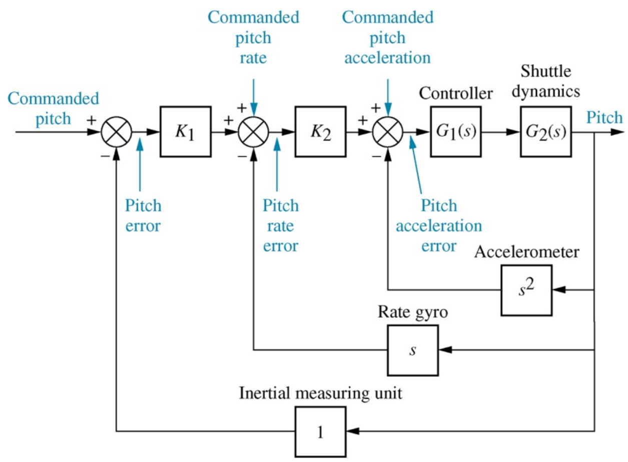
Studio #5: Block Diagram Reduction

The objective of this studio is to reinforce recently learnt concepts of block diagrams in the class.

1) During ascent, the space shuttle is steered by commands generated by the computer's guidance calculations. These commands are in the form of vehicle attitude, attitude rates, and attitude accelerations obtained through measurements made by the vehicle's inertial measuring unit, rate gyro assembly, and accelerometer assembly, respectively. The ascent digital autopilot uses the errors between the actual versus commanded attitudes rates, and accelerations to gimbal the space shuttle main engines (called thrust vectoring) and the solid rocket boosters to affect the desired vehicle attitude. The space shuttle's attitude control system employs the same method in pitch, roll, and yaw control systems. A simplified model of the pitch control system is shown below in block diagram form.



The studio instructor will now:

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

$$T(s) = \frac{K_1K_2G_1(s)G_2(s)}{1 + K_1K_2G_1(s)G_2(s)\left[1 + \frac{s}{K_1} + \frac{s^2}{K_1K_2}\right]}$$

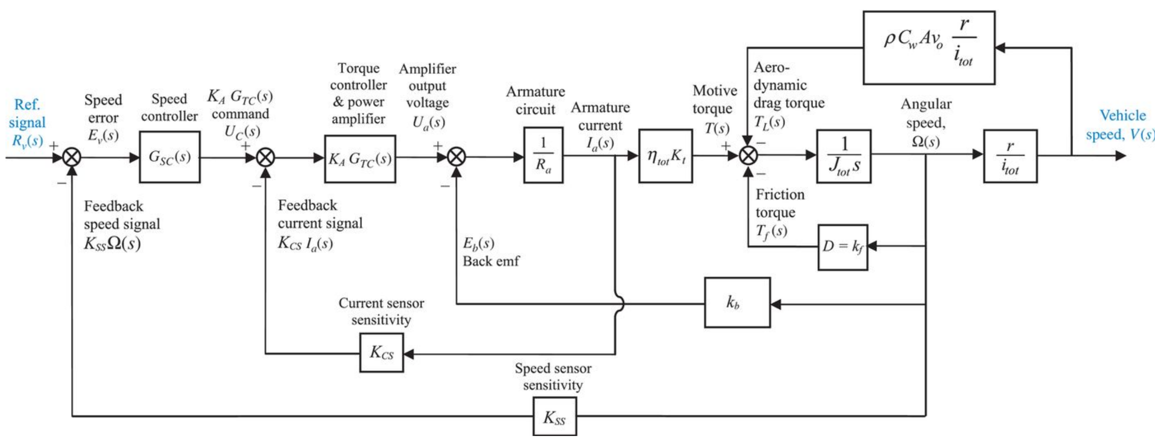
(b) Verify that the closed-loop transfer function from the commanded pitch rate input to actual pitch rate when all other inputs are assumed zero is given by

$$T(s) = \frac{K_2sG_1(s)G_2(s)}{1 + G_1(s)G_2(s)[s^2 + K_2s + K_1K_2]}$$

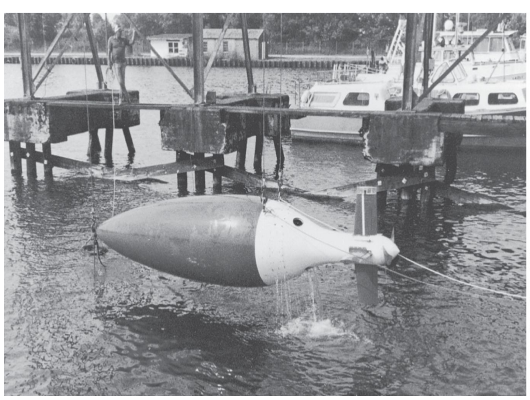
(c) Verify that the closed-loop transfer function from the commanded pitch acceleration input to actual pitch acceleration when all other inputs are assumed zero is given by

