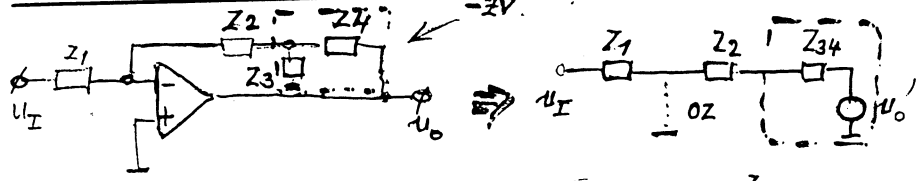
K lineárním aplikacím OZ

(A) INVERTUJÍCÍ VERZE:



$$u_o' = u_o \cdot \frac{Z_3}{Z_3+Z_4}$$

$$Z_{34} = Z_3 \parallel Z_4 = \frac{Z_3 \cdot Z_4}{Z_3+Z_4}$$

Přenos $\frac{u_o}{u_I} = ?$

1. Z proudů:

$$\frac{u_I - 0}{Z_1} = \frac{0 - u_o'}{Z_2 + Z_{34}}$$

$$\frac{u_I}{Z_1} = -\frac{u_o}{Z_2+Z_{34}} \cdot \frac{Z_3}{Z_3+Z_4}$$

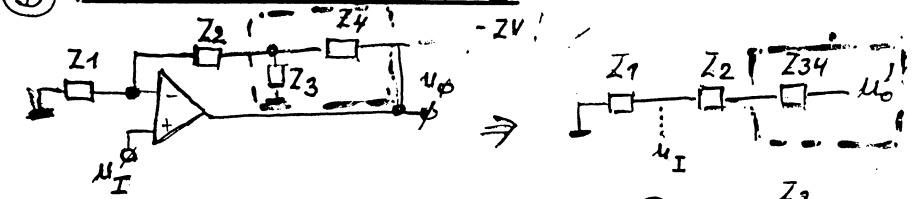
$$\Rightarrow \frac{u_o}{u_I} = -\frac{Z_3+Z_4}{Z_3} \cdot \frac{Z_2+Z_{34}}{Z_1}$$

2. Přes přenos:

$$\frac{u_o'}{u_I} = -\frac{Z_2+Z_{34}}{Z_1}$$

$$\Rightarrow \frac{u_o}{u_I} = -\frac{Z_3+Z_4}{Z_3} \cdot \frac{Z_2+Z_{34}}{Z_1}$$

(B) NEINVERTUJÍCÍ VERZE:



$$u_o' = u_o \cdot \frac{Z_3}{Z_3+Z_4}$$

$$Z_{34} = Z_3 \parallel Z_4$$

Přenos $\frac{u_o}{u_I} = ?$

1. Z proudů:

$$\frac{u_o' - u_I}{Z_2 + Z_{34}} = \frac{u_I - 0}{Z_1}$$

$$u_o' Z_1 - u_I Z_1 = u_I (Z_2 + Z_{34})$$

$$u_o \cdot \frac{Z_3 Z_1}{Z_3+Z_4} = u_I \cdot (Z_1 + Z_2 + Z_{34})$$

$$\Rightarrow \frac{u_o}{u_I} = \frac{Z_3+Z_4}{Z_1 Z_3} \cdot (Z_1 + Z_2 + Z_{34})$$

2. Přes dělič

$$\frac{u_I}{u_o'} = \frac{Z_1}{Z_1+Z_2+Z_{34}}$$

$$u_I = u_o \cdot \frac{Z_3}{Z_3+Z_4} \cdot \frac{Z_1}{Z_1+Z_2+Z_{34}}$$

$$\Rightarrow \frac{u_o}{u_I} = \frac{Z_3+Z_4}{Z_1 Z_3} \cdot (Z_1+Z_2+Z_{34})$$

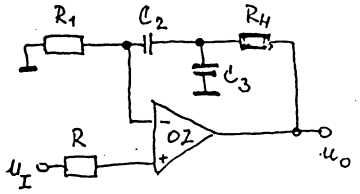
3. Přes přenos

$$\frac{u_o'}{u_I} = 1 + \frac{Z_2+Z_{34}}{Z_1}$$

$$\Rightarrow \frac{u_o}{u_I} = \frac{Z_3+Z_4}{Z_3} \cdot \left(1 + \frac{Z_2+Z_{34}}{Z_1}\right)$$

