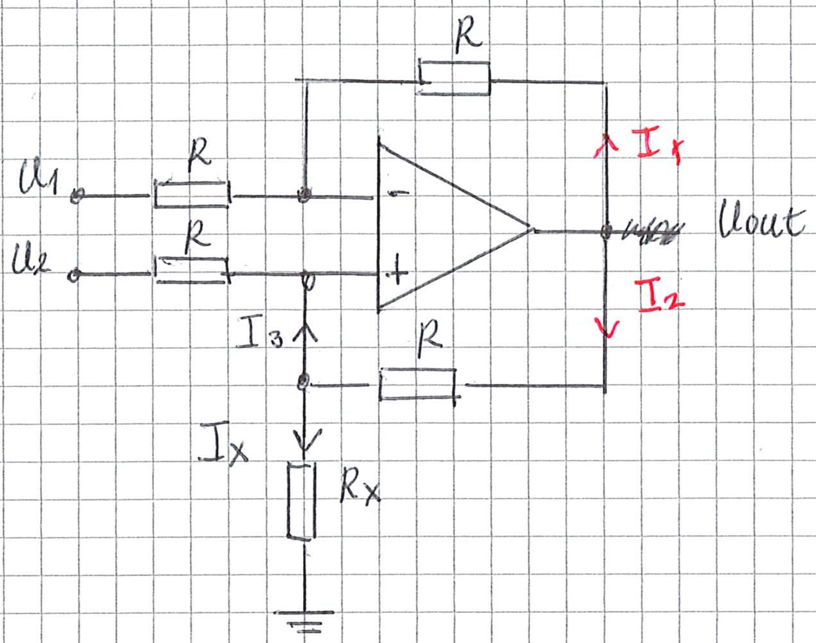
1a)



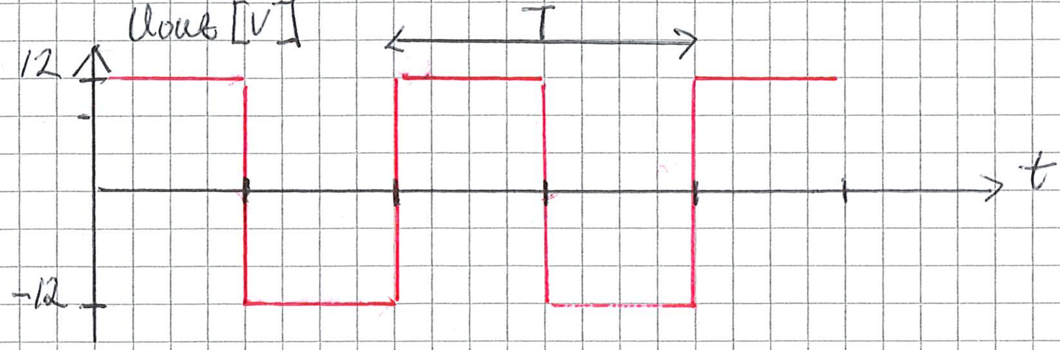
Negative feedback + Ideal OpAmp $\rightarrow U_{IN}^{+} = U_{IN}^{-}$

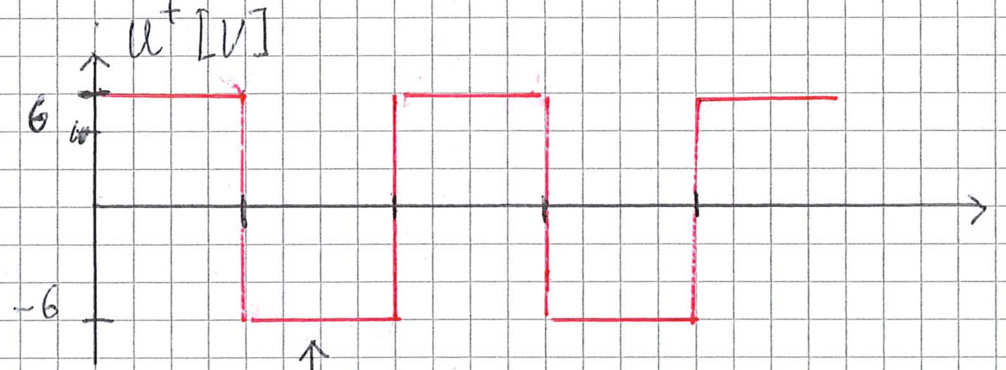
$$\left|\begin{array}{l} U_{IN}^{+} = U_{out} - R I_1 \\ U_{IN}^{-} = U_{out} - R I_2 \end{array}\right) \longrightarrow I_1 = I_2 \quad \text{since } U_{IN}^{+} = U_{IN}^{-}$$