$$T(s) = \frac{s^2G_1(s)G_2(s)}{1 + G_1(s)G_2(s)[s^2 + K_2s + K_1K_2]}$$

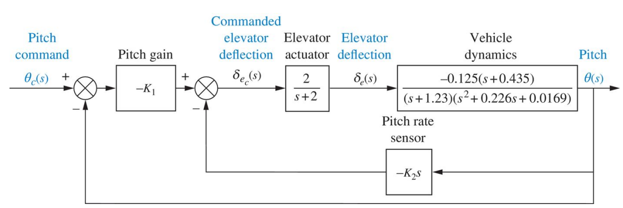
2) The figure below shows the block diagram of a possible cascade control system for a Hybrid Electrical Vehicle driven by a DC motor. Let the speed controller $G_{SC} = 100 + \frac{40}{s}$, the torque controllers and the power amp $K_A G_{TC} = 10 + \frac{6}{s}$, the current sensor sensitivity $K_{CS} = 0.5$, the speed sensor sensitivity $K_{SS} = 0.0433$. Also, $\frac{1}{R_a} = 1$; $\eta_{tot} K_t = 1.8$; $k_b = 2$; $D = k_f = 0.1$; $J_{tot} = 7.226$; $\frac{r}{i_{tot}} = 0.0615$; and $\frac{\rho C_W A v_o r}{i_{tot}} = 0.6154$. Substituting these values in the block diagram below, the studio instructor will now demonstrate the computation of the transfer function $T(s) = \frac{V(s)}{R_v(s)}$ using block diagram reduction rules.



3) The control system below was discussed in the previous studio. The studio instructor will now compute the transfer function $\theta(s)/\theta_c(s)$ using block diagram reduction rules.



Courtesy of the Naval Research Laboratory.



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Exercises

Each student shall complete the exercises below and get their work checked off by the studio instructor.

For remote Students and Students and Students who do not finish within studio session:

Compile the answers and outputs of Exercises 1 and 2 as well as your Matlab code/Simulink model in a word file and name it LastNameFirstNameStudio5.docx. Upload your file to Canvas under the Studio05 link.

Exercise 1. Control Design via Block Diagram Reduction: An Example

Assume that the motor with a transfer function $G(s) = \frac{25}{s(s+1)}$ is used as the forward path of a closed-loop, unity feedback system shown in Figure 1.

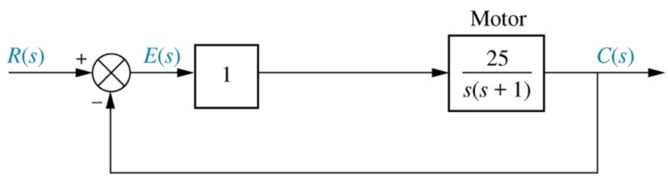


Figure 1

(a) Calculate %OS and T_s both by hand and using Matlab and compare your answers.

(b) Since the motor cannot be changed, an amplifier and a tachometer are inserted into the loop as shown in Figure 2.

Find the values of K_1 and K_2 to achieve 16% OS and a settling time T_s =0.2 sec.

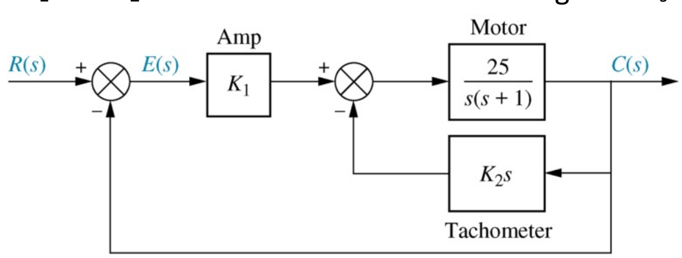
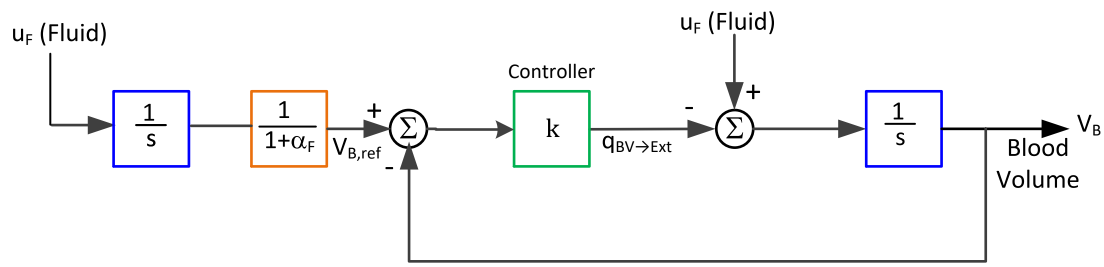


Figure 2

(c) Using the computed values of K_1 and K_2, plot the step response and verify the performance parameters, including: %OS, settling time, rise time, peak time, and peak value.

Exercise 2. Develop a Simulink model of the body fluid balance dynamics shown below and compare the blood volume response in two different situations:



(a) The controller consists of a proportional component, i.e., $k = -0.06$.
(b) The controller consists of proportional and integral components, i.e., $k = -0.06 - \frac{0.004}{s}$.

Plot the blood volume response from t=0 to t=120 min. Fluid is infused for the initial 20 min with a constant rate of 0.033 l/min. There is no infusion after 20 min. Consider $\alpha_F = 2.3$.
Comparing the blood volume response for (a) and (b), which response shows oscillatory behavior? Find the transfer functions of the body fluid balance dynamics for (a) and (b) and discuss the reason(s).