PŘÍKLAD 1:

ES



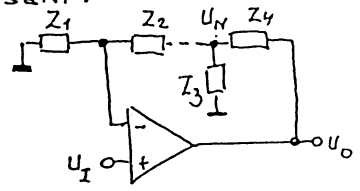
ÚKOLY:

① Určete přenos $\frac{U_o(p)}{U_I(p)}$ obecně pro OZ ideální

② Napište přenos pro $R_1 = R_H$ a $C_2 = C_3$

③ Určete totéž pro hodnoty: $R_1 = R_H = 15k$, $C_2 = C_3 = 22n$

ŘEŠENÍ:

① 

$$u_N = \frac{Z_3}{Z_3 + Z_4} \cdot u_o \quad \text{(napěťový dělič)}$$

$$u_I = U_N \cdot \frac{Z_1}{Z_1 + Z_2 + \frac{Z_3 \cdot Z_4}{Z_3 + Z_4}} \quad \text{při } u_{ID} = 0$$

Potom: $u_I = u_o \cdot \frac{Z_3}{Z_3 + Z_4} \cdot \frac{Z_1}{Z_1 + Z_2 + \frac{Z_3 \cdot Z_4}{Z_3 + Z_4}} = u_o \cdot \frac{Z_1 Z_3}{Z_2 Z_3 + Z_2 Z_4 + Z_1 Z_3 + Z_1 Z_4 + Z_3 Z_4}$

$$\Rightarrow \frac{u_o}{u_1} = \frac{Z_3(Z_1 + Z_2 + Z_4) + Z_4(Z_1 + Z_2)}{Z_1 Z_3} = 1 + \frac{Z_2}{Z_1} + \frac{Z_4}{Z_3} + \frac{Z_4}{Z_1} + \frac{Z_2 Z_4}{Z_1 Z_3}$$

Pro: $Z_1 = R_1$, $Z_2 = \frac{1}{pC_2}$, $Z_3 = \frac{1}{pC_3}$, $Z_4 = R_4$:

$$\frac{U_o(p)}{U_I(p)} = 1 + \frac{1}{pR_1C_2} + pC_3R_4 + \frac{R_4}{R_1} + \frac{pR_4C_3}{pR_1C_2}$$

② Pro $R_1 = R_4 \equiv R$, $C_2 = C_3 = C$:

$$\frac{U_o(p)}{U_I(p)} = 1 + \frac{1}{pRC} + pRC + 1 + 1 = 3 + \frac{1}{pRC} + pRC$$

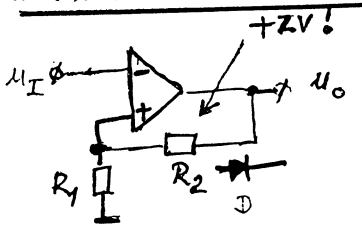
③ Pro $R = 15.10^3\,\Omega$, $C = 22.10^{-9}\,F$:

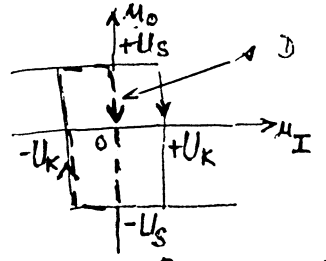
$$\frac{U_o(p)}{U_I(p)} = 3 + \frac{1}{p.330.10^{-6}} + 330.10^{-6}.p =$$

