ENME 462 STUDIO 5

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OUTLINES

- Block Diagrams Algebra
- Space Shuttle pitch control
- Hybrid electronical vehicle
- UFSS pitch control

CLOSED-LOOP TRANSFER FUNCTION

From the block diagram

$$C(s) = G(s)E(s)$$

$$E(s) = R(s) - C(s)H(s)$$

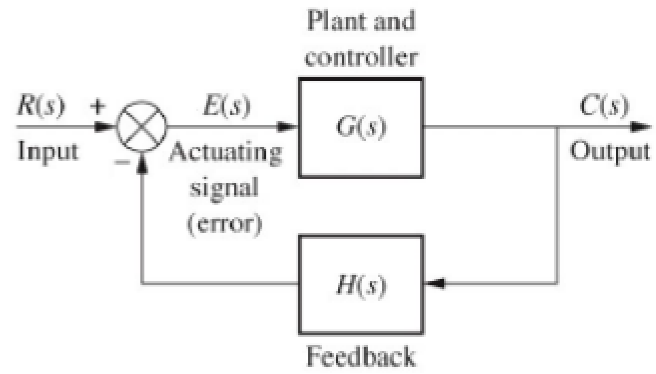
$$= R(s) - G(s)H(s)E(s)$$

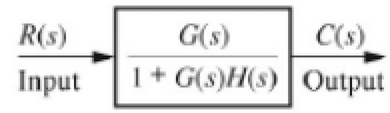
Therefore

$$E(s) = \frac{1}{1+G(s)H(s)} R(s)$$

And

$$C(s) = \frac{G}{1+G(s)H(s)} R(s)$$





- Transfer function $$T(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)H(s)}$$

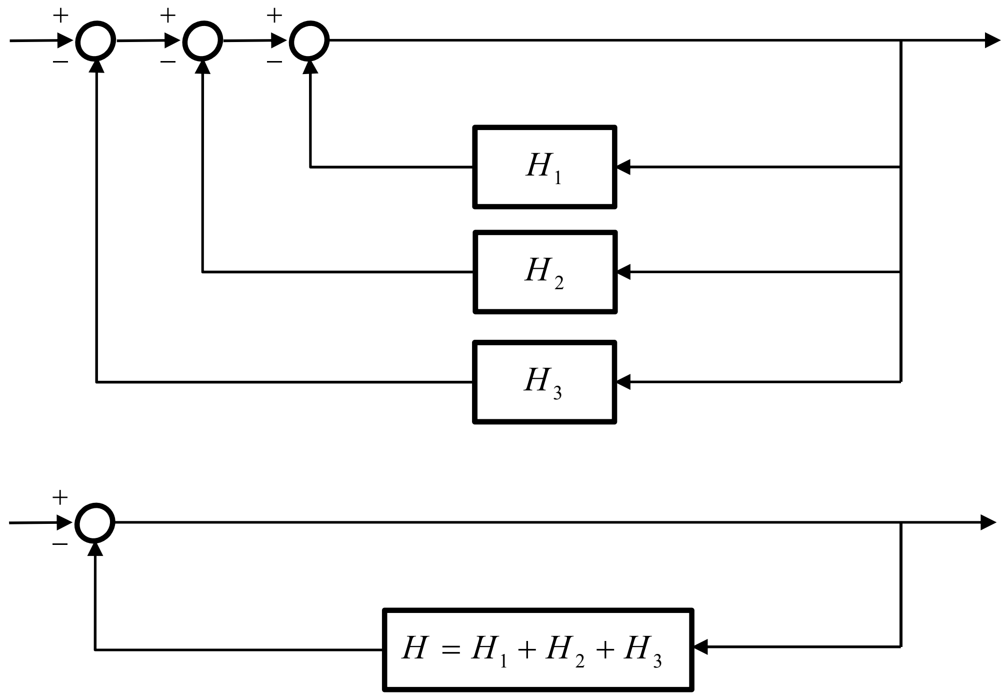
SERIES

$$\xrightarrow{A} \boxed{G_1} \xrightarrow{B} \boxed{G_2} \xrightarrow{C} \boxed{G_3} \xrightarrow{D}$$

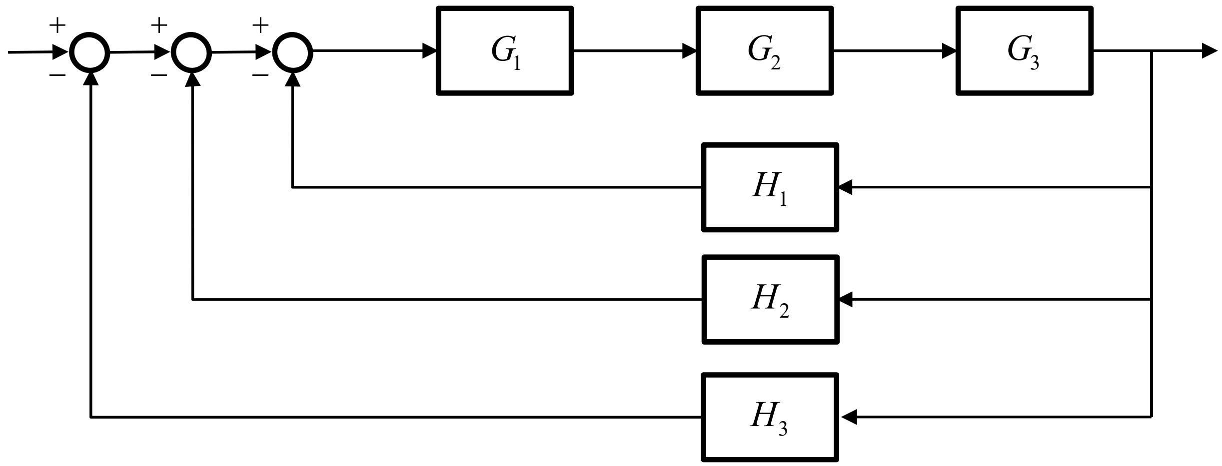
$$\xrightarrow{A} \boxed{G = G_1 \bullet G_2 \bullet G_3} \xrightarrow{D}$$

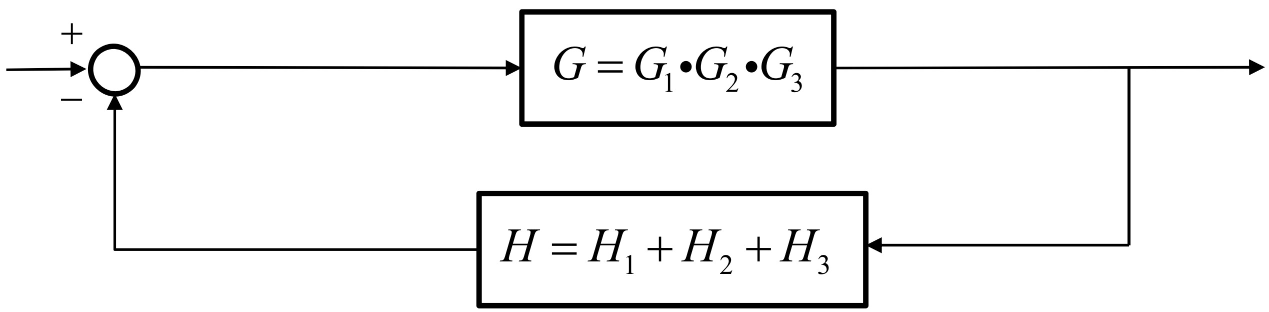
$$\frac{D}{A} = \frac{D}{C} \bullet \frac{C}{B} \bullet \frac{B}{A} \qquad G = G_3 \bullet G_2 \bullet G_1$$

