Compensation Filter for Aircraft Control System

PREPARED
BY

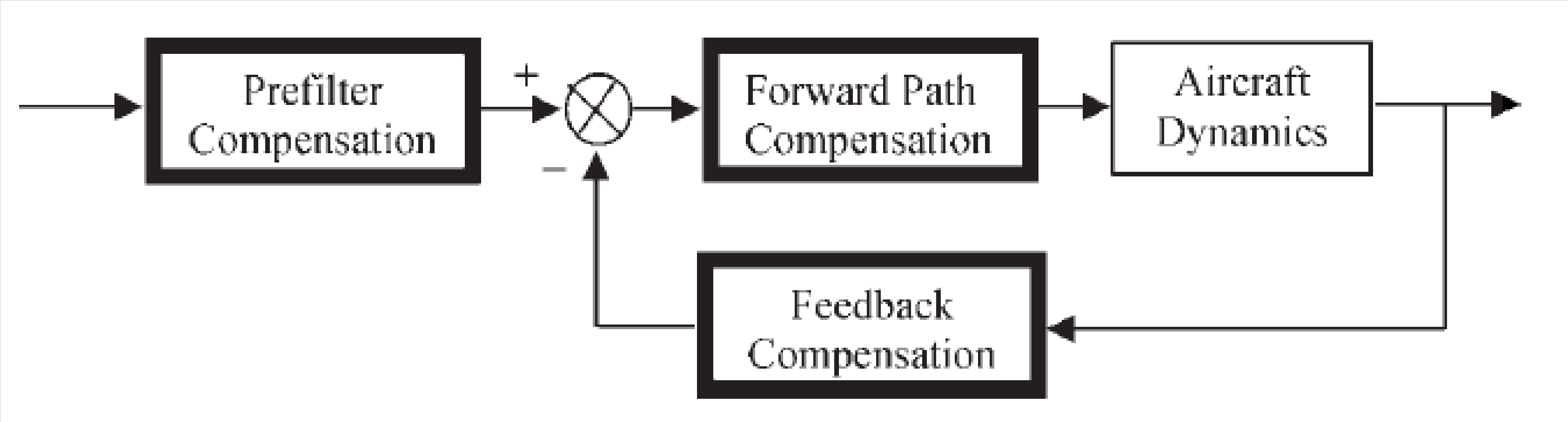
KAVIYARASU A
ASSISTANT PROFESSOR
DEPARTMENT O AEROSPACE ENGINEERING
MADRAS INSTITUTE OF TECHNOLOGY
CHROMEPET
CHENNAI

- A powerful tool available to the control system designer is a compensation filter. Compensation filters can take a variety of forms and are very effective in tailoring the aircraft response

- In a generic feedback control system, a compensation filter can be located in generally three possible positions

  i) Pre filter compensation
  ii) Forward path compensation
  iii) Feedback compensation

- Pre-filter compensation modifies the closed loop transfer function directly, while forward path and feedback compensation modify the forward path and feedback path transfer functions, which are inputs for the root locus.



Possible locations of compensation filters

- Pre-filter compensators generally use the principle of cancellation of an undesirable closed-loop pole with a Pre-filter zero, and cancellation of a closed-loop zero with a Pre-filter pole.

- Forward path and feedback path compensation filter allows modification of the root locus through the addition of poles and zeros in desire location.

- The filters are generally implemented in the flight control computer and can be thought of as a added software for digital systems and additional circuitry for analog systems.

Lead compensators

- Magnitude of zero is high than the magnitude of pole.
- Lead compensators are generally used to quicken the system response by increasing natural frequency and/or decreasing time constant.
- Lead compensator shift the root locus towards the left hand side of the complex s plane.
- It help to increase the stability of the system as we all speed of response (shifts gain crossover freq to higher value).
- Additional positive phase increases the phase margin and thus increases the stability of the system.
- It minimize system overshoots and also increases the velocity constant of a system (Kv).

note: washout circuit is an example for lead network

- Lead compensator has general form of

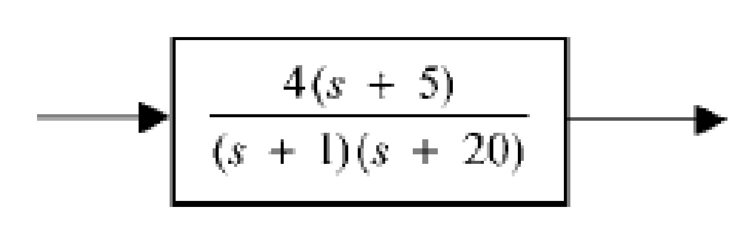
$$TF_{lead\ compensator} = \frac{b(s+a)}{a(s+b)} \qquad a < b$$

- The practical limit in choosing the pole and zero for the lead compensator is b < 10a.

