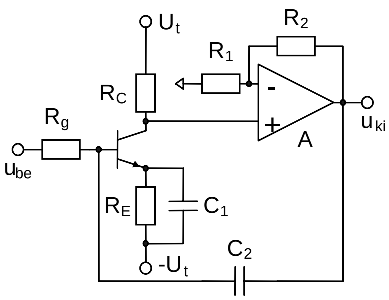
1. Példa (Lásd: Jegyzet)

2.Példa

(A tranzisztor saját frekvenciafüggése elhanyagolható és az A ideális)!



T: n-p-n tranzisztor

U_{BE0}=0,6V; β=99;

$U_t = 15\,V,\ R_g = 10\,k\Omega,\ R_C = 6{,}5\,k\Omega,\ R_E = 7{,}1\,k\Omega,$

$R_1 = 10\,k\Omega, R_2 = 10\,k\Omega,$

$C_1 \to \infty, C_2 = 47\,pF$

Kérdések:

a.) $I_{E0} = ?$,

b.) $U_{ki0} = ?$, ha I_{E0}=2mA?

c.) $A_u = \dfrac{u_{ki}}{u_{be}} = ?$;

d.) Mekkora a kapcsolás felső 3dB-es határfrekvenciája, $\omega_f = ?$

Megoldás:

a.) $I_{E0} = ?$ $\qquad I_{B0} = \dfrac{1}{1+B} I_{E0}$

$$U_t = I_{B0} R_g + U_{BE0} + I_{E0} R_E \quad \rightarrow \quad \boxed{I_{E0} = \frac{U_t - U_{BE0}}{R_E + \dfrac{R_g}{1+B}} = \frac{15-0.6}{7.1+0.1} = \frac{14.4}{7.2} = 2mA}$$

b.) $U_{ki0} = ?$, ha I_{E0}=2mA?

A tranzisztor kollektor feszültsége, (a műveleti er. bemenete):

$$U_{C0} = U_t - I_{C0} R_C = U_t - \frac{B}{1+B} I_{E0} R_C = 15 - 0.99 * 6.5 * 2 = 15 - 12.87 = 2.13V$$

$$\boxed{U_{ki0} = U_{C0}\left(1 + \frac{R_2}{R_1}\right) = 2.13 * \left(1 + \frac{10}{10}\right) = 4.26V}$$

c.) $A_u = \dfrac{u_{ki}}{u_{be}} = ?; \quad \rightarrow \qquad A_u = \dfrac{u_{ki}}{u_{be}} = L_0 A_{tr} A_{me}$ a $C_2 = 0$ feltétellel.

Ahol: $L_0 = \dfrac{u_b}{u_{be}} = \dfrac{R_{be}}{R_g + R_{be}} = \dfrac{(1+\beta) r_d}{R_g + (1+\beta) r_d}$ $\qquad r_d = \dfrac{U_T}{I_{E0}} = \dfrac{26mV}{2mA} = 13\Omega$

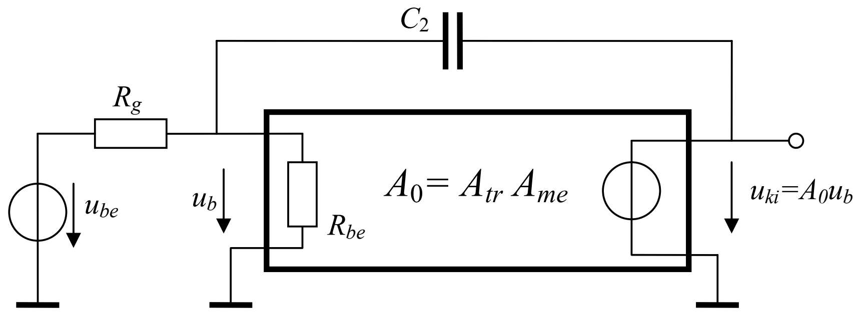
$R_{be} = (1+\beta) r_d = 1.3k\Omega$ $\qquad L_0 = \dfrac{R_{be}}{R_g + R_{be}} = \dfrac{1.3}{10+1.3} = 0.115$

