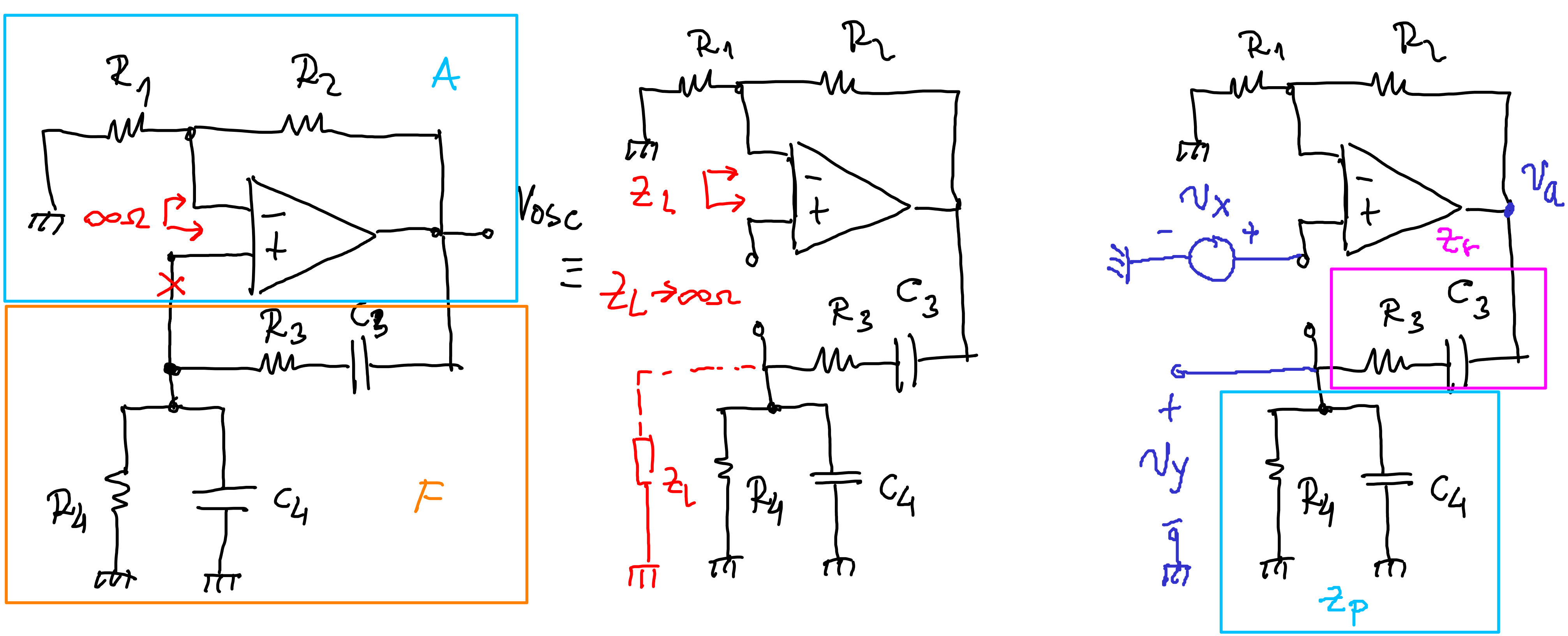
P1




$$B = A \cdot F = \frac{v_y}{v_x} = \frac{v_y}{v_a} \cdot \frac{v_a}{v_x} = \frac{Z_p}{Z_p + Z_r} \cdot k \, , \quad k = 1 + R_2/R_1$$

$$B = \frac{\dfrac{R_4}{1 + sC_4R_4}}{\dfrac{R_4}{1 + sC_4R_4} + \dfrac{1 + sC_3R_3}{sC_3}} \cdot k = \frac{k \cdot sC_3R_4}{sC_3R_4 + (1 + sC_3R_3)(1 + sC_4R_4)}$$

$$B = \frac{k \cdot s C_3 R_4}{1 + s\left[C_3(R_4+R_3) + C_4 R_4\right] + s^2 C_3 R_3 C_4 R_4} = 1$$

$$1 + s\left[C_3\left(R_4(1-k) + R_3\right) + C_4 R_4\right] + s^2 C_3 R_3 C_4 R_4 = 0$$