$$\left|\begin{array}{l} U_1 = -R I_1 + U_{IN}^{-} \\ U_2 = -R I_3 + U_{IN}^{+} \\ I_x = I_2 - I_3 = I_1 - I_3 \end{array}\right.$$

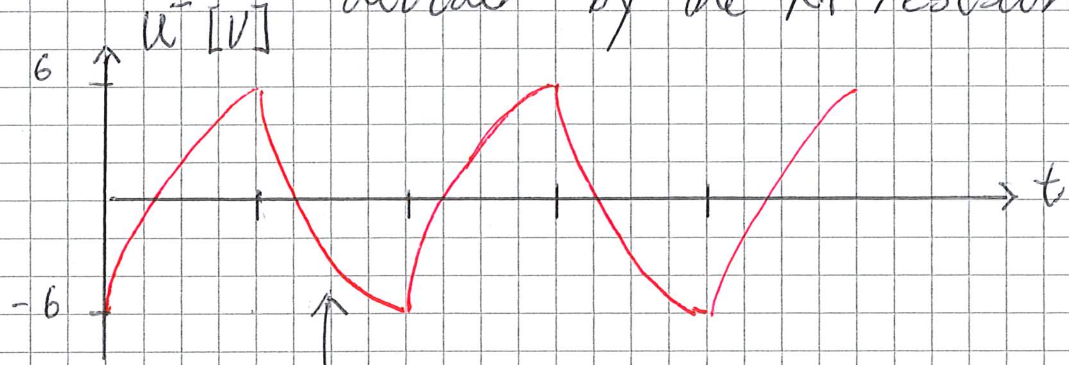
$$I_x = \frac{-U_1 + U_{IN}^{-}}{R} - \frac{-U_2 + U_{IN}^{+}}{R} = /U_{IN}^{+} = U_{IN}^{-}/ = \underline{\frac{U_2 - U_1}{R}} \ [A]$$

1b





Amplitude ±6 [V] since the voltage divider by the R1 resistors.



Charge/discharge of RC circuit. The comparator (with hystrisis) switch state at ±6 [V].

RC-circuit: $U_c(t) = U_s - (U_s - U_{init})\, e^{-t/RC}$, $t > 0$

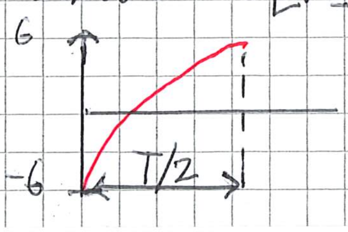
supply voltage

initial charge /voltage of cap.

<u>Identification</u>

$U_s = 12$ [V]

$U_{init} = -6$ [V]



Eq: to solve

$$u_c\left(\frac{T}{2}\right) = 12 - (12 - -6)\, e^{-T/2RC} = 6$$

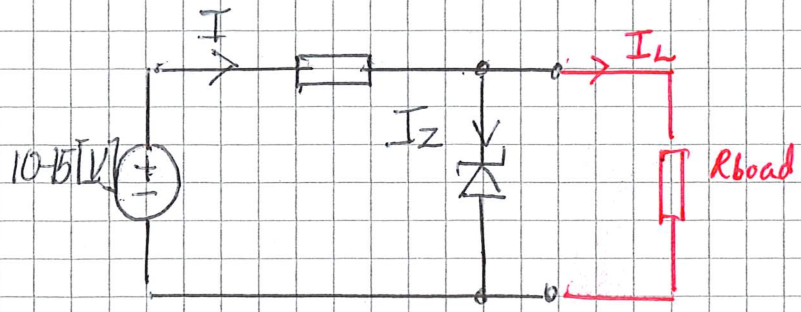
$$\longrightarrow \quad 6 = 18\, e^{-T/2RC}$$

$$\longrightarrow \quad T/(2RC) = \ln(3)$$

$$\longrightarrow \quad T = 2RC \ln(3)$$

$$\longrightarrow \quad T = \underline{RC \ln(9)} \quad [s]$$

2a



$U_Z = 4{,}7\,[V]$

$I_{Z\,min} = 10\,[mA]$ (Minimum backword bias current for zene diod to work)

