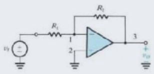
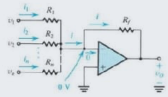
Formule elettronica - Amplificatori operazionali

Configurazione invertente



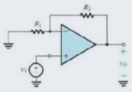
$i_1 = i_2 = \frac{V_I - V_1}{R_1} = \frac{V_I}{R_1}$ $\quad G = \frac{V_O}{V_I} = -\frac{R_2}{R_1}$ $\quad G = \frac{-R_2/R_1}{1+(1+R_2/R_1)/A}$

Configurazione invertente con segnali multipli



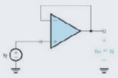
$$V_O = -\left(\sum_{i=1}^{n} \frac{V_i}{R_i}\right) R_f = -\sum_{i=1}^{n} i_i R_f$$

Configurazione non invertente



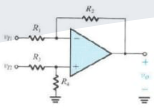
$i_1 = i_2 = \frac{V_I}{R_1}$ $\quad G = \frac{V_O}{V_I} = 1 + \frac{R_2}{R_1}$ $\quad G = \frac{1+R_2/R_1}{1+(1+R_2/R_1)/A}$

Inseguitore di tensione



$R_1 = \infty$ $\quad R_O = 0$ $\quad V_O = V_I$ $\quad G = 1$

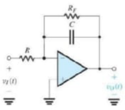
Amplificatore di differenza



$$A_{cm} = \frac{V_O}{V_{Icm}} = \frac{R_4}{R_4 + R_3} + R_3\left(1 - \frac{R_3}{R_4}\frac{R_2}{R_1}\right)$$

$A_d = \frac{R_2}{R_1}$ $\quad R_{Id} = 2R_1$ $\quad CMRR = 20\,log_{10}\left(\frac{|A_d|}{|A_{cm}|}\right)$

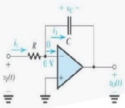
Circuito integratore



$$G(s) = \frac{-R_2/R_1}{1 + sCR_2}$$

$k = \frac{R_2}{R_1}$ $\quad \omega_C = \frac{1}{CR_2} = 2 \times \pi \times f_C$

Circuito integratore di Miller

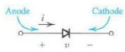


$$V_O(t) = -\frac{1}{RC}\int_0^t V_I(t)\ dt$$

$$V_C(t) = V\_C - \frac{1}{RC}\int_0^t V_I(t)\ dt$$

$$G(s) = \frac{1}{sRC}$$

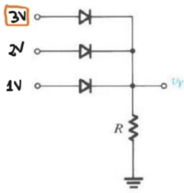
Formule elettronica - Diodi



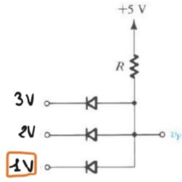
$V_{catodo} > V_{anodo}$ $(I < 0)$ => POLARIZZAZIONE INVERSA (circuito aperto)

$V_{catodo} < V_{anodo}$ $(I > 0)$ => POLARIZZAZIONE DIRETTA (cortocircuito)

Modelli dei diodi

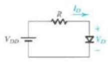


Si sceglie la tensione che dia la caduta di tensione maggiore (TENSIONE MAX)



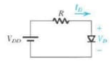
Si sceglie la tensione che dia la caduta di tensione maggiore (TENSIONE MIN)

Modello ideale



$V_D = 0$ $\quad I_D = \frac{V_{DD}}{R}$

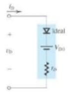
Modello esponenziale



Da iterare (V_1 e I_1 => iterazione precedente / V_2 e I_2 => iterazione successiva)

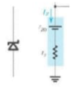
$I_D = \frac{V_{DD} - V_D}{R}$ $\quad V_2 = V_1 + 2{,}3nV_T log(I_2/I_1)$

Modello di piccolo segnale



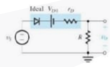
$I_D = \frac{V_{DD} - V_D}{R}$ $\quad r_d = \frac{nV_T}{I_D}$ $\quad i_d = \frac{v_d}{r_d}$