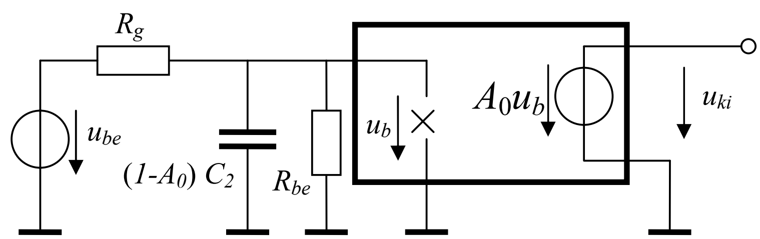
$$A_{tr} = \frac{u_c}{u_b} = -\alpha \frac{R_c}{r_d} = -\frac{\beta}{1+\beta} \frac{R_c}{r_d} = -0.99 \frac{6500}{13} = -495$$

$$\boxed{A_u = L_0 A_{tr}\left(1 + \frac{R_2}{R_1}\right) = L_0 A_0 = -0.115 * 495 * 2 = -113.85}$$

d.) Mekkora a kapcsolás felső 3dB-es határfrekvenciája, $\omega_f = ?$

Miller kapacitásként kezeljük a C_2 kapacitást:





$$A_0 = A_{tr} A_{me} = -\alpha \frac{R_c}{r_d}\left(1+\frac{R_2}{R_1}\right) = -495 * 2 = -990$$

$$C_2^* = (1 - A_0)C_2 = 991 * 47\,pF = 46.58nF$$

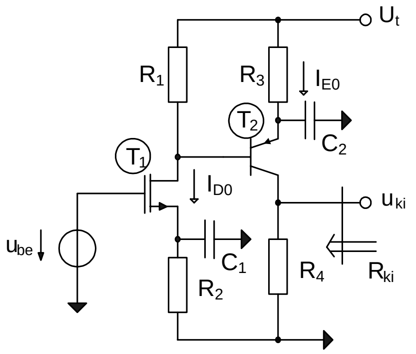
$$A_u(p) = \frac{u_{ki}(p)}{u_{be}} = \frac{R_{be} \times \frac{1}{pC_2^*}}{R_g + R_{be} \times \frac{1}{pC_2^*}} A_0 = \frac{\frac{R_{be}}{1 + pR_{be}C_2^*}}{R_g + \frac{R_{be}}{1 + pR_{be}C_2^*}} A_0 =$$

$$= \frac{R_{be}}{R_g + R_{be}} \frac{1}{1 + pC_2^*(R_g \times R_{be})} A_0 = L_0 A_0 \frac{1}{1 + \frac{p}{\omega_f}}$$

Ahol: $$\omega_f = \frac{R_g + R_{be}}{C_2^* R_g R_{be}} = \frac{10 + 1.3}{46.58 * 10^{-9} * 1.3 * 10 * 10^3} = \frac{11.3}{60.55} 10^6 = 186.6 krad/\sec$$

$$f_f = \frac{\omega_f}{2\pi} = 29.7 kHz$$

3. Példa



U_t=15 *V*

R_1=5,6 *kΩ*, R_2=2 *kΩ*, R_3=2,5 *kΩ*, R_4=2,5 *kΩ*,

T_1: **n-csatornás kiürítéses** MOS FET,

I_{D00}=4 mA, U_P= - 4 V,

$$i_d = I_{D00}\left(\frac{u_{GS} - U_P}{U_P}\right)^2$$

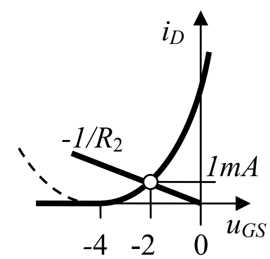
T_2: p-n-p tranzisztor, $\beta_2 = B_2 \to \infty$ U_{EB0}=0,6 V

Kérdések: **a.)** I_{E0}**=?,** I_{D0}**=?**

b.) $\frac{u_{ki}}{u_{be}} = ?$, ha : r_d=13 Ω, *S*=1 mS, $C_1 = C_2 \to \infty$

c.) $\frac{u_{ki}}{u_{be}} = ?$, ha: r_d=13 Ω, *S*=1 mS, $C_1 \to \infty$, C_2=0,

d.) R_{ki}**=?**



Megoldás:

a.) I_{E0}**=?,** I_{D0}**=?**

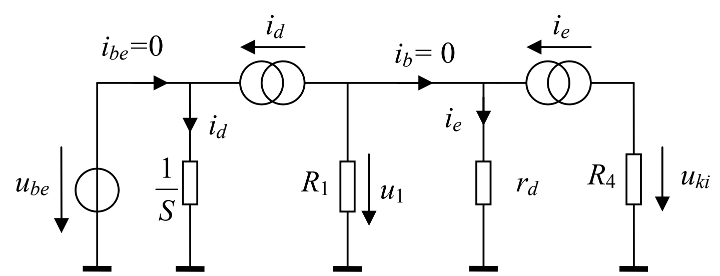
$$U_{GS0} + I_{D0}R_2 = 0 \;\rightarrow\; U_{GS0} + I_{D00}R_2\left(\frac{U_{GS0} - U_P}{U_P}\right)^2 = U_{GS0} + \frac{8}{16}\left(U_{GS0} + 4\right)^2 = 0$$

