

Struktury analogových IO – vnitřní zapojení OZ

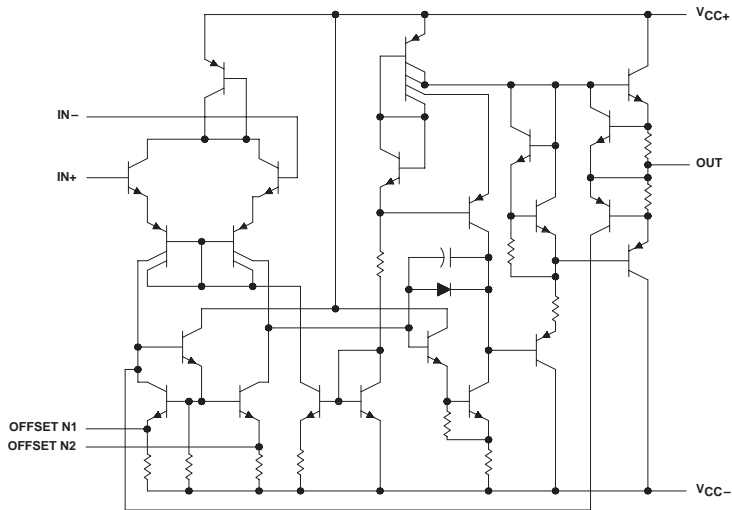
Jiří Hospodka

Elektrické obvody – analýza a simulace

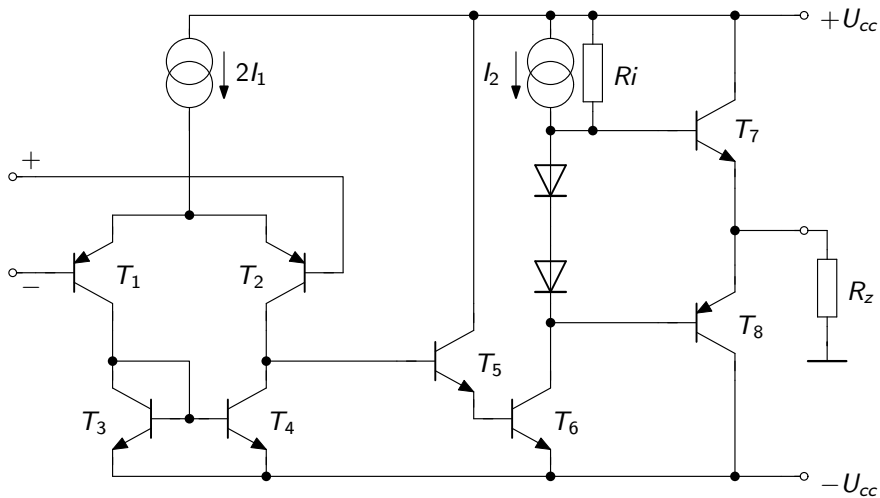
katedra Teorie obvodů, 804/B3
ČVUT FEL

7. přednáška

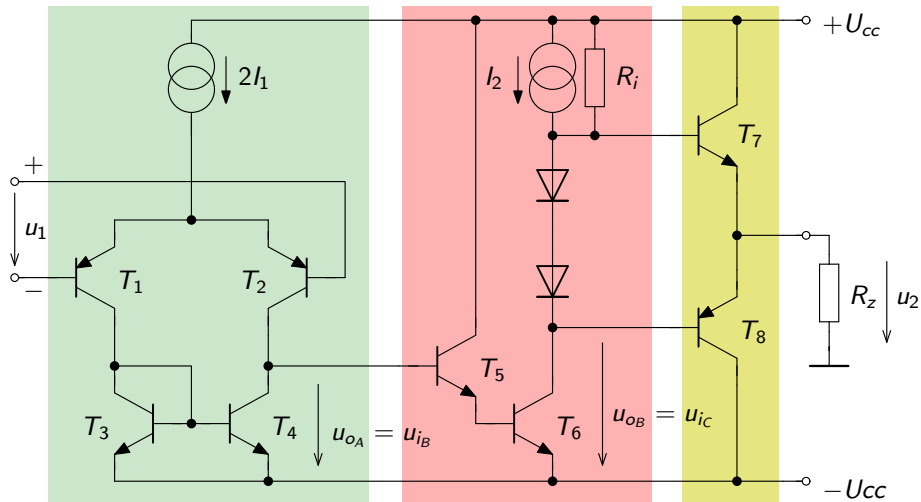
Struktury analogových IO – vnitřní zapojení OZ