Diodo zenzer



$V_Z = V_{ZO} - r_Z I_Z$ $\quad \Delta V = \Delta I \cdot r_Z$

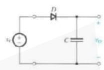
Raddrizzatore a singola semionda



$\theta = arcsen(V_{DO}/V_S)$ $\quad PIV = V_S$

$V_{O_{dc}} = \frac{V_S}{\pi} - \frac{V_{DO}}{2}$ $\quad I_{picco} = \frac{V_S - V_{DO}}{R}$

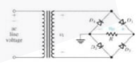
Raddrizzatore di picco



$V_{pp} = \frac{V_1}{fCR}$ $\quad \omega\Delta t = \sqrt{2\frac{V_{pp}}{V_p}}$ $\quad I_L = \frac{V_p}{R}$

$I_{D_{max}} = I_L\left(1 + 2\pi\sqrt{2\frac{V_{pp}}{V_r}}\right)$ $\quad I_{D_{max}} = I_L\left(1 + \pi\sqrt{2\frac{V_{pp}}{V_r}}\right)$

Raddrizzatore a ponte



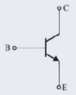
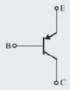
$V_{S_{eff}} = \frac{V_P}{\sqrt{2}}$ $\quad V_r = \frac{V_p}{2fRC} = \frac{V_p - 2V_D}{2fRC}$ $\quad I_L = \frac{V_{O_{dc}}}{R}$

$\omega\Delta t = \sqrt{\frac{2V_r}{V_p - 2V_D}}$ $\quad PIV = V_p - V_D$

$V_{O_{dc}} = \left(V_p - \frac{V_r}{2}\right) - 2V_D$ $\quad I_{D_{max}} = I_L\left(1 + 2\pi\sqrt{\frac{V_p - 2V_D}{V_r}}\right)$

$$I_{D_{max}} = I_L\left(1 + \pi\sqrt{\frac{V_p - 2V_D}{V_r}}\right)$$

Formule elettronica – Transistor BJT

npn

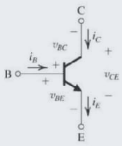
ZAD $V_{CB} > 0$ $V_{BE} = 0.7V$

Saturazione $V_{CB} < 0$ $V_{CE_{sat}} = 0.2V$

pnp

ZAD $V_{BC} > 0$ $V_{EB} = 0.7V$

Saturazione $V_{BC} < 0$ $V_{EC_{sat}} = 0.2V$



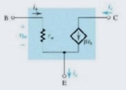
$\alpha = \frac{\beta}{\beta+1}$ $\beta = \frac{\alpha}{\alpha-1}$

$I_C = \alpha I_E = \beta I_B$ $I_B = \frac{I_C}{\beta} = \frac{I_E}{\beta+1}$

Nel caso in cui $V_C < V_E$ in npn o $V_E < V_C$ in pnp è necessario forzare β

$V_{C_{sat}} = V_C + V_{CE_{sat}} \Rightarrow I_{C_{sat}}$ $\beta_{forzato} = \frac{I_{C_{sat}}}{I_B}$

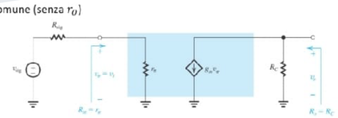
Modello di piccolo segnale



$g_m = \frac{I_C}{V_T}$ $r_\pi = \frac{\beta}{g_m}$ $r_O = \frac{V_A}{I_C}$

$A_v = \frac{v_O}{v_I}$ $A_i = \frac{i_O}{i_I}$ $G_v = \frac{v_O}{v_{sig}}$

Modello emettitore comune (senza r_O)



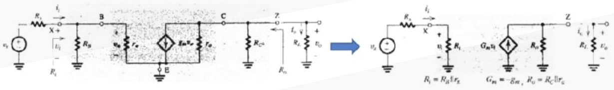
$R_{in} = r_\pi$ $R_O = R_C$ $R_{OUT} = R_C//R_L$