$$U_{GS0}^2 + 10U_{GS0} + 16 = 0 \;\rightarrow\; U_{GS0} = \begin{cases} -8V & hamis \\ -2V & OK \end{cases} \qquad \boxed{I_{D0} = -\frac{U_{GS0}}{R_2} = \frac{2V}{2k\Omega} = 1mA}$$

$$U_{R1} = I_{D0}R_1 = 1 * 5.6 = 5.6V$$

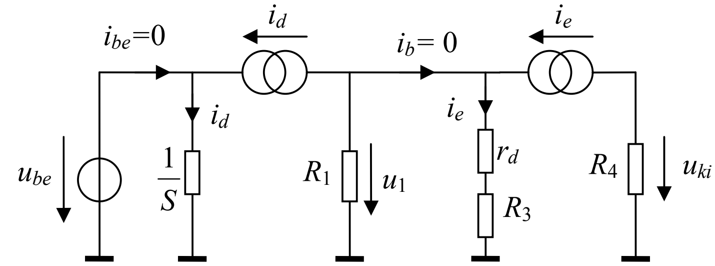
$$U_{R1} = I_{E0}R_3 + U_{EB0} \;\rightarrow\; \boxed{I_{E0} = \frac{U_{R1} - U_{EB0}}{R_3} = \frac{5.6 - 0.6}{2.5} = \frac{5.0}{2.5} = 2mA}$$

b.) $\frac{u_{ki}}{u_{be}} = ?$, ha : r_d=13 Ω, *S*=1 mS, $C_1 = C_2 \to \infty$



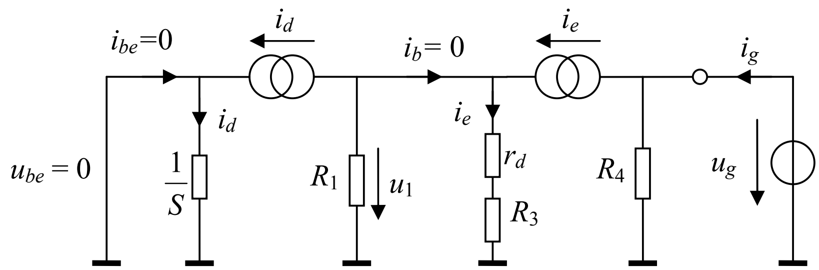
$$u_1 = -i_d R_1 = -SR_1 u_{be} \qquad u_{ki} = -\frac{R_4}{r_d}u_1 \qquad \boxed{\frac{u_{ki}}{u_{be}} = SR_1\frac{R_4}{r_d} = 1 * 5.6\frac{2500}{13} = 1077}$$

c.) $\frac{u_{ki}}{u_{be}} = ?$, ha: r_d=13 Ω, S=1 mS, $C_1 \to \infty$, C_2=0,



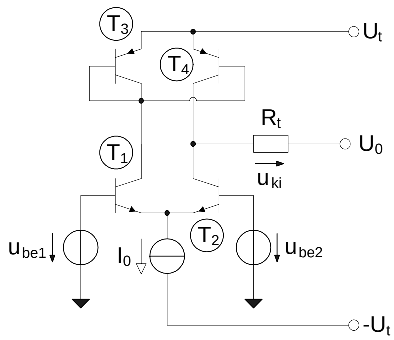
$$u_1 = -i_d R_1 = -SR_1 u_{be} \qquad u_{ki} = -\frac{R_4}{r_d + R_3} u_1 \qquad \boxed{\frac{u_{ki}}{u_{be}} = SR_1 \frac{R_4}{r_d + R_3} = 1 * 5.6 \frac{2500}{2513} = 5.571}$$

d.) ***R_ki*=?**



$$\boxed{R_{ki} = \left.\frac{u_g}{i_g}\right|_{U\,be=0} = R_4 = 2.5k\Omega} \qquad \text{mivel} \quad i_d = i_e = 0$$