Základní koncepce OZ

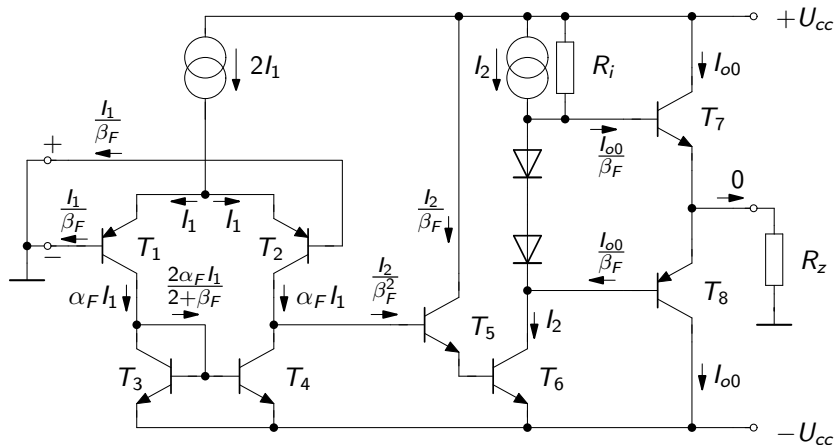


Základní koncepce OZ – rozdělení na bloky



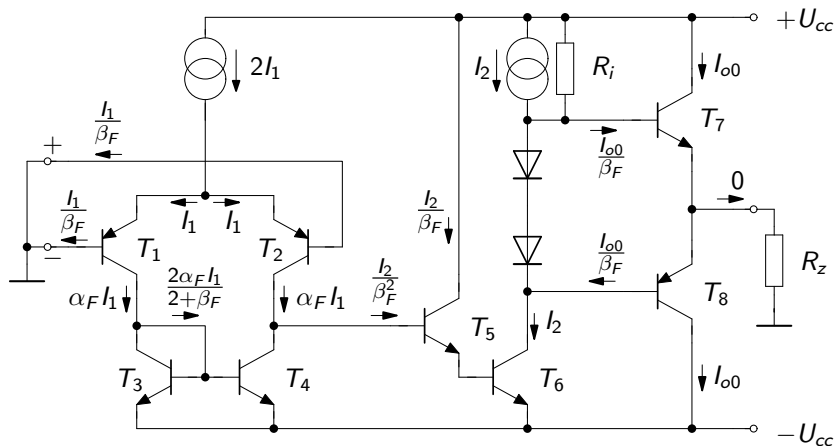
Vstupní část, rozkmitový a koncový stupeň

Základní koncepce OZ – nastavení pracovních bodů



$$I_{in} = 80 \text{ nA}, I_{out_{max}} = 20 \text{ mA}, \beta_F = \beta = 80, U_A = 100 \text{ V}, R_z = 2 \text{ k}\Omega$$

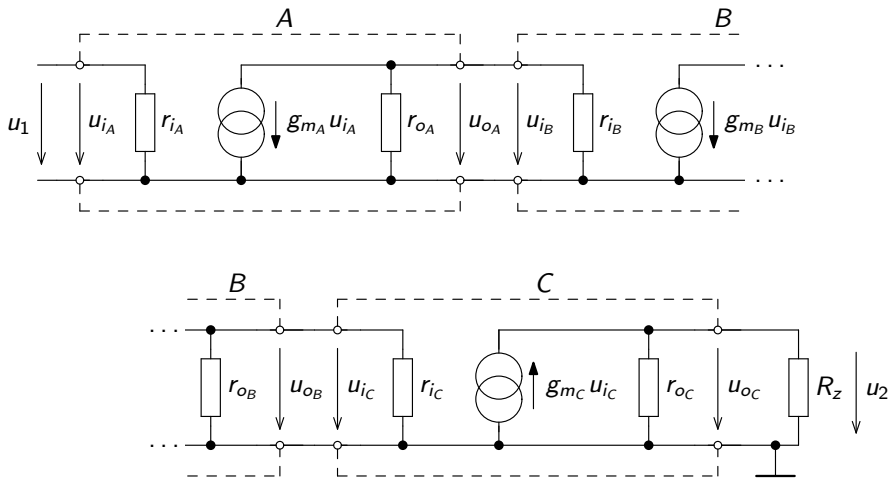
Základní koncepce OZ – nastavení pracovních bodů