$v_i = \frac{R_{in}}{R_{sig}+R_{in}} v_{sig}$ $v_i = v_\pi$

$A_{vo} = -g_m R_O$ $A_v = -g_m R_{OUT}$ $A_i = -\frac{g_m v_\pi}{v_\pi/R_{in}} = -g_m R_{in}$

$G_v = \frac{v_o}{v_{sig}} = \frac{v_i}{v_{sig}} A_v = -\frac{R_{in}}{R_{sig}+R_{in}} g_m R_{OUT}$

Modello emettitore comune (con r_O e R_B)



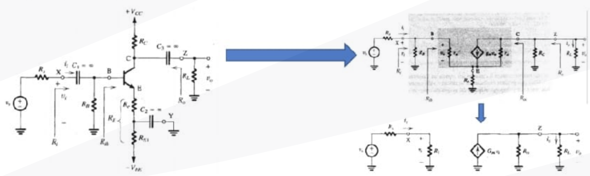
$R_{in} = R_B//R_{ib} = R_B//r_\pi$ $R_O = R_C//r_O$ $R_{OUT} = R_O//R_L$

$v_i = \frac{R_{in}}{R_{sig}+R_{in}} v_{sig}$ $v_i = v_\pi$

$A_{vo} = -g_m R_O$ $A_v = -g_m R_{OUT}$ $A_i = -\frac{g_m v_\pi}{v_\pi/R_{in}} = -g_m R_{in}$

$$G_v = \frac{v_o}{v_{sig}} = \frac{v_i}{v_{sig}} A_v = -\frac{R_{in}}{R_{sig} + R_{in}} g_m R_{OUT}$$

Modello emettitore comune con degenerazione

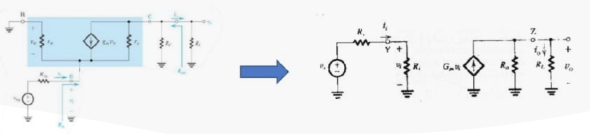


$R_{ib} = r_\pi + (\beta+1) R_e$ $R_{in} = R_B//R_{ib}$ $G_m = -\frac{g_m}{1+g_m R_e}$

$R_O = R_C//r_O$ $R_{OUT} = R_O//R_L$ $v_i = \frac{R_{in}}{R_{sig}+R_{in}} v_{sig} = v_\pi + I_e R_e$

$A_{vo} = G_m R_O$ $A_v = G_m R_{OUT}$ $A_i = G_m R_{in}$ $G_v = -\beta \frac{R_{OUT}}{R_{sig}+r_\pi+(\beta+1) R_e}$

Modello base comune

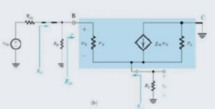


$R_{in} = r_e$ $G_m = g_m$

$R_O = R_C//r_O$ $R_{OUT} = R_O//R_L$

$A_{vo} = G_m R_O$ $A_v = G_m R_{OUT}$ $A_i = G_m R_{in} = \alpha$ $G_v = \alpha \frac{R_{OUT}}{R_{sig}+r_e}$

Modello collettore comune

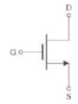
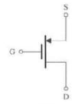


$R_{ib} = r_\pi + (\beta+1) R_L//r_O$ $R_{in} = R_B//R_{ib}$

$R_O = r_O$ $R_{OUT} = R_O//R_L$ $v_i = \frac{R_{in}}{R_{sig}+R_{in}} v_{sig} = R_{in} I_B$

$A_{vo} = \alpha \cong 1$ $A_v = \frac{(\beta+1) R_{OUT}}{R_{ib}}$ $G_v = A_v \frac{R_{in}}{R_{sig}+R_{in}}$