PARALLEL



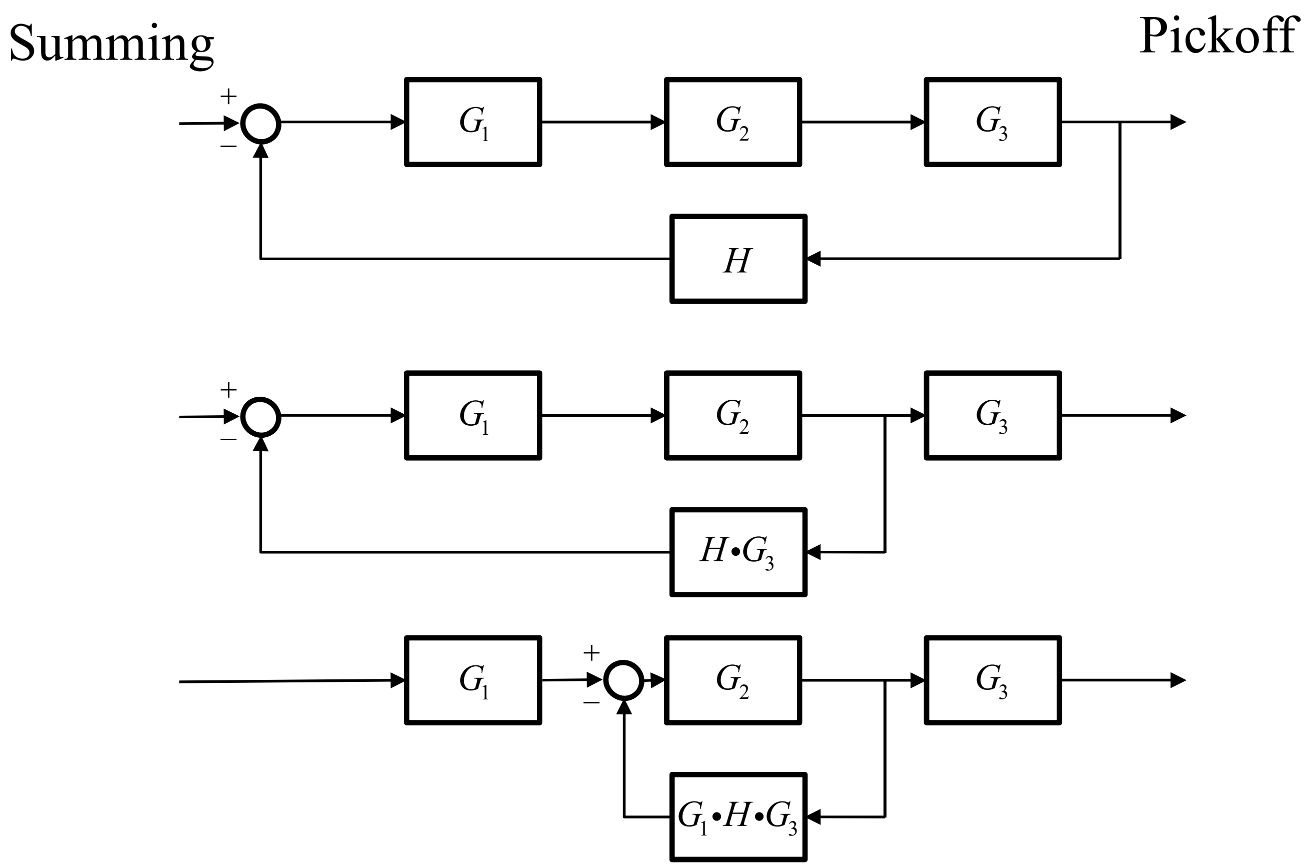
CLOSED-LOOP TRANSFER FUNCTION





$$T = \frac{G}{1 + G \bullet H} = \frac{G_1 \bullet G_2 \bullet G_3}{1 + (G_1 \bullet G_2 \bullet G_3)(H_1 + H_2 + H_3)}$$

REDUCTION TECHNIQUES



$$T = \frac{G_1 G_2 G_3}{1 + G_1 G_2 G_3 H}$$

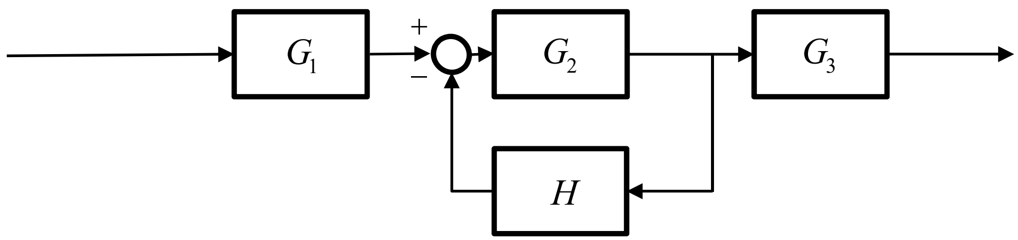
$$T = \frac{G_1 G_2}{1 + G_1 G_2 \bullet H G_3} \bullet G_3$$

$$T = G_1 \bullet \frac{G_2}{1 + G_2 \bullet H G_1 G_3} \bullet G_3$$

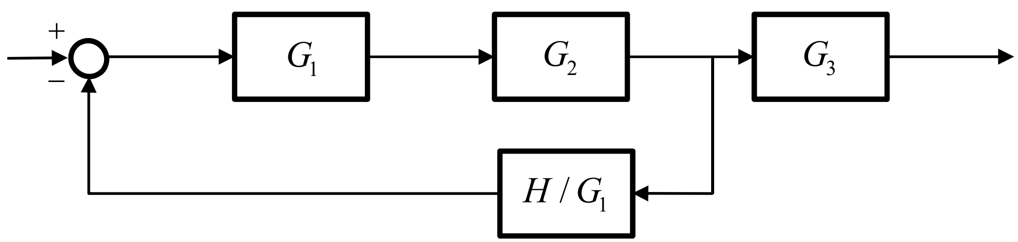
REDUCTION TECHNIQUES

Pickoff

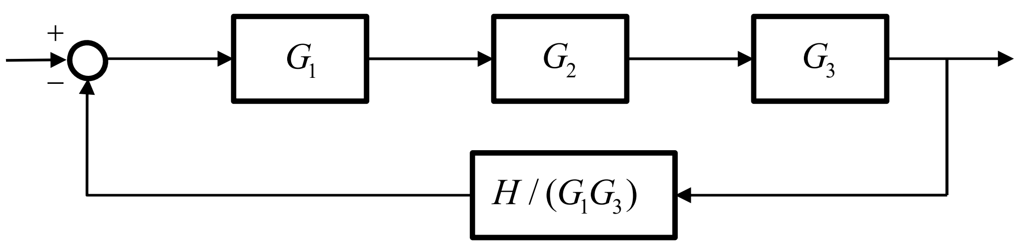
Summing



$$T = G_1 \bullet \frac{G_2}{1+G_2H} \bullet G_3$$



$$T = \frac{G_1G_2}{1+_1 G_1G_2H/G_1} \bullet G_3$$

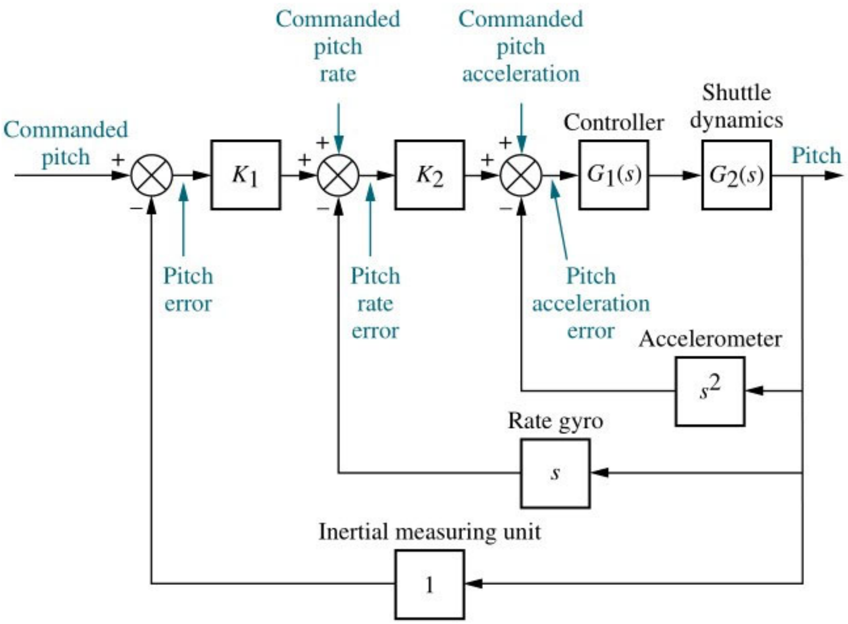


$$T = \frac{G_1G_2G_3}{1+_1 G_1G_2G_3H/(G_1G_3)}$$

SPACE SHUTTLE PITCH CONTROL

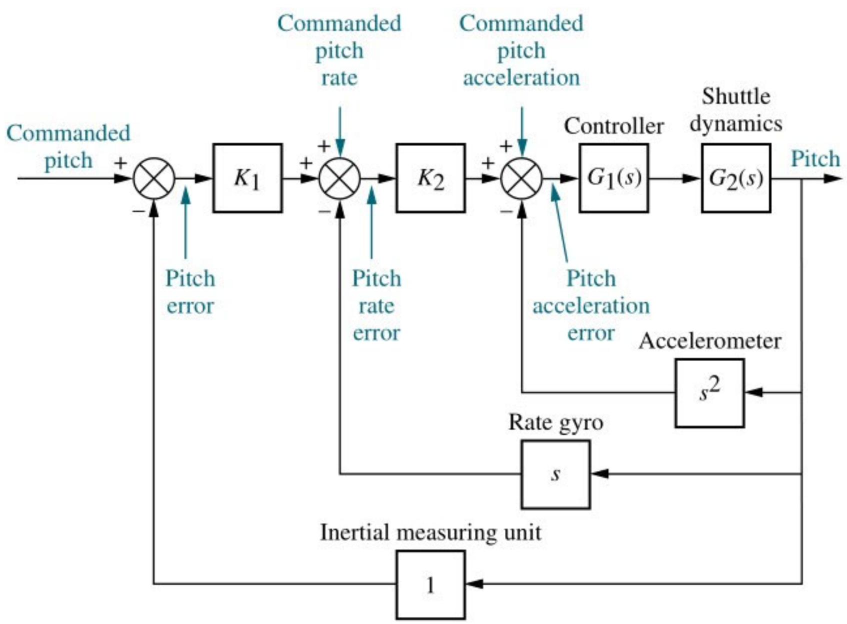
- Verify that the closed-loop transfer function from the commanded pitch input to actual pitch output is given by (assume all other inputs are zeros)

