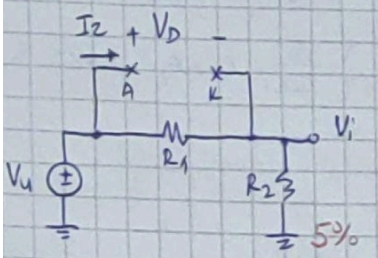
За непроводну диоду важи:



$$V_i = \frac{R_2}{R_1 + R_2} V_u = \frac{3}{4} V_u \quad 5\%$$

$$I_Z = 0 \quad 5\%$$

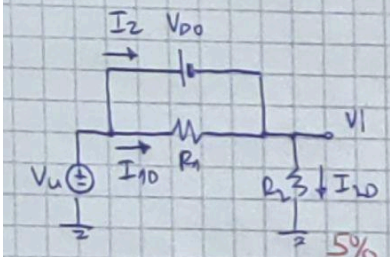
$$V_D = \frac{R_1}{R_1 + R_2} V_u = \frac{1}{4} V_u$$

Диода проводи директно за $V_D \geq V_{D0}$, тј. за $\frac{1}{4} V_u \geq 0.6V$, тј. за $V_u \geq 2.4V$

Диода је у пробоју за $V_D \leq -V_{Z0}$, тј. за $\frac{1}{4} V_u \leq -2V$, тј. за $V_u \leq -8V$

На основу претходног, диода не води за $-8V < V_u < 2.4V$ $3 \times 5\%$

Када диода води директно, важи:



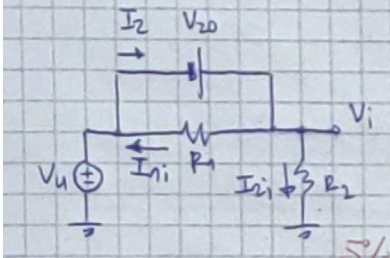
$$V_i = V_u - V_{D0} = V_u - 0.6V \quad 5\%$$

$$I_Z = I_{2D} - I_{1D} = \frac{V_i}{R_2} - \frac{V_{D0}}{R_1}$$

$$= \frac{V_u - 0.6V}{3k\Omega} - \frac{0.6V}{1k\Omega}$$

$$= \frac{V_u}{3k\Omega} - 0.8mA \quad 5\%$$

Када диода води инверзно, важи:



