

$$x \begin{bmatrix} \theta_p \\ \theta_c \end{bmatrix} \quad u \begin{bmatrix} u_c \\ \theta_e \end{bmatrix}$$

$$H_1(s) = k_E$$

$$H_2(s) = \frac{1}{k_p}$$

$$H_3(s) = \frac{1}{s T_p}$$

$$H_4(s) = 1$$

$$H_5(s) = k_p/k_c$$

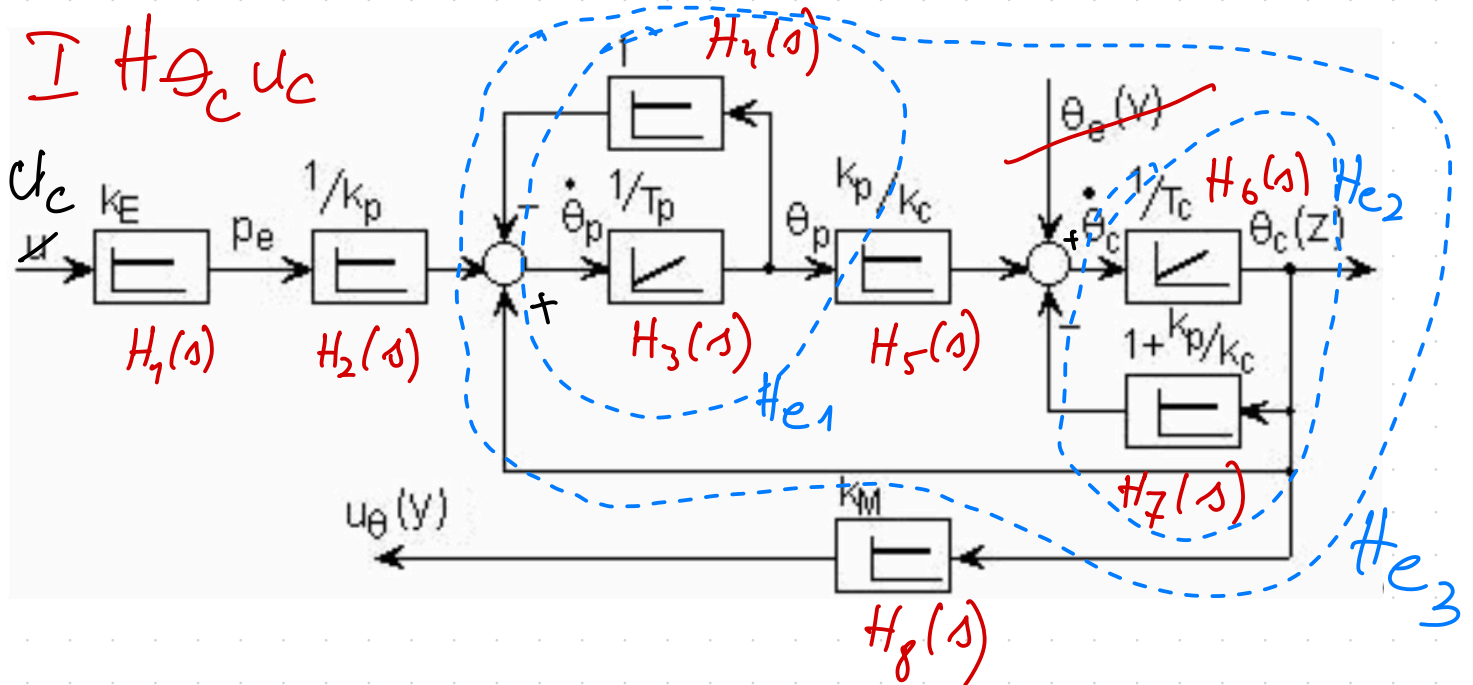
$$H_6(s) = \frac{1}{s T_c}$$

$$H_7(s) = 1 + k_p/k_c$$

$$H_8(s) = k_M$$

| Tipul ET | Simbolizare | Funcția de transfer în timp continuu |
|----------|-------------|--------------------------------------|
| P        |             | $H(s) = k$                           |
| I        |             | $H(s) = \frac{k_i}{s}$               |
| D        |             | $H(s) = s k_D$                       |
| PT1      |             | $H(s) = \frac{k}{sT + 1}$            |
| PI       |             | $H(s) = \frac{k}{sT} (sT + 1)$       |

I H<sub>Θ<sub>c</sub>u<sub>c</sub></sub>



$$H_{e1} = \frac{H_3(s)}{1 + H_3(s) H_4(s)} = \frac{\frac{1}{sT_p}}{1 + \frac{1}{sT_p} \cdot 1} = \frac{1}{sT_p + 1} = \frac{1}{sT_p + 1}$$

$$H_{e2}(s) = \frac{H_6(s)}{1 + H_6(s) H_7(s)} = \frac{\frac{1}{sT_c}}{1 + \frac{1}{sT_c} (1 + k_p/k_c)} = \frac{1}{sT_c + k_p/k_c + 1}$$

$$H_{e3}(s) = \frac{H_{e1}(s) H_5(s) \cdot H_{e2}(s)}{1 - H_{e1}(s) H_5(s) \cdot H_{e2}(s)} =$$

$$\frac{1}{sT_p + 1} \cdot \frac{k_p}{k_c} \cdot \frac{1}{sT_c + k_p/k_c + 1} =$$

$$k_p/k_c$$

$$= \frac{k_p/k_c}{s^2 T_p T_c + s T_p k_p/k_c + s T_p + s T_c + k_p/k_c + 1}$$

$$H_{e3}(s) = \frac{\frac{k_p/k_c}{(s)}}{1 - \frac{k_p/k_c}{(s)}} = \frac{k_p/k_c}{(s) - k_p/k_c} = \frac{k_p/k_c}{s^2 T_p T_c + s(T_p k_p/k_c + T_p + T_c) + 1}$$

$$H_{\mathcal{D}_C \cup C}(s) = H_1(s) \cdot H_2(s) \cdot H_{e_3}(s)$$

$$H_{e_3}(s) = \frac{H_{e_1}(s) \cdot H_5(s) \cdot H_{e_2}(s)}{1 - H_{e_1}(s) H_5(s) \cdot H_{e_2}(s)}$$

$$H_{e_2}(s) = \frac{H_6(s)}{1 + H_6(s) H_7(s)}$$

$$H_{e_1}(s) = \frac{H_3(s)}{1 + H_3(s) H_4(s)}$$

$$H_{e_3}(s) = \frac{\frac{H_3(s)}{1 + H_3(s) H_4(s)} \cdot H_5(s) \cdot \frac{H_6(s)}{1 + H_6(s) H_7(s)}}{1 - \frac{H_3(s)}{1 + H_3(s) H_4(s)} \cdot H_5(s) \cdot \frac{H_6(s)}{1 + H_6(s) H_7(s)}}$$

$$\frac{H_3(s)}{1 + H_3(s) H_4(s)} \cdot H_5(s) \cdot \frac{H_6(s)}{1 + H_6(s) H_7(s)} = \frac{H_3(s) H_5(s) H_6(s)}{1 + H_3(s) H_4(s) + H_6(s) H_7(s) + H_5(s) H_4(s) H_6(s) H_7(s)}$$