$$\doteq 3 + \frac{3.10^3}{p} + 3{,}3.10^{-4}.p$$

K nelineárním aplikacím OZ

(B) INVERTUJÍCÍ KOMPARÁTOR S HYSTEREZÍ

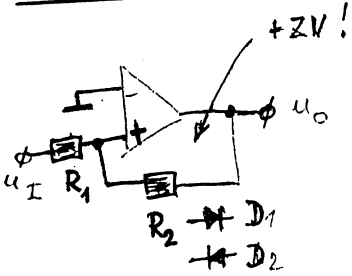


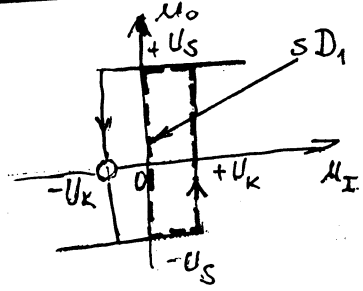


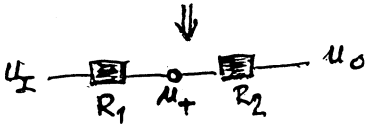
$$U_K = U_S \cdot \frac{R_1}{R_1 + R_2} = k \cdot U_S$$

$$U_H = 2U_K$$

(C) NEINVERTUJÍCÍ KOMPARÁTOR S HYSTEREZÍ







$$u_+ = u_o \cdot \frac{R_1}{R_1 + R_2} + u_I \frac{R_2}{R_1 + R_2}$$

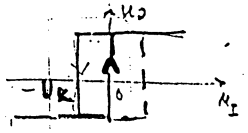
Při překlopení např. $u_o = U_S$ a $u_I = -U_K$:

$$0 = U_S \cdot \frac{R_1}{R_1 + R_2} - U_K \cdot \frac{R_2}{R_1 + R_2}$$

$U_K = +U_S \cdot \frac{R_1}{R_2}$ $\quad U_H = 2U_K$

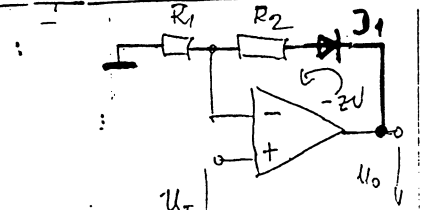
(D1) $\quad U_H = U_K$

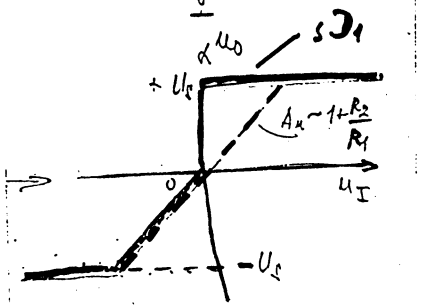
(D2)



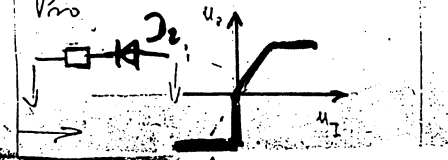
POZOR PŘI ZÁMĚNĚ VSTUPŮ:

k (A):

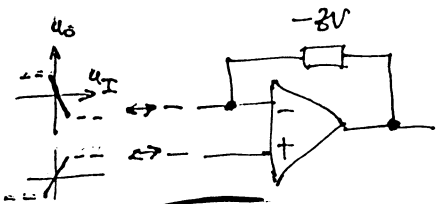




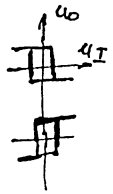
Pro D2:

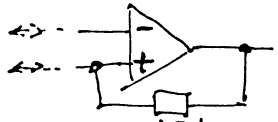


CELKOVĚ!



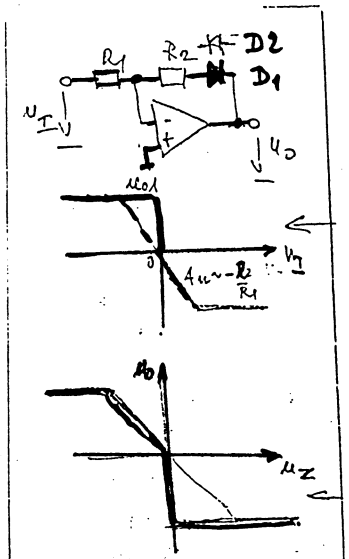
zesilovače



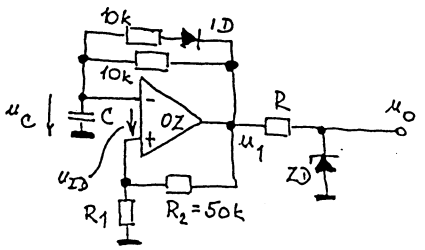


komparátory

k (B):