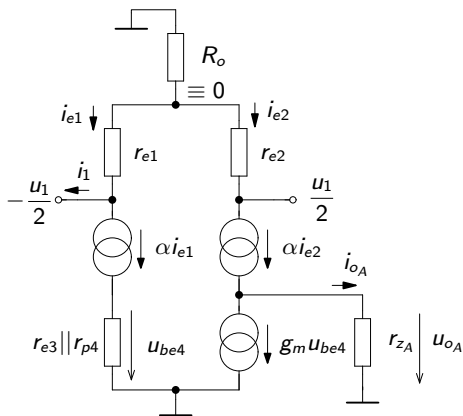
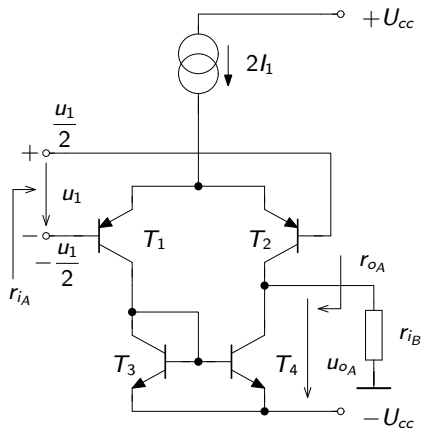
$$I_{in} = 80 \text{ nA}, \quad I_{out_{max}} = 20 \text{ mA}, \quad \beta_F = \beta = 80, \quad U_A = 100 \text{ V}, \quad R_z = 2 \text{ k}\Omega$$

$$I_1 = \beta_F I_{in}, \quad I_2 = I_{out_{max}} / \beta_F, \quad I_{00} \approx I_2.$$

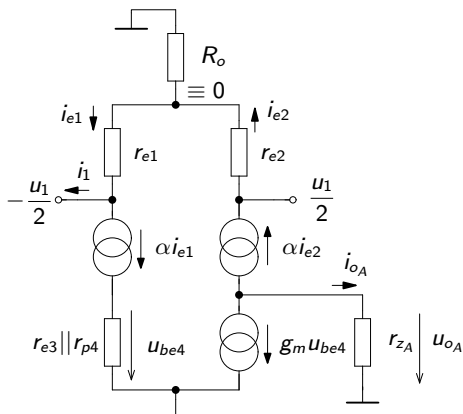
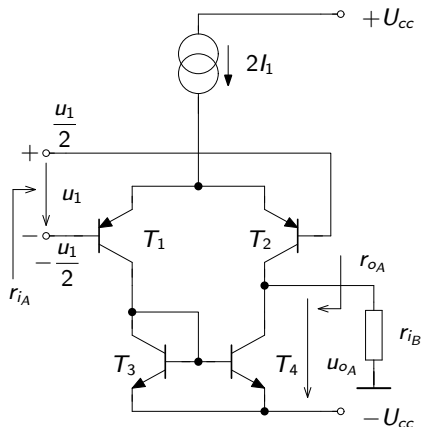
Metoda dělení řetězce



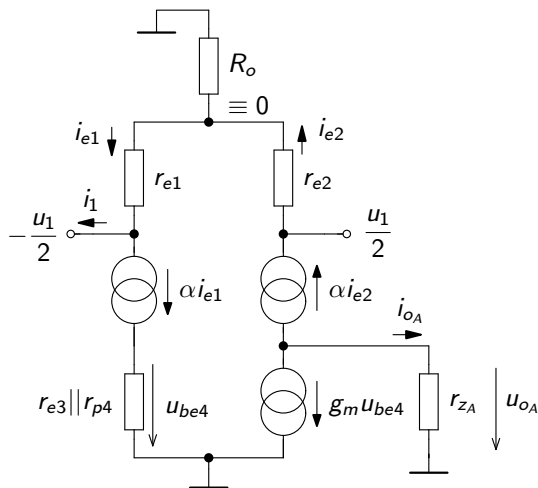
Diferenční zesílení



Diferenční zesílení



Diferenční zesílení



$$r_{e1} = r_{e2} = r_e$$

$$i_{e1} = i_{e2} = i_e = \frac{u_1}{2r_e}$$

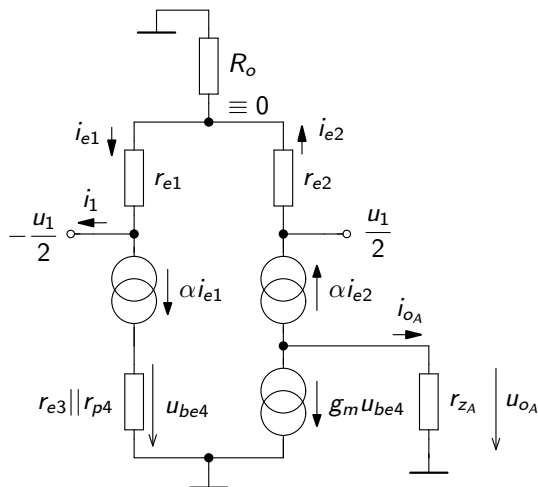
$$g_m u_{be4} = \alpha i_{e1} \frac{\beta}{\beta + 2} \doteq \alpha i_{e1} = \alpha i_e$$