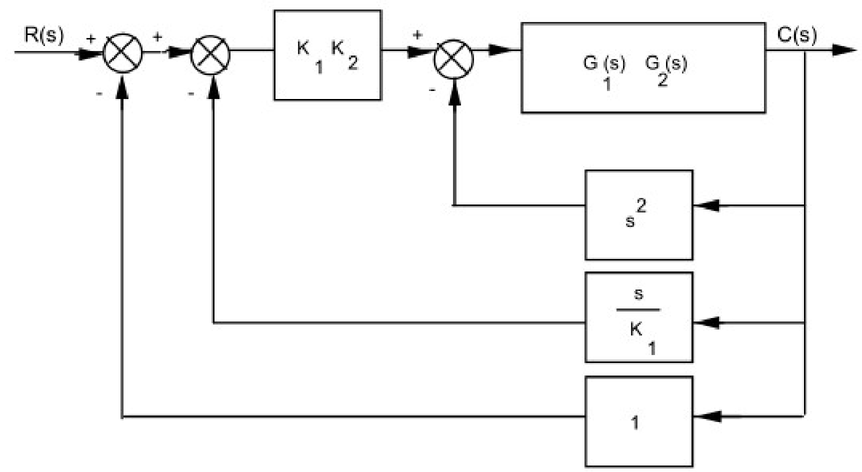
$$T(s) = \frac{K_1 K_2 G_1(s) G_2(s)}{1 + K_1 K_2 G_1(s) G_2(s)[1 + \frac{s}{K_1} + \frac{s^2}{K_1 K_2}]}$$



SPACE SHUTTLE PITCH CONTROL

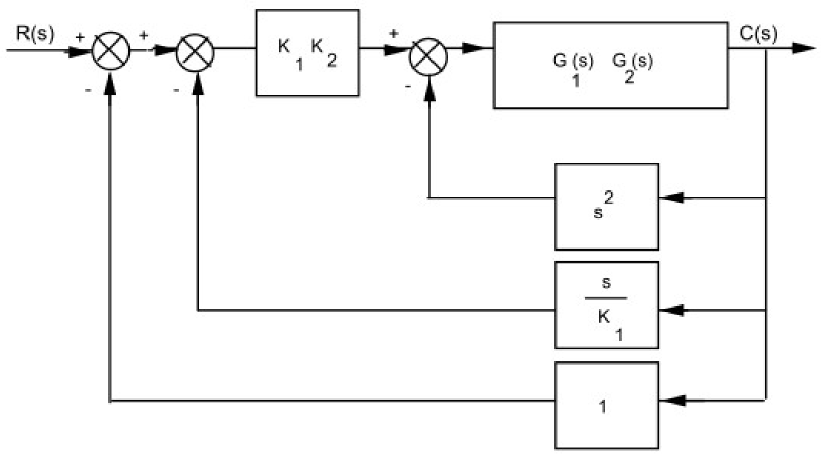
- a) combine G_1 and G_2. Then push K_1 to the right past the summing junction

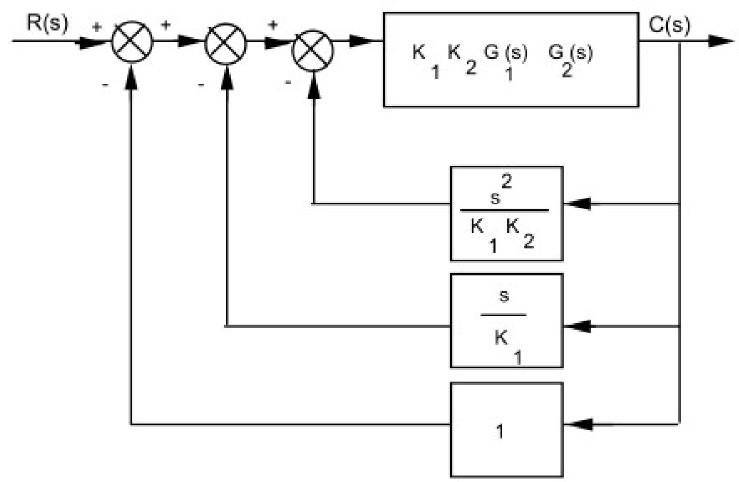




SPACE SHUTTLE PITCH CONTROL

- b) Push $K_1 K_2$ to the right past the summing junction

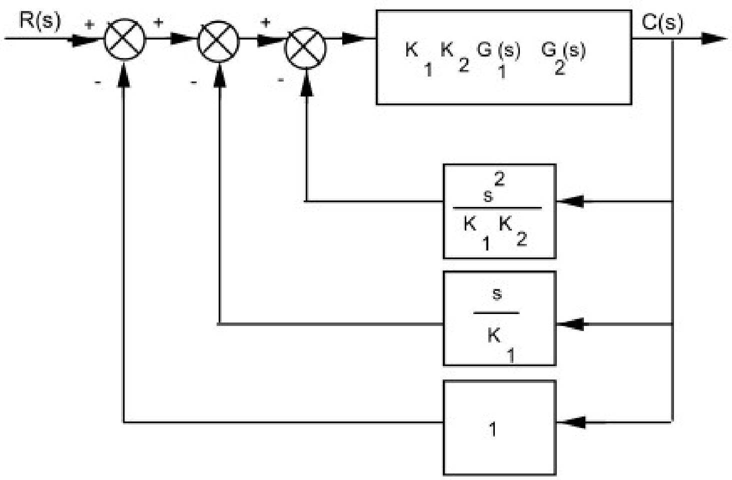




SPACE SHUTTLE PITCH CONTROL

- c) Write the transfer function

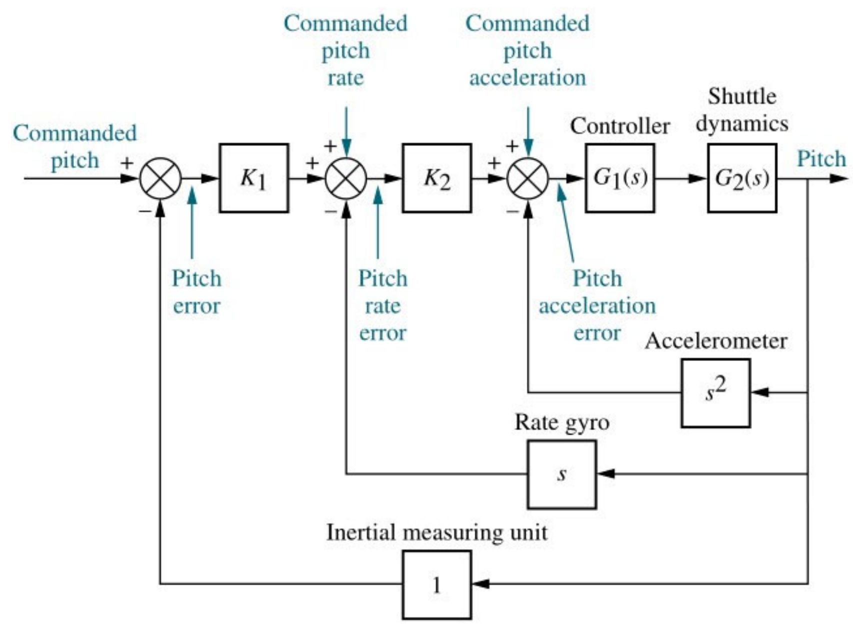
$$T(s) = \frac{K_1 K_2 G_1(s) G_2(s)}{1 + K_1 K_2 G_1(s) G_2(s)[1 + \frac{s}{K_1} + \frac{s^2}{K_1 K_2}]}$$



