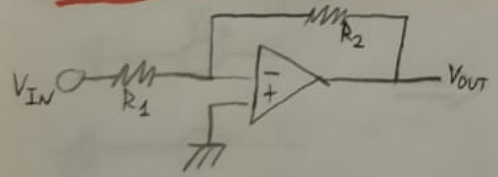
1. $R_{IN} = \infty \Rightarrow I_{IN} = 0$
2. $R_{OUT} = 0$
3. GUADAGNO INFINITO AD ANELLO APERTO
4. SE HO SEGNALI COMUNI $\Rightarrow A_{CM} \to 0 \Rightarrow CMRR = \frac{A_D}{A_{CM}} \to +\infty$
   $V_{OUT} = \not{0}$
5. ACCOPPIAMENTO DIRETTO $\Rightarrow$ AMPLIFICANO SIA IL SEGNALE CHE LA COMPONENTE DC
6. LARGHEZZA DI BANDA INFINITA $\Rightarrow$ AMPLIFICO DA $0\,Hz$ A $+\infty\,Hz$

- **PRINCIPIO DI MASSA VIRTUALE**

  1. $A = \infty$ AD ANELLO APERTO
  2. V_{OUT} FINITA
  3. FEEDBACK NEGATIVO

  $$V_+ = V_-$$

- **AMPLIFICATORE INVERTENTE**

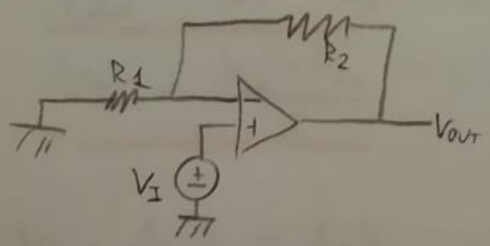


$$V_{OUT} = -\frac{R_2}{R_1} V_{IN}$$

$R_{IN} = R_1$

$R_{OUT} = \not{0}\,\Omega$

- **AMPLIFICATORE NON INVERTENTE**

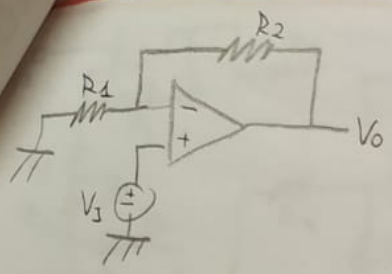


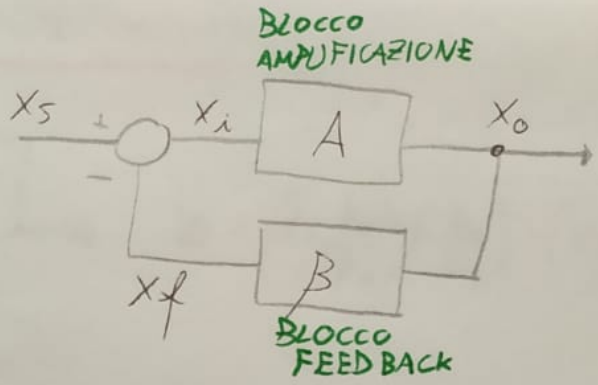
$$V_{OUT} = \left(1 + \frac{R_2}{R_1}\right) V_{IN}$$

$R_{IN} = \infty$

$R_{OUT} = 0$

SCHEMA A BLOCCHI





A = GUADAGNO AD ANELLO APERTO

$X_o = A \cdot X_i$

$X_f = \beta \cdot X_o$

$X_i = X_s - X_f$

A_f = GUADAGNO ANELLO CHIUSO

$$A_f = \frac{A}{1 + A \cdot \beta}$$

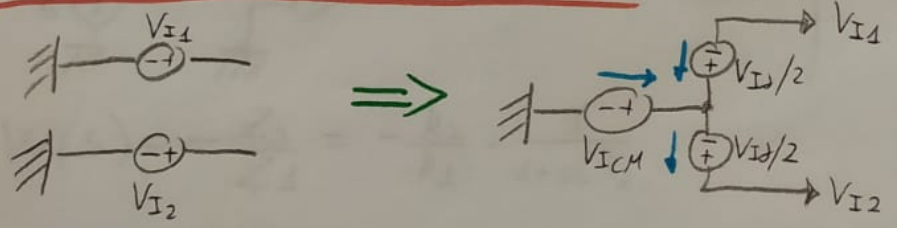
$1 + A \cdot \beta$ = QUANTITÀ DI FEEDBACK

$A \cdot \beta$ = GUADAGNO ANELLO

PER $A \to +\infty$ $\quad A_f = \frac{1}{\beta} = \left(1 + \frac{R_2}{R_1}\right)$