$$i_{oA} = -2\alpha i_e$$

$$u_{oA} = -2\alpha \frac{u_1}{2r_e} r_{ZA} = -g_m r_{ZA} u_1 = A_{uA} u_1$$

$$r_{ZA} = (r_{o2} || r_{o4}) || r_{iB}$$

Diferenční zesílení



$$r_{e1} = r_{e2} = r_e$$

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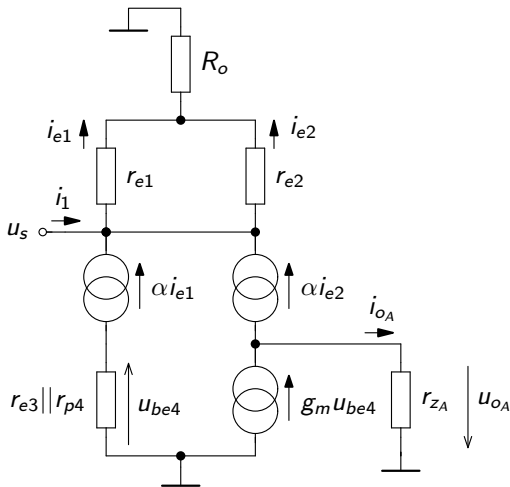
$$g_m u_{be4} = \alpha i_{e1} \frac{\beta}{\beta + 2} \doteq \alpha i_{e1} = \alpha i_e$$

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$$r_{ZA} = (r_{o2} || r_{o4}) || r_{iB}$$

Souhlasné zesílení – ideové schéma



$$i_{e1} = i_{e2} = i_e = \frac{u_s}{r_e + 2R_o}$$

pokud $g_m u_{be4} = i_e$,

pak $i_{oA} = 0$ a $A_s = 0!$

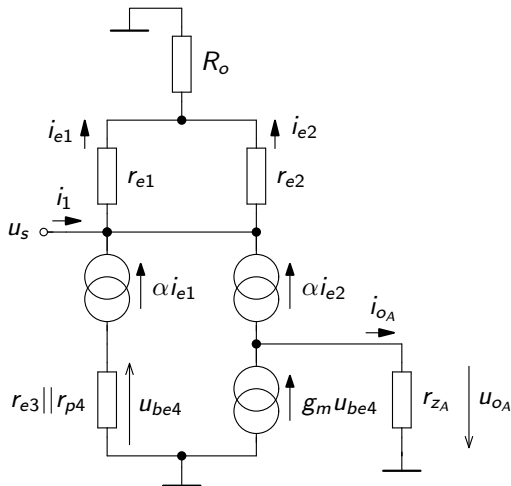
$$\text{zde: } g_m u_{be4} = \alpha i_{e1} \frac{\beta}{\beta + 2}$$

$$u_{oA} = i_{oA} r_{ZA} = \dots \doteq -\frac{u_s}{R_o \beta} r_{ZA}$$

$$A_s = \frac{u_{oA}}{u_s} \doteq -\frac{r_{ZA}}{R_o \beta}, R_o \gg r_e$$

$$H = \left| \frac{A_{uA}}{A_s} \right| \doteq g_m R_o \beta$$

Souhlasné zesílení – ideové schéma



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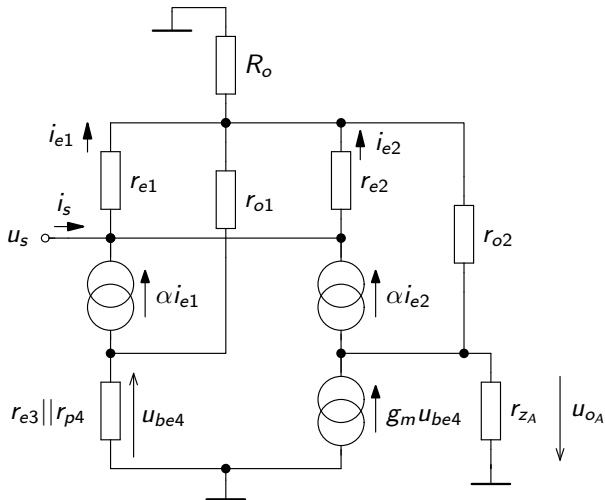
$$\text{zde: } g_m u_{be4} = \alpha i_{e1} \frac{\beta}{\beta + 2}$$