$P_Z = U_Z \cdot I_Z < 0{,}5\,[W]$

$I_L = 10 - I_{L\,max}\,[mA]$

* Maximum current through diode

$P_Z = U_Z \cdot I_Z < 0{,}5 \longrightarrow I_{Z\,max} \leq P_Z / U_Z = 0{,}5/4{,}7 \approx 106\,[mA]$

* Minimum allowable resistanc

- I_Z is max if $I_L = 10\,[mA]$

$I = I_{Z\,max} + I_L$

$I = \dfrac{U_S - U_Z}{R} \leq \dfrac{15 - 4{,}7}{R}$

$\longrightarrow R \geq \dfrac{15 - 4{,}7}{I_{Z\,max} + I_L} \geq \dfrac{15 - 4{,}7}{0{,}106 + 0{,}01} \approx$ 88,8 Ohm

* Maximum allowable load

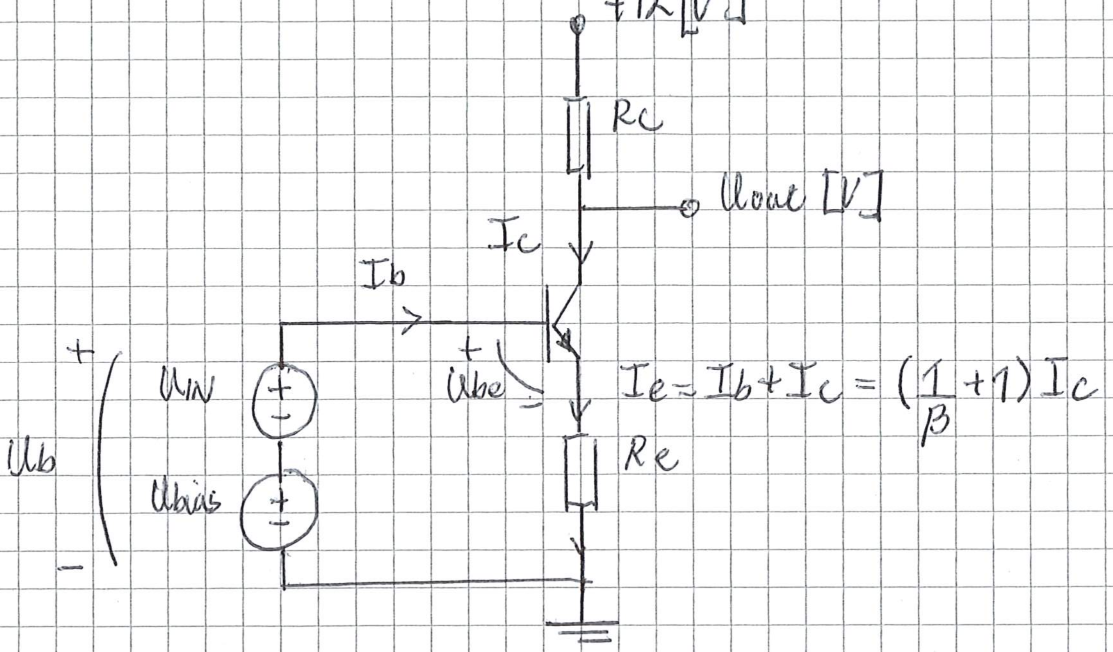
$U_Z = U_S - RI = U_S - R(I_Z + I_{load})$ (Most hold for voltage. reg.)