$s = j\omega_0$

$$Re: \; 1 - \omega_0^2 C_3 R_3 C_4 R_4 = 0 \Rightarrow$$

$$\boxed{\omega_0 = \frac{1}{\sqrt{C_3 R_3 C_4 R_4}}, \quad f_0 = \frac{\omega_0}{2\pi} \; [Hz]}$$

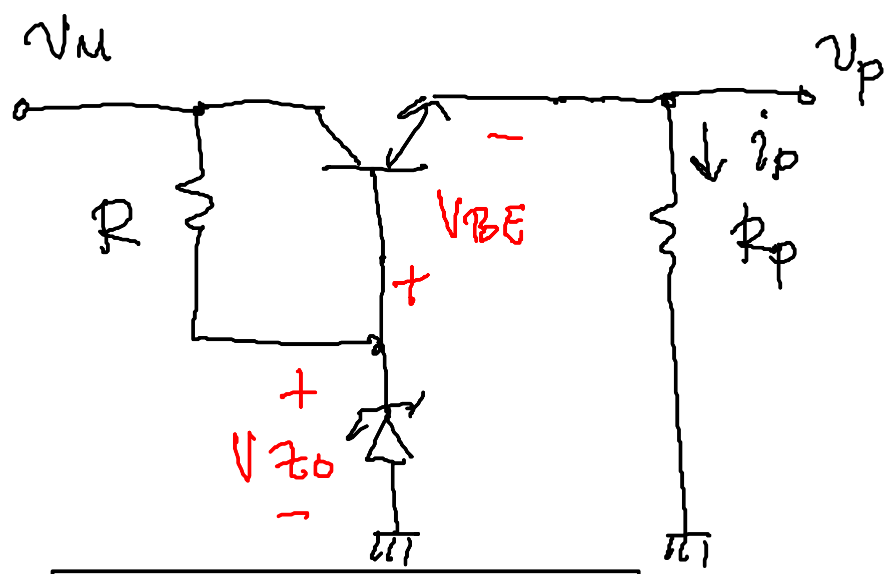
$$Im: \; \omega_0\left[C_3\left(R_4(1-k) + R_3\right) + C_4 R_4\right] = 0$$

$$C_3 R_4 - C_3 R_4 k + C_3 R_3 + C_4 R_4 = 0$$

$$k = \frac{C_3(R_4+R_3) + C_4 R_4}{C_3 R_4} = 1 + \frac{R_3}{R_4} + \frac{C_4}{C_3} \; ; \; k = 1 + \frac{R_2}{R_1}$$

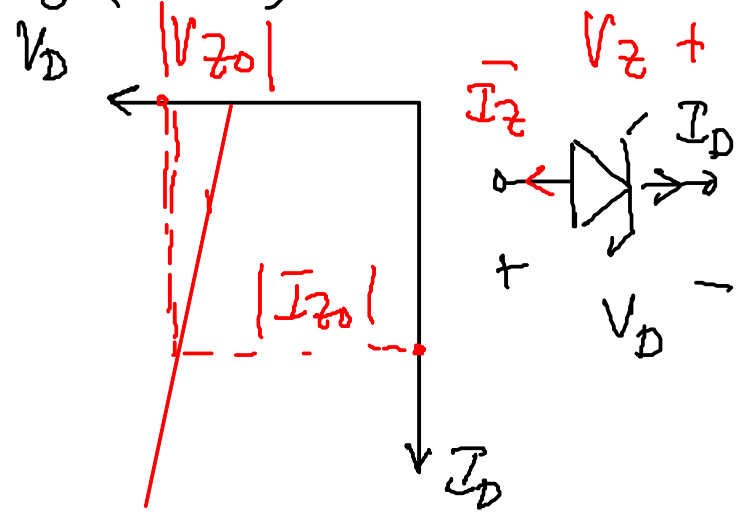
$$\not{1} + \frac{R_2}{R_1} = \not{1} + \frac{R_3}{R_4} + \frac{C_4}{C_3} \Rightarrow \boxed{\frac{R_2}{R_1} = \frac{R_3}{R_4} + \frac{C_4}{C_3}}$$