SPACE SHUTTLE PITCH CONTROL

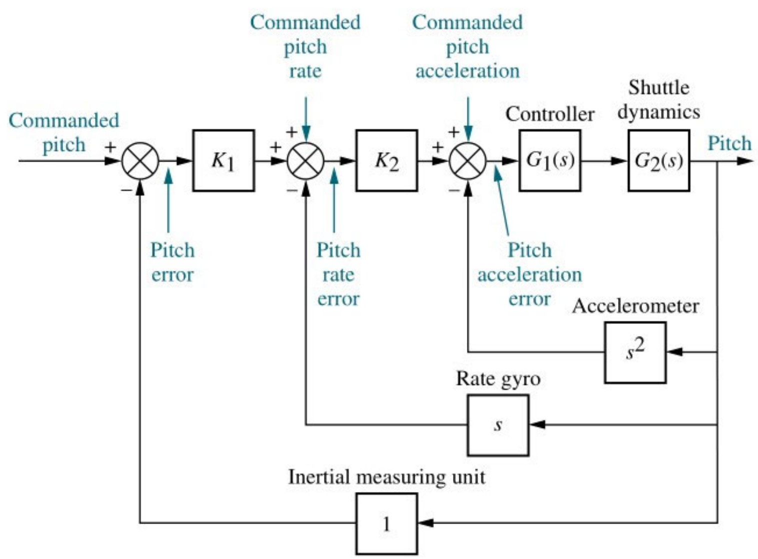
- Verify that the closed-loop transfer function from the ***commanded pitch rate input*** to ***actual pitch rate*** is given by (assume all other inputs are zeros)

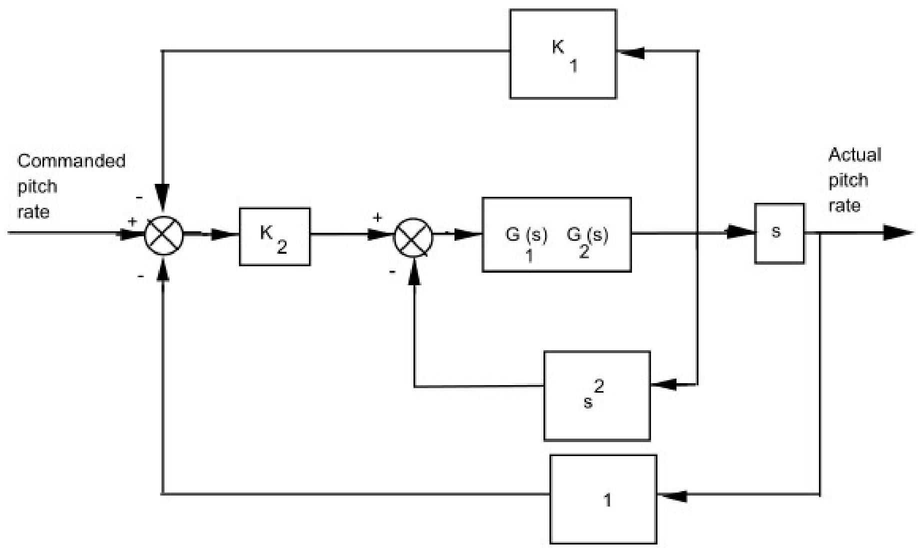
$$T(s) = \frac{K_2 s G_1(s) G_2(s)}{1 + G_1(s)G_2(s)[s^2 + K_2\, s + K_1 K_2]}$$



SPACE SHUTTLE PITCH CONTROL

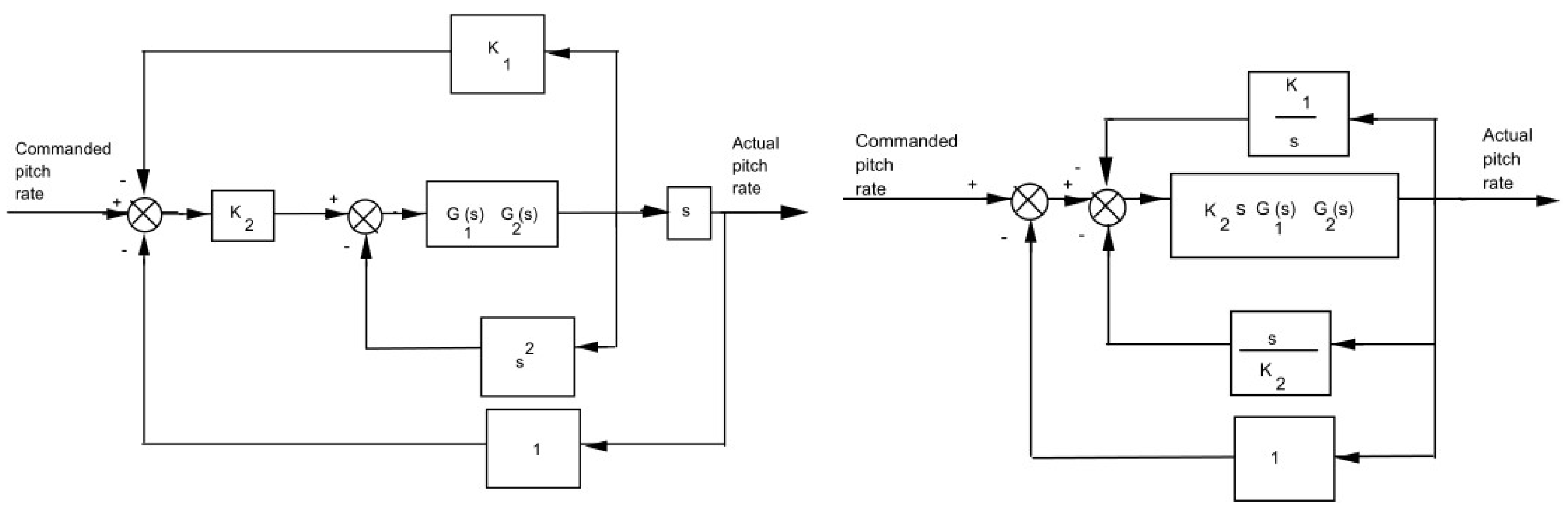
- Rearranging the block diagram to show commanded pitch rate as the input and actual pitch rate as the output:





SPACE SHUTTLE PITCH CONTROL

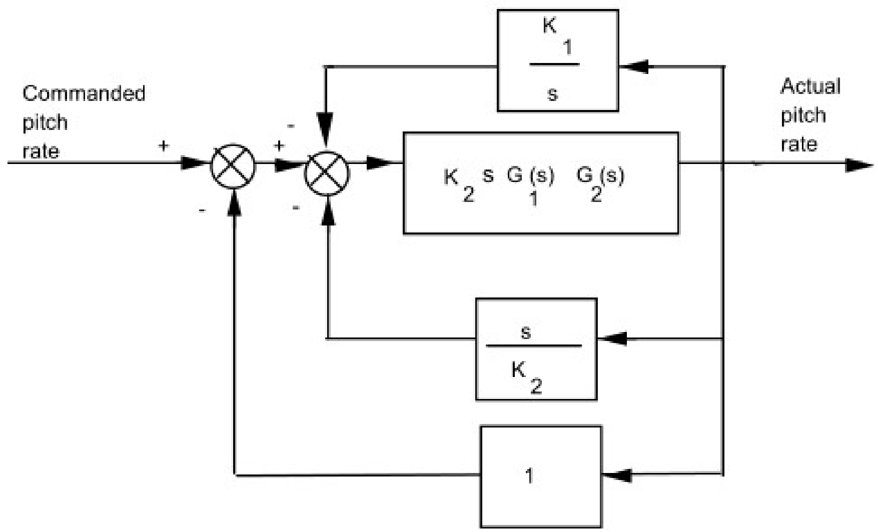
- Push K_2 to the right past the summing junction; and push s to the left past the pick-off point yields,



SPACE SHUTTLE PITCH CONTROL

- Then the closed-loop transfer function:

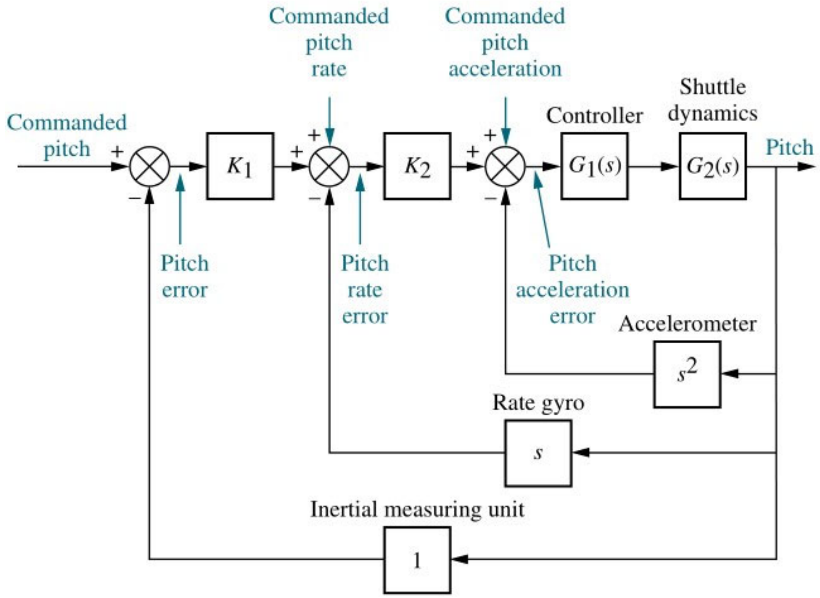
$$T(s) = \frac{K_2 s G_1(s) G_2(s)}{1 + K_2 s G_1(s) G_2(s)\left(1 + \frac{s}{K_2} + \frac{K_1}{s}\right)} = \frac{K_2 s G_1(s) G_2(s)}{1 + G_1(s) G_2(s)(s^2 + K_2 s + K_1 K_2)}$$



SPACE SHUTTLE PITCH CONTROL

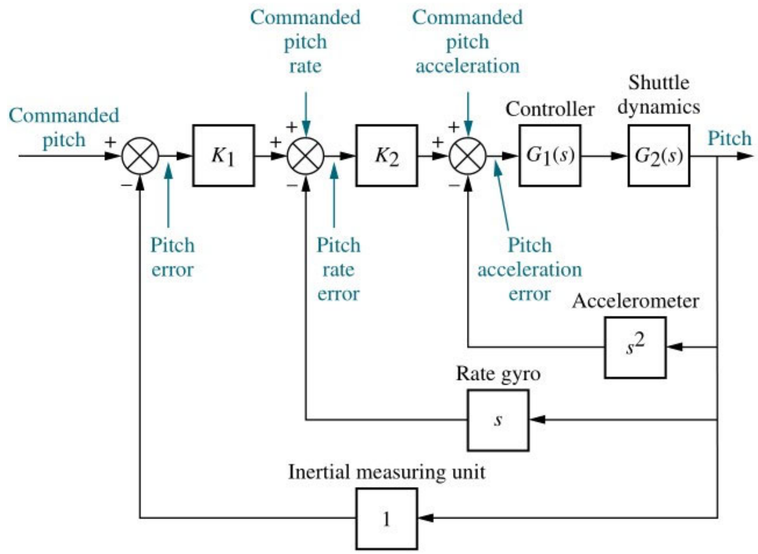
- Verify that the closed-loop transfer function from the ***commanded pitch acceleration input*** to ***actual pitch acceleration*** is given by (assume all other inputs are zeros)

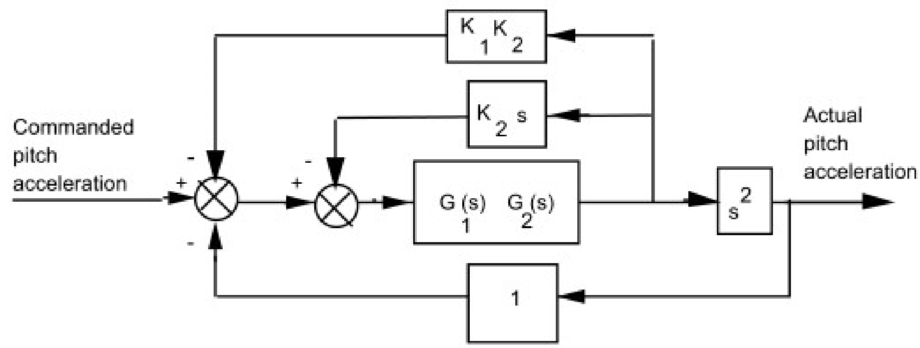
$$T(s) = \frac{s^2 G_1(s) G_2(s)}{1 + G_1(s) G_2(s)[\mathrm{s}^2 + K_2\,\mathrm{s} + K_1 K_2]}$$



SPACE SHUTTLE PITCH CONTROL

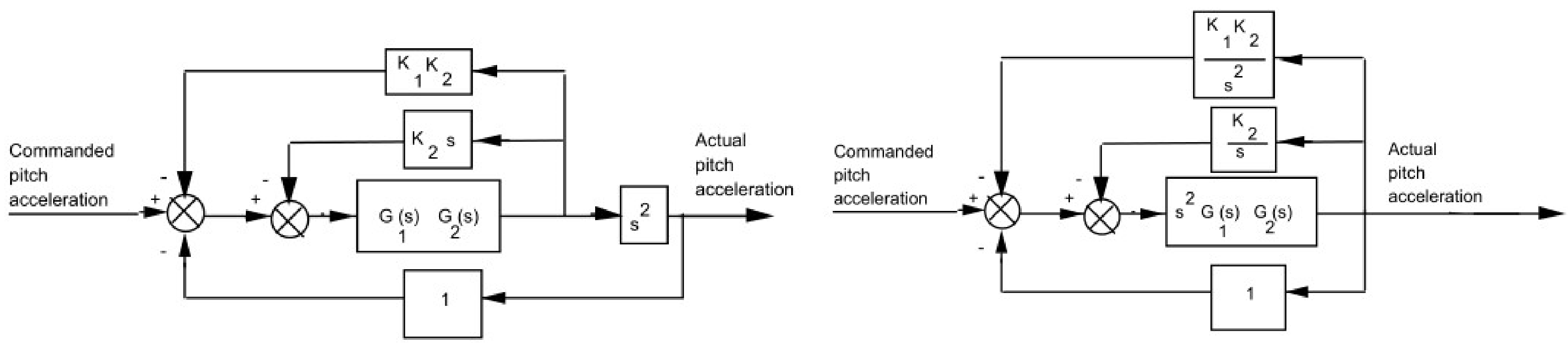
- Rearranging the block diagram to show commanded pitch acceleration as the input and actual pitch acceleration as the output:





SPACE SHUTTLE PITCH CONTROL

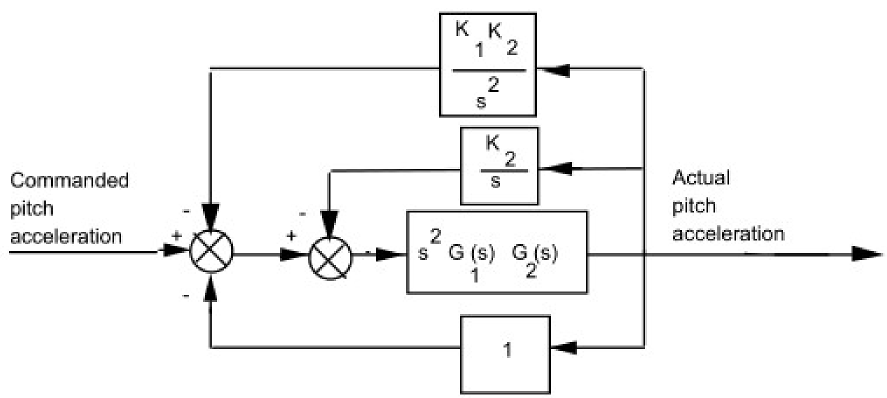
- Push s^2 to the left past the pick-off point yields,



SPACE SHUTTLE PITCH CONTROL

- Then the closed-loop transfer function:

$$T(s) = \frac{s^2 G_1(s) G_2(s)}{1 + s^2 G_1(s) G_2(s)\left(1 + \frac{K_1 K_2}{s^2} + \frac{K_2}{s}\right)} = \frac{s^2 G_1(s) G_2(s)}{1 + G_1(s) G_2(s)(s^2 + K_2 s + K_1 K_2)}$$