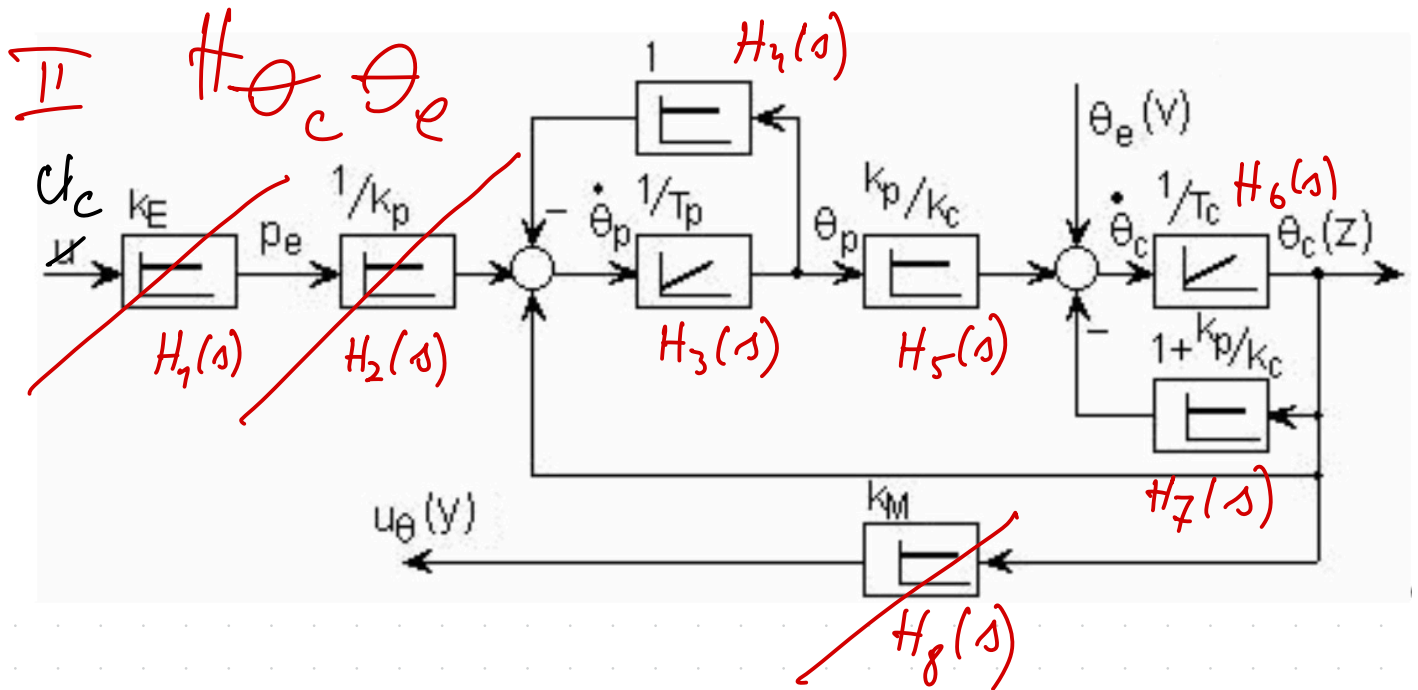
$$\mathcal{D}_C \rightarrow H_1 \rightarrow H_2 \rightarrow H_{e_3} \rightarrow \mathcal{D}_C$$

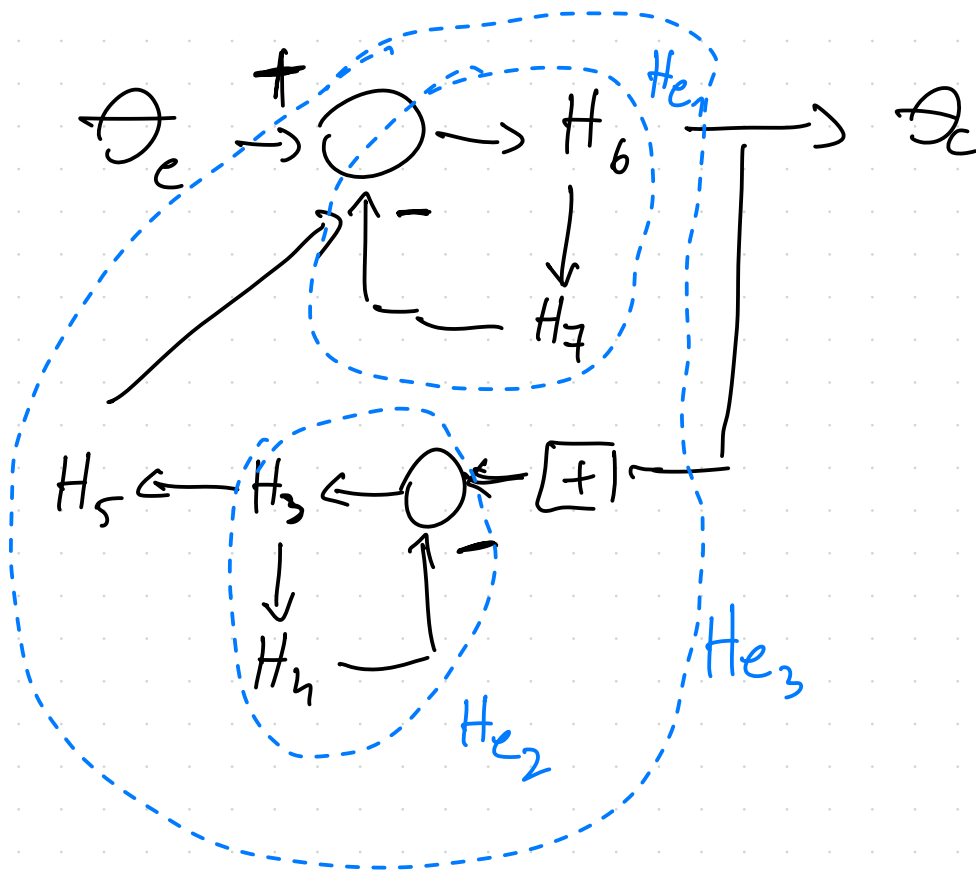
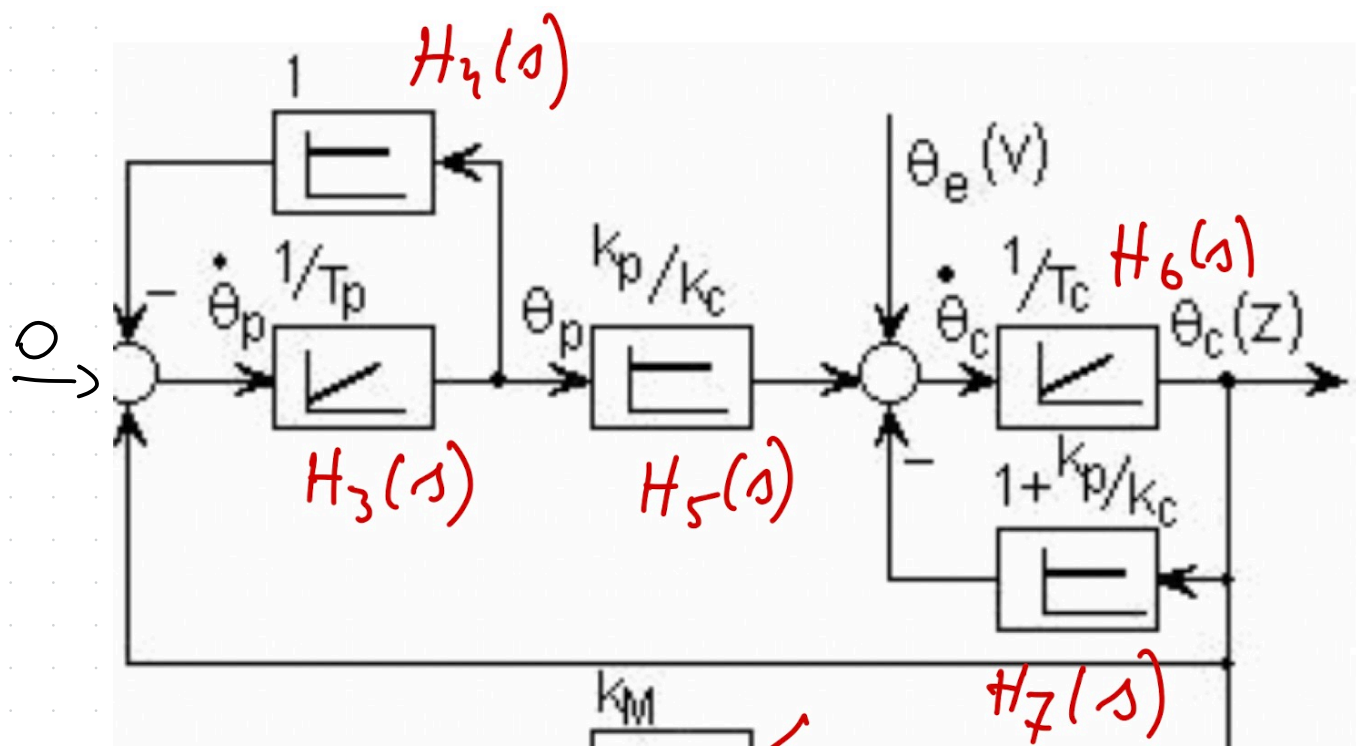
$$H_{\theta_c, u_c}(s) = \frac{H_1(s) H_2(s) H_3(s) H_4(s) H_6(s)}{1 + H_3(s) H_4(s) + H_6(s) H_7(s) + H_3(s) H_4(s) H_6(s) H_7(s)}$$