$\rightarrow I_{load} = \dfrac{U_S - U_Z}{R} - I_Z$

$\rightarrow I_{Z\,min} = 10\,mA$ & $U_{S\,min} = 10\,[V]$

$\longrightarrow I_{L\,max} < \dfrac{10 - 4{,}7}{88.8\ \text{Ohm}} - 10^{-2} \approx$ 45 [mA] 50 [mA]

2b



$$\begin{cases} U_{out} = 12 - R_c \cdot I_c \\ I_e = (U_b - U_{be})/R_e \\ I_c = \beta I_b \\ I_e = (\frac{1}{\beta}+1) I_c \end{cases}$$

$$\longrightarrow U_{out} = 12 - \frac{R_c (U_b - U_{be})}{R_e (\frac{1}{\beta}+1)} = 12 - \frac{R_c (U_{in} + U_{bias} - U_{be})}{R_e (1+\frac{1}{\beta})}$$

- $U_{be} = 0{,}6$ [V], $\beta >> 1$, $U_{IN} = 0{,}1 \sin(t)$ [V]
- We want $U_{out} = 6 - 5\sin(t)$
- 2 unknowns: R_c/R_e & U_{bias} → 2 equ. needed

$t = 0 \rightarrow U_{IN}(t) = 0 \rightarrow U_{out} = 12 - \frac{R_c}{R_e}(+U_{bias} - 0{,}6) = 6$

$t = \pi/2 \rightarrow U_{IN}(t) = 0{,}1 \rightarrow U_{out} = 12 - \frac{R_c}{R_e}(0{,}1 + U_{bias} - 0{,}6) = 1$

$\longrightarrow R_c/R_e = 50$ [-], $U_{bias} = 0{,}18$ [V] 0.72 [V]

3a) Truth table

Digit	X_0	X_1	X_2	D_1	D_2	D_3	D_4	D_5	D_6	D_7
1	1	0	0	0	0	0	1	0	0	0
2	0	1	0	1	0	0	0	0	0	1
3	1	1	0	1	0	0	1	0	0	1
4	0	0	1	1	0	1	0	1	0	1
5	1	0	1	1	0	1	1	1	0	1
6	0	1	1	1	1	1	0	1	1	1
0	0	0	0	–	–	–	–	–	–	–
7	1	1	1	–	–	–	–	–	–	–

Doesn't matter

K-map ~~Truth~~ table D_1 & D_7

X_0 \ X_1X_2	00	01	11	10
0	–	1	1	1
1	0	1	–	1

$D_7 = D_1 = \overline{X_0} + X_1 + X_2$

Red circle is wrong. x_0 not need

K-map ~~Truth~~ table D_2 & D_6

X_0 \ X_1X_2	00	01	11	10
0	–	0	1	0
1	0	0	–	0

$D_6 = D_2 = X_1 X_2$

K-map ~~Truth~~ table D_3 & D_5

X_0 \ X_1X_2	00	01	11	10
0	–	1	1	0
1	0	1	–	0

$D_3 = D_5 = X_2$

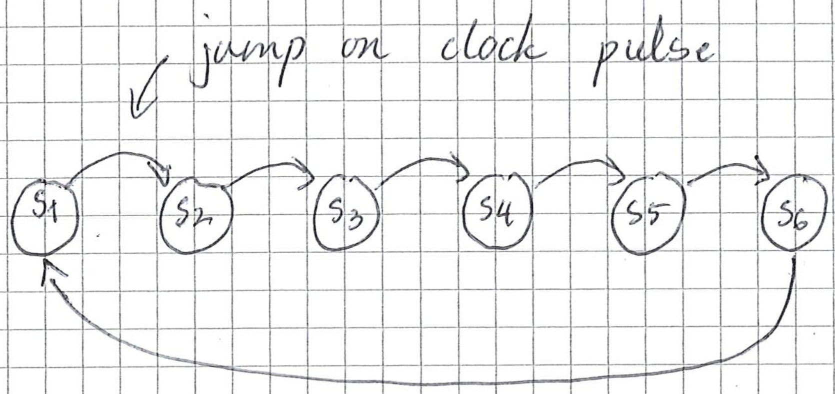
K-map

~~Truth~~ table D4

X_0 \ X_1X_2	00	01	11	10
0	–	0	0	0
1	1	1	–	1

$D4 = X_0$

3b)