P2



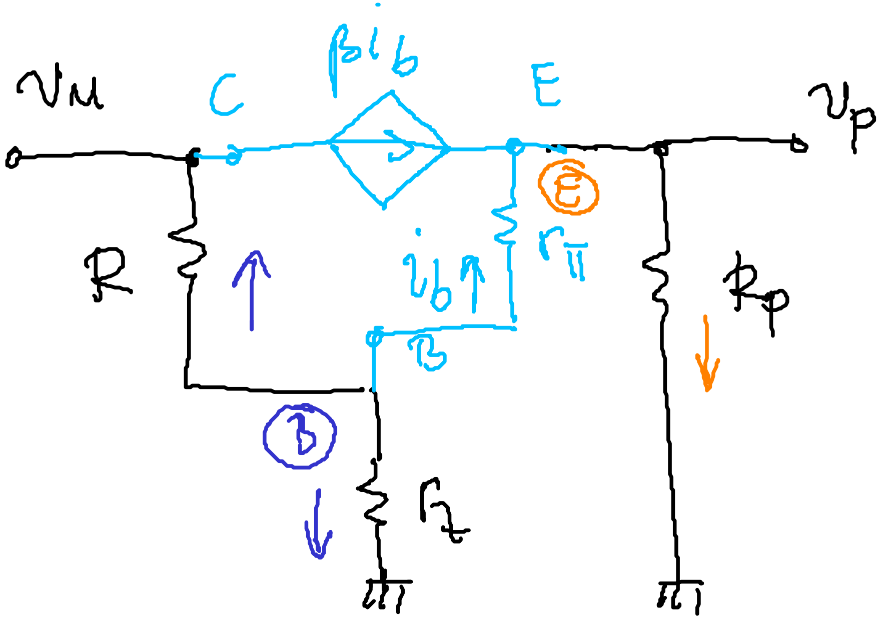

a) DC НАПОН НА ИЗЛАЗУ, $V_P$

$(\beta \gg 1)$, $V_{Z0} = (3-12)V$, $r_{Z0} \approx (10-20)\Omega$




a) $V_P = V_{Z0} - V_{BE}$

b) $S_V = \frac{v_P}{v_U}$ (АНАЛИЗА МАЛИХ СИГНАЛА - AC)




(B) $$\frac{v_b - v_M}{R} + \frac{v_b}{r_z} + i_b = 0$$

(E) $$\frac{v_p}{R_p} - (1+\beta) i_b = 0$$

(HJ) $$i_b = \frac{v_b - v_p}{r_\pi}$$

---

$$\begin{bmatrix} \frac{1}{R} + \frac{1}{r_z} + \frac{1}{r_\pi} & -\frac{1}{r_\pi} \\ -\frac{(1+\beta)}{r_\pi} & \frac{1}{R_p} + \frac{(1+\beta)}{r_\pi} \end{bmatrix} \begin{bmatrix} v_b \\ v_p \end{bmatrix} = \begin{bmatrix} \frac{v_M}{R} \\ 0 \end{bmatrix}$$

$$S_v = \frac{v_p}{v_M} = \frac{\Delta v_p}{\Delta} \cdot \frac{1}{v_M}$$

$$\Delta V_p = \begin{vmatrix} \frac{1}{R}+\frac{1}{r_z}+\frac{1}{r_\pi} & \frac{v_u}{R} \\ -\frac{(1+\beta)}{r_\pi} & 0 \end{vmatrix} = \frac{(1+\beta)\,v_u}{r_\pi \cdot R}$$