PŘÍKLAD 2: ES



OZ: $U_S = \pm 15\,V$

$U_{1Dmax} = 5\,V$

ZD: $U_Z = 5\,V$ .... $I_Z = 5\,mA$

$I_{Zmax} = 50\,mA$

$I_{Fmax} = 50\,mA$

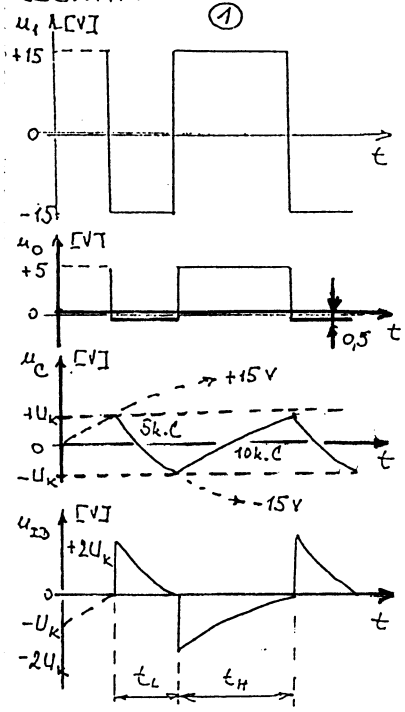
$U_F = 0{,}5\,V$

1D: ideální dioda

ÚKOLY:

1. Nakreslete průběhy $u_1, u_O, u_C, u_{1D}(t)$
2. Určete R_1 v souvislosti s U_{1Dmax} a volte $R_1 = 0{,}8 . R_{1max}$
3. -"- C pro dobu $t_H = 10\,ms$, kdy $U_O \equiv U_H > U_L$
4. -"- f_O kmitočet
5. -"- určete R (omezovač)

ŘEŠENÍ:



2. $U_K = U_S \cdot \frac{R_1}{R_1+R_2} < \frac{U_{1Dmax}}{2}$

$15 \cdot \frac{R_1}{R_1+50k} < 2{,}5 \Rightarrow R_{1max} = 10k$

$R_1 = 8k$

3. $t_H = 10k . C . \ln \frac{-U_K - 15}{+U_K - 15} = 10k . C . \ln \underbrace{\frac{14{,}1}{12{,}9}}_{0{,}28} \equiv 10\,ms$

při $U_K = 15 \cdot \frac{8k}{8k+50k} \doteq 2{,}1\,V$

$\Rightarrow C \doteq \frac{10m}{0{,}28 . 10k} \doteq 3{,}6\,\mu F$

4. $t_L = 0{,}28 . 5k . 3{,}6 . 10^{-6} \doteq 5\,ms \equiv \frac{t_H}{2}$

$f_O = \frac{1}{10m+5m} \doteq 67\,Hz$

5. $R > \frac{15-5}{50m} = 200$ při t_H

$R > \frac{15-0{,}5}{50m} = 290$ při t_L

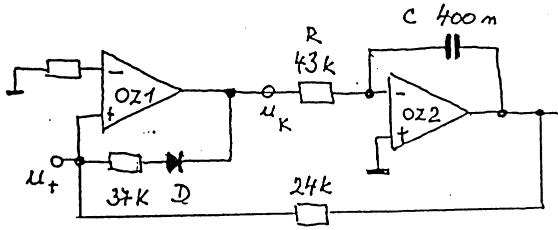
$R < \frac{15-5}{5m} = 2k$ při t_H

$290 < R < 2k$

ES

PŘÍKLAD 3:

7



OZ : $U_S = \pm 10\,V$

D : ideální dioda

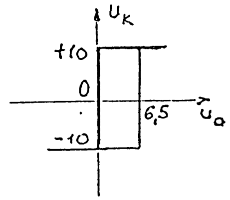
ÚKOLY:
1. Nakreslete charakteristiku komparátoru s OZ1
2. –"– průběhy $u_0, u_K, u_+ (t)$
3. Určete doby t_1, t_2 a t_0
4. Zvažte vliv reálné D ($U_F \doteq 0{,}7\,V$), tj. nový f_0'

ŘEŠENÍ:

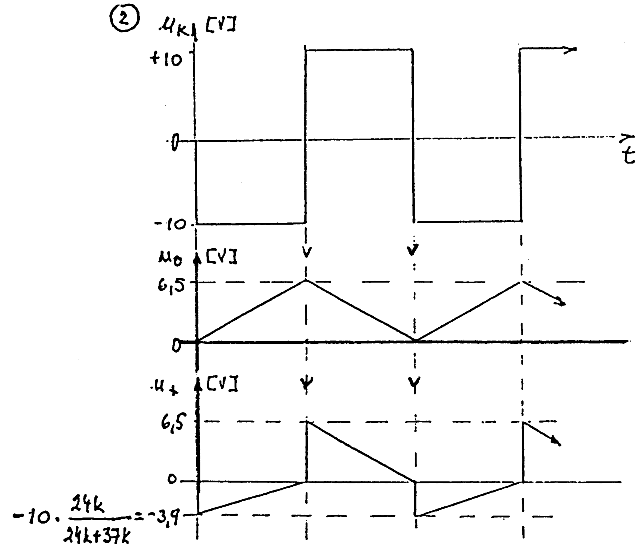
① $U_S > 0 \Rightarrow U_K = 0\,V$

$U_S < 0 \Rightarrow U_K \cdot \frac{37k}{37k+24k} - 10 \cdot \frac{24k}{37k+24k} = 0$

$U_K = 10 \cdot \frac{24}{37} \doteq 6{,}5\,V$



②



③ $\Delta U_0 = \frac{1}{C} \cdot \frac{U_S}{R} \cdot t$

$t_1 = t_2 = t$

$\Rightarrow t = \frac{43 \cdot 10^3 \cdot 0{,}4 \cdot 10^{-6} \cdot 6{,}5}{10} = \doteq 11{,}2\,ms$

$f_0 = \frac{1}{2 \cdot 11{,}2m} \doteq 45\,Hz$

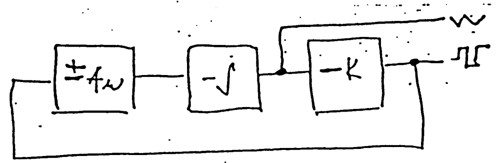
④ $U_K' = (10 - 0{,}7) \cdot \frac{24}{37} \doteq 6\,V$

$t' = t \cdot \frac{U_K'}{U_K} = 11{,}2 \cdot \frac{6}{6{,}5} \doteq 10{,}3\,ms$

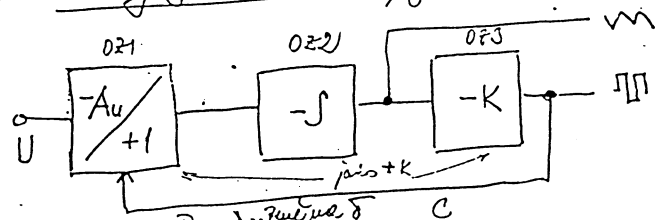
$f_0' = \frac{1}{2 \cdot 10{,}3} = 48{,}5\,Hz$