6 states → 3 flip-flops (memory states)

state	coding			state$^+$	coding$^+$		
S_i	X_0	X_1	X_2	S_i^+	X_0^+	X_1^+	X_2^+
1	1	0	0	2	0	1	0
2	0	1	0	3	1	1	0
3	1	1	0	4	0	0	1
4	0	0	1	5	1	0	1
5	1	0	1	6	0	1	1
6	0	1	1	1	1	0	0

K-map X_0^+

X_0 \ X_1X_2	00	01	11	10
0	–	1	1	1
1	0	0	–	0

$X_0^+ = \overline{X_0}$

K-map X_1^+

$X_0 \backslash X_1X_2$	00	01	11	10
0	–	0	0	1
1	1	1	–	0

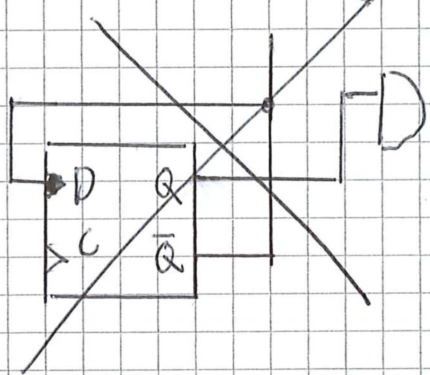
$$X_1^+ = \overline{X_0}\,\overline{X_2} + X_0\overline{X_1}$$