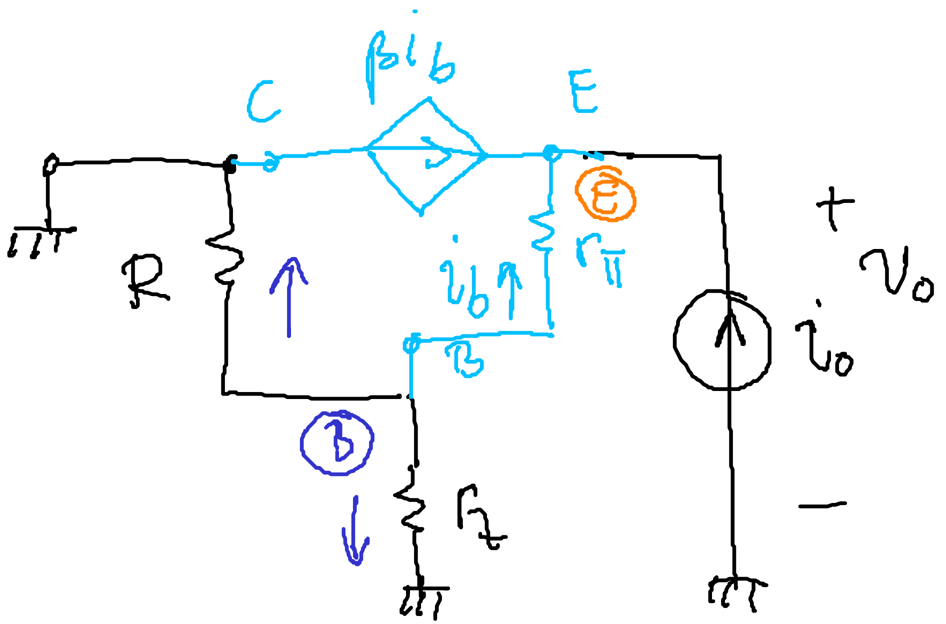
$$\Delta = \begin{vmatrix} \frac{1}{R}+\frac{1}{r_z}+\frac{1}{r_\pi} & -\frac{1}{r_\pi} \\ -\frac{(1+\beta)}{r_\pi} & \frac{1}{R_p}+\frac{(1+\beta)}{r_\pi} \end{vmatrix} = \left(\frac{1}{R}+\frac{1}{r_z}+\frac{1}{r_\pi}\right)\left(\frac{1}{R_p}+\frac{(1+\beta)}{r_\pi}\right)-\frac{(1+\beta)}{r_\pi^2}$$

$$S_V = \frac{\frac{(1+\beta)}{r_\pi R}}{\left(\frac{1}{R}+\frac{1}{r_z}+\frac{1}{r_\pi}\right)\left(\frac{1}{R_p}+\frac{(1+\beta)}{r_\pi}\right)-\frac{(1+\beta)}{r_\pi^2}} = \frac{\frac{(1+\beta)}{r_\pi \cdot R}}{\left(\frac{1}{R}+\frac{1}{r_z}\right)\frac{(1+\beta)}{r_\pi}+\frac{1}{R_p}\left(\frac{1}{R}+\frac{1}{r_z}+\frac{1}{r_\pi}\right)}$$

$$\lim_{r_z \to 0} S_V = \frac{(1+\beta)/(r_\pi \cdot R)}{\frac{(1+\beta)}{r_\pi} \cdot \frac{1}{r_z} + \frac{1}{R_p} \cdot \frac{1}{r_z}} \approx r_z \cdot \frac{(1+\beta)}{R + r_\pi \frac{R}{R_p}} \approx$$

$$\approx \frac{(1+\beta) r_z}{R\left(1 + r_\pi / R_p\right)} = \frac{R_p}{R_p + r_\pi} \cdot (1+\beta) \cdot \frac{r_z}{R} \Bigg| \quad r_z << \{R_p, r_\pi, R\}$$

c) Riz (ANALIZA MALIH SIGNALA - AC)




$$R_{iz} = \frac{v_o}{i_o}$$

(E) $(1+\beta) i_b + i_o = 0$

(B) $v_b \left(\frac{1}{R} + \frac{1}{r_z}\right) + i_b = 0$ → $\frac{1}{R \| r_z}$