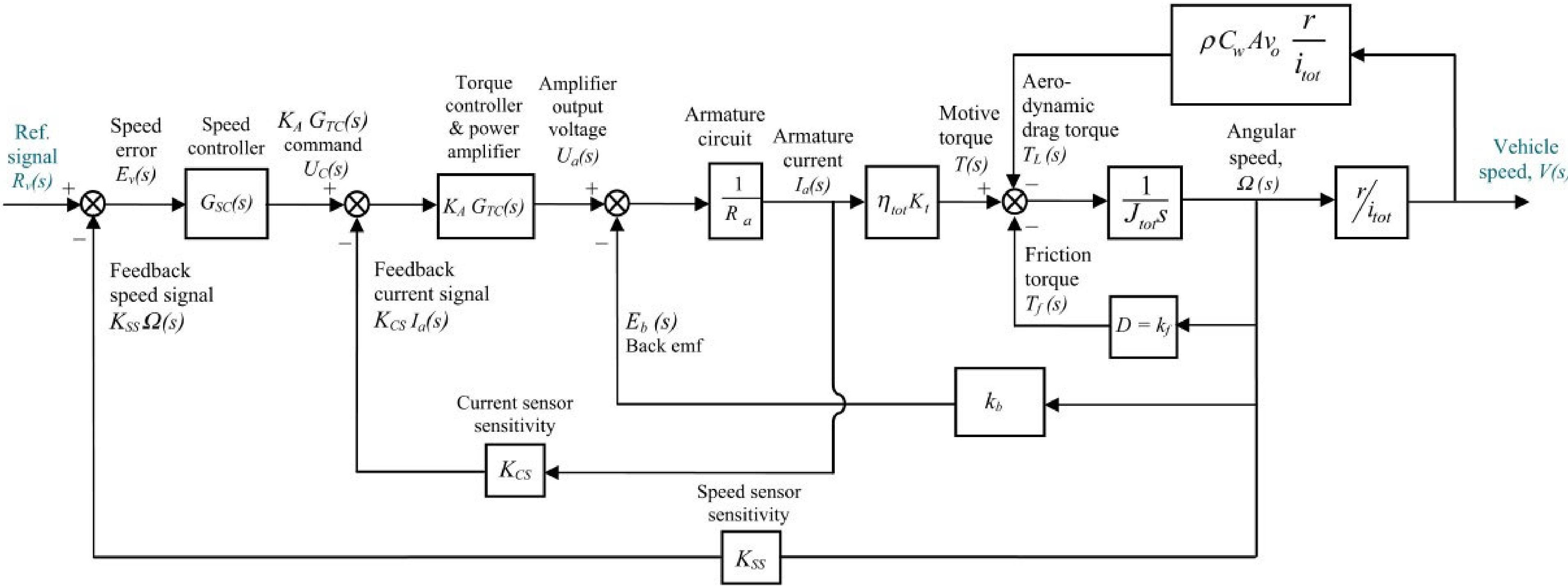


HYBRID ELECTRICAL VEHICLE

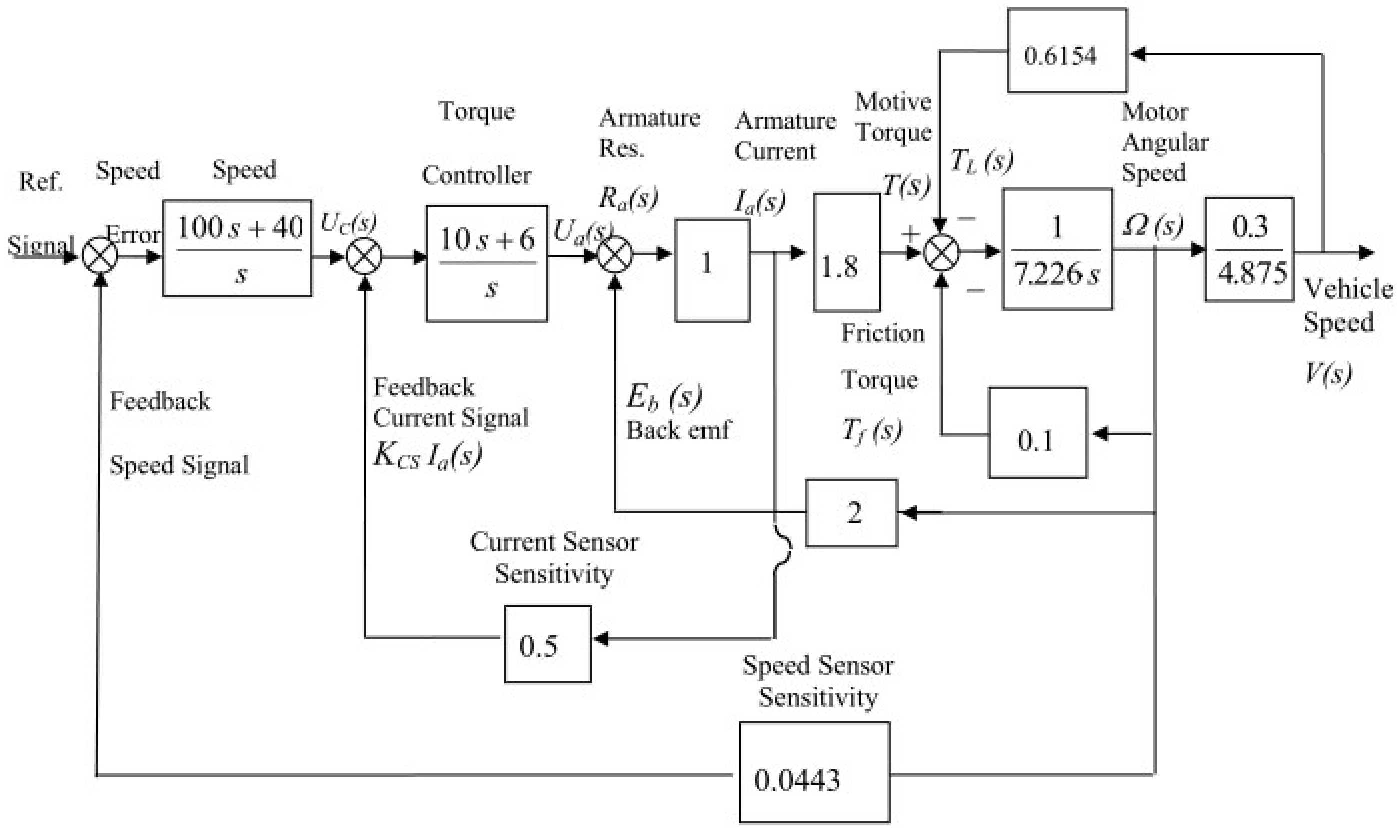
- The figure below shows the block diagram for a Hybrid Electrical Vehicle driven by a DC motor. Let the speed controller $G_{SC} = 100 + \frac{40}{s}$ the torque controller and the power amp $K_A G_{TC} = 10 + \frac{6}{s}$, the current sensor sensitivity $K_{SS} = 0.0433$.

$$\frac{1}{R_a} = 1;\ \eta_{tot} K_t = 1.8;\ k_b = 2;\ D = k_f = 0.1;\ \frac{1}{J_{tot}} = \frac{1}{7.226};\ \frac{r}{i_{tot}} = 0.0615;\ \rho C_w A v_0 \frac{r}{i_{tot}} = 0.6154$$

HYBRID ELECTRICAL VEHICLE



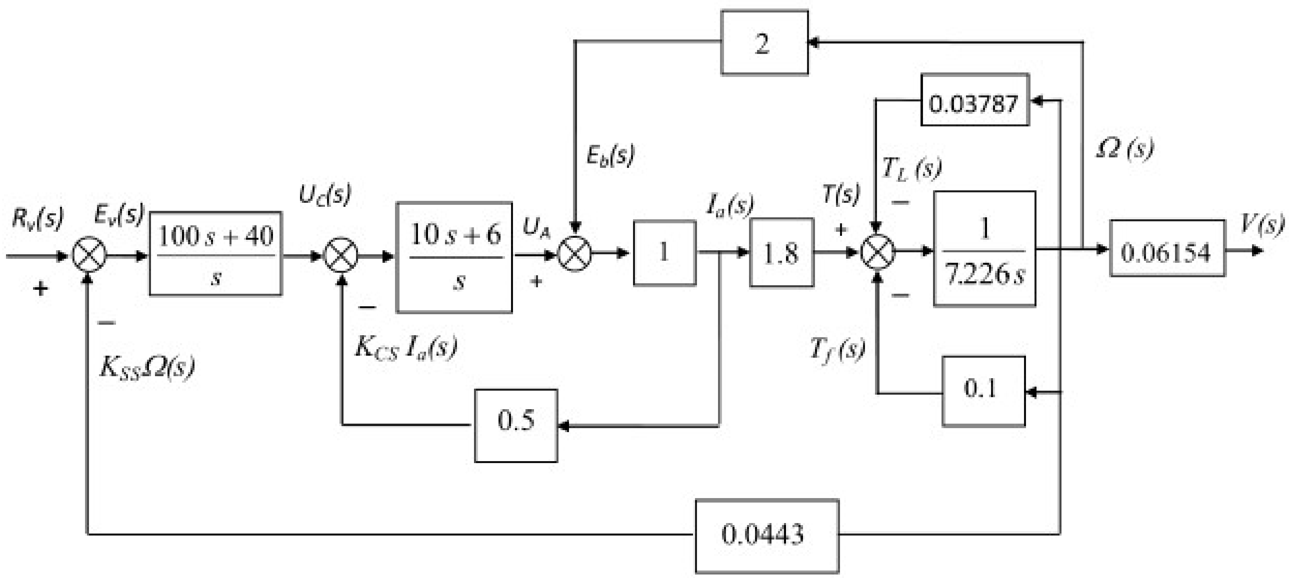
HYBRID ELECTRICAL VEHICLE



HYBRID ELECTRICAL VEHICLE

- Moving the last pick-off point to the left past the $\frac{r}{i_{tot}} = \frac{0.3}{4.875} = 0.06154$