$$u_{oA} = i_{oA} r_{ZA} = \dots \doteq -\frac{u_s}{R_o \beta} r_{ZA}$$

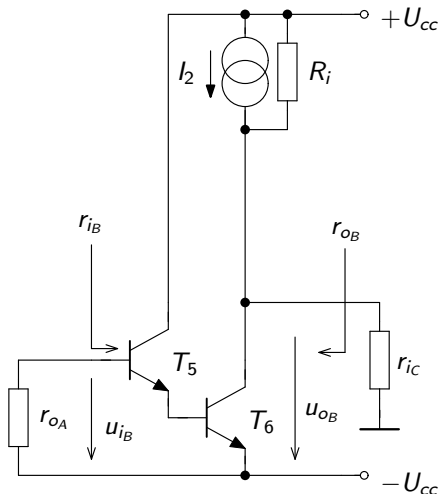
$$A_s = \frac{u_{oA}}{u_s} \doteq -\frac{r_{ZA}}{R_o \beta}, \quad R_o \gg r_e$$

$$H = \left| \frac{A_{uA}}{A_s} \right| \doteq g_m R_o \beta$$

Souhlasné zesílení – kompletní zapojení



Analýza základní koncepce OZ – rozkmitový stupeň



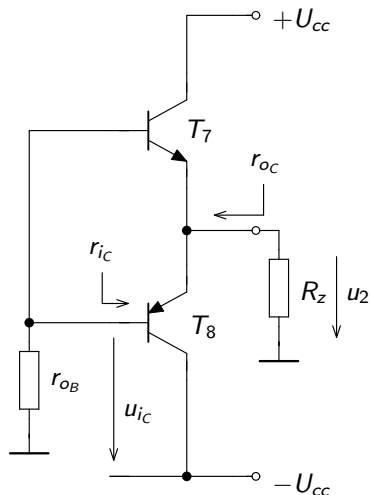
$$r_{iB} = (\beta + 1)(r_{e5} + r_{\pi6}) = (\beta + 1)2r_{\pi6} = 2r_{\pi5}$$

$$A_{uB} = -\frac{g_{m6}r_{zB}}{2}$$

$$r_{zB} = r_{oB} \parallel r_{iC} = (R_i \parallel r_{o6}) \parallel r_{iC}$$

$$R_i \approx r_{o6}$$

Analýza základní koncepce OZ – koncový stupeň

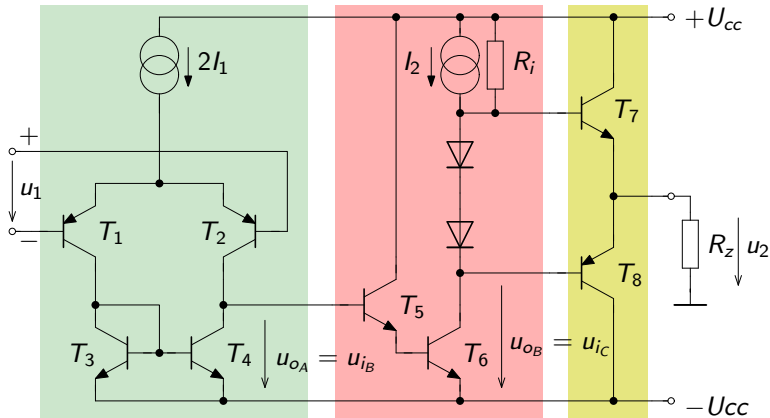


$$r_{iC} = (\beta + 1)R_Z$$

$$A_{u_C} = \frac{R_Z}{R_Z + r_{ek}} \doteq 1, \quad r_{ek} = r_{e7} = r_{e8}$$

$$r_{oC} = r_{ek} + \frac{r_{oB}}{\beta + 1} \doteq \frac{r_{oB}}{\beta + 1}$$

Modelový příklad výpočtu zesílení OZ



$$\beta = 80$$

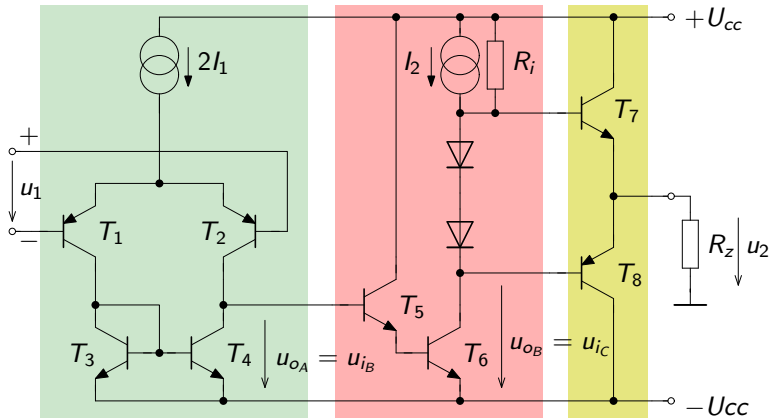
$$U_A = 100 \text{ V}$$

$$R_z = 2 \text{ k}\Omega$$

$$I_1 = 6,4 \mu\text{A} \Rightarrow r_{e1} \doteq 4 \text{ k}\Omega, r_{\pi 1} \doteq 300 \text{ k}\Omega, r_{oA} \doteq 8 \text{ M}\Omega$$