$$H_{\theta_c, u_c}(s) = H_1(s) H_2(s) \cdot H_6(s)$$

$$= k_E / \cancel{k_p} \cdot \frac{\cancel{k_p} / k_c}{s^2 T_p T_c + s(T_p k_p / k_c + T_p + T_c) + 1} = \frac{k_E / k_c}{s^2 T_p T_c + s(T_p k_p / k_c + T_p + T_c) + 1}$$

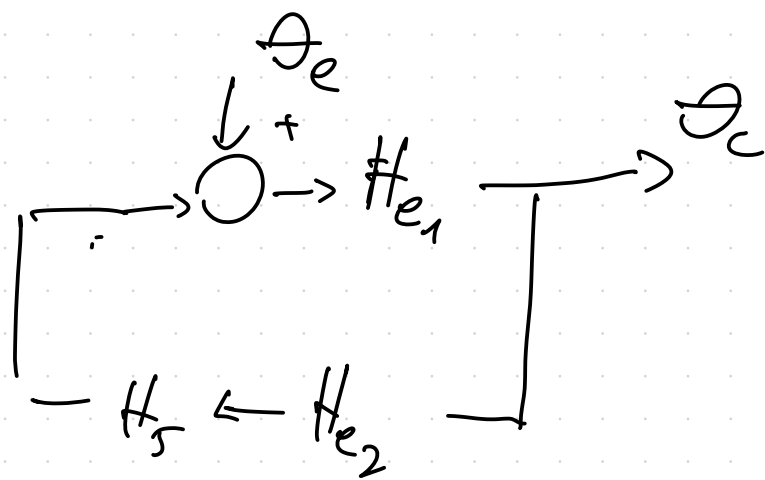
$$H_{\theta_c, u_c}(s) = \frac{k_E / k_c}{s^2 T_p T_c + s(T_p k_p / k_c + T_p + T_c) + 1}$$





$$H_{e1}(s) = \frac{H_6(s)}{1 + H_6(s)H_7(s)} = \frac{1}{sT_c + k_p/k_c + 1}$$

$$H_{e2}(s) = \frac{H_3(s)}{1 + H_3(s)H_2(s)} = \frac{1}{sT_p + 1}$$



$$H_{\Theta_c, \Theta_e}(s) = \frac{H_{e1}(s)}{1 - H_{e1}(s) H_{e2}(s) H_s}$$

$$e_1 = \frac{1}{sT_c + kp/k_c + 1}$$

$$e_2 = \frac{1}{sT_p + 1}$$

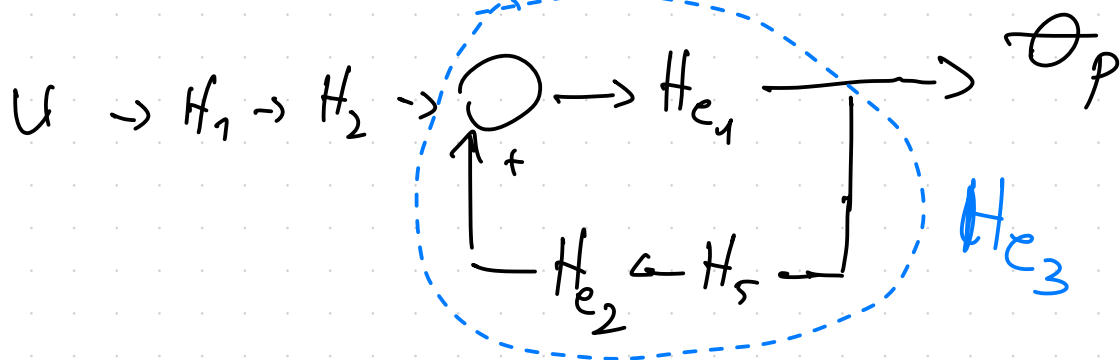
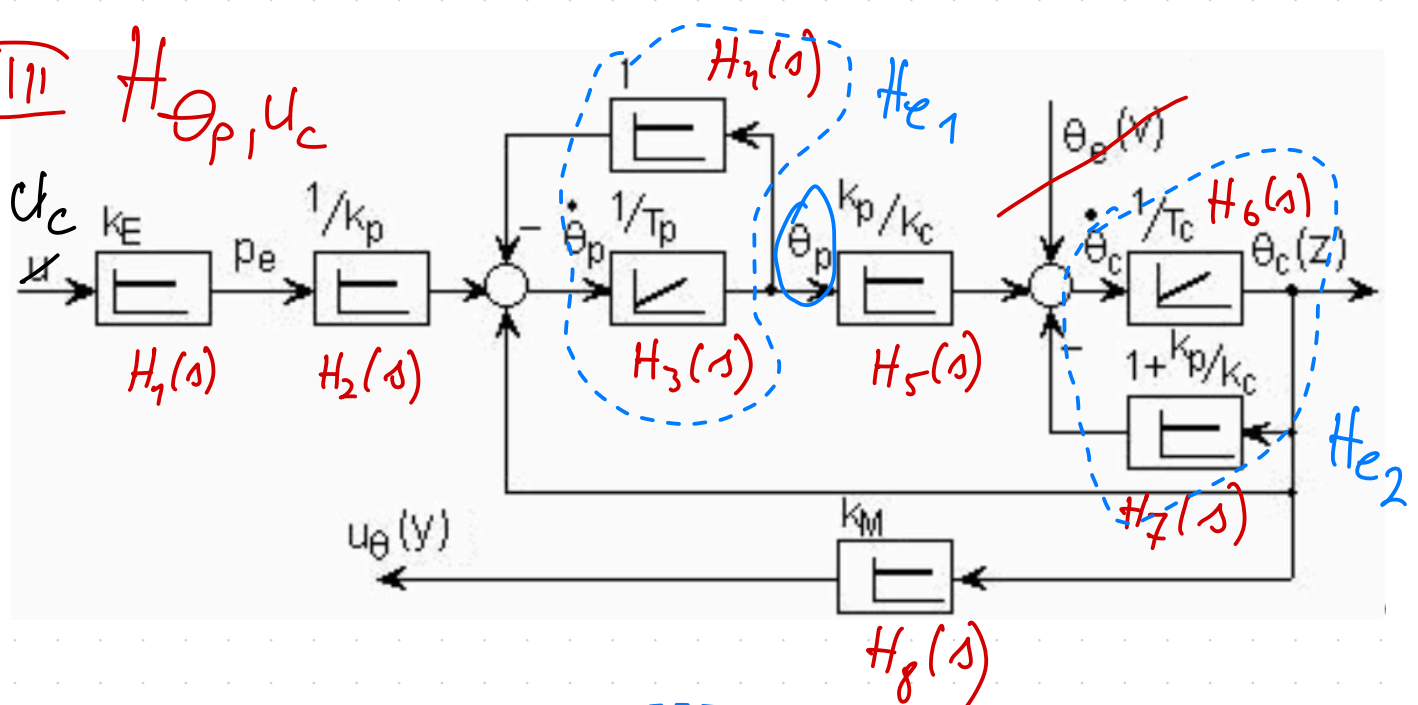
$$H_{\Theta_c, \Theta_e}(s) = \frac{1}{sT_c + kp/k_c + 1} \cdot \frac{1}{1 - \frac{1}{sT_c + kp/k_c + 1} \cdot \frac{1}{sT_p + 1} \cdot \frac{kp}{k_c}}$$