Formule elettronica – Transistor MOSFET

NMOS

Saturazione $v_{DS} \geq v_{OV}$

Triodo $v_{DS} < v_{OV}$

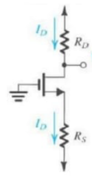
Interdizione $v_{GS} < V_T$

PMOS

Saturazione $v_{SD} \geq |v_{OV}|$

Triodo $v_{SD} < |v_{OV}|$

Interdizione $v_{SG} < |V_T|$



$k'_p = \mu_p C_{ox}$ $k'_n = \mu_n C_{ox}$

$|v_{OV}| = v_{GS} - |V_T|$ $|v_{OV}| = v_{SG} - |V_T|$

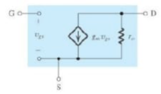
Saturazione

$I_D = \frac{1}{2} k'_n \frac{W}{L} v_{OV}^2 (1 + \lambda v_{DS})$ $I_D = \frac{1}{2} k'_p \frac{W}{L} v_{OV}^2 (1 + \lambda v_{SD})$

Triodo

$I_D = k'_n \frac{W}{L} (v_{OV} v_{DS} - \frac{1}{2} v_{DS}^2)$ $I_D = k'_p \frac{W}{L} (v_{OV} v_{SD} - \frac{1}{2} v_{SD}^2)$

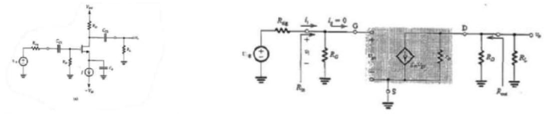
Modello di piccolo segnale



$g_m = \frac{2 I_D}{v_{OV}}$ $r_O = \frac{V_A}{I_D}$

$A_v = \frac{v_O}{v_I}$ $A_i = \frac{i_O}{i_I}$ $G_v = \frac{v_O}{v_{sig}}$

Source comune



$R_{in} = R_G$ $R_O = r_O//R_D$ $R_{OUT} = r_O//R_D//R_L$ $v_i = v_{sig} \frac{R_G}{R_G+R_{sig}} = v_{GS}$

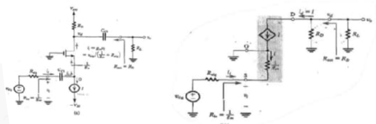
$A_{vo} = -g_m R_O$ $A_v = -g_m R_{OUT}$ $G_v = -\frac{R_G}{R_G+R_{sig}} g_m R_{OUT}$

Source comune con R_S

$R_{in} = R_G$ $R_O = r_O//R_D$ $R_{OUT} = r_O//R_D//R_L$ $v_i = v_{sig} \frac{R_G}{R_G+R_{sig}} = v_{GS}$

$A_{vo} = -\frac{g_m}{1+g_m R_S} R_O$ $A_v = -\frac{g_m}{1+g_m R_S} R_{OUT}$ $G_v = -\frac{R_G}{R_G+R_{sig}} \frac{g_m}{1+g_m R_S} R_{OUT}$

Gate comune



$R_{in} = \frac{1}{g_m}$ $R_O = R_D$ $R_{OUT} = R_D//R_L$

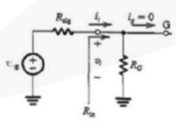
$A_{vo} = g_m R_O$ $A_v = g_m R_{OUT}$ $G_v = -\frac{g_m R_{OUT}}{1+g_m R_S}$

Drain comune

$R_{in} = R_G$ $R_O = \frac{1}{g_m}//r_O \cong \frac{1}{g_m}$ $R_{OUT} = R_O//R_L$

$A_{vo} = \frac{1}{1+(1/g_m r_O)}$ $A_v = A_{vo} \frac{R_L}{R_O+R_L} = \frac{R_L//r_O}{(R_L//r_O)+(R_O)} = G_v$

Nel caso fosse presente una resistenza sul generatore R_{sig}



$$G_v = -\frac{R_G}{R_G + R_{sig}} \frac{R_L//r_O}{(R_L//r_O) + R_O}$$