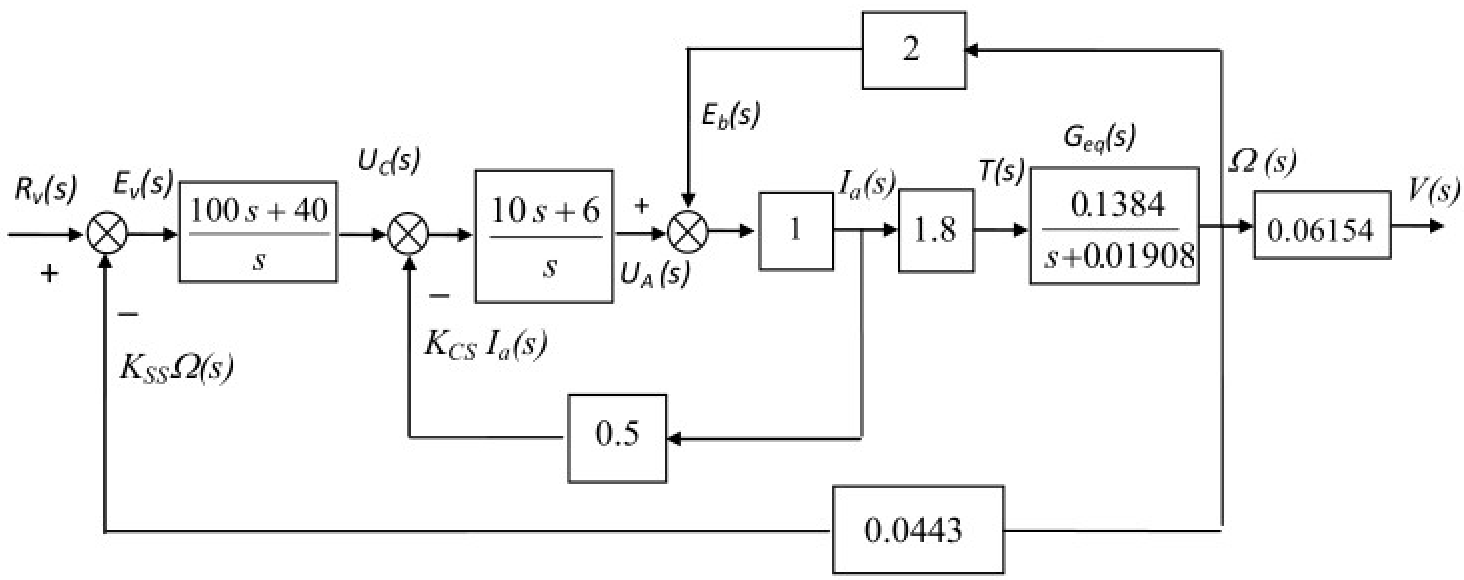
$$0.6154 \times \frac{0.3}{4.875} = 0.03787$$



HYBRID ELECTRICAL VEHICLE

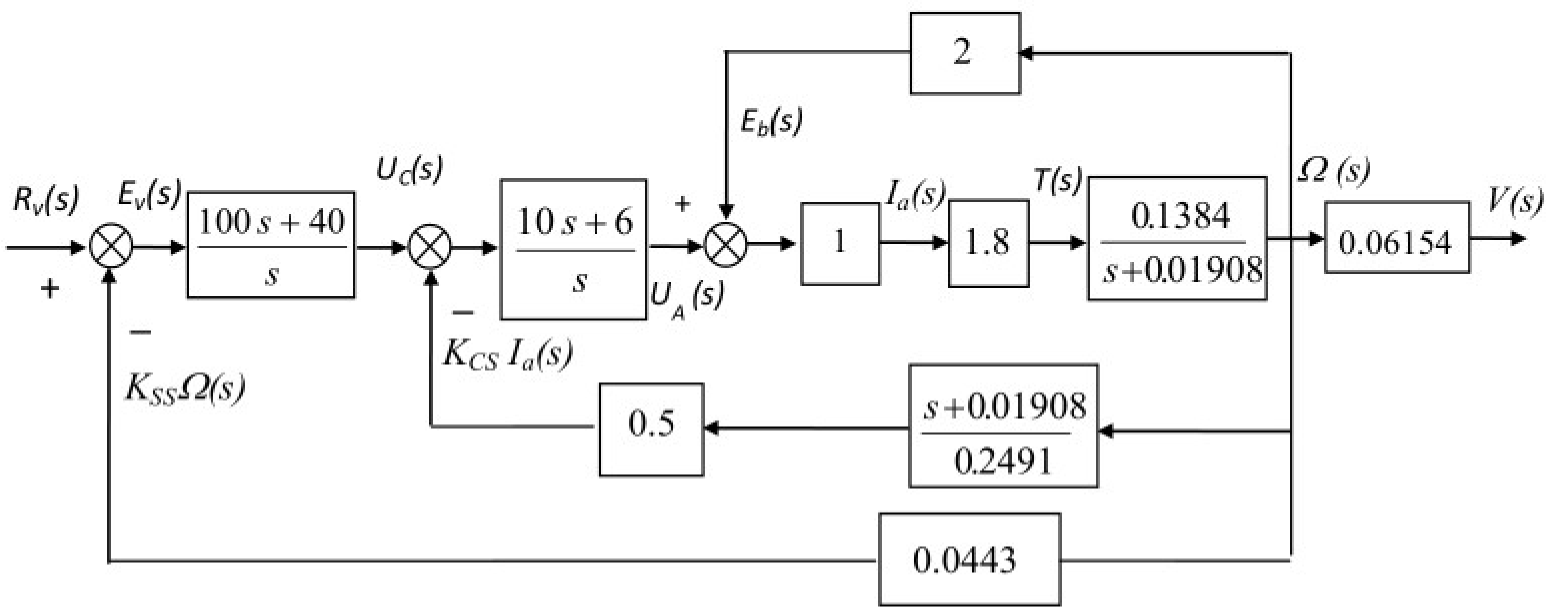
- Transfer function

$$G_{eq}(s) = \frac{\Omega(s)}{T(s)} = \frac{\dfrac{1}{7.226s}}{1+\dfrac{0.13787}{7.226s}} = \frac{0.1384}{s+0.01908}$$



HYBRID ELECTRICAL VEHICLE

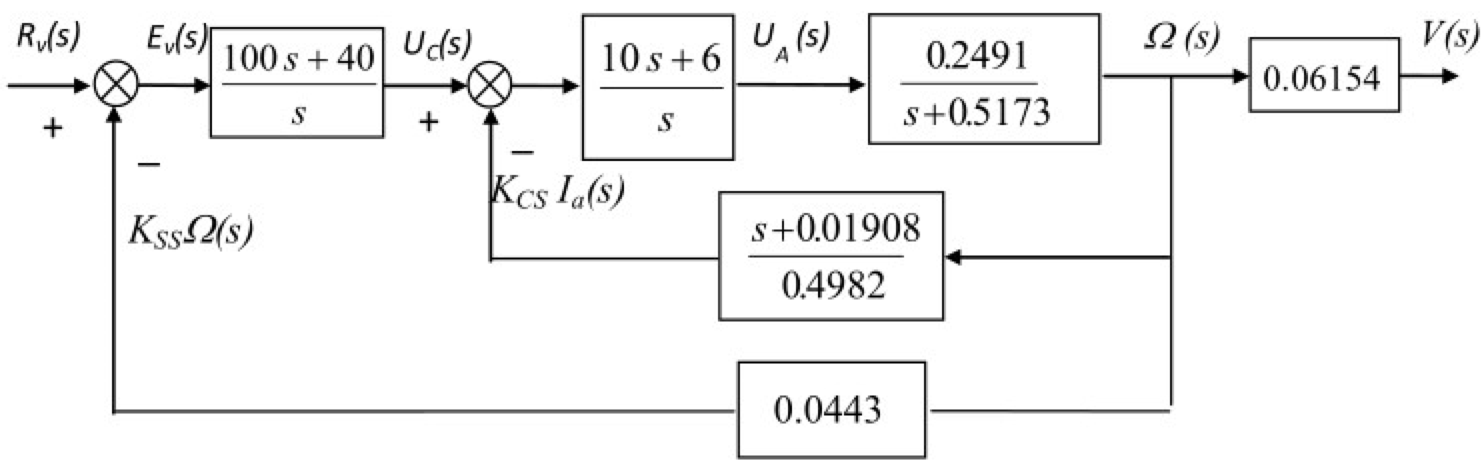
$$\frac{s+0.01908}{1.8\times 0.2491}=\frac{s+0.01908}{0.2491}$$