$$V_i = V_u + V_{Z0} = V_u + 2V \quad 5\%$$

$$I_Z = I_{1i} + I_{2i} = \frac{V_{Z0}}{R_1} + \frac{V_i}{R_2}$$

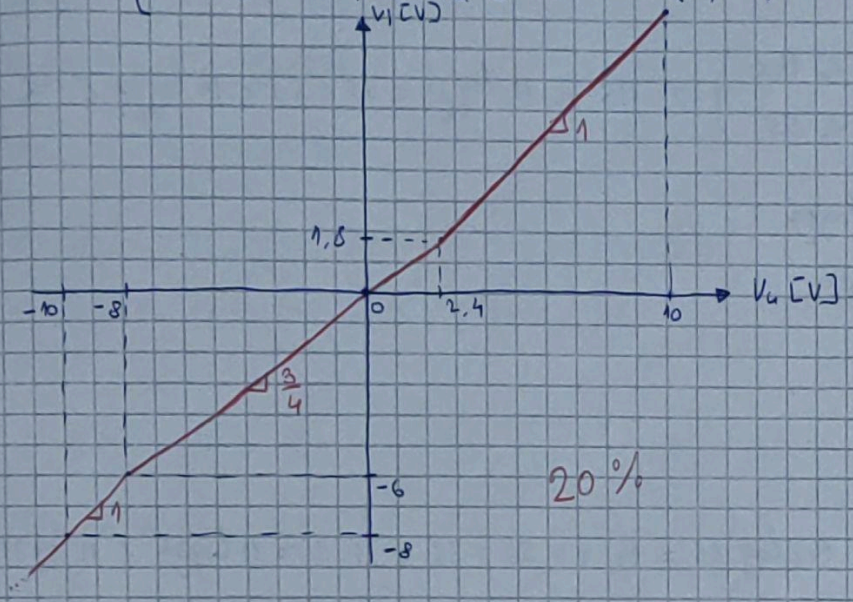
$$= 2mA + \frac{V_u + 2V}{3k\Omega}$$

$$= \frac{V_u}{3k\Omega} + \frac{8}{3}mA$$

$$\approx \frac{V_u}{3k\Omega} + 2.666...\,mA \quad 5\%$$

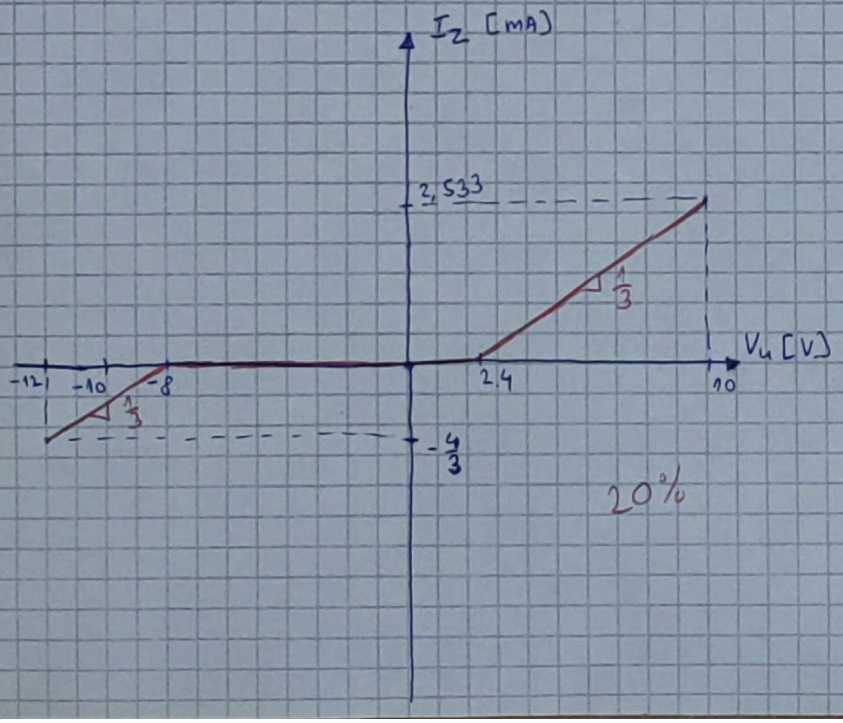
Конечно:

$$V_i[V] = \begin{cases} V_u[V] + 2, & V_u \leq -8V \\ \frac{3}{4} V_u[V], & -8V < V_u < 2.4V \\ V_u[V] - 0.6, & V_u \geq 2.4V \end{cases}$$



20 %

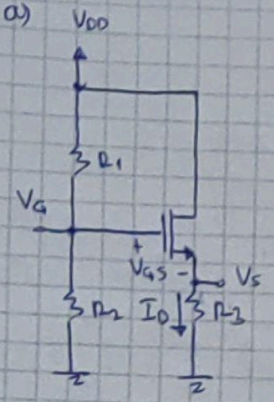
$$I_Z[mA] = \begin{cases} \frac{V_u[V]}{3} + \frac{8}{3}, & V_u \leq -8V \\ 0, & -8V < V_u < 2.4V \\ \frac{V_u[V]}{3} - 0.8, & V_u \geq 2.4V \end{cases}$$



20%

2. а) 30% б) 45% в) 25%

а)



10%

$V_G = \frac{R_2}{R_1+R_2} V_{DD} = \frac{4}{5} V_{DD} = 4V$ 5%

$V_{OV} = V_{GS} - V_{TH}$, $I_D = A(V_{GS} - V_{TH})^2 = AV_{OV}^2$

$V_G = V_{GS} + R_3 \cdot I_D = V_{OV} + V_{TH} + R_3 \cdot A \cdot V_{OV}^2$ 5%

$R_3 \cdot A \cdot V_{OV}^2 + V_{OV} + V_{TH} - V_G = 0$

$1,5 \cdot 10^3 \cdot 8 \cdot 10^{-3} V^{-1} \cdot V_{OV}^2 + V_{OV} - 3,5V = 0$

$12V^{-1} \cdot V_{OV}^2 + V_{OV} - 3,5V = 0$

$V_{OV1/2} = \frac{-1 \pm \sqrt{1 - 4 \cdot (12V^{-1}) \cdot (-3.5)V}}{2 \cdot 12V^{-1}}$