(HJ) $i_b = \frac{v_b - v_o}{r_\pi}$

$$\begin{bmatrix} \frac{(1+\beta)}{r_\pi} & -\frac{(1+\beta)}{r_\pi} \\ \frac{1}{R \| r_z} + \frac{1}{r_\pi} & -\frac{1}{r_\pi} \end{bmatrix} \begin{bmatrix} v_b \\ v_o \end{bmatrix} = \begin{bmatrix} -i_o \\ 0 \end{bmatrix} \qquad R_{iz} = \frac{v_o}{i_o} = \frac{\Delta v_o}{\Delta} \cdot \frac{1}{i_o}$$

$$\Delta_{v_o} = \begin{vmatrix} \frac{(1+\beta)}{r_\pi} & -i_o \\ \frac{1}{R \| r_z} + \frac{1}{r_\pi} & 0 \end{vmatrix} = i_o \left( \frac{1}{R \| r_z} + \frac{1}{r_\pi} \right)$$

$$\Delta = \begin{vmatrix} \frac{(1+\beta)}{r_\pi} & -\frac{(1+\beta)}{r_\pi} \\ \frac{1}{R \| r_z} + \frac{1}{r_\pi} & -\frac{1}{r_\pi} \end{vmatrix} = -\cancel{\frac{(1+\beta)}{r_\pi^2}} + \cancel{\frac{(1+\beta)}{r_\pi^2}} + \frac{(1+\beta)}{R \| r_z} \frac{1}{r_\pi}$$

$$R_{iz} = \left(\frac{1}{R \| r_z} + \frac{1}{r_\pi}\right) \Big/ \frac{(1+\beta)}{R \| r_z} \frac{1}{r_\pi} = \frac{r_\pi + R \| r_z}{(1+\beta)}$$

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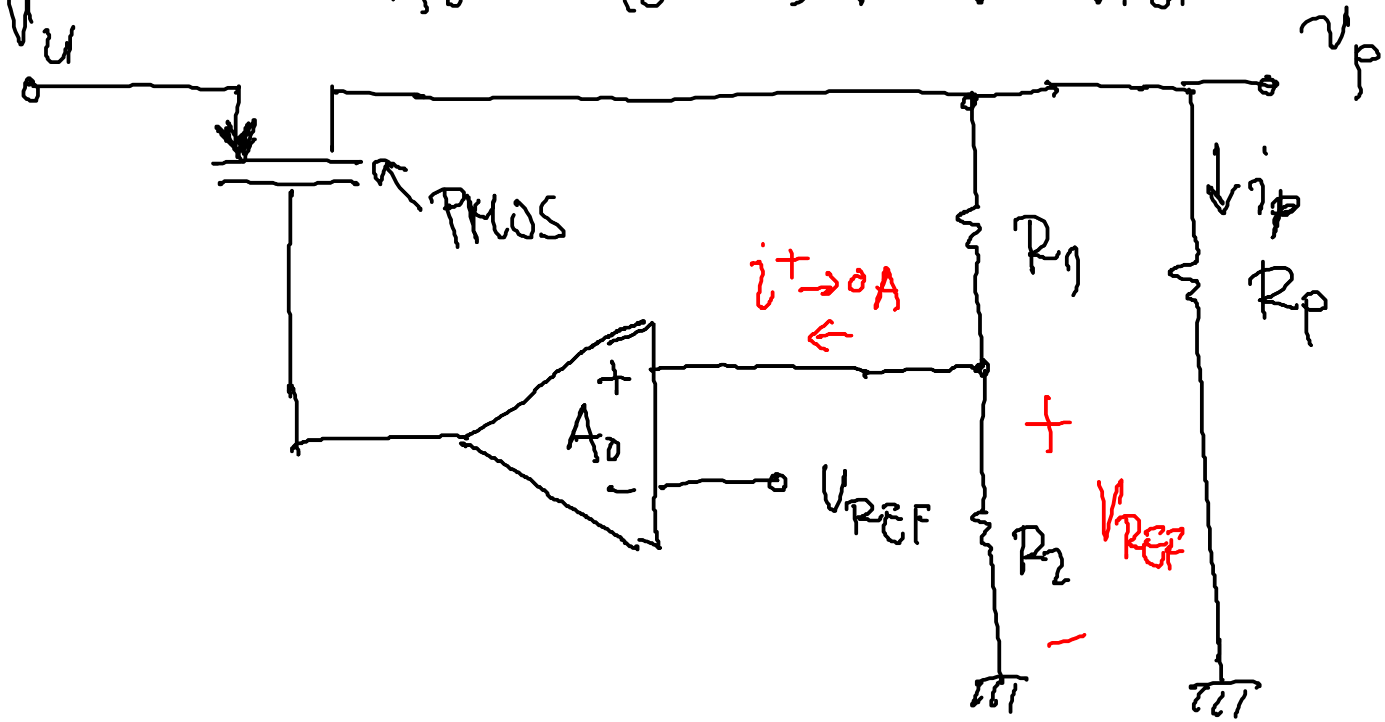
P3