HYBRID ELECTRICAL VEHICLE

- Transfer function for torque controller

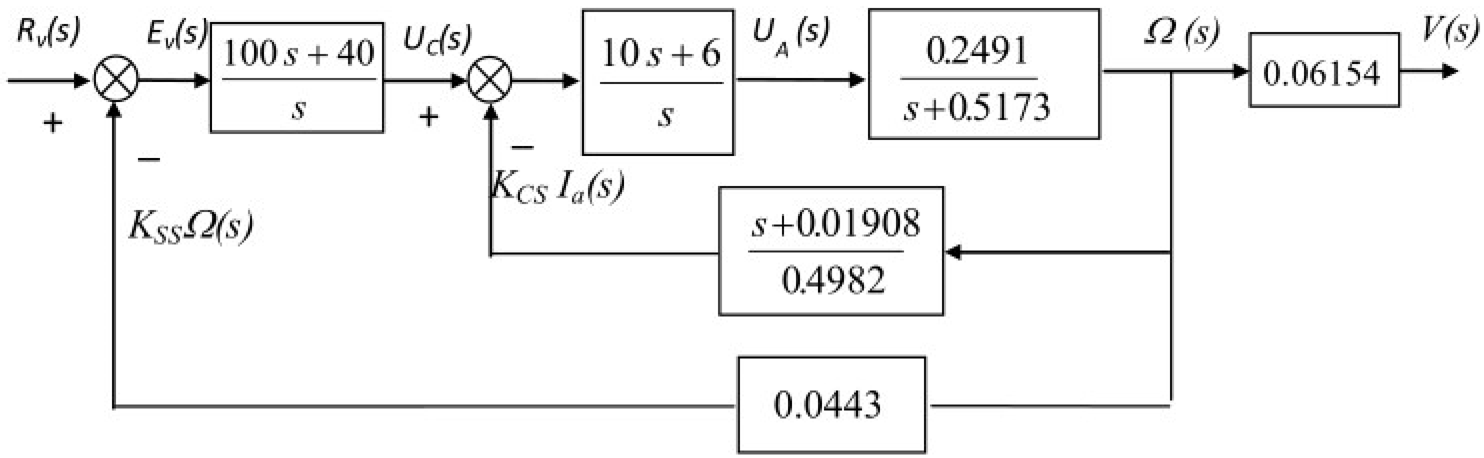
$$\frac{\Omega(s)}{U_A(s)} = \frac{\dfrac{0.2491}{s+0.01908}}{1+\dfrac{0.2491}{s+0.01908}\times 2} = \frac{0.2491}{s+0.5173}$$



HYBRID ELECTRICAL VEHICLE

- Thus

$$\frac{\Omega(s)}{U_c(s)} = \frac{\left(\frac{10s+6}{s}\right)\left(\frac{0.2491}{s+0.5173}\right)}{1+\left(\frac{10s+6}{s}\right)\left(\frac{0.2491}{s+0.5173}\right)\left(\frac{s+0.01908}{0.4982}\right)} = \frac{0.2491(10s+6)}{s\left(s+0.5173\right)+0.5(10s+6)(s+0.01908)}$$



HYBRID ELECTRICAL VEHICLE

- Thus

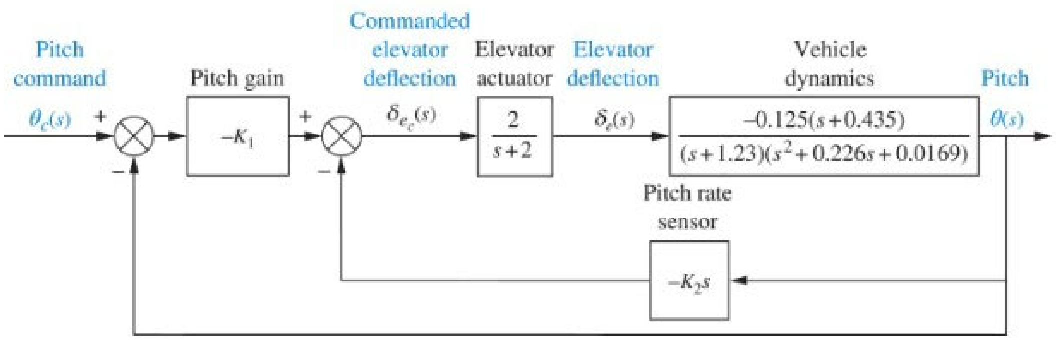
$$\frac{\Omega(s)}{R_v(s)} = \frac{\left(\frac{100s+40}{s}\right)\left(\frac{0.2491(10s+6)}{s\left(s+0.5173\right)+0.5(10s+6)(s+0.01908)}\right)}{1+0.0443\left(\frac{100s+40}{s}\right)\left(\frac{0.2491(10s+6)}{s\left(s+0.5173\right)+0.5(10s+6)(s+0.01908)}\right)}$$

$$\frac{\Omega(s)}{R_v(s)} = \frac{2491(s+0.4)(s+0.6)}{6s^3+14.644s^2+11.09s+2.65}$$

$$\frac{V(s)}{R_v(s)} = 0.06154\frac{\Omega(s)}{R_v(s)} = \frac{15.33(s+0.4)(s+0.6)}{6s^3+14.644s^2+11.09s+2.65}$$

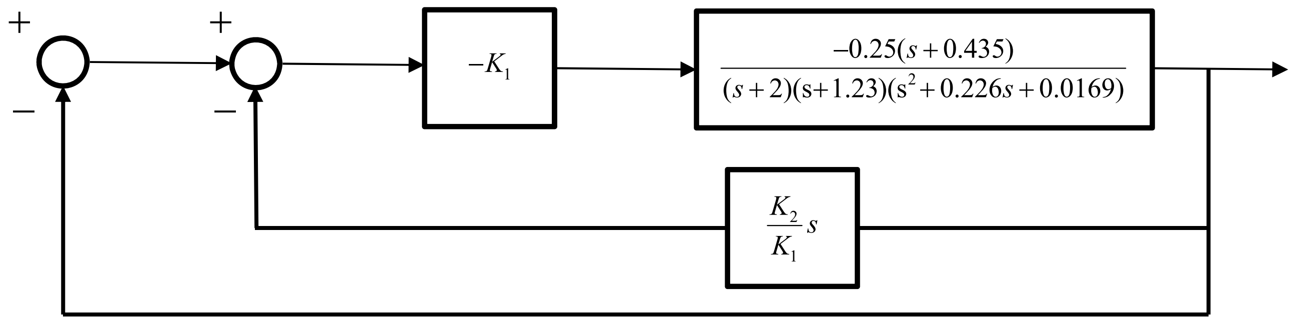
UFSS

- Transfer function $\theta(s)/\theta_c$ using block diagram reduction rules.



UFSS

- Transfer function $\theta(s)/\theta_c$ using block diagram reduction rules.



$$\frac{\theta(s)}{\theta_c(s)} = \frac{\dfrac{0.25K_1(s+0.435)}{(s+2)(s+1.23)(s^2+0.226s+0.169)}}{1+\dfrac{0.25K_1(s+0.435)}{(s+2)(s+1.23)(s^2+0.226s+0.169)}(\dfrac{K_2}{K_1}\mathrm{s}+1)}$$

UFSS

- Transfer function $\theta(s)/\theta_c$ using block diagram reduction rules.

$$\longrightarrow \boxed{\frac{\theta(s)}{\theta_c(s)}} \longrightarrow$$

$$\frac{\theta(s)}{\theta_c(s)} = \frac{0.25K_1(s+0.435)}{(s+2)(s+1.23)(s^2+0.226s+0.169)+0.25K_1(s+0.435)(\frac{K_2}{K_1}\mathrm{s}+1)}$$

$$\frac{\theta(s)}{\theta_c(s)} = \frac{0.25K_1(s+0.435)}{s^4+3.456s^3+(3.359+0.25K_2)s^2+(1.102+0.25K_1+0.109\,\mathrm{K}_2)s+(0.416+0.109\,\mathrm{K}_1)}$$