4. Példa



$I_0 = 2\ mA, U_t = 12\ V, R_t = 10\ k\Omega,$ $T_1 \equiv T_2$

T_1, T_2 n-p-n tranzisztorok, $\beta_1 = B_1 = \beta_2 = B_2 = 99$, $U_{BE0} = 0{,}6$ V,

T_3, T_4 p-n-p tranzisztorok, $\beta_3 = B_3 = \beta_4 = B_4 = 99$, $U_{EB0} = 0{,}6$ V,

Kérdések:

a.) $A_D = ?$, ha **$T_1 \equiv T_2$, $T_3 \equiv T_4$,**

b.) $A_K = ?$, ha **$T_1 \equiv T_2$, $T_3 \equiv T_4$,**

c.) $U_{off} = ?$, ha a T_1 és T_2 tranzisztor felületeinek aránya:

$F_2 = 1{,}1 \cdot F_1$, **$T_3 \equiv T_4$,**

d.) $U_{off} = ?$, ha a T_3 és T_4 tranzisztor felületeinek aránya:

$F_3 = 1{,}1 \cdot F_4$, **$T_1 \equiv T_2$,**

Megoldás:

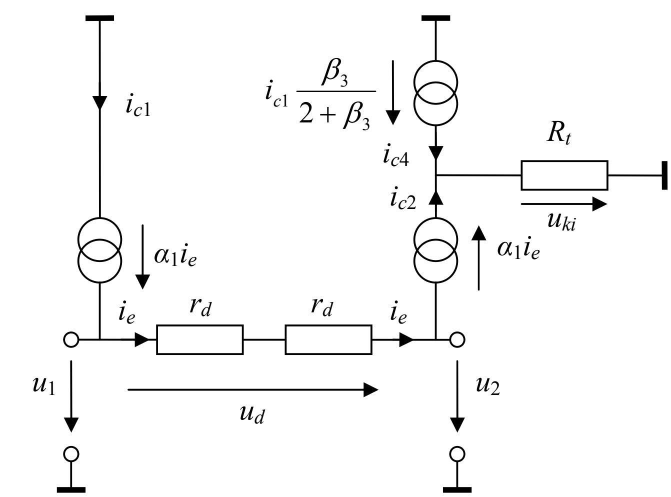
ha $T_1 \equiv T_2$, $T_3 \equiv T_4$ és $U_{be1} = U_{be2}$ $\rightarrow$ $I_{E01} = I_{E02} = \frac{I_0}{2} = 1mA$ $\qquad r_d = \frac{U_T}{I_{E01}} = \frac{26mV}{1mA} = 26\Omega$

Az áramtükör miatt: $I_{C03} = I_{C04} \qquad I_{B03} = I_{B04}$

Ugyanakkor: $I_{C01} = I_{C03} + I_{B03} + I_{B04} = I_{C03}\left(1 + 2\frac{I_{B03}}{I_{C03}}\right) = I_{C03}\left(1 + 2\frac{1}{B_3}\right) = I_{C03}\frac{B_3 + 2}{B_3}$

Amiből: $I_{C03} = I_{C04} = I_{C01}\frac{B_3}{2 + B_3}$ a kisjelű viselkedés hasonló: $i_{c4} = i_{c1}\frac{\beta_3}{2 + \beta_3}$

a.) $A_D = ?$,



$$i_e = \frac{u_d}{2r_d} \qquad i_{c1} = \alpha_1 i_e = \frac{\beta_1}{1 + \beta_1}\frac{u_d}{2r_d} \qquad i_{c4} = i_{c1}\frac{\beta_3}{2 + \beta_3}$$

$$u_{ki} = (i_{c2} + i_{c4})R_t = (i_{c1} + i_{c4})R_t = i_{c1}\left(1 + \frac{\beta_3}{2 + \beta_3}\right)R_t = \frac{\beta_1}{1 + \beta_1}\left(1 + \frac{\beta_3}{2 + \beta_3}\right)\frac{R_t}{2r_d}u_d$$

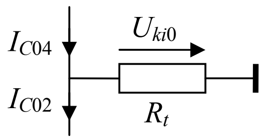
$$\boxed{A_d = \frac{u_{ki}}{u_d} = \frac{\beta_1}{1 + \beta_1}\left(1 + \frac{\beta_3}{2 + \beta_3}\right)\frac{R_t}{2r_d} = 0.99 * 1.98 * \frac{10000}{2 * 26} = 376.96}$$

b.) $A_K = ?$, ha $T_1 \equiv T_2$, $T_3 \equiv T_4$,

$$\boxed{A_K = 0}$$

Az I_0 áramgenerátor végtelen belső ellenállása miatt.