A NORMALE $\quad A_f = \frac{A}{1 + A \cdot \left(\frac{1}{1 + R_2/R_1}\right)}$

- AMPLIFICATORE DIFFERENZIALE



$$V_{Id} = V_{I1} - V_{I2} \qquad V_{I1} = V_{ICM} - \frac{V_{Id}}{2}$$

$$V_{ICM} = \frac{V_{I1} + V_{I2}}{2} \qquad V_{I2} = V_{ICM} + \frac{V_{Id}}{2}$$

$V_o = A_2 V_{I2} - A_1 V_{I1}$ $\quad A_D = \frac{A_2 - A_1}{2}$ $\quad A_{CM} = A_2 + A_1$

$CMRR = 20 \log \frac{|A_d|}{|A_{CM}|}$

FORMULARIO

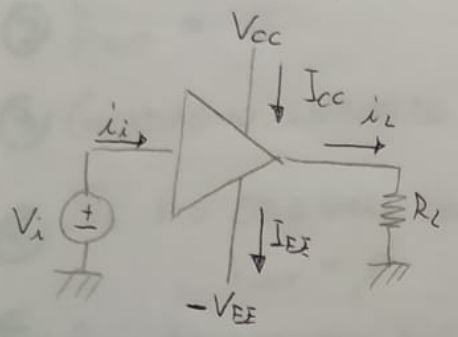
- **GUADAGNO**

① $A_V = \frac{V_o}{V_i} \Rightarrow 20\log_{10}|A_V|$

② $A_i = \frac{i_o}{i_i} \Rightarrow 20\log_{10}|A_i|$

③ $A_P = \frac{V_o \cdot i_o}{V_i \cdot i_i} \Rightarrow 10\log_{10}|A_P|$

$A_P = A_V \cdot A_i$



$P_{DC} = V_{CC} \cdot I_{CC} + V_{EE} \cdot I_{EE}$

$P_{DC} + P_i = P_L + P_{DISSIPATA}$

$\eta = \frac{P_L}{P_{DC}} \cdot 100$

- **CLASSIFICAZIONE AMPLIFICATORI**

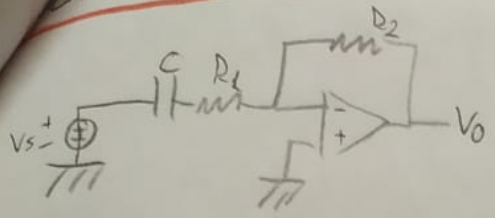
		R_{IN}	R_{OUT}
• DI TENSIONE	$V_{OUT} = A_V \cdot V_i$	∞	0
• DI CORRENTE	$I_{OUT} = A_i \cdot I_i$	0	∞
• TRANSRESISTIVO	$V_{OUT} = R \cdot I_i$	0	0
• TRANSCONDUTTIVO	$I_{OUT} = G \cdot V_I$	∞	∞

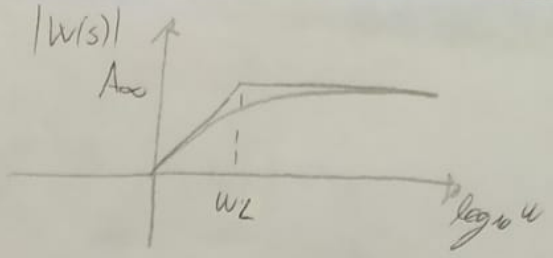
- **R_{IN} E R_{OUT}**

R_{IN} → TROVO V_{IN}, I_{IN} $\quad R_{IN} = \frac{V_{IN}}{I_{IN}}$

R_{OUT} →
① STACCO CARICO
② ANNULLO SEGNALE INGRESSO
③ APPLICO GENERATORE DI TEST COMPLEMENTARE ALL'USUALE
④ $R_O = \frac{V_{TEST}}{I_{TEST}}$

FILTRO PASSA ALTO





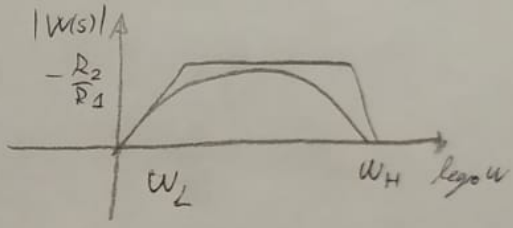
$$W(s) = -\frac{Z_2}{Z_1} = -\frac{sCR_2}{1+sR_1C}$$