8

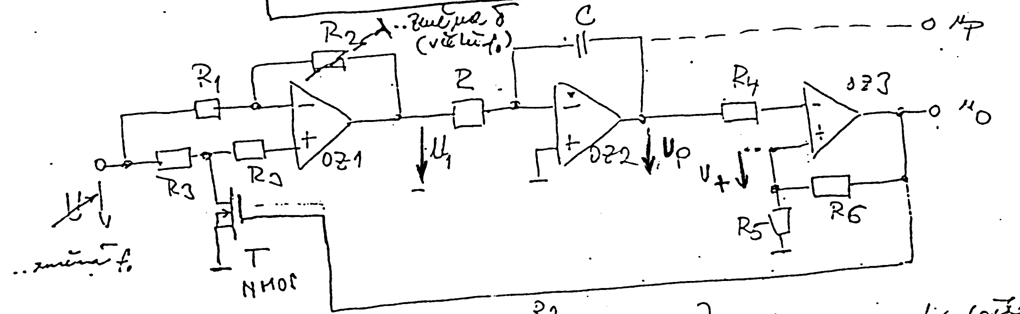
Varianta:



(B) Řízený generátor $\div f_0(U)$



OZ1 … obrac. bez. odděl. síťka (znam. + i velikost)

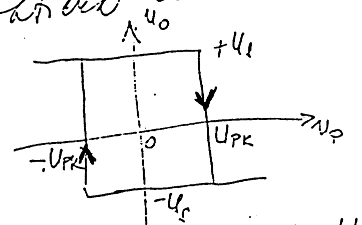


(OZ1) $U_0 = +U_S \Rightarrow U_{1-} = -U \cdot \frac{R_2}{R_1}$

$U_0 = -U_S \Rightarrow U_{1+} = U \cdot +1 = +U$

} . U > 0 … aby došlo ke komparaci

(OZ3) Statická charakteristika komparátoru!