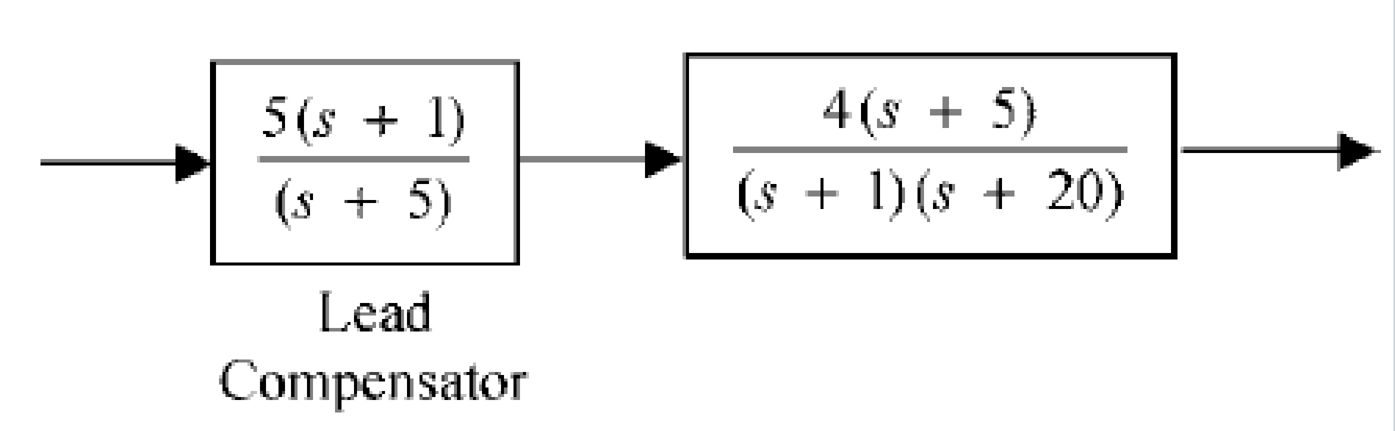
- A common application of lead compensators is to cancel a pole at s = - a, which is slowing the time response or causing the system to be unstable.