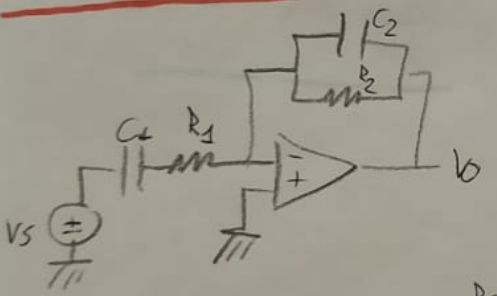
$$W(s) = \frac{-\frac{R_2}{R_1}s}{s+\frac{1}{R_1C}}$$

$A_\infty = -\frac{R_2}{R_1}$ → GUADAGNO AD ALTA FREQUENZA

$\omega_L = \frac{1}{R_1C}$ → FREQUENZA DI TAGLIO

FILTRO PASSA BANDA





$$A = -\frac{Z_2}{Z_1} = -\frac{\frac{R_2}{j\omega C_2}}{R_2+\frac{1}{j\omega C_2}} \cdot \frac{1}{R_1+\frac{1}{j\omega C_1}}$$

$$A = -\frac{R_2}{R_1} \cdot \frac{1}{1+j\frac{\omega}{\omega_{H1}}} \cdot \frac{1}{1-j\frac{\omega_L}{\omega}}$$

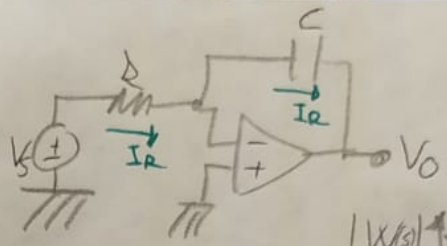
$\omega_2 = \frac{1}{R_1C_1}$ → FREQ. TAGLIO INFERIORE

$\omega_H = \frac{1}{R_2C_2}$ → FREQ. TAGLIO SUPERIORE

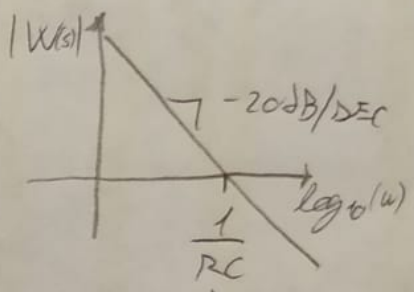
$A_{CB} = -\frac{R_2}{R_1}$ → GUADAGNO CENTRO BANDA

FONDAMENTI

• CIRCUITO INTEGRATORE

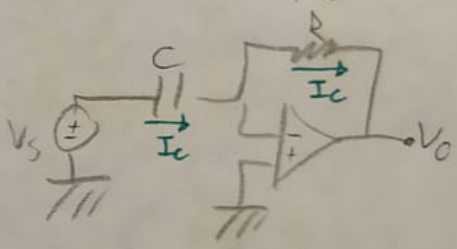


$$W(s) = -\frac{Z_2}{Z_1} = -\frac{1}{sC} \cdot \frac{1}{R} = -\frac{1}{sRC}$$

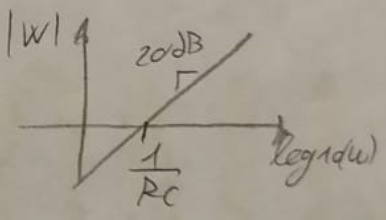


$$V_o = -\frac{1}{RC} \cdot \int V_s(t)\,dt$$

• CIRCUITO DERIVATORE



$$W(s) = -\frac{Z_2}{Z_1} = -R \cdot sC = -sRC$$

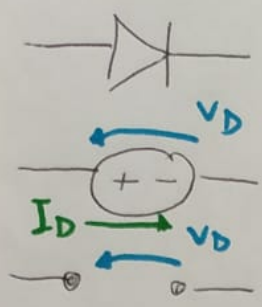


$$V_o = -R \cdot i_C \qquad i_C = C \cdot \frac{dV_s}{dt}$$

$$V_o = -RC\frac{dV_s}{dt}$$

FORMULARIO

DIODO



SE IL DIODO È IDEALE

$V_{ON} = 0\,V$

ACCESO Ip $V_D = V_{ON}$ Tr $I_D > 0$

SPENTO Ip $I_D = 0$ Tr $V_D < V_{ON}$

MOSFET NMOS

① INTERDIZIONE

Hp $I_D = 0 \Rightarrow$ Tr $\underline{V_{GS} < V_{TH}}$

② SATURAZIONE

Hp $I_D = \frac{1}{2} k_n (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS}) \Rightarrow$ Tr $\underline{V_{GS} > V_{TH}}$ $\underline{V_{GD} < V_{TH}}$

[OPPURE $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{TH}}\right)^2 (1 + \lambda V_{DS})$]