$U_{PK} = U_S \cdot \frac{R_5}{R_5 + R_6}$

$U_H = 2 U_{PK}$

zaf. vzdále.: Doby t: $2U_{PK} = \frac{1}{C} \cdot \frac{U_1}{R} \cdot t_i$

$\Rightarrow t_i = 2RC \frac{U_{PK}}{|U_i|}$

$\Rightarrow t_1 = 2RC \frac{U_{PK}}{|U_{1+}|} = 2RC U_{PK} \cdot \frac{1}{U}$

$t_2 = 2RC \frac{U_{PK}}{|U_{1-}|} = 2RC U_{PK} \cdot \frac{1}{U}$

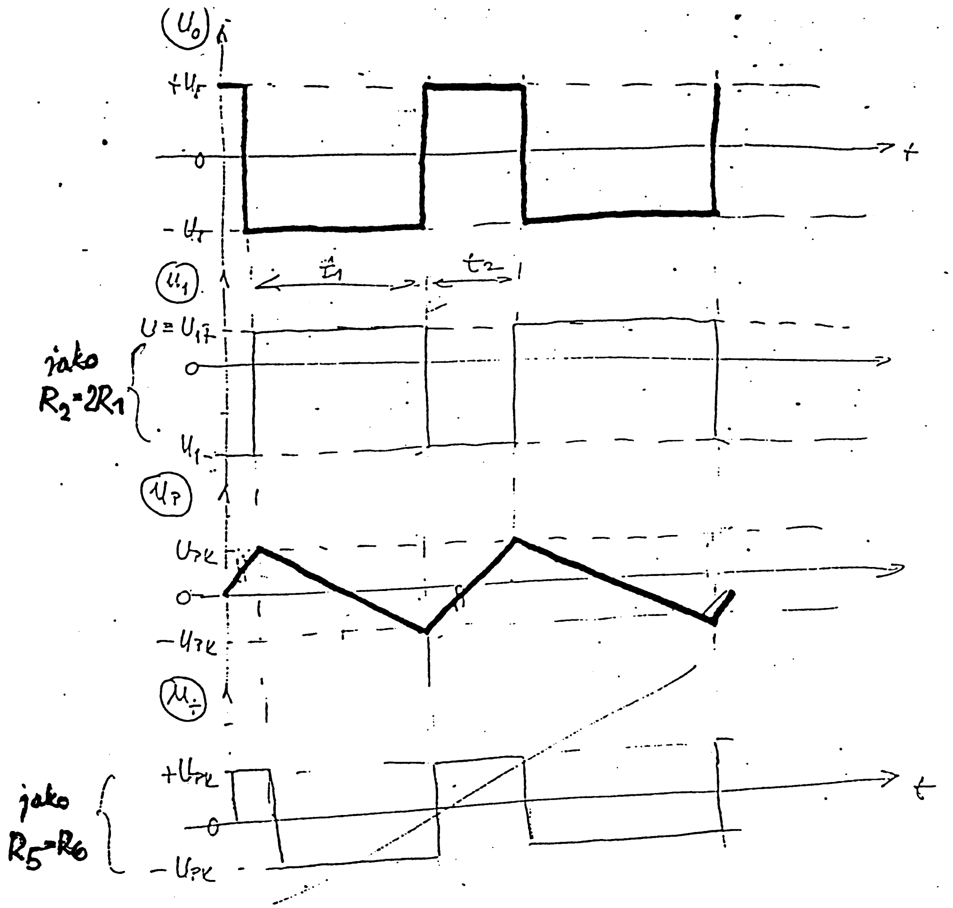
$\sim k \cdot \frac{1}{U}$

$= t_1 \cdot \frac{R_1}{R_2} \sim \frac{t_1}{|A_u|}$

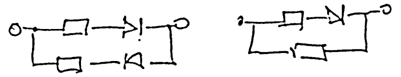
$t_0 = t_1 + t_2 = t_1 (1 + \frac{R_1}{R_2})$

$f_0 = \frac{1}{t_0}$

[9]



Varianty v S, k, ?



a pod.

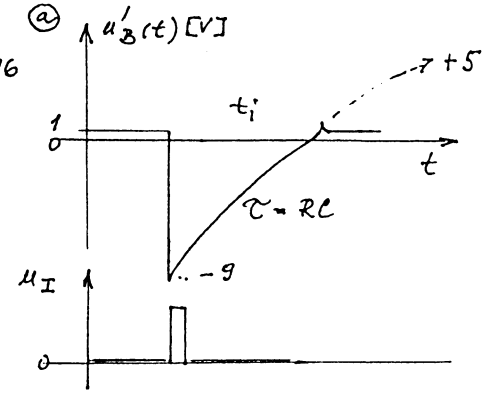
Vliv napětí $U_=$ dvod.

ŘEŠENÍ VZOROVÝCH PŘÍKLADŮ Z ES 1 PŘÍLOHA B.

ad 1

k obr. 3.16

ⓐ



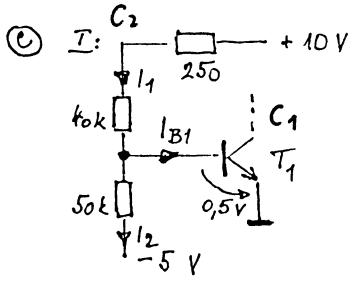
ⓑ $I_{C2M} = \frac{10}{250} = 40\,mA$

$I_{B2N} = \frac{40m}{100} = 0{,}4\,mA$

$I_{B2} = 2 \cdot 0{,}4m = 0{,}8\,mA$

$R = \frac{5 - 2 \cdot 0{,}5}{0{,}8m} = \underline{\underline{5\,k\Omega}}$

ⓒ



$I_1 = \frac{10 - 0{,}5}{40k + 0{,}25k} = 236\,\mu A$

$I_2 = \frac{5 + 0{,}5}{50k} = 110\,\mu A$

$I_{B1} = 236\mu - 110\mu = \boxed{126\,\mu A}$

$I_{C1M} = \frac{10}{1k} = 10\,mA$

$I_{B1N} = \frac{10m}{100} = \boxed{100\,\mu A} \Rightarrow s = \frac{126\mu}{100\mu} = 1{,}26 < 2\ !$

$\Rightarrow$ T_1 bude otevřen, ale v mezním s

II. Při T_2 otevřeném bude

$U_{B1} = -5 \cdot \frac{40}{40+50} + 0\,\frac{50}{40+50} = -2{,}2\,V$

$\Rightarrow$ T_1 bude zavřen

ⓓ $t_i = \tau \cdot \ln \frac{-9 - 5}{U_K - 5} = RC \ln \frac{-9-5}{(0 \div 1) - 5} = RC \ln(2{,}8 \div 3{,}5)$