$$= \frac{1}{sT_c + kp/k_c + 1} \cdot \frac{(sT_c + kp/k_c + 1)(sT_p + 1)k_c - kp}{(sT_c + kp/k_c + 1)(sT_p + 1)k_c}$$

$$H_{\Theta_c, \Theta_e}(s) = \frac{(sT_p + 1)k_c}{s^2 k_c T_p T_c + s k_c T_p + s k_p T_p + s k_c T_c + k_c}$$

$$H_{\Theta_c, \Theta_e}(s) = \frac{sT_p + 1}{s^2 T_p T_c + sT_p + T_p kp/k_c + sT_c + 1}$$

III  $H_{\theta_p, u_c}$



$$H_{e3}(s) = \frac{H_{e1}(s)}{1 - H_{e1}(s) H_{e2}(s) H_{e5}(s)}$$

$$H_{e1}(s) = \frac{1}{sT+1} \quad H_{e2}(s) = \frac{1}{sT_c + k_p/k_c + 1}$$

$$H_{e3}(s) = \frac{\frac{1}{sT+1}}{1 - \left(\frac{1}{sT+1}\right) \left(\frac{1}{sT_c + k_p/k_c + 1}\right) \cdot \frac{k_p}{k_c}}$$

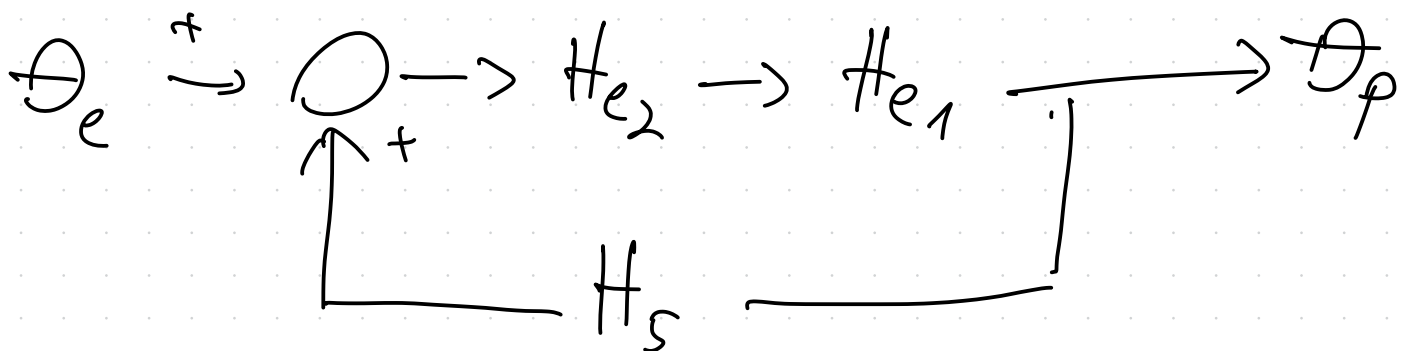
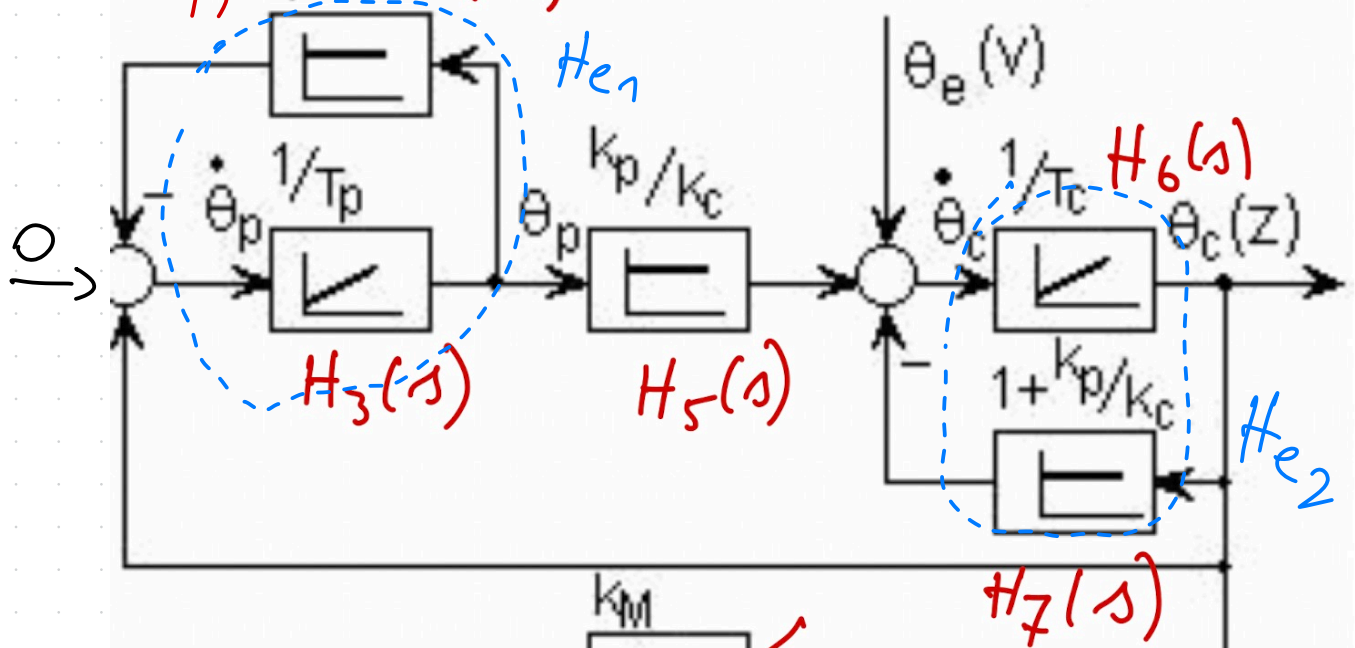
$$H_{e3}(s) = \frac{1}{sT+1} \cdot \frac{(sT+1)(sT_c + k_p/k_c + 1) k_c}{(sT+1)(sT_c + k_p/k_c + 1) k_c - k_p}$$

$$H_{\theta_p, u_c}(s) = H_1(s) H_2(s) H_3(s)$$

$$= \frac{k_E}{k_p} \cdot \frac{s T_c + k_p/k_c + 1}{s^2 k_c T_p T_c + s k_c T_p + s k_p T_p + s k_c T_c + k_c}$$

$$H_{\theta_p, u_c}(s) = \frac{s T_c k_E/k_p + k_E/k_c + k_E/k_p}{s^2 k_c T_p T_c + s k_c T_p + s k_p T_p + s k_c T_c + k_c}$$