=

$V_U$

$A_0 \gg 100 \Rightarrow V^+ \approx V^- = V_{REF}$

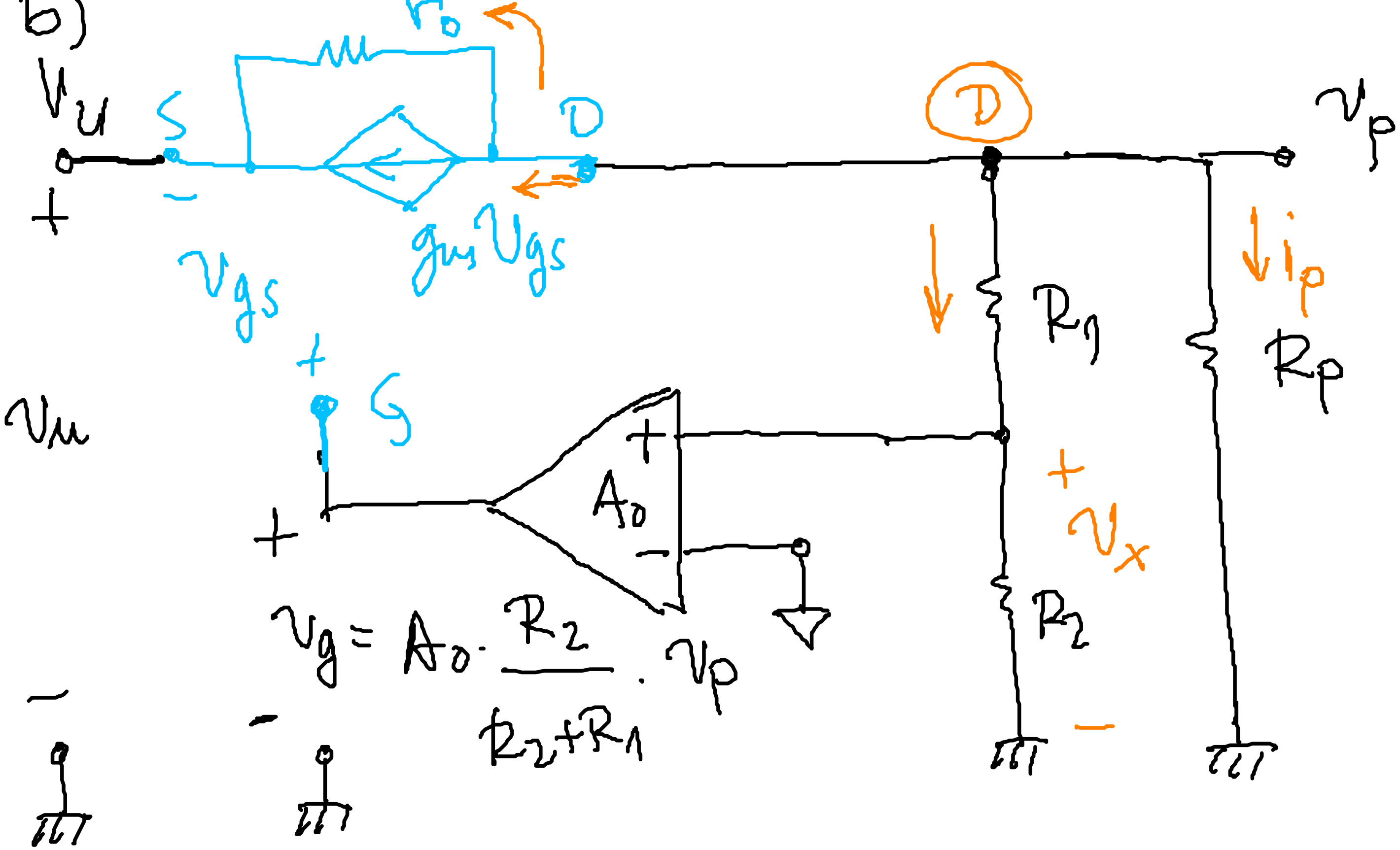



a) DC НАПОН НА ИЗЛАЗУ.