c.) $U_{off} = ?$, ha a T_1 és T_2 tranzisztor felületeinek aránya: $F_2 = 1{,}1 \cdot F_1$**,** $T_3 \equiv T_4$,



A bemenetek közé kapcsolt $U_{off} = U_1 - U_2$ feszültség hatására a kimenő feszültség legyen zérus. $U_{ki0} = 0$ ha $I_{C04} = I_{C02}$

$$I_{C01} = I_{S0} \exp\left(\frac{U_1}{U_T}\right) \qquad I_{C02} = \frac{F_2}{F_1} I_{S0} \exp\left(\frac{U_2}{U_T}\right) \qquad I_{C04} = I_{C01} \frac{B_3}{2+B_3} = \frac{B_3}{2+B_3} I_{S0} \exp\left(\frac{U_1}{U_T}\right)$$

$$\frac{I_{C04}}{I_{C02}} = 1 = \frac{F_1}{F_2} \frac{B_3}{2+B_3} \exp\left(\frac{U_1 - U_2}{U_T}\right) \quad \rightarrow$$

$$\boxed{U_{off} = U_1 - U_2 = U_T \ln\left(\frac{F_2}{F_1} \frac{2+B_3}{B_3}\right) = 26 \ln\left(\frac{1.1}{0.98}\right) = 3mV}$$

d.) $U_{off} = ?$, ha a T_3 és T_4 tranzisztor felületeinek aránya: $F_3 = 1{,}1 \cdot F_4$**,** $\mathbf{T_1 \equiv T_2}$**,**

A gondolatmenet hasonló a fentiekhez.

Most:

$$I_{C01} = I_{S0} \exp\left(\frac{U_1}{U_T}\right) \qquad I_{C02} = I_{S0} \exp\left(\frac{U_2}{U_T}\right)$$

$$I_{C03} = \frac{F_3}{F_4} I_{C04} \qquad I_{B03} = \frac{F_3}{F_4} I_{B04} \qquad (\text{ mivel } \quad U_{EB03} = U_{EB04})$$

A csomóponti egyenlet:

$$I_{C01} = I_{C03} + I_{B03} + I_{B04} = I_{C03}\left(1 + \frac{1}{B_3}\right) + I_{C04} \frac{1}{B_4} = I_{C04}\left[\frac{F_3}{F_4}\left(1 + \frac{1}{B_3}\right) + \frac{1}{B_4}\right]$$

$$I_{C01} = I_{C04}\left[\frac{F_3}{F_4}\left(1 + \frac{1}{B_3}\right) + \frac{1}{B_4}\right] = I_{C02}\left[\frac{F_3}{F_4}\left(1 + \frac{1}{B_3}\right) + \frac{1}{B_4}\right]$$

$$I_{S0} \exp\left(\frac{U_1}{U_T}\right) = I_{S0} \exp\left(\frac{U_2}{U_T}\right)\left[\frac{F_3}{F_4}\left(1 + \frac{1}{B_3}\right) + \frac{1}{B_4}\right]$$

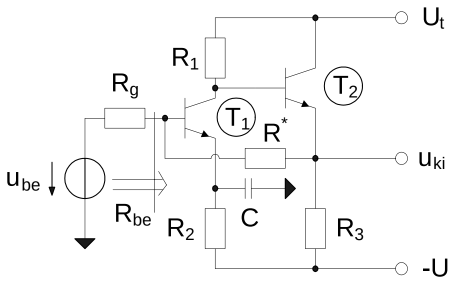
$$\boxed{U_{off} = U_1 - U_2 = U_T \ln\left[\frac{F_3}{F_4}\left(1 + \frac{1}{B_3}\right) + \frac{1}{B_4}\right] = 26 \ln[1.1 * 1.01 + 0.01] = 2.97mV}$$

Elfogadható még az alábbi közelítés is:

$$U_{off} = U_1 - U_2 = U_T \ln\frac{F_2}{F_1} \approx 2.9mV$$

5. Példa

Határozza meg az alábbi kapcsolás paramétereit!



