ΒΑΣΙΚΕΣ ΕΞΙΣΩΣΕΙΣ ΗΛΕΚΤΡΟΝΙΚΗΣ ΙΙΙ

Πολυβάθμιοι ενισχυτές

$A_v = \frac{e_{out}}{V_S} = \prod_{i=1}^{n} A_i = \frac{R_{in,1}}{R_{in,1} + R_S} \cdot \frac{R_{in,2}}{R_{in,2} + R_{out,1}} \cdot \ldots \cdot \frac{R_L}{R_L + R_{out,n}}$

Με n όμοιες βαθμίδες: $\omega_{nL} = \frac{\omega_0}{\sqrt{2^{1/n} - 1}}$. Με n βαθμίδες με $f_{Lj},\ j = 1, \ldots, n$: $f_{nL} \approx 1.1 \sqrt{\sum_{j=1}^{n} f_{Lj}^2}$

Με n όμοιες βαθμίδες: $\omega_{nH} = \omega_0 \sqrt{2^{1/n} - 1}$. Με n βαθμίδες με $f_{Hj},\ j = 1, \ldots, n$: $f_{nH} \approx \left(1.1 \sqrt{\sum_{j=1}^{n} f_{Hj}^2}\right)^{-1}$

Ζεύγος κοινού συλλέκτη - κοινής βάσης:

$\frac{V_o}{V_{sig}} = \frac{1}{2}\left(\frac{R_{in}}{R_{in} + R_{sig}}\right)(g_m R_L)$ $\qquad R_{in} = 2r_\pi$

$f_{P1} = \frac{1}{2\pi\left(\frac{C_\pi}{2} + C_\mu\right)(R_{sig} \parallel 2r_\pi)}$ $\qquad f_{P2} = \frac{1}{2\pi C_\mu R_L}$ $\qquad f_H \cong 1 \Big/ \sqrt{\frac{1}{f_{P1}^2} + \frac{1}{f_{P2}^2}}$

Ζεύγος κοινής πηγής - κοινής πύλης (κασκοδική συνδεσμολογία):

$R_{out} = r_{o2} + [1 + (g_{m2} + g_{mb2})\, r_{o2}]\, r_{o1}$ $\qquad A_v = -A_0^2 \frac{R_L}{R_L + A_0 r_0}$ $\qquad f_H \cong \frac{1}{2\pi\tau_H}$

$R_{gd1} = (1 + g_{m1} R_{d1}) R_{sig} + R_{d1}$ $\qquad \tau_H = R_{sig}\left[C_{gs1} + C_{gd1}(1 + g_{m1}R_{d1})\right] + R_{d1}\left(C_{gd1} + C_{db1} + C_{gs2}\right) + (R_L \parallel R_{out})\left(C_L + C_{gd2}\right)$

Ζεύγος κοινού εκπομπού - κοινής βάσης (κασκοδική συνδεσμολογία):

$A_M = -\frac{r_\pi}{r_\pi + r_x + R_{sig}} g_m (\beta r_0 \parallel R_L)$ $\qquad R_{c1} = r_{01} \parallel \left[r_{e2}\left(\frac{r_{o2} + R_L}{r_{o2} + R_L/(\beta_2 + 1)}\right)\right]$

$R'_{sig} = r_{\pi 1} \parallel \left(r_{x1} + R_{sig}\right)$ $\qquad \tau_H = C_{\pi 1} R_{\pi 1} + C_{\mu 1} R_{\mu 1} + (C_{cs1} + C_{\pi 2}) R_{c1} + \left(C_L + C_{cs2} + C_{\mu 2}\right)(R_L \parallel R_{out})$

$R_{\mu 1} = R'_{sig}(1 + g_{m1} R_{c1}) + R_{c1}$ $\qquad f_H \simeq \frac{1}{2\pi\tau_H}$

Τελεστικός ενισχυτής MOS δύο βαθμίδων:

$A_v = -g_{m1}(r_{ds2} \parallel r_{ds4})$ $\qquad g_{m1} = \sqrt{2\mu_p C_{ox}\left(\frac{W}{L}\right)_1 I_{D1}} = \sqrt{2\mu_p C_{ox}\left(\frac{W}{L}\right)_1 \frac{I_{bias}}{2}}$

$R_B = \frac{2}{\sqrt{2\mu_n C_{ox}\,(W/L)_{12}\, I_B}}\left(\sqrt{\frac{(W/L)_{12}}{(W/L)_{13}}} - 1\right)$

$g_{m12} = \frac{2}{R_B}\left(\sqrt{\frac{(W/L)_{12}}{(W/L)_{13}}} - 1\right)$ $\qquad g_{mi} = g_{m12}\sqrt{\frac{I_{Di}\,(W/L)_i}{I_B\,(W/L)_{12}}}$ $\qquad g_{mi} = g_{m12}\sqrt{\frac{\mu_p I_{Di}\,(W/L)_i}{\mu_n I_B\,(W/L)_{12}}}$

$C_1 = C_{gd4} + C_{db4} + C_{gd2} + C_{gs6}$ $\qquad C_2 = C_{db6} + C_{db7} + C_{gd7} + C_L$

$\omega_Z = \frac{G_{m2}}{C_C}$ $\qquad \omega_{P1} = \frac{1}{C_1 R_1 + C_2 R_2 + C_C(G_{m2} R_2 R_1 + R_1 + R_2)} \cong \frac{1}{R_1 C_C G_{m2} R_2}$