$$I_2 = 250 \mu\text{A} \Rightarrow r_{iB} \doteq 1,3 \text{ M}\Omega, r_{oB} \doteq 200 \text{ k}\Omega, r_{iC} \doteq 160 \text{ k}\Omega$$

Modelový příklad výpočtu zesílení OZ



$$\beta = 80$$

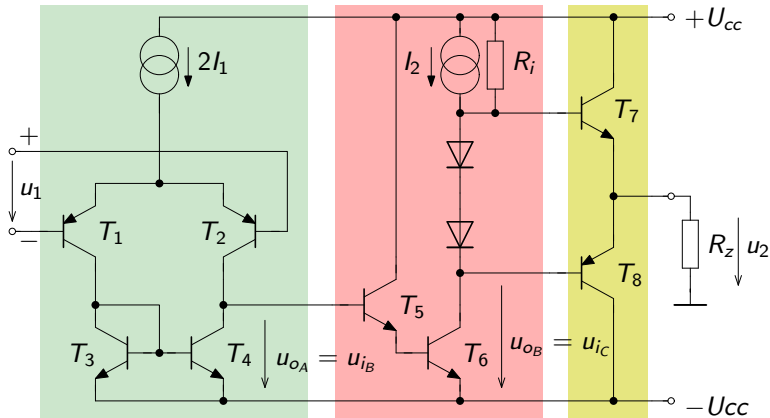
$$U_A = 100 \text{ V}$$

$$R_Z = 2 \text{ k}\Omega$$

$$A_{uA} = \frac{u_{OA}}{u_1} = -g_m(r_{oA} \parallel r_{iB}) \doteq -280, A_{uB} = \frac{u_{OB}}{u_{iB}} = -\frac{g_{m6}(r_{oB} \parallel r_{iC})}{2} \doteq -890,$$