$\doteq (1 \div 1{,}25) \cdot RC$

$\Rightarrow C = \frac{100 \cdot 10^{-3}}{(1 \div 1{,}25) \cdot 5 \cdot 10^3} = \underline{\underline{(20 \div 16)\,\mu F}}$

---

ad 2

k obr. 3.17

ⓐ $I_{C1M} = \frac{5 - 0{,}5}{500} = 9\,mA$

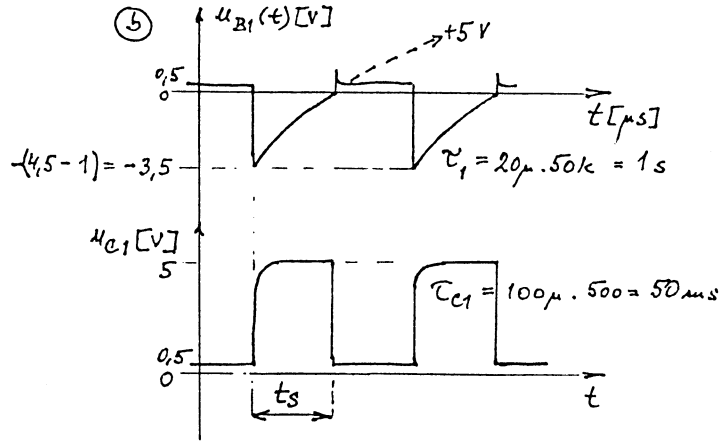
$I_{B1N} = \frac{9m}{100} = 90\,\mu A \Rightarrow R_1 = \frac{5 - 0{,}5}{90\mu} = \underline{\underline{50\,k\Omega}}$

$I_{C2M} \doteq \frac{5 - 2 \cdot 0{,}5}{500} + \frac{10 - 0{,}5}{R_Z} = 8m + \frac{9{,}5}{200} = 8m + 47{,}5m = 55{,}5\,mA$

$R_Z \doteq \frac{10}{50m} = 200\,\Omega$

$I_{B2N} = \frac{55{,}5m}{100} = 555\,\mu A \Rightarrow R_2 = \frac{5 - 0{,}5}{555\mu} = \underline{\underline{8{,}1\,k\Omega}}$

ⓑ



ⓒ $t_s = \tau_1 \cdot \ln \frac{-3{,}5 - 5}{(0 \div 0{,}5) - 5} = 1 \cdot \ln(1{,}7 \div 1{,}9) = \underline{\underline{(0{,}53 \div 0{,}64)\,s}}$

(2)

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ad 3

k obr. 3.18

ⓐ $I_{C1M} = \frac{10 - 0{,}5}{1k} + \frac{10 - 2 \cdot 0{,}5}{1k} = 9{,}5m + 9m = 18{,}5\,mA$

$I_{B1N} = \frac{18{,}5m}{50} = 370\,\mu A \Rightarrow R_1 = \frac{10 - 0{,}5}{370\mu} = \underline{\underline{25{,}7\,k\Omega}}$

$I_{C2M} = \frac{10 - 0{,}5}{2k} = 4{,}75\,mA$

$I_{B2N} = \frac{4{,}75m}{50} = 95\,\mu A \Rightarrow R_2 = \frac{10 - 0{,}5}{45\mu} = \underline{\underline{100\,k\Omega}}$

ⓒ $t_1 = 100m \cdot (25{,}7k + 0{,}5k) \cdot \ln \frac{-4{,}25 - 10}{(0 \div 0{,}5) - 10} = 2{,}62\,m \cdot \ln(1{,}4 \div 1{,}5) =$

$\doteq \underline{\underline{(0{,}93 \div 1{,}06)\,ms}}$

ⓓ $t_2 = 10m \cdot \ln \frac{-2{,}5 - 10}{(0 \div 0{,}5) - 10} = \ldots = (6{,}15 \div 6{,}67)\,ms \Rightarrow f_0 = \underline{\underline{(141 \div 129)\,Hz}}$