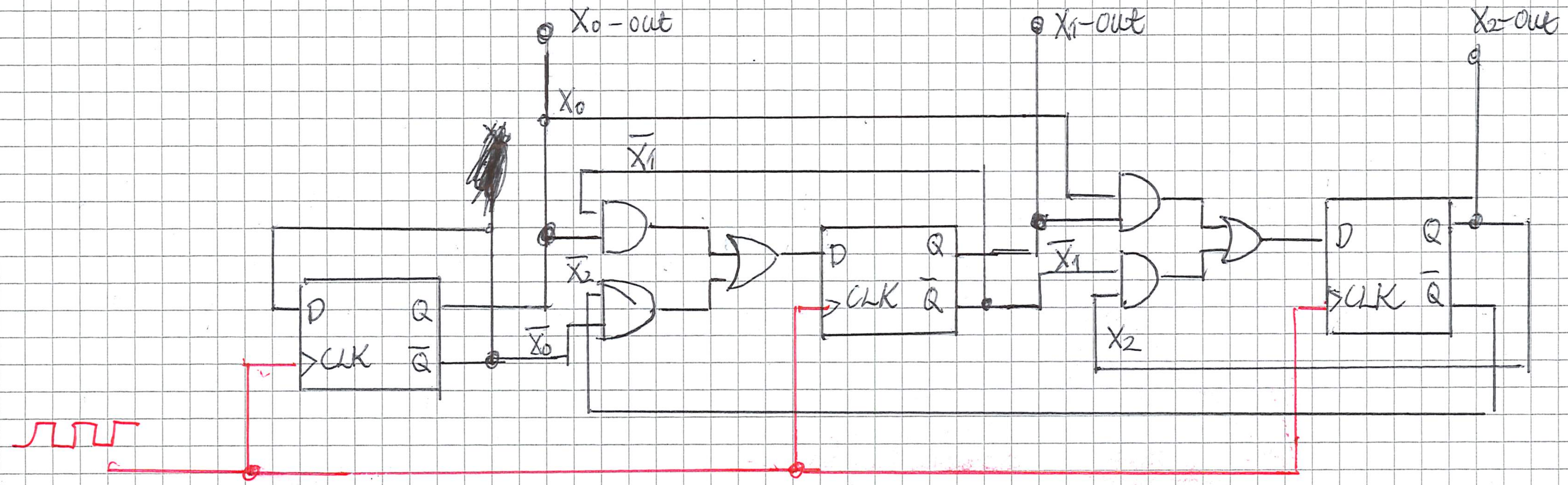
K-map X_2^+

$X_0 \backslash X_1X_2$	00	01	11	10
0	–	1	0	0
1	0	1	–	1

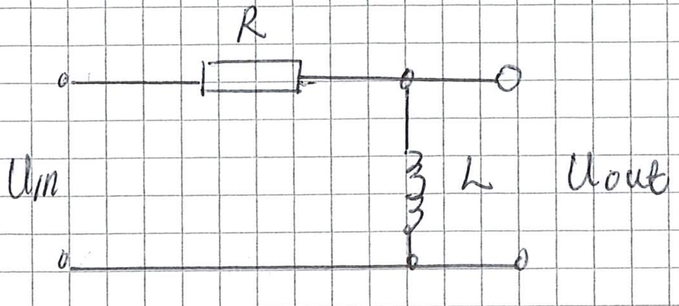
$$X_2^+ = \overline{X_1}X_2 + X_0X_1$$

See next page




X0 - out
X1-out
X2-out
X0
X1
X2
X0
X1
X2
D
Q
CLK
Q

4a



$U_{in} = A\cos(\omega t)$

$$H(j\omega) = \frac{U^c_{out}}{U^c_{in}} = \frac{\frac{Z_L}{Z_L+Z_R} \cdot U^c_{IN}}{U^c_{IN}} = \frac{Z_L}{Z_L+Z_R} =$$

$$= \frac{j\omega L}{j\omega L + R} = |H(j\omega)|\, e^{j\angle H(j\omega)}$$

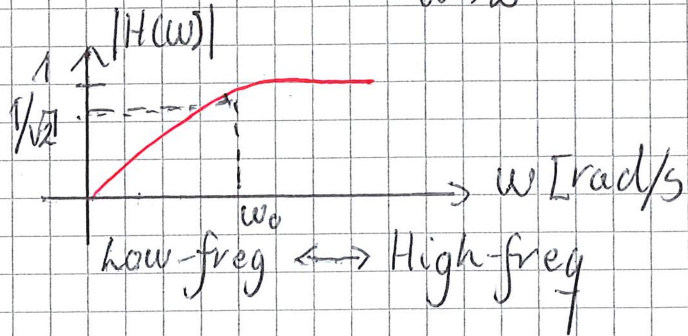
$$|H(j\omega)|^2 = H(j\omega) \cdot H^*(j\omega) = \frac{j\omega L}{j\omega L + R} \cdot \frac{-j\omega L}{-j\omega L + R} = \frac{\omega^2 L^2}{\omega^2 L^2 + R^2}$$

$$\angle H(j\omega) = \angle j\omega L - \angle j\omega L + R = \frac{\pi}{2} - \arctan(\omega L/R)$$

$$\longrightarrow H(j\omega) = \frac{\omega L}{\sqrt{\omega^2 L^2 + R^2}} \cdot e^{j\left(\frac{\pi}{2} - \arctan(\omega L/R)\right)}$$

4b

$|H(0)| = 0 \qquad \lim_{\omega \to \infty} |H(\omega)| = 1$



$\longrightarrow$ HP-filter

4c

$$|H(\omega_0)| = \frac{1}{\sqrt{2}} \lim_{\omega \to \infty} |H(\omega)| \longrightarrow \frac{\omega_0^2 L^2}{\omega_0^2 L^2 + R^2} = \frac{1}{2}$$

$$\longrightarrow 2\omega_0^2 L^2 = \omega_0^2 L^2 + R^2 \longrightarrow \omega_0^2 = R^2/L^2$$

$$\longrightarrow \omega_0 = R/L \text{ [rad/s]}$$

LTI-system (passive RLC components)