$= \frac{-1 \pm 13}{24} V$

$V_{OV1} = -1V$ $V_{OV2} = 0,5V$

$V_{OV} > 0 \Rightarrow$ $\boxed{V_{OV} = 0,5V}$ 5%

$V_{GS} = V_{OV} + V_{TH} = 1V$

$\boxed{V_S = V_G - V_{GS} = 3V}$ 5%

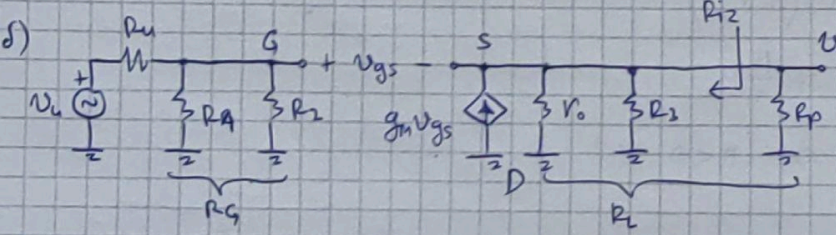
Треба нам за под б):

$I_D = AV_{OV}^2 = 2mA$

$g_m = 2A V_{OV} = 8mS$ 5%

$r_o = \frac{V_A}{I_D} = 50k\Omega$ 5%

б)



10%

$R_G = R_1 \| R_2 = 80k\Omega$ $R_L = r_o \| R_3 \| R_P \approx 1,137k\Omega$

$v_g = \frac{R_G}{R_u + R_G} v_u \approx v_u$ 5% (ЗАТО ЩТО $R_G >> R_u$)

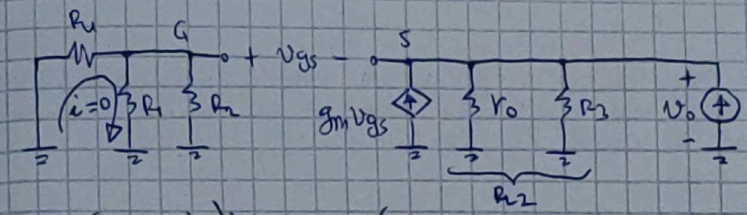
(*) $v_s = v_i = R_L \cdot g_m v_{gs}$ 5%

$v_{gs} = v_g - v_s \approx v_u - g_m R_L v_{gs} \Rightarrow$ (**) $v_{gs} = \frac{v_u}{1 + g_m R_L}$ 5%

$\boxed{A_n = \frac{v_i}{v_{gs}} \cdot \frac{v_{gs}}{v_u} = g_m R_L \cdot \frac{1}{1 + g_m R_L} \approx 0.9}$ 10%

(*) (**)

в)



$v_g = (R_1 \| R_2) \cdot i = 0$ (нема генератора) $\Rightarrow v_{gs} = -v_s$

$v_s = v_0 \Rightarrow v_{gs} = -v_0$ ← 5%

$R_{12} = r_0 \| R_3 \approx 1{,}456\ k\Omega$

За чвор S важи:

$\frac{v_s}{R_{12}} = g_m v_{gs} + i_0$ 5%

$\frac{v_0}{R_{12}} = -g_m v_0 + i_0$

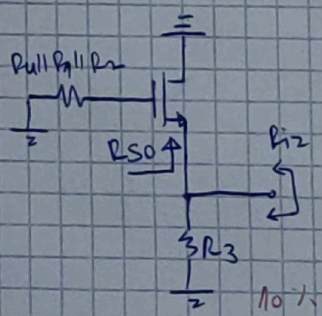
$\left(\frac{1}{R_{12}} + g_m\right) v_0 = i_0 \Rightarrow \boxed{R_{iz} = \frac{v_0}{i_0} = \frac{1}{\frac{1}{R_{12}} + g_m} \approx 115{,}12\ \Omega}$ 5%

Може и преко импеданси:

$\mu = g_m r_0 = 400$

$R_{s0} = \frac{r_0}{\mu + 1} = 124{,}69\ \Omega$ 10%

$R_{iz} = R_3 \| R_{s0} = 115{,}12\ \Omega$ 5%



3.