IV  $H_{\theta_p, \theta_e}(s)$





$$H_{\theta_p \theta_e}(s) = \frac{H_{e_1}(s) H_{e_2}(s)}{1 - H_{e_1}(s) H_{e_2}(s) H_s(s)}$$

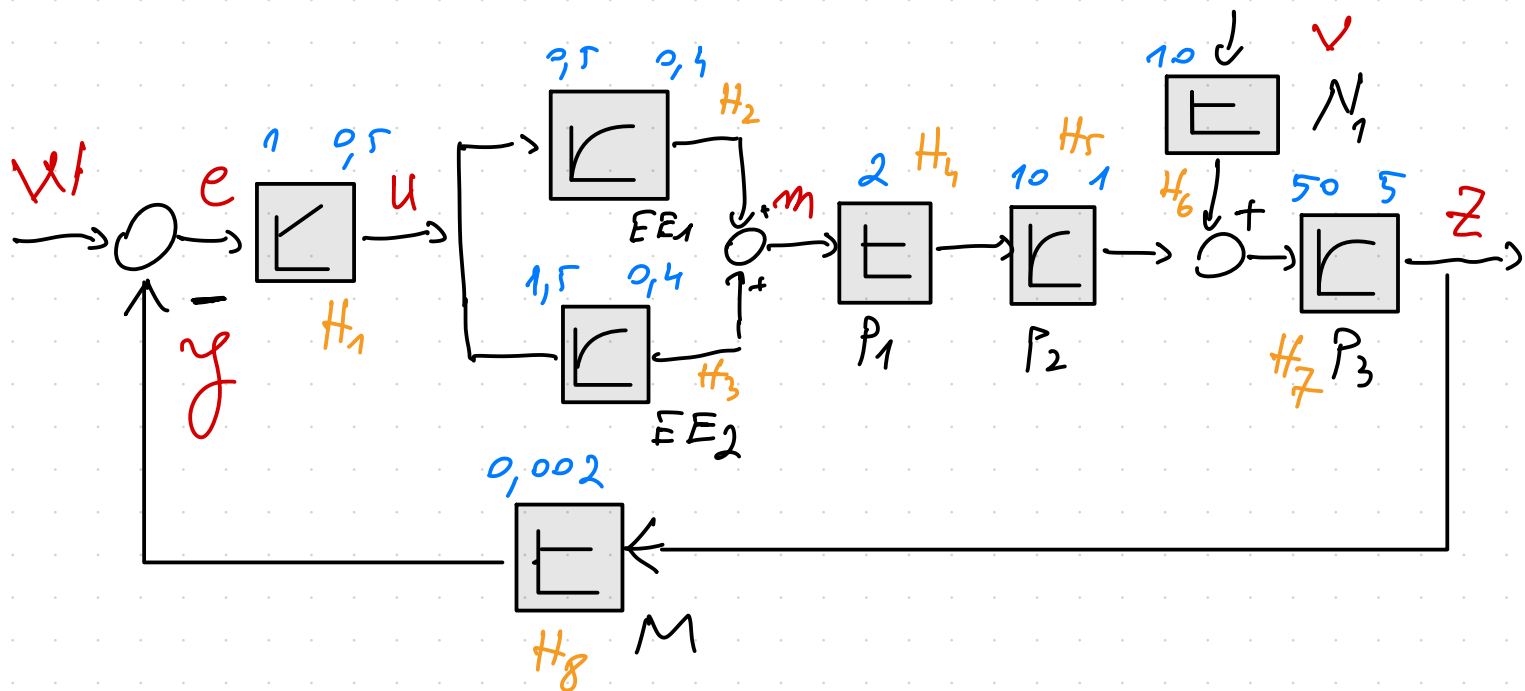
$$H_{e_1}(s) = \frac{1}{sT_p + 1} \quad H_{e_2}(s) = \frac{1}{sT_c + k_p/k_c + 1}$$

$$H_{\theta_p \theta_e}(s) = \frac{H_{e_1}(s) H_{e_2}(s)}{1 - \left(\frac{1}{sT_p + 1}\right) \left(\frac{1}{sT_c + k_p/k_c + 1}\right) \cdot \frac{k_p}{k_c}}$$

$$H_{\theta_p \theta_e}(s) = \frac{\frac{1}{sT_p + 1} \cdot \frac{1}{sT_c + k_p/k_c + 1}}{(sT_p + 1)(sT_c + k_p/k_c + 1)k_c - k_p}$$

$$\frac{\cancel{(sT_p + 1)} \cancel{(sT_c + k_p/k_c + 1)} k_c}{\cancel{(sT_p + 1)} \cancel{(sT_c + k_p/k_c + 1)} k_c}$$

$$H_{\theta_p \theta_e}(s) = \frac{1}{s^2 T_p T_c + s T_p k_p/k_c + sT_p + sT_c + k_p/k_c + 1}$$



$$H_1(s) = \frac{k}{sT} (sT + 1) = \frac{1}{s \cdot \frac{1}{2}} \left( s \frac{1}{2} + 1 \right) = \frac{\frac{s}{2} + 1}{\frac{s}{2}} = \frac{s+2}{s}$$

$$H_2(s) = \frac{k}{sT+1} = \frac{0,5}{s(0,4)+1} = \frac{\frac{1}{2}}{\frac{4s}{10}+1} = \frac{\frac{1}{2}}{\frac{4s+10}{10}} = \frac{5}{4s+10}$$

$$H_3(s) = \frac{1,5}{s(0,4)+1} = \frac{\frac{3}{2}}{\frac{4s+10}{10}} = \frac{15}{4s+10}$$

