Today's goals

- **So far**
  - Sketching the root locus
  - Adjusting the gain in a given root locus to shape the transient response or achieve a given steady-state error
- **Today and next week**
  - Modifying the root locus in a desirable way by adding poles/zeros ("adding a compensator"
  - Eliminating steady-state error without changing the transient:
    - ideal integral compensator, proportional-integral (PI) control: **today**
    - implementation of the PI controller in the flywheel plant: **this week's Labs**
    - other types of compensators: **next week Lectures**

Feedback compensators

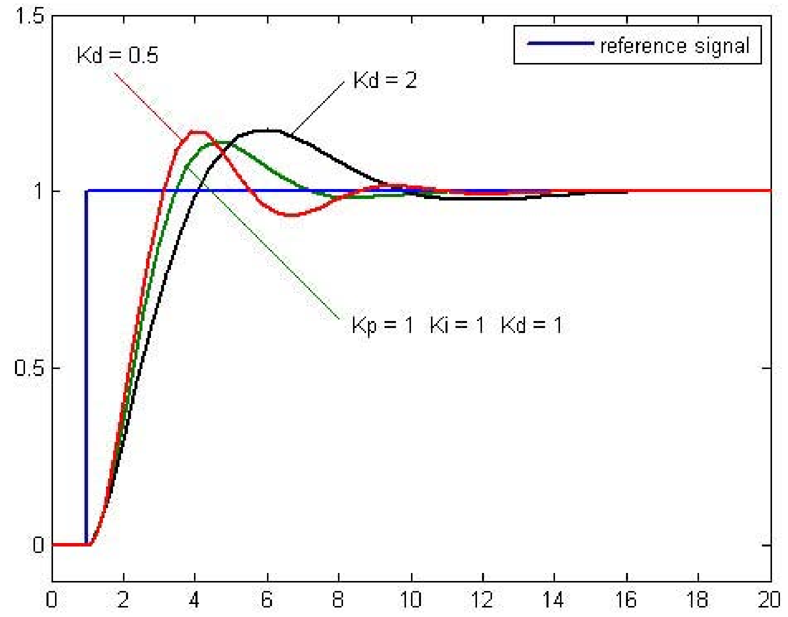


Image removed due to copyright restrictions.
Please see: Fig. 9.1a in Nise, Norman S. *Control Systems Engineering*.
4th ed. Hoboken, NJ: John Wiley, 2004.

Problem: we desire faster rise/peak time with same overshoot, which would be given by a pole at B; but B is not at the present root locus so it is not available