а) Потколо које чине R_3, R_4 и операциони појачавач представља неинвертујући појачавач који појачава напон у чвору ②. На излазу овог потколо налази се напон V_i, па важи:

$$V_i = \left(1 + \frac{R_4}{R_3}\right) V_2$$

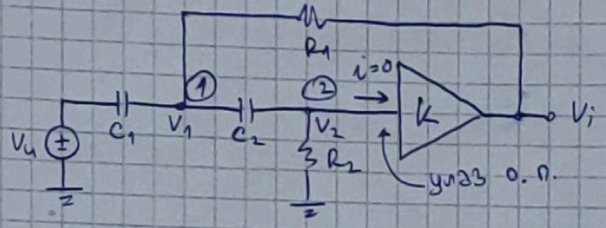
Ради једноставности, нека је $K = 1 + \frac{R_4}{R_3}$, тј. $V_i = K V_2$ 20%

односно $V_2 = \frac{V_i}{K}$

Еквивалентна шема: (~~R1, R2, R3, KR~~),

($R_1 = R_2 = R_3 = R = 10\,k\Omega$

$C_1 = C_2 = C = 10\,nF$, $\tau = RC = 100\,\mu s$



Први к. З.:

① $sC_1(V_1 - V_u) + sC_2(V_1 - V_2) + \frac{1}{R_1}(V_1 - V_i) = 0$ 10%

$sC\left(V_1 - V_u\right) + sC\left(V_1 - \frac{V_i}{K}\right) + \frac{1}{R}\left(V_1 - V_i\right) = 0 \quad / \cdot R$

$s\tau\left(2V_1 - V_u - \frac{V_i}{K}\right) + V_1 - V_i = 0$

$2s\tau V_1 - s\tau V_u - \frac{s\tau}{K} V_i + V_1 - V_i = 0$

$(2s\tau + 1) V_1 - \left(\frac{s\tau}{K} + 1\right) V_i = s\tau V_u$

② Разделник напона:

$$V_2 = \frac{R_2}{R_2 + \frac{1}{sC_2}} \cdot \frac{sC_2}{sC_2} V_1 = \frac{sR_2C_2}{sR_2C_2 + 1} V_1 = \frac{s\tau}{1 + s\tau} V_1$$ 10%

$$V_1 = \frac{1 + s\tau}{s\tau} V_2 = \left(\frac{1}{s\tau} + 1\right) \cdot \frac{V_i}{K}$$

Убацивањем овог резултата у ① добија се:

$\left(2s\tau + 1\right)\left(\frac{1}{s\tau} + 1\right) \cdot \frac{V_i}{K} - \left(\frac{s\tau}{K} + 1\right) V_i = s\tau V_u \quad / \cdot Ks\tau$

$\left(2s\tau + 1\right)\left(s\tau + 1\right) V_i - \left(s^2\tau^2 + Ks\tau\right) V_i = Ks^2\tau^2 V_u$

$$\left[(2s^2\tau^2 + s\tau + 2s\tau + 1) - (s^2\tau^2 + Ks\tau)\right] V_i = Ks^2\tau^2 V_u$$

$$(s^2\tau^2 + (3-K)s\tau + 1) V_i = Ks^2\tau^2 V_u$$

$$H(s) = \frac{V_i}{V_u} = \frac{Ks^2\tau^2}{s^2\tau^2 + (3-K)s\tau + 1} = \left(1+\frac{R_4}{R_3}\right) \cdot \frac{s^2R^2C^2}{s^2R^2C^2 + \left(2-\frac{R_4}{R_3}\right)sRC + 1}$$

20%

а) При ниски честоти:

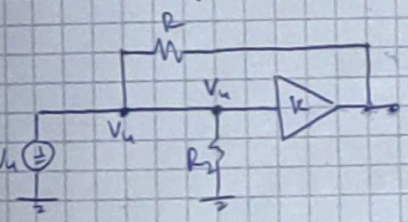
$$\lim_{s\to 0} H(s) = \lim_{s\to 0} \frac{Ks^2\tau^2}{s^2\tau^2 + (3-K)s\tau + 1} \cdot \frac{\frac{1}{s^2}}{\frac{1}{s^2}}$$

$$= \lim_{s\to 0} \frac{K\tau^2}{\tau^2 + \frac{(3-K)\tau}{s} + \frac{1}{s^2}} = \frac{K\tau^2}{\tau^2} = K = 10 \Rightarrow 1 + \frac{R_4}{R_3} = 10$$

$$R_4 = 9R_3 = 90\,k\Omega$$ 20%

Или:

На ниски честоти: C ≡ прекъсване



$$V_i = KV_u \Rightarrow H_\infty = \frac{V_i}{V_u} = K \Rightarrow R_4 = 90\,k\Omega$$

б) $D(s) = s^2\tau^2 + (3-K)s\tau + 1 = s^2\tau^2 - 7s\tau + 1$

$D(s_{p1/2}) = 0$

$$s_{p1/2} = \frac{7\tau \pm \sqrt{49\tau^2 - 4\tau^2}}{2\tau^2} = \frac{7\tau \pm \tau\sqrt{45}}{2\tau^2} = \left(\frac{7 \pm \sqrt{45}}{2}\right) \cdot \frac{1}{\tau}$$

$\tau = 100\,\mu s$, $\frac{1}{\tau} = 10^4 \frac{rad}{sec}$

$$s_{p1} = \frac{7+\sqrt{45}}{2} \cdot 10^4 \frac{rad}{sec} = 6{,}85 \cdot 10^4 \frac{rad}{sec}$$

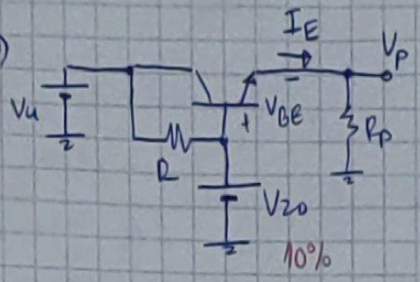
нестабилен ;(

20%

$$s_{p2} = \frac{7-\sqrt{45}}{2} \cdot 10^4 \frac{rad}{sec} = 0{,}146 \cdot 10^4 \frac{rad}{sec}$$

4.

а)



$\Rightarrow V_P \approx V_{20} - V_{BE} = 3.1\,V$ 5%

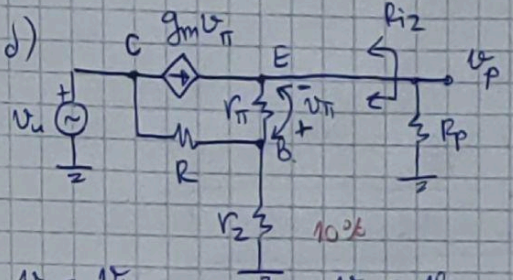
Трябва нам за б) и в):

$I_E = \frac{V_P}{R_P} = 15,5\ mA$

$I_B = \frac{I_E}{\beta+1} = 77,11\ \mu A \Rightarrow r_\pi = \frac{V_T}{I_B} = 337,18\,\Omega$ 5%

$g_m = \frac{I_C}{V_T} = \frac{\beta I_B}{V_T} = 503,15\ mS$ 5%

д)



$v_c = v_u$ $\quad v_e = v_P$

Ⓑ $\frac{1}{R}(v_B - v_u) + \frac{1}{r_2} v_B + \frac{1}{r_\pi}(v_B - v_P) = 0$ 10%

$\vdots$

$\underbrace{\left(\frac{1}{R} + \frac{1}{r_2} + \frac{1}{r_\pi}\right)}_{g_B} v_B - \frac{1}{r_\pi} v_P = \frac{1}{R} v_u$ ~~10%~~

Ⓔ $\frac{1}{r_\pi}(v_P - v_B) + \frac{1}{R_P} v_P - g_m v_\pi = 0$ 10%

Между тях, $v_\pi = v_B - v_P$ 5%

$\frac{1}{r_\pi}(v_P - v_B) + \frac{1}{R_P} v_P - g_m (v_B - v_P) = 0$

$\vdots$

$-\left(\frac{1}{r_\pi} + g_m\right) v_B + \overbrace{\left(\frac{1}{r_\pi} + \frac{1}{R_P} + g_m\right)}^{g_P} v_P = 0$