$\omega_{P2} = \frac{G_{m2} C_C}{C_1 C_2 + C_C(C_1 + C_2)}$ $\qquad \omega_t = (G_{m1} R_1 G_{m2} R_2)\,\omega_{P1}$ $\qquad$ Επιλογή C_C ώστε $\omega_t < \omega_Z < \omega_{P2}$

$\mathrm{PSRR} = g_{mN}(r_{oP} \parallel r_{oN})$ $\qquad \mathrm{SR} \equiv \left.\frac{\mathrm{d}V_{out}}{\mathrm{d}t}\right|_{\max} = \frac{I_{SS}}{C_L}$

$\mathrm{GB} = A_v(0) \cdot |p_1| = (g_{m1} g_{m2} R_I R_{II}) \cdot \left(\frac{1}{g_{m2} R_I R_{II} C_C}\right) = \frac{g_{m1}}{C_C}$

$\mathrm{PM} = \mathrm{Arg}\,[AB] = \pm 180° - \arctan\left(\frac{\omega}{|p_1|}\right) - \arctan\left(\frac{\omega}{|p_2|}\right) - \arctan\left(\frac{\omega}{Z}\right)$

Για περιθώριο φάσης (PM) 45° και $Z \geqslant 10 \cdot \mathrm{GB}$: $|p_2| \geqslant 1.22 \cdot \mathrm{GB}$

Για περιθώριο φάσης (PM) 60° και $Z \geqslant 10 \cdot \mathrm{GB}$: $|p_2| \geqslant 2.22 \cdot \mathrm{GB}$

$Z = \frac{1}{C_C\left(\frac{1}{g_{m2}} - R_Z\right)}$

Τελεστικός ενισχυτής με είσοδο n-MOS

$$\max(V_{in}) = V_{DD} - \sqrt{\frac{I_5}{\beta_3}} - \max(|V_{T03}|) + \min(V_{T01}) \qquad \min(V_{in}) = V_{SS} + \sqrt{\frac{I_5}{\beta_1}} + \max(V_{T01}) + V_{DS5_{sat}} \qquad V_{DS_{sat}} = \sqrt{\frac{2I_{DS}}{\beta}}$$

Τελεστικός ενισχυτής με είσοδο p-MOS

$$\max(V_{in}) = V_{DD} - \sqrt{\frac{I_5}{\beta_1}} - V_{DS5_{sat}} - \max(|V_{T01}|) \qquad \min(V_{in}) = V_{SS} + \sqrt{\frac{I_5}{\beta_3}} + \max(V_{T03}) - \min(|V_{T01}|)$$

Σχεδίαση τελεστικού ενισχυτή με είσοδο n-MOS

$$\mathrm{SR} = \frac{I_5}{C_C} \qquad A_{v1} = \frac{-g_{m1}}{g_{ds2} + g_{ds4}} = \frac{-2g_{m1}}{I_5 \cdot (\lambda_2 + \lambda_4)} \qquad A_{v2} = \frac{-g_{m6}}{g_{ds6} + g_{ds7}} = \frac{-g_{m6}}{I_6 \cdot (\lambda_6 + \lambda_7)}$$

$$\mathrm{GB} = \frac{g_{m1}}{C_C} \qquad p_2 = \frac{-g_{m6}}{C_L} \qquad Z = \frac{g_{m6}}{C_C} \qquad \beta = k' \frac{W}{L} \cong \mu_0 C_{ox} \frac{W}{L} \ \ (\mathrm{A/V^2})$$

$$C_C > 0.22 C_L \qquad I_5 = \mathrm{SR} \cdot C_C \qquad S_3 = \left(\frac{W}{L}\right)_3 = \frac{I_5}{k'_3 \left[V_{DD} - \max(V_{in}) - \max(|V_{T03}|) + \min(V_{T01})\right]^2}$$

$$\frac{g_{m3}}{2C_{gs3}} > 10 \cdot \mathrm{GB} \qquad g_{m1} = \mathrm{GB} \cdot C_C \Longrightarrow S_1 = S_2 = \frac{g_{m2}^2}{k'_2 I_5}$$

$$V_{DS5_{sat}} = \min(V_{in}) - V_{SS} - \sqrt{\frac{I_5}{\beta_1}} - \max(V_{T01}) \geqslant 100\mathrm{mV} \qquad S_5 = \frac{2I_5}{k'_5 V_{DS5_{sat}}^2}$$

$$g_{m6} = 2.2 g_{m2} \left({}^{C_L}\!/\!{}_{C_C}\right) \qquad S_6 = S_4 \frac{g_{m6}}{g_{m4}} \qquad I_6 = \frac{g_{m6}^2}{2k'_6 S_6}$$

$$S_6 = \frac{g_{m6}}{k'_6 V_{DS6_{sat}}} \qquad V_{DS6} = \min(V_{DS6}) = V_{DS6_{sat}} = V_{DD} - \max(V_{out}) \qquad S_7 = S_5 \frac{I_6}{I_5}$$

$$A_v = \frac{2 g_{m2} g_{m6}}{I_5 (\lambda_2 + \lambda_4) I_6 (\lambda_6 + \lambda_7)} \qquad P_{diss} = (I_5 + I_6) \cdot (V_{DD} + |V_{SS}|)$$