$$A_{uC} \doteq 1, A_u = A_{uA} A_{uB} A_{uC} \doteq 250\,000.$$

Modelový příklad výpočtu zesílení OZ



$$\beta = 80$$

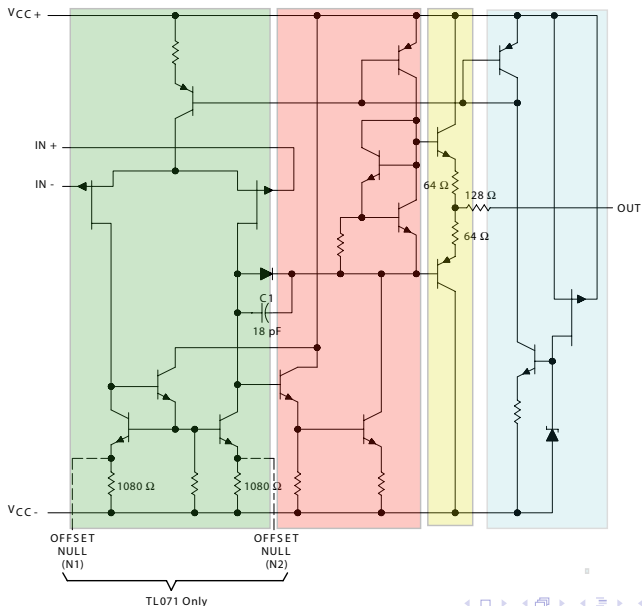
$$U_A = 100 \text{ V}$$

$$R_Z = 2 \text{ k}\Omega$$

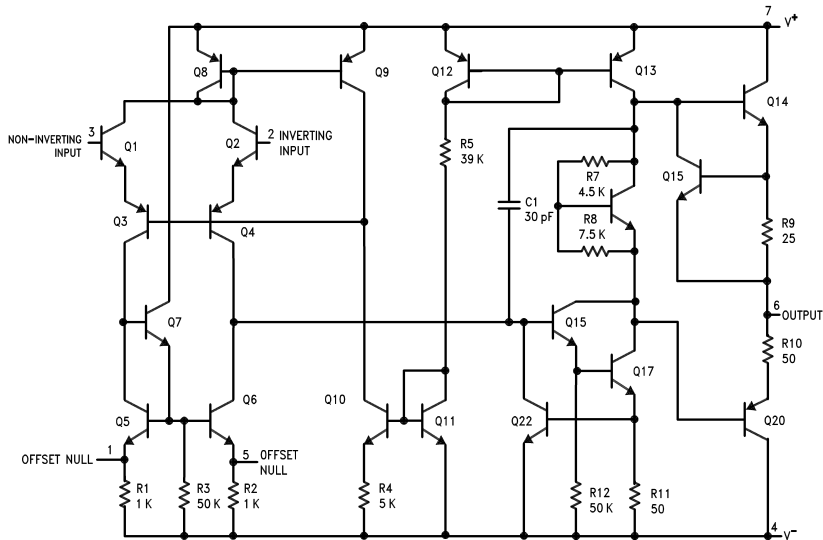
$$A_{uA} = \frac{u_{oA}}{u_1} = -g_m(r_{oA} \parallel r_{iB}) \doteq -280, A_{uB} = \frac{u_{oB}}{u_{iB}} = -\frac{g_{m6}(r_{oB} \parallel r_{iC})}{2} \doteq -890,$$

$$R_Z \rightarrow \infty \Rightarrow A_{uB} = 2000! \quad \text{a} \quad A_u \doteq 560\,000 \quad \text{oproti původním } 250\,000.$$