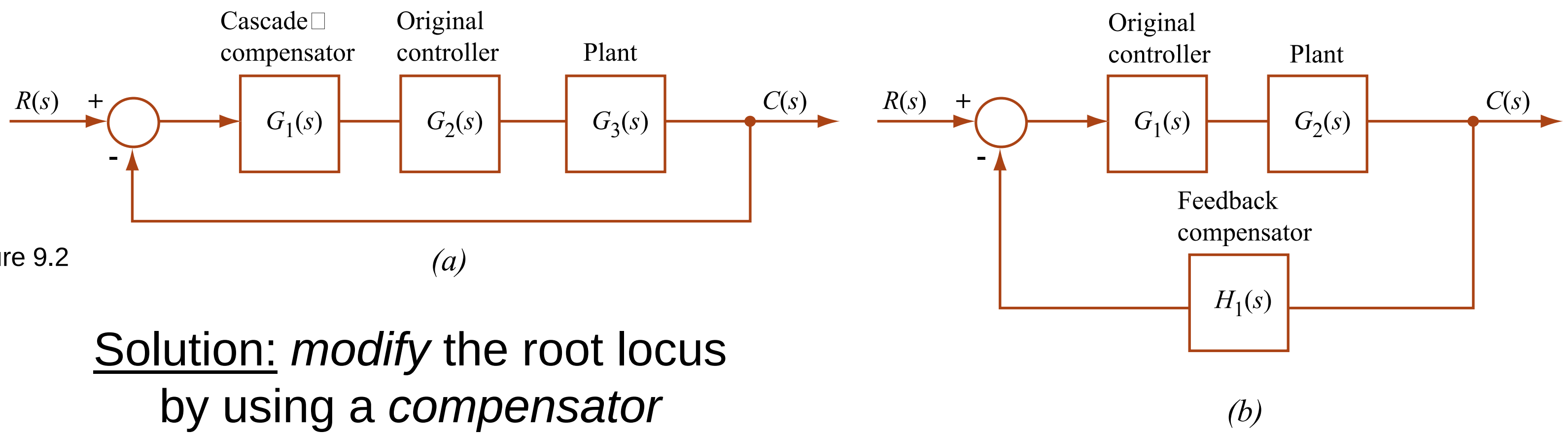


Figure 9.2

Solution: *modify* the root locus by using a *compensator*

Figure by MIT OpenCourseWare.

Improving the steady-state error

Image removed due to copyright restrictions.
Please see: Fig. 9.3a in Nise, Norman S. *Control Systems Engineering*.
4th ed. Hoboken, NJ: John Wiley, 2004.

<u>Proportional Control:</u>

Steady-state error decreases as feedback gain K increases;

however, the steady-state error will never be exactly zero; moreover, high gain will result in undesirable transient (large overshoot)

So, if we've found a desirable pole at A (i.e., acceptable overshoot), our problem is that the steady-state error is still not zero.

Note the angular contributions of the open-loop poles to the closed-loop pole at A.

Improving the steady-state error

Image removed due to copyright restrictions.

Please see: Fig. 9.3b in Nise, Norman S. *Control Systems Engineering*. 4th ed. Hoboken, NJ: John Wiley, 2004.

Integrator as a Compensator:

Eliminates the steady-state error, since it increases the system Type;

however, our desirable closed-loop pole A is no longer on the root locus;

this is because the new pole at s=0 changes the total angular contributions to A so that the 180° condition is no longer satisfied.

This means that our desirable transient response characteristics that would have been guaranteed by A are no longer available ☹

Improving the steady-state error

Image removed due to copyright restrictions.

Please see: Fig. 9.3c in Nise, Norman S. *Control Systems Engineering*. 4th ed. Hoboken, NJ: John Wiley, 2004.

Ideal Integral Compensator
(or Proportional-Integral Compensator):

Includes a zero on the negative real axis but close to the integrator's pole at the origin. The zero

- has approximately the same angular contribution to A as the integrator's pole at the origin; therefore, the two cancel out;
- moreover, it contributes the same magnitude to the pole at A, so A is reached with the same feedback gain K.

The net effect is that *we have fixed the steady-state error without affecting the transient response* ☺