$\Rightarrow v_B = \frac{\frac{1}{r_\pi} + \frac{1}{R_P} + g_m}{\frac{1}{r_\pi} + g_m} v_P = \left(1 + \frac{\frac{1}{R_P}}{\frac{1}{r_\pi} + g_m}\right) v_P = \left(1 + \frac{\frac{1}{R_P} \cdot r_\pi}{1 + g_m r_\pi}\right) v_P$

убацивамо претходног резултата у Ⓑ:

$$\left(\frac{1}{R}+\frac{1}{r_2}+\frac{1}{r_\pi}\right)\left(\frac{1}{r_\pi}+\frac{1}{R_p}+g_m\right)$$

$$v_6 = \left(1+\frac{1}{R_p}\cdot\frac{r_\pi}{\beta+1}\right)v_p \quad \left(\text{jer } \beta = g_m r_\pi\right)$$

ово убацимо у Ⓑ и добијамо:

$$\left(\frac{1}{R}+\frac{1}{r_2}+\frac{1}{r_\pi}\right)\cdot\left(1+\frac{1}{R_p}\cdot\frac{r_\pi}{\beta+1}\right)v_p - \frac{1}{r_\pi}v_p = \frac{1}{R}v_u$$

$$\left[\left(\frac{1}{R}+\frac{1}{r_2}+\frac{1}{r_\pi}\right)\left(1+\frac{1}{R_p}\cdot\frac{r_\pi}{\beta+1}\right)-\frac{1}{r_\pi}\right]v_p = \frac{1}{R}v_u$$

$$\left[\left(\frac{1}{R}+\frac{1}{r_2}\right)\left(1+\frac{1}{R_p}\cdot\frac{r_\pi}{\beta+1}\right)+\frac{1}{r_\pi}\left(1+\frac{1}{R_p}\cdot\frac{r_\pi}{\beta+1}\right)-\frac{1}{r_\pi}\right]v_p = \frac{1}{R}v_u$$

Ⓑ $g_6 v_6 - \frac{1}{r_\pi}v_p = \frac{1}{R}v_u$ $\quad g_6 = \frac{1}{R}+\frac{1}{r_2}+\frac{1}{r_\pi} \approx 103.8\,mS$

Ⓔ $-\left(\frac{1}{r_\pi}+g_m\right)v_6 + g_p v_p = 0$ $\quad g_p = \frac{1}{r_\pi}+\frac{1}{R_p}+g_m \approx 601,11\,mS$

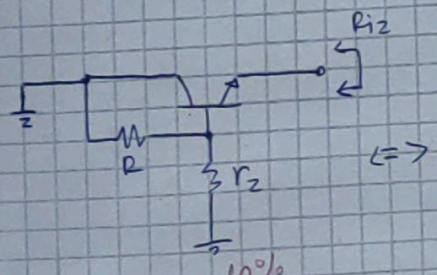
$$\hookrightarrow v_6 = \frac{g_p}{\frac{1}{r_\pi}+g_m}v_p$$

$$g_6\cdot\frac{g_p}{\frac{1}{r_\pi}+g_m}v_p - \frac{1}{r_\pi}v_p = \frac{1}{R}v_u$$

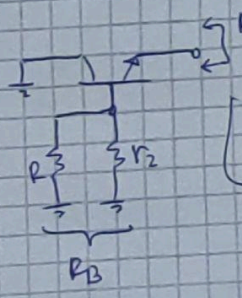
$$S = \frac{v_p}{v_u} = \frac{\frac{1}{R}}{g_6\cdot\frac{g_p}{\frac{1}{r_\pi}+g_m}-\frac{1}{r_\pi}} = 0,0082$$

4%

в)



$\Leftrightarrow$



$R_B = R \| r_2 \approx 9,92\,\Omega$

$$R_{i2} = \frac{r_\pi + R_B}{\beta+1} = 1,73\,\Omega$$

15%