$$V_p = \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

$$V_{REF} = \frac{R_2}{R_2 + R_1} \cdot V_p$$

b)




$$v_g = A_0 \cdot \frac{R_2}{R_2+R_1} \cdot v_p$$

$$S_v = \frac{v_p}{v_u}$$

$$v_x = \frac{R_2}{R_2+R_1} \cdot v_p$$

$$v_g = A_0 \cdot v_x$$

$$v_s = v_u$$

(D) $$g_m v_{gs} + \frac{v_p - v_x}{R_1} + \frac{v_p}{R_p} + \frac{v_p - v_u}{r_o} = 0$$

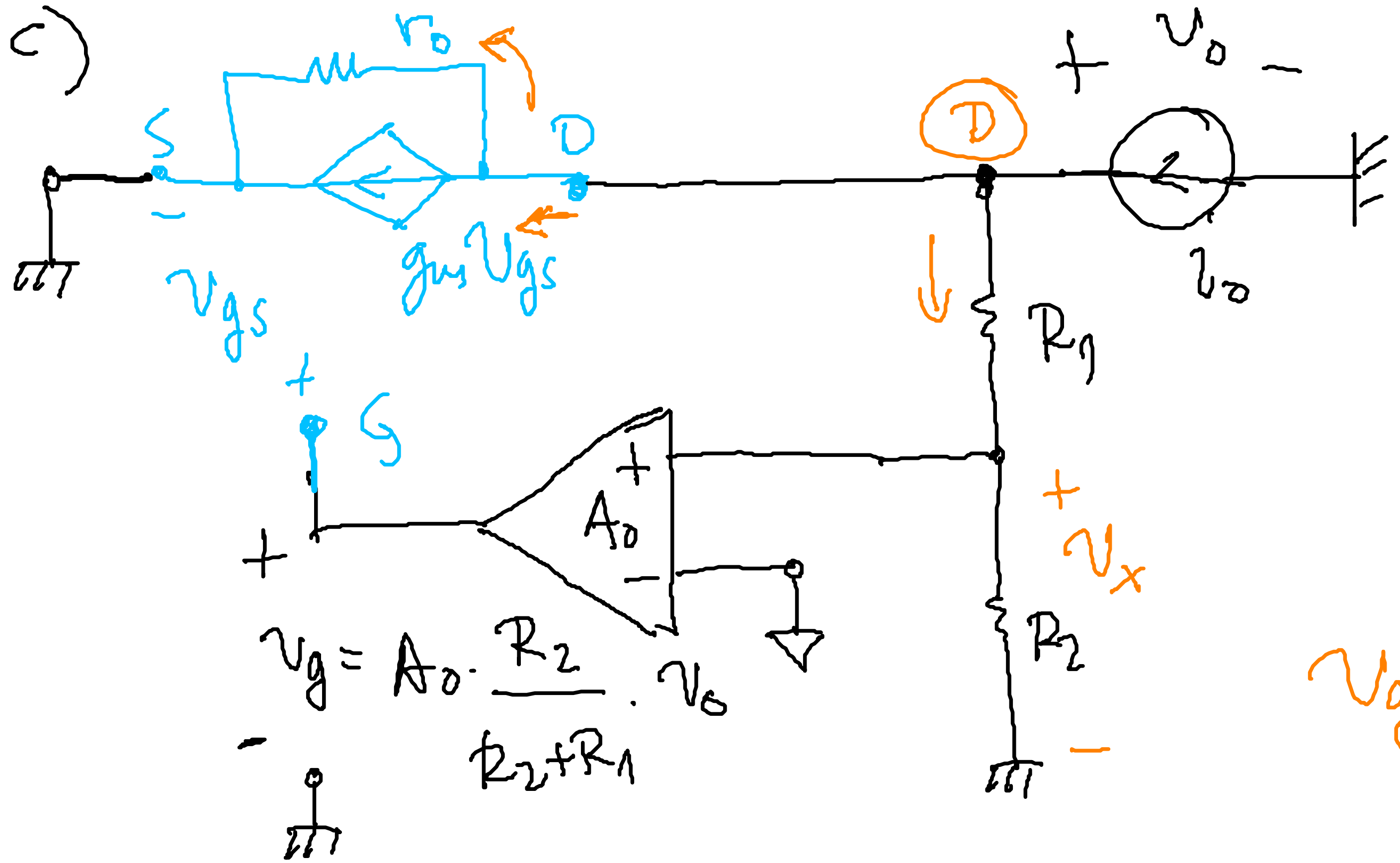
$$g_m \left( A_0 \frac{R_2}{R_2+R_1} \cdot v_p - v_u \right) + v_p \left( \frac{1}{R_1} + \frac{1}{R_p} + \frac{R_2}{R_2+R_1} \cdot \frac{1}{R_1} + \frac{1}{r_o} \right) - v_u / r_o = 0$$