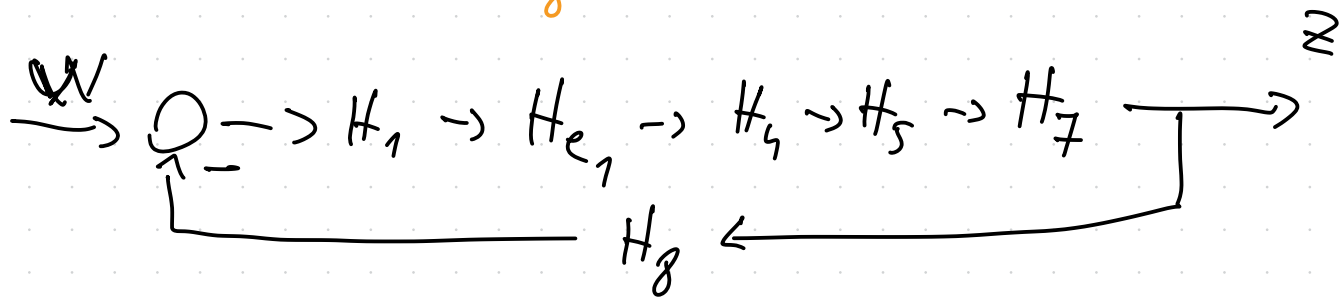
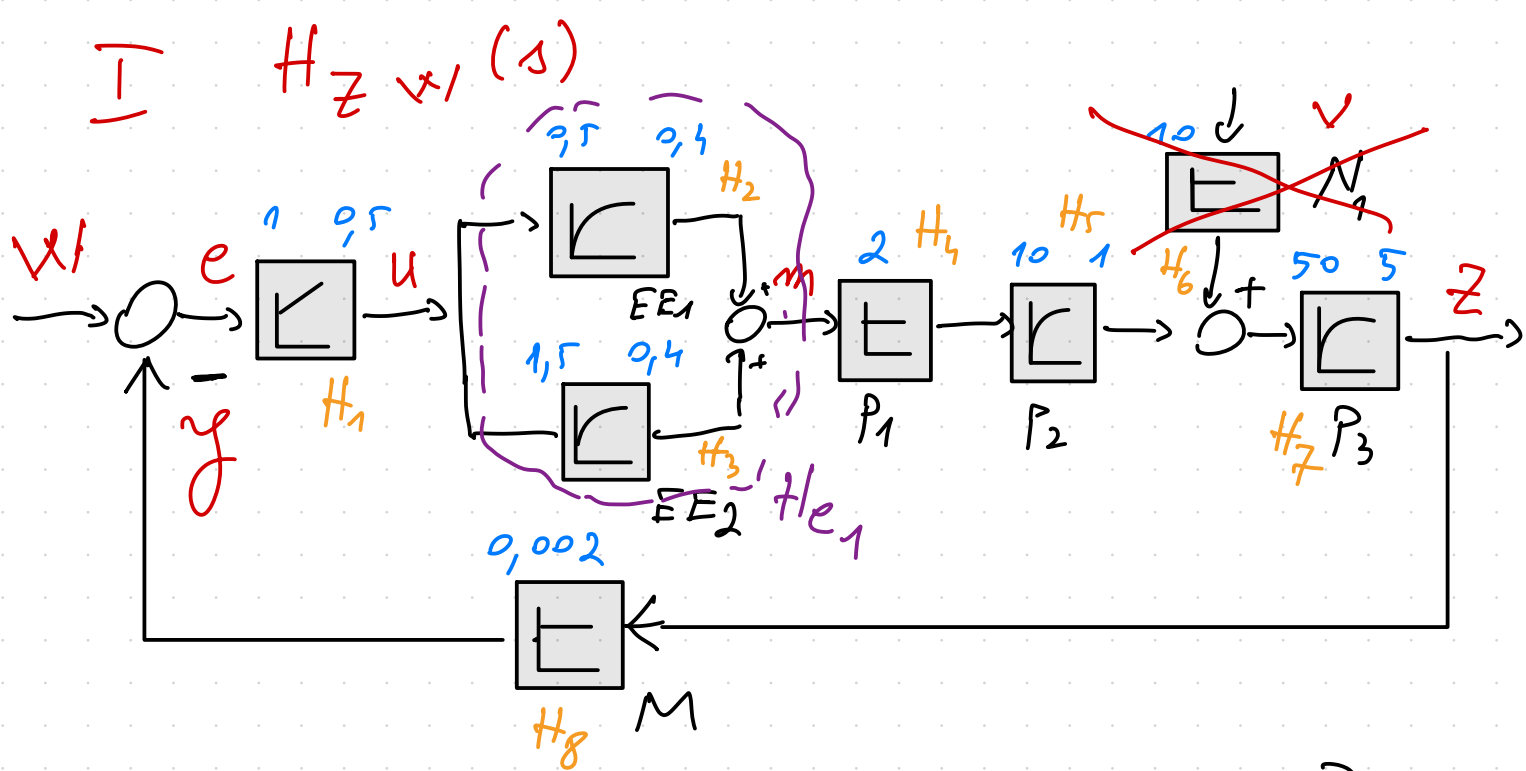
$$H_4(s) = 2$$

$$H_5(s) = \frac{10}{s+1}$$

$$H_6(s) = 10$$

$$H_7(s) = \frac{50}{5s+1}$$

$$H_8(s) = 0,002 = \frac{2}{1000}$$



$$H_{zw}(s) = \frac{H_1(s)(H_2(s) + H_3(s))H_4(s)H_5(s)H_7(s)}{1 + H_1(s)(H_2(s) + H_3(s))H_4(s)H_5(s)H_7(s)H_8(s)}$$

$$H_1(s)(H_2(s) + H_3(s))H_4(s)H_5(s)H_7(s) = \frac{s+2}{s} \cdot \frac{20}{4s+40} \cdot 2 \cdot \frac{10}{s+1} \cdot \frac{50}{5s+1}$$

$$= \frac{10^4 (s+2)}{s(s+1)(2s+5)(5s+1)}$$

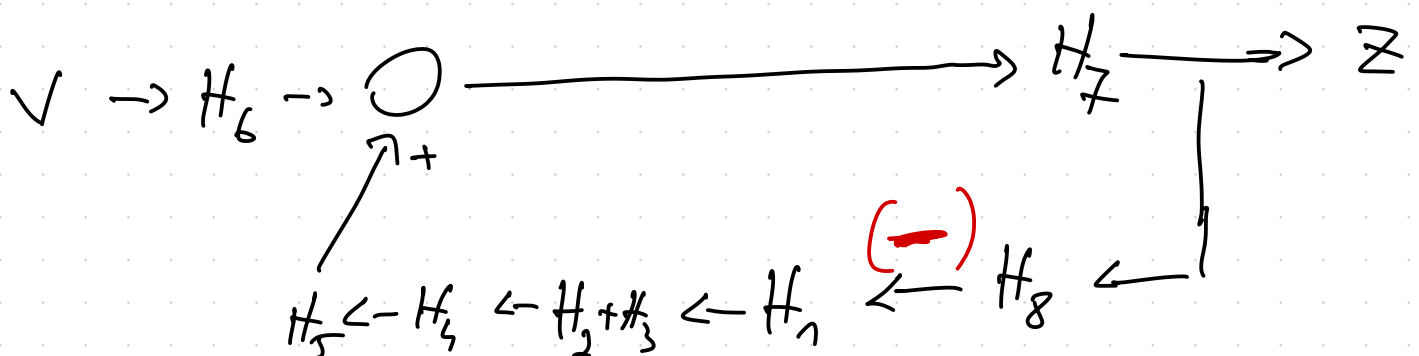
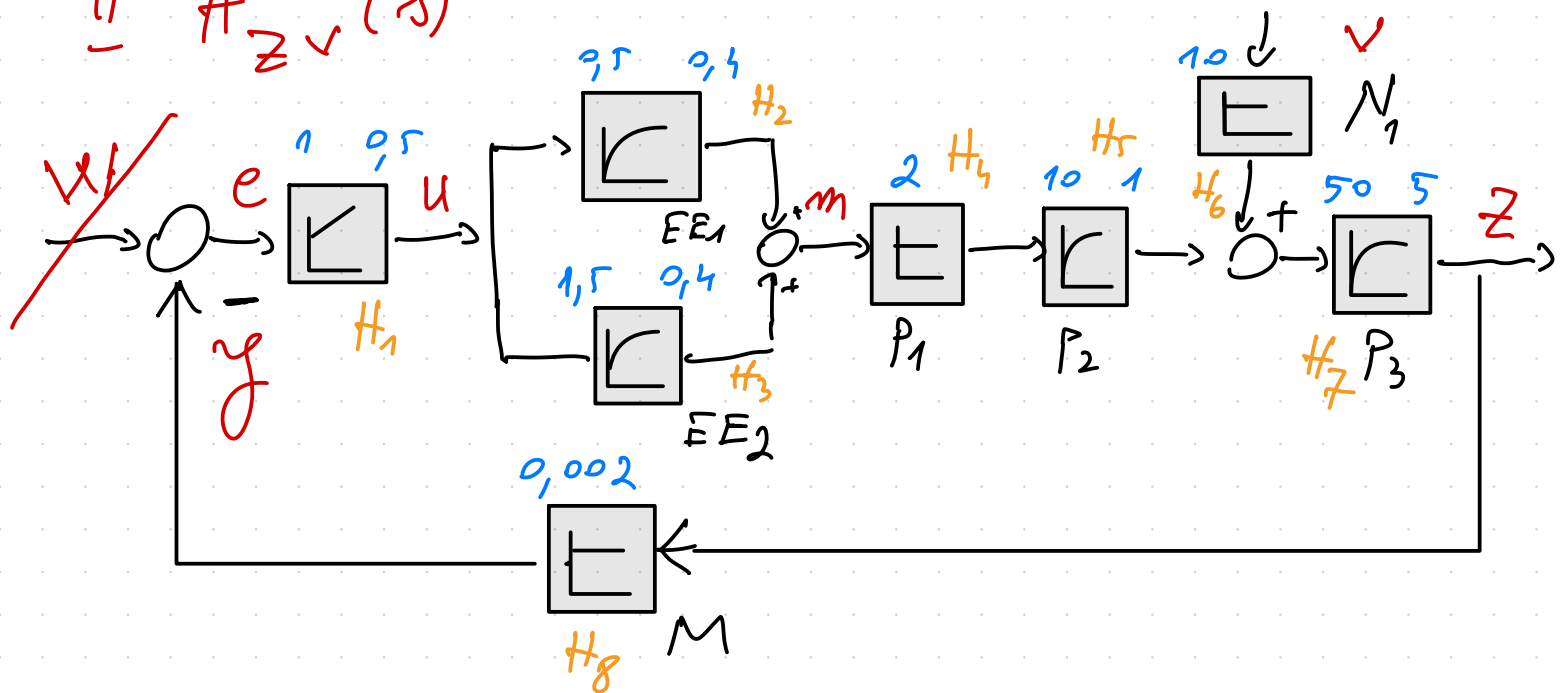
$$H_{zw}(s) = \frac{\frac{10^4 (s+2)}{s(s+1)(2s+5)(5s+1)}}{1 + \frac{20(s+2)}{s(s+1)(2s+5)(5s+1)}}$$