Implementing the PI controller

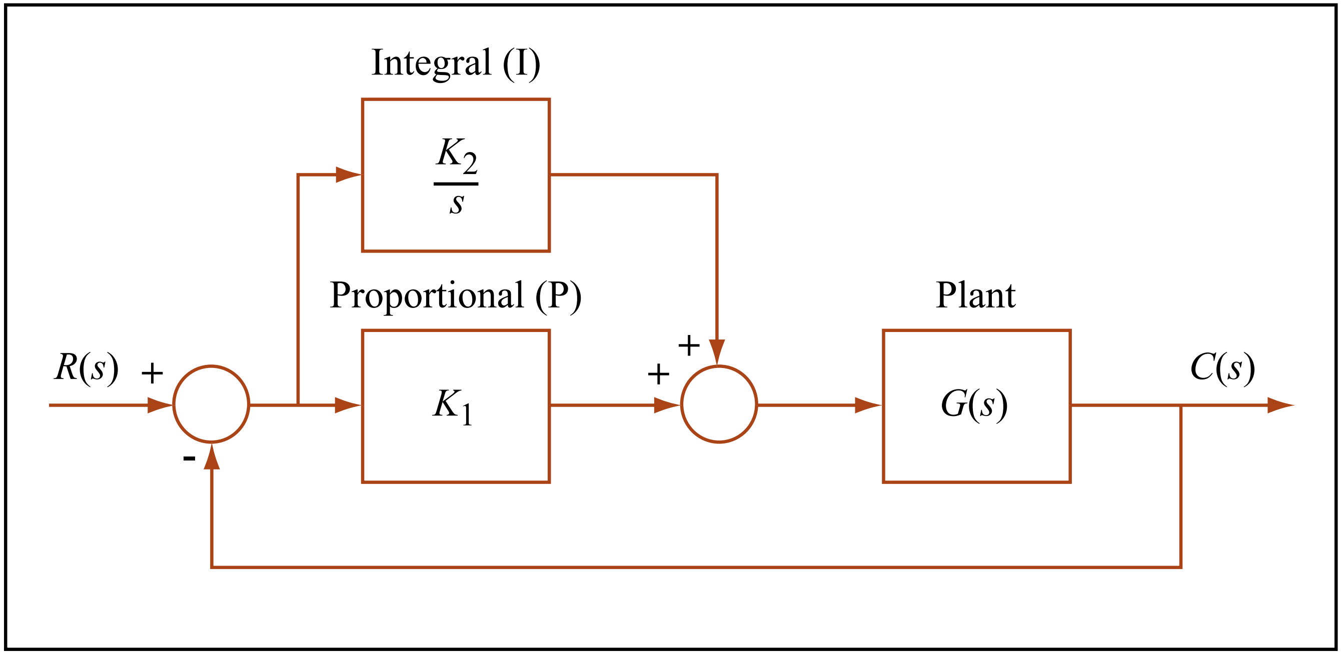


Figure by MIT OpenCourseWare.

Figure 9.8

$$\text{Controller TF } G_c(s) = K_1 + \frac{K_2}{s} = \frac{K_1\left(s + \frac{K_2}{K_1}\right)}{s}.$$

Another implementation is the "lag compensator," which we will see on Monday.

Example (Nise 9.1)

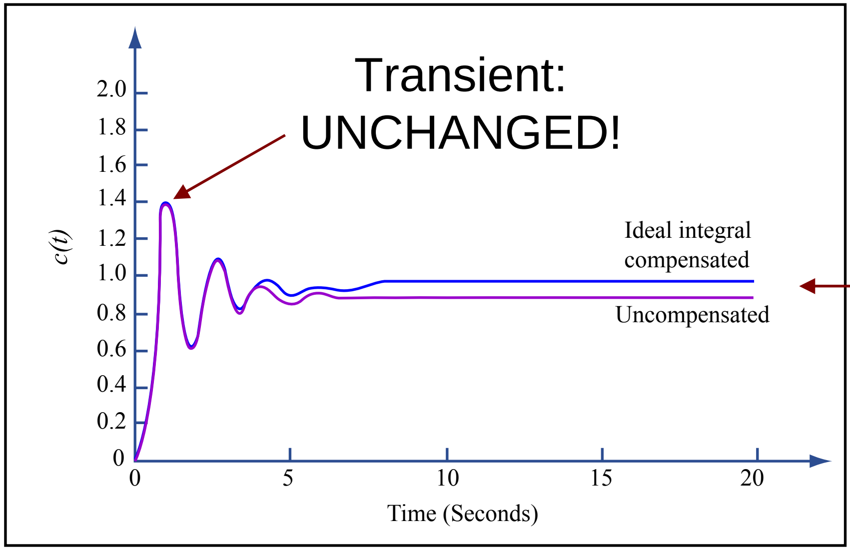
Image removed due to copyright restrictions.

Please see: Fig. 9.4 in Nise, Norman S. *Control Systems Engineering.* 4th ed. Hoboken, NJ: John Wiley, 2004.

Steady-state and transients with the PI controller

Images removed due to copyright restrictions.

Please see: Fig. 9.5 and 9.6 in Nise, Norman S. *Control Systems Engineering*. 4th ed. Hoboken, NJ: John Wiley, 2004.



Steady-state error=0 FIXED!

Figure by MIT OpenCourseWare.

Figure 9.7