$$S_v = \frac{v_p}{v_M} = \frac{g_m + 1/r_0}{\frac{1}{R_1} + \frac{1}{R_p} + \frac{R_2}{R_2 + R_1}\left(\frac{1}{R_1} + g_m \cdot A_0\right)}$$

$$\lim_{A_0 \to \infty} S_v = \frac{g_m + 1/r_0}{\frac{R_2}{R_2 + R_1} \cdot g_m A_0} = \left(1 + \frac{R_1}{R_2}\right) \cdot \frac{1 + \frac{1}{\mu}}{A_0} \Bigg| \to 0$$

$$\mu = g_m r_0 \gg 1$$

c)




$$R_{iz} = \frac{v_o}{i_o}$$

$$v_s = 0\,V$$

$$v_x = \frac{R_2}{R_2+R_1} \cdot v_o$$

$$v_g = A_o v_x = A_o \frac{R_2}{R_1+R_2} v_o$$

$$v_g = A_o \cdot \frac{R_2}{R_2+R_1} \cdot v_o$$

(D) $$g_m V_{gs} + \frac{v_o}{r_o} + \frac{v_o - v_x}{R_1} = i_o$$

$$\left(g_m A_o \frac{R_2}{R_2+R_1} + \frac{1}{r_o} + \frac{1}{R_1} - \frac{1}{R_1} \cdot \frac{R_2}{R_1+R_2}\right) v_o = i_o$$

$$R_{iz} = \frac{v_0}{i_0} = \frac{1}{\left(g_m A_0 \frac{R_2}{R_2+R_1} + \frac{1}{r_0} + \frac{1}{R_1} - \frac{1}{R_1} \cdot \frac{R_2}{R_1+R_2}\right)}$$

$$= \frac{1}{g_m A_0 \frac{R_2}{R_1+R_2} + \frac{1}{r_0} + \frac{1}{R_1}\left(1 - \frac{R_2}{R_1+R_2}\right)}$$

$$= \frac{r_0}{\mu A_0 \frac{R_2}{R_1+R_2} + 1 + \frac{r_0}{\cancel{R_1}}\left(\frac{\cancel{R_1}}{R_1+R_2}\right)}$$

$$\boxed{R_{iz} = \frac{r_0}{1 + \mu A_0 \cdot \frac{R_2}{R_1+R_2} + \frac{r_0}{R_1+R_2}} \quad [\Omega]}$$

* EKSTRA SREĐIVANJE: $F = \frac{R_2}{R_2+R_1}$

$$R_{iz} = \frac{\frac{r_0}{1+\mu A_0 \cdot F}}{1 + \frac{r_0}{1+\mu A_0 \cdot F} \cdot \frac{1}{R_1+R_2}} = \frac{(R_1+R_2) \cdot \frac{r_0}{1+\mu A_0 \cdot F}}{(R_1+R_2) + \frac{r_0}{1+\mu A_0 \cdot F}}$$

$$\boxed{R_{iz} = (R_1+R_2) \,||\, \left(\frac{r_0}{1+\mu A_0 \cdot F}\right)}$$