③ LINEARE

Hp $I_D = k_n \left[(V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2\right] \Rightarrow$ Tr $\underline{V_{GS} > V_{TH}}$ $\underline{V_{GD} > V_{TH}}$

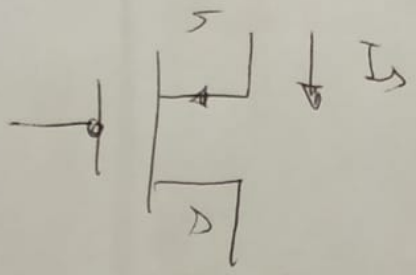
$$k_n = \underbrace{\mu C_{ox}}_{k_n'} \cdot \frac{W}{L} \qquad I_{DSS} = \frac{1}{2} k_n \cdot V_T^2$$

$$g_m = \frac{2 I_D}{V_{OV}} = \frac{2 I_D}{V_{GS} - V_{TH}}$$

$$g_m = \sqrt{2 k_n \cdot I_D}$$

$$r_o = \frac{1}{\lambda I_D} \qquad |V_A| = \frac{1}{\lambda}$$

MOSFET PMOS



① INTERDIZIONE

$V_{GS} > V_{TN}$

② SATURAZIONE

$V_{GS} < V_{TN}$

$V_{GD} > V_{TN}$

$$I_D = \frac{1}{2} K_n (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

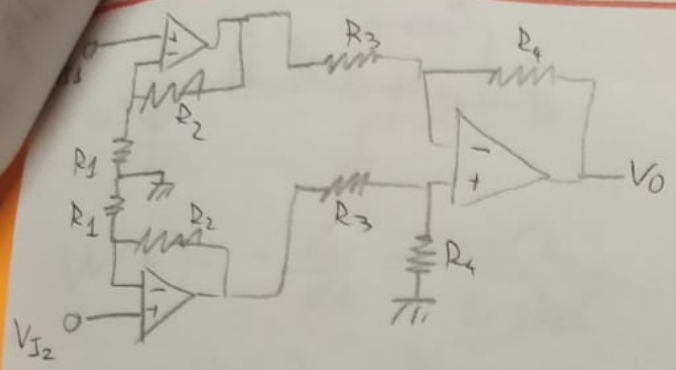
③ LINEARE

$V_{GS} < V_{TN}$

$V_{GD} < V_{TN}$

$$I_D = K_n \left[(V_{GS} - V_{TN}) V_{DS} - \frac{1}{2} V_{DS}^2 \right]$$

AMPLIFICATORE PER STRUMENTAZIONE



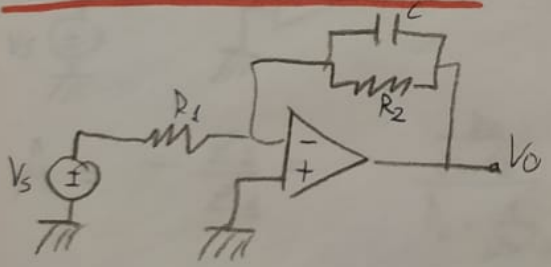
$$V_o = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3}\right) \cdot (V_{I_2} - V_{I_1})$$

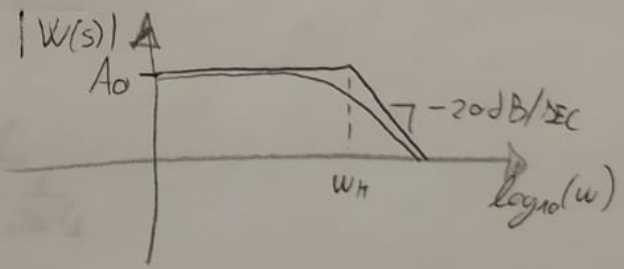
- **RISPOSTA IN FREQUENZA**

- **INDUTTORE** —lll—
  A] $V(t) = L \cdot \frac{di(t)}{dt}$
  B] $\frac{V_o}{I_o} = \omega \cdot L$
  C] $X_L = j\omega L$

- **CONDENSATORE** —||—
  A] $i(t) = C \cdot \frac{dv(t)}{dt}$
  B] $-\frac{1}{\omega C} = \frac{V_o}{I_o}$
  C] $X_C = -\frac{j}{\omega C}$

- **FILTRO PASSA BASSO**





$$W(s) = -\frac{Z_2}{Z_1} = -\frac{R_2}{R_1} \cdot \frac{1}{1 + sCR_2}$$

$A_0 = -\frac{R_2}{R_1}$ → GUADAGNO A BASSA FREQUENZA

$\omega_H = \frac{1}{R_2 C}$ → FREQUENZA DI TAGLIO (−3 dB)