$$H_{ZW}(s) = \frac{\frac{10^4 (s+2)}{s(s+1)(2s+5)(5s+1)}}{1 + \frac{20(s+2)}{s(s+1)(2s+5)(5s+1)}} =$$

$$= \frac{10^4 (s+2)}{\cancel{s}} \cdot \frac{\cancel{(s+1)(2s+5)(5s+1)}}{(s+1)(2s+5)(5s+1) + 20(s+2)} = \frac{10^4 (s+2)}{(s+1)(2s+5)(5s+1) + 20(s+2)}$$

$$H_{ZW}(s) = \frac{10^4 (s+2)}{s(s+1)(2s+5)(5s+1) + 20(s+2)}$$

II  $H_{ZV}(s)$



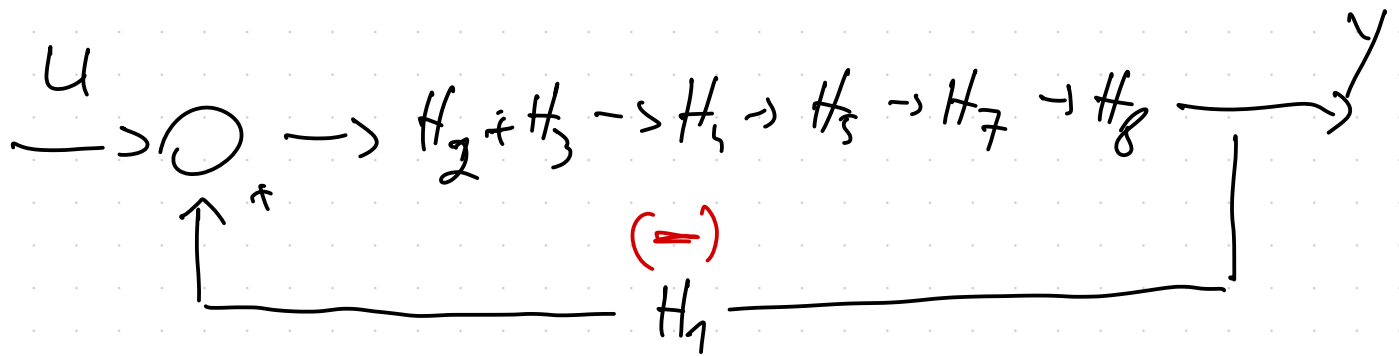
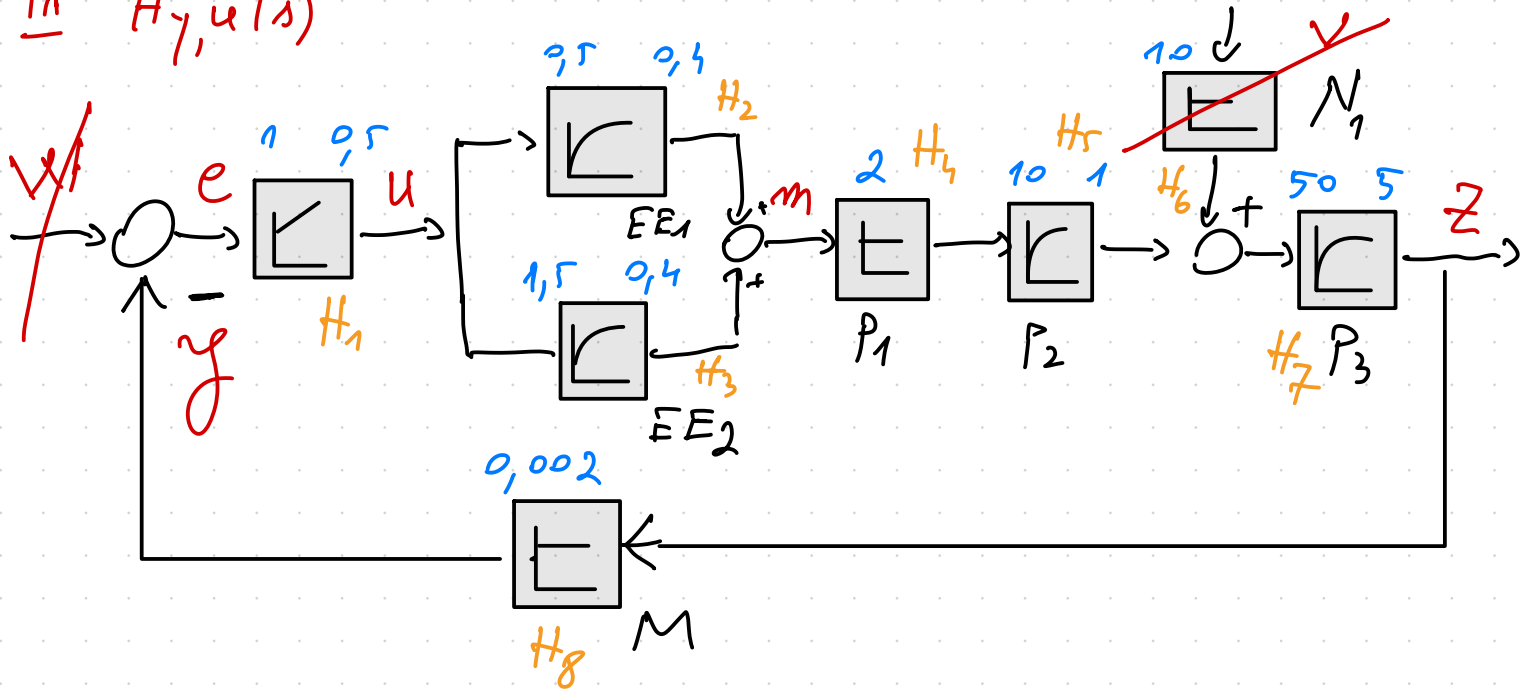
$$H_{z,v}(s) = H_6(s) \cdot \frac{H_7(s)}{1 + H_7(s)(H_2(s) + H_3(s))H_4(s)H_5(s)H_7(s)H_8(s)}$$

$$H_{z,v}(s) = 10 \cdot \frac{\frac{50}{s+1}}{1 + \frac{20(s+2)}{s(s+1)(2s+5)(s+1)}}$$

$$= \frac{500}{s+1} \cdot \frac{s(s+1)(2s+5)\cancel{(s+1)}}{s(s+1)(2s+5)(s+1) + 20(s+2)}$$