Vnitřní struktura IO, operačního zesilovače TL071

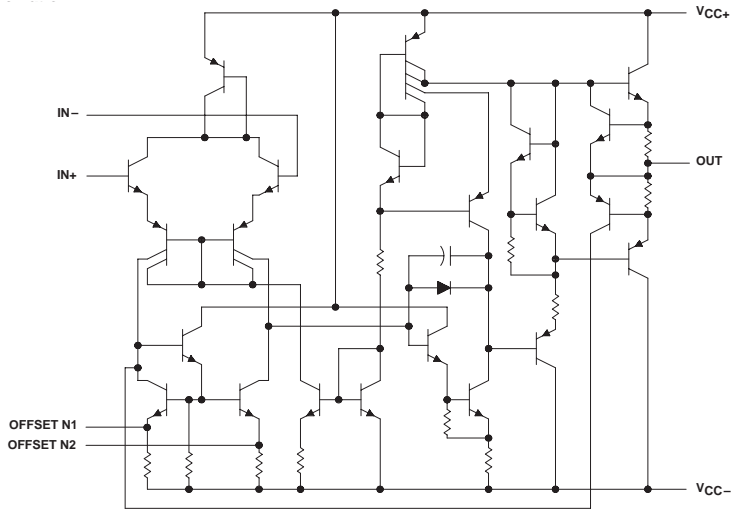


Vnitřní struktura IO, OZ LM741

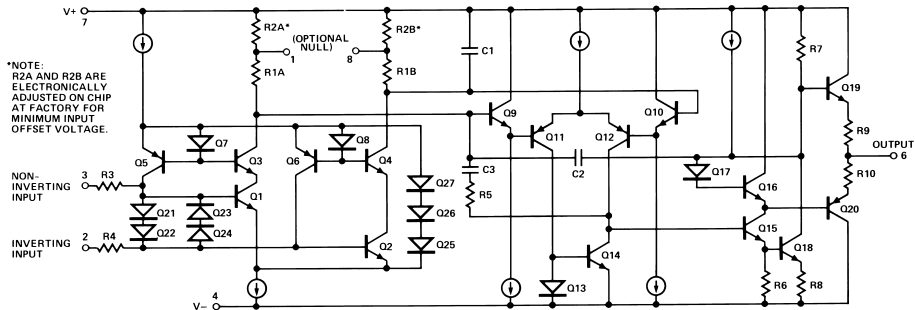


Vnitřní struktura IO, OZ μ A741

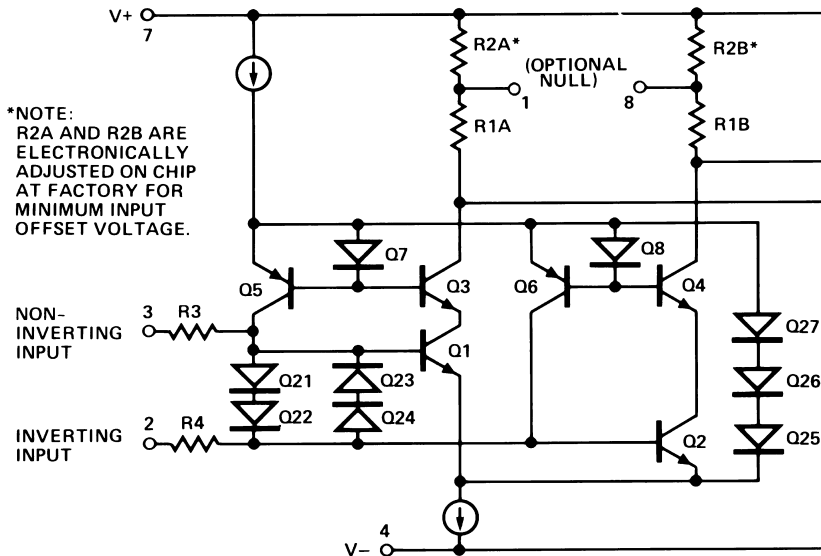
Figure 10-1



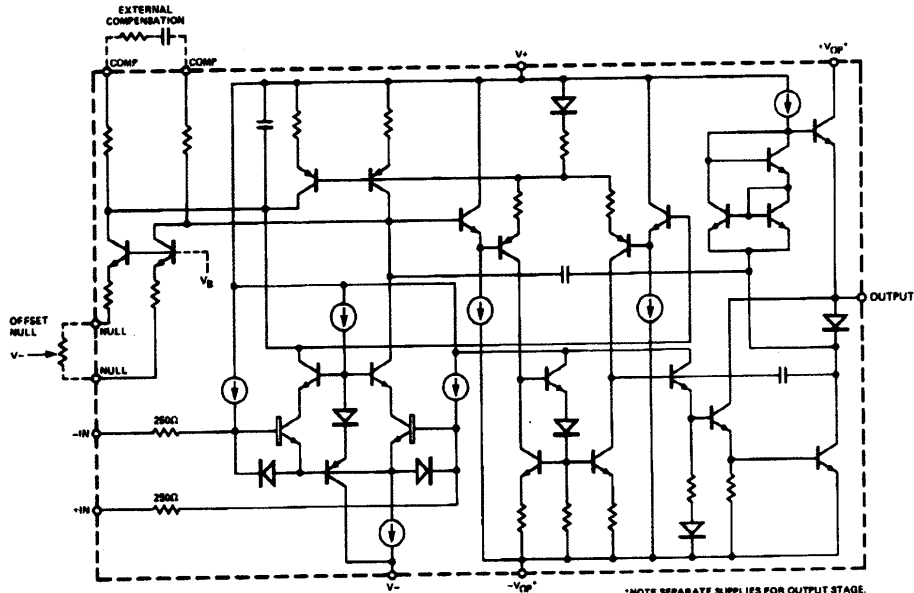
Vnitřní struktura IO, operačního zesilovače OP07



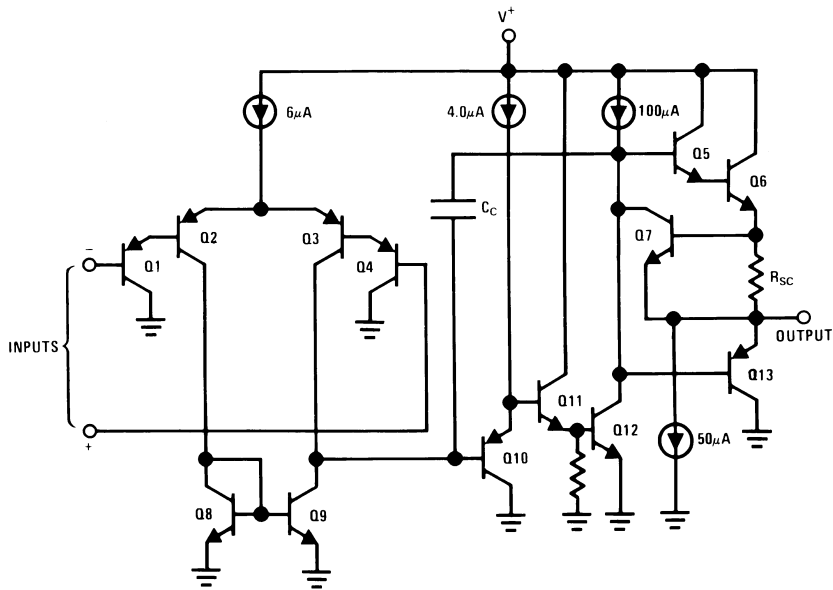
Vstupní obvody operačního zesilovače OP07



Vnitřní struktura IO, operačního zesilovače OP50



Vnitřní struktura IO, operačního zesilovače LM358





Děkuji za pozornost.