$U_t = 10V, \quad C \to \infty, \quad R_1 = R_2 = 9{,}4k\Omega, \quad R_3 = 2{,}5k\Omega, \quad I_{E01} = 1mA,$
$I_{E02} = 4mA, \quad R_g = 1k\Omega,$

T1, T2: n-p-n tranzisztorok, $\beta_1 = B_1 = \beta_2 = B_2 \to \infty$,

a.) A visszacsatolás típusa? Az R^* ellenállás véges,

b.) $\frac{u_{ki}}{u_{be}} = ?$, az R^* ellenállás értéke végtelen,

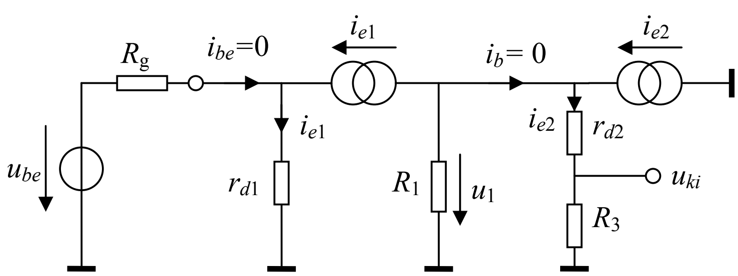
c.) (βA)=?, R^* =1 kΩ, (r_{d2} közelíthető nullával),

d.) R_{be}=?, R^* =1 kΩ, (r_{d2} közelíthető nullával)

Megoldás:

a.) Negatív, párhuzamos feszültség visszacsatolás

b.) $\frac{u_{ki}}{u_{be}} = ?$, az R^* ellenállás értéke végtelen,

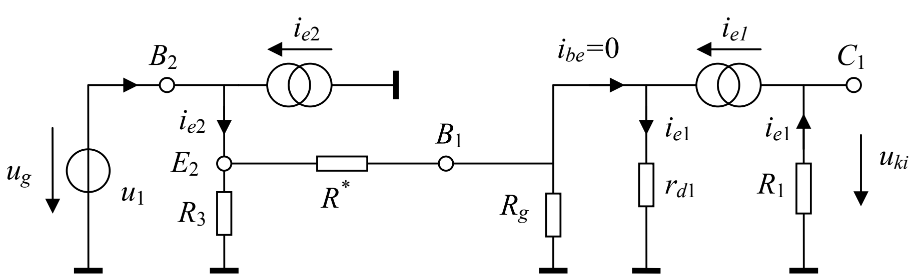


$$r_{d1} = \frac{26mV}{1mA} = 26\Omega$$

$$r_{d2} = \frac{26mV}{4mA} = 6.5\Omega$$

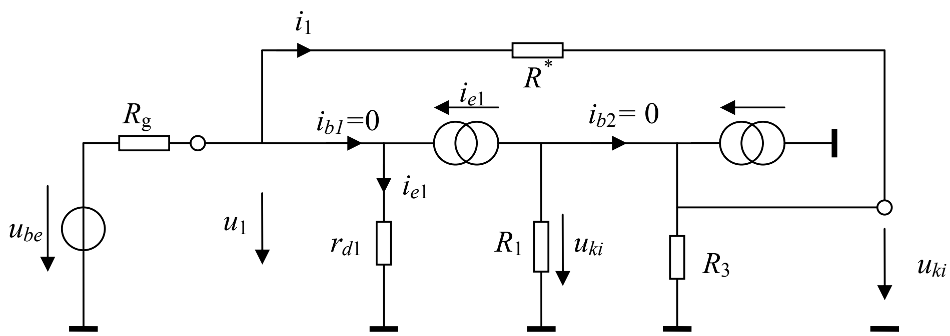
$$\frac{u_{ki}}{u_{be}} = -\frac{R_3}{r_{d2} + R_3}\frac{R_1}{r_{d1}} = -\frac{2500}{2506.5}\frac{9400}{26} = -360.6$$

c.) (βA)=?, R^* =1 kΩ, (r_{d2} közelíthető nullával),



$$(A\beta) = -\frac{u_{ki}}{u_g} = -\frac{R_g}{R_g + R^*}\left(-\frac{R_1}{r_{d1}}\right) = \frac{1}{1+1}\frac{9400}{26} = 180.8$$

d.) R_{be}=?, R^* =1 kΩ, (r_{d2} közelíthető nullával)



$$i_1 = \frac{u_1 - u_{ki}}{R^*} = \frac{u_1 - u_1\left(-\frac{R_1}{r_{d1}}\right)}{R^*}$$

$$\boxed{R_{be} = \frac{u_1}{i_1} = \frac{R^*}{1 + \frac{R_1}{r_{d1}}} = \frac{1000}{1 + \frac{9400}{26}} = 2.76\Omega}$$