$$H_{z,v}(s) = \frac{500 s(s+1)(2s+5)}{s(s+1)(2s+5)(s+1) + 20(s+2)}$$

III  $H_{y,u}(s)$



$$H_{y,u}(s) = \frac{(H_2^{(1)} + H_3^{(1)}) H_4^{(1)} H_5^{(1)} H_7^{(1)} H_8^{(1)}}{1 - (-H_1^{(1)}) (H_2^{(1)} + H_3^{(1)}) H_4^{(1)} H_5^{(1)} H_7^{(1)} H_8^{(1)}}$$

$$H_{y,u}(s) = \frac{\frac{10}{2s+5} \cdot 2 \cdot \frac{10}{s+1} \cdot \frac{50}{5s+1} \cdot \frac{2}{1000}}{1 + \frac{s+2}{s} \cdot \frac{10}{2s+5} \cdot 2 \cdot \frac{10}{s+1} \cdot \frac{50}{5s+1} \cdot \frac{2}{1000}}$$

$$H_{y,u}(s) = \frac{\frac{20}{(s+1)(5s+1)(2s+5)}}{1 + \frac{20(s+2)}{s(2s+5)(s+1)(5s+1)}}$$

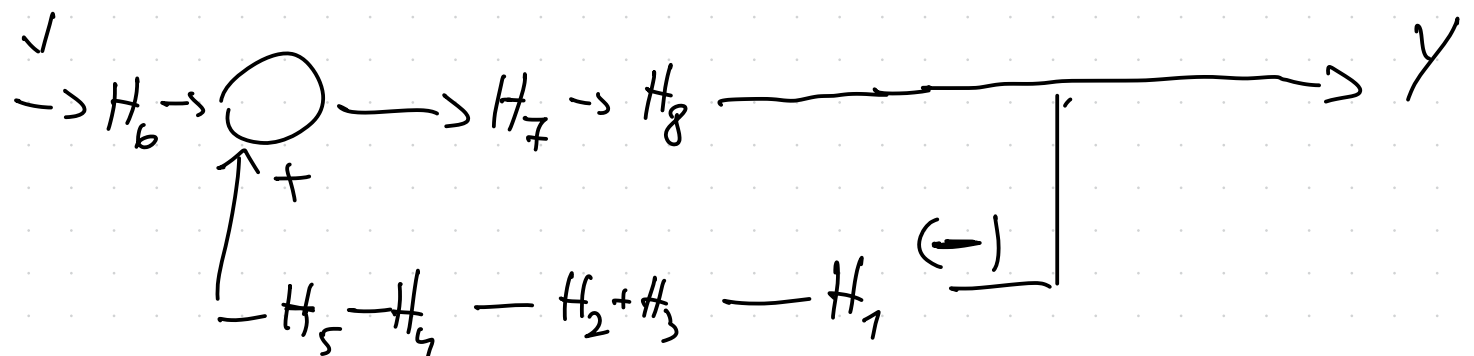
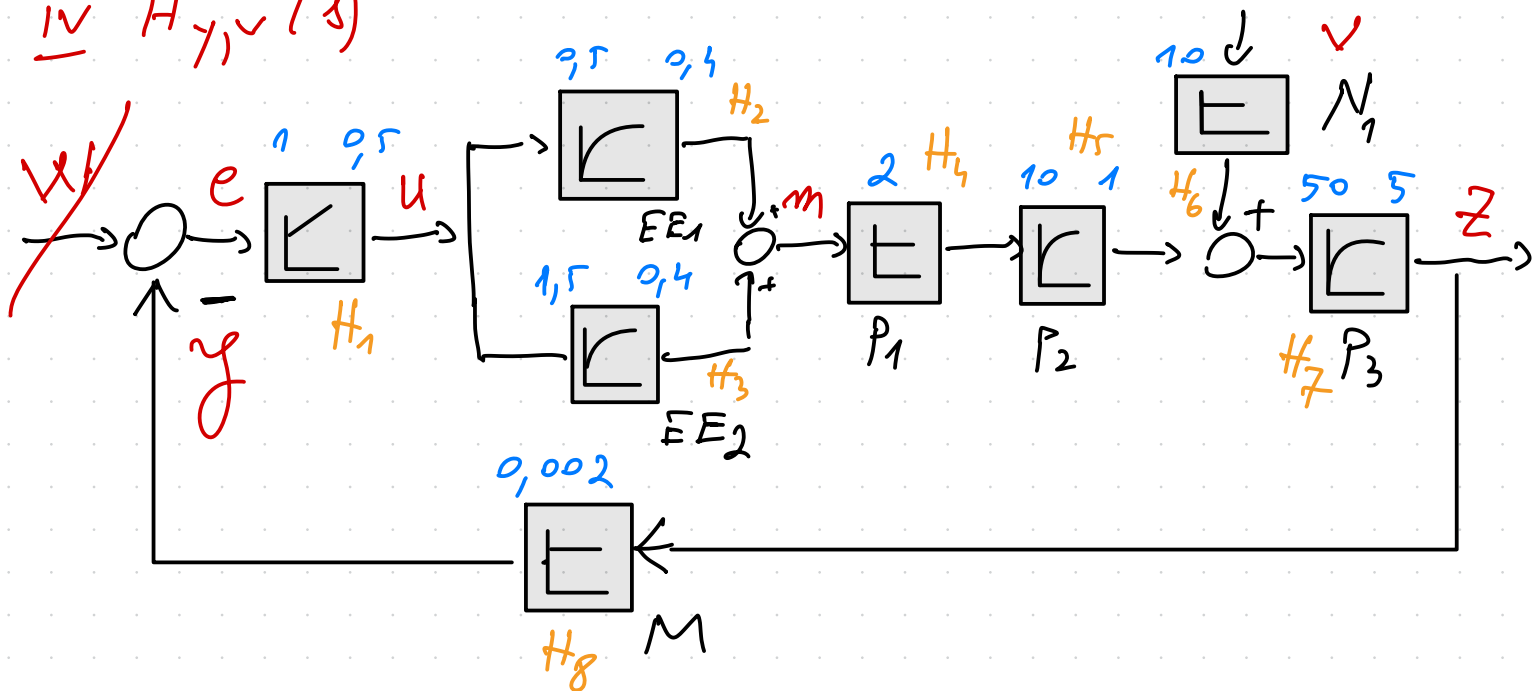
$$H_{y,u}(s) = \frac{20}{(s+1)(5s+1)(2s+5)}$$

$$1 + \frac{20(s+2)}{s(2s+5)(s+1)(5s+1)}$$

$$H_{y,u}(s) = \frac{20}{s} \cdot \frac{s}{s(s+2)}$$

$$H_{y,u}(s) = \frac{20s}{s(2s+5)(s+1)(5s+1) + 20(s+2)}$$

IV  $H_{y,v}(s)$



$$H_{y,v}(s) = H_6(s) \frac{H_7(s) H_8(s)}{1 - (-H_1(s)(H_2(s)+H_3(s))H_4(s)H_5(s)H_7(s)H_8(s))}$$

$$H_{y,v}(s) = \frac{\cancel{10} \cdot \frac{\cancel{50}}{5s+1} \cdot \frac{\cancel{2}}{\cancel{1000}}}{1 + \frac{20(s+2)}{s(2s+5)(s+1)(5s+1)}}$$

$$H_{y,v}(s) = \frac{1}{\cancel{5s+1}} \frac{s(2s+5)(s+1)(\cancel{5s+1})}{s(2s+5)(s+1)(5s+1) + 20(s+2)}$$

$$H_{y,v}(s) = \frac{s(2s+5)(s+1)}{s(2s+5)(s+1)(5s+1) + 20(s+2)}$$