4d) | sin-in $\rightarrow$ sin-out

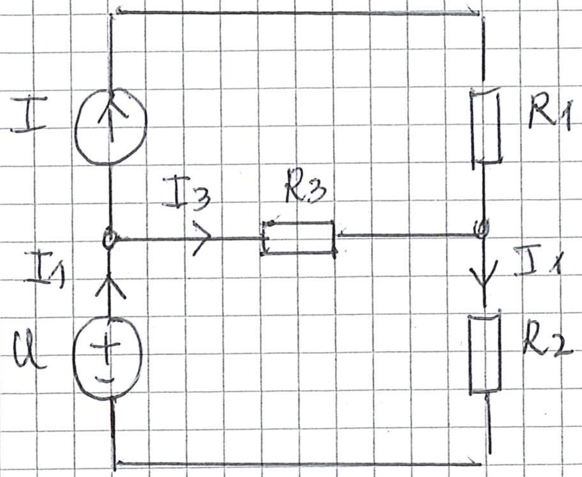
| $ax_1 + bx_2 \rightarrow ay_1 + by_2$ (linear sys)

$$\rightarrow u_{out}(t) = |H(j\omega_0)| \cdot A\cos(\omega_0 t + \angle H(j\omega_0))$$

$$+ |H(j\omega_0)| \cdot B\sin(\omega_0 t + \angle H(j\omega_0)) =$$

$$= \frac{A}{\sqrt{2}} \cos\left(\omega_0 t + \frac{3\pi}{4}\right) + \frac{B}{\sqrt{2}} \sin\left(\omega_0 t + \frac{3\pi}{4}\right) [V]$$

5a)



$$\begin{cases} I_1 = I + I_3 & (KCL) \\ U - R_3 I_3 - I_1 R_2 = 0 & (KVL) \end{cases}$$

$\rightarrow U - R_3 I_3 - (I + I_3) R_2 = 0$

$\rightarrow I_3 (R_2 - R_3) = -U + I R_2$

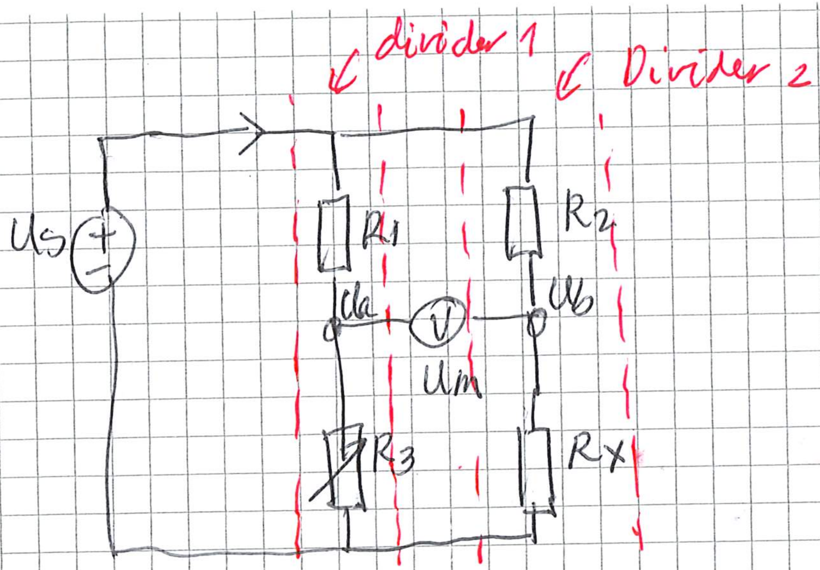
$\longrightarrow I_3 = \dfrac{U - I R_2}{R_3 \boxed{+} R_2} \quad [A]$

=U(R2+R3)/(U+I*R3)

$R_{equ} = U / I_1 = \ldots R_2 =$

$= \dfrac{U(R_3 - R_2 \ldots}{U + I(R_3 \ldots}$

5b)



If $U_m = 0\,[V]$ then $I_m = 0\,[A]$. $\rightarrow$ The 2 voltage dividers can be treated separately.

$$U_a = \frac{R_3}{R_1 + R_3} \cdot U_s \qquad U_b = \frac{R_x}{R_x + R_2} \cdot U_s$$

$$U_a = U_b \longrightarrow \frac{R_3}{R_1 + R_3} = \frac{R_x}{R_x + R_2}$$

$$\longrightarrow \frac{1}{1 + \frac{R_1}{R_3}} = \frac{1}{1 + \frac{R_2}{R_x}}$$

$$\longrightarrow \frac{R_1}{R_3} = \frac{R_2}{R_x}$$

$$\longrightarrow R_x = \frac{R_2 \cdot R_3}{R_1}\ [\Omega]$$