Example

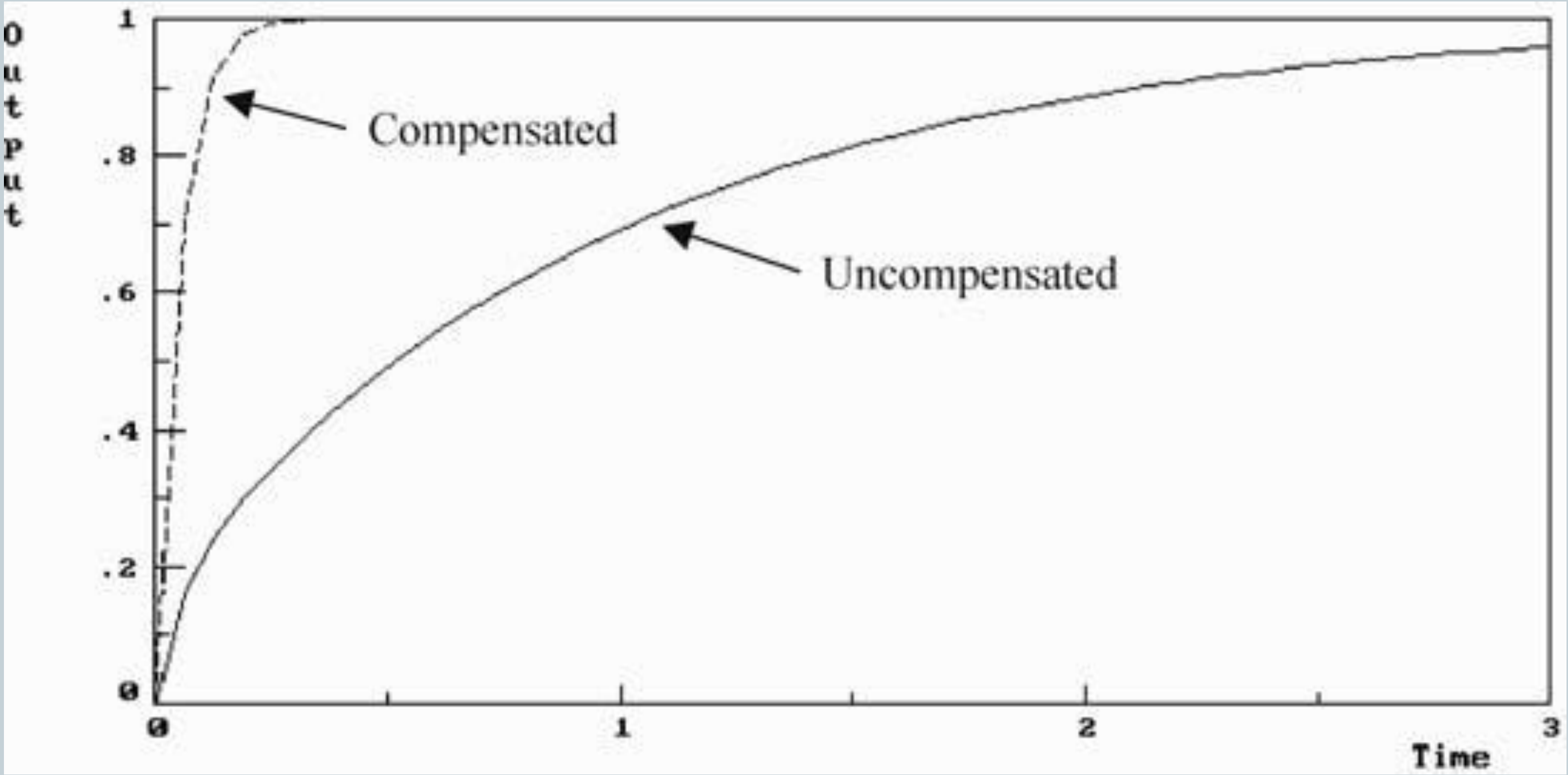
- Design a pre filter lead compensator to decrease the time constant of the following system to less than 0.2 s.



- The time response of the system will be composed of two components, each directly dependent on the characteristics of the two poles. Notice that the pole at s=-1 has a time constant of approximately 1 s. The pole at s =- 20 has a time constant of 1/20th of a second and is not a problem. A simple lead compensator can be used to cancel the problem pole.



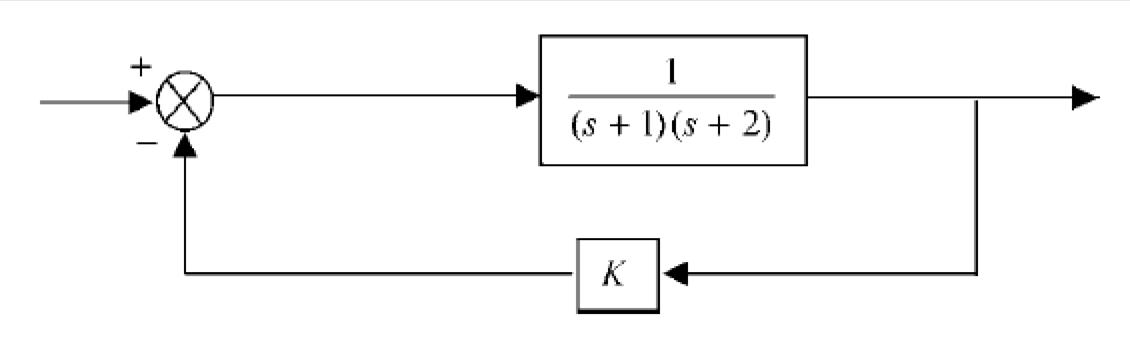
- Notice also that we have cancelled the zero at s =-5 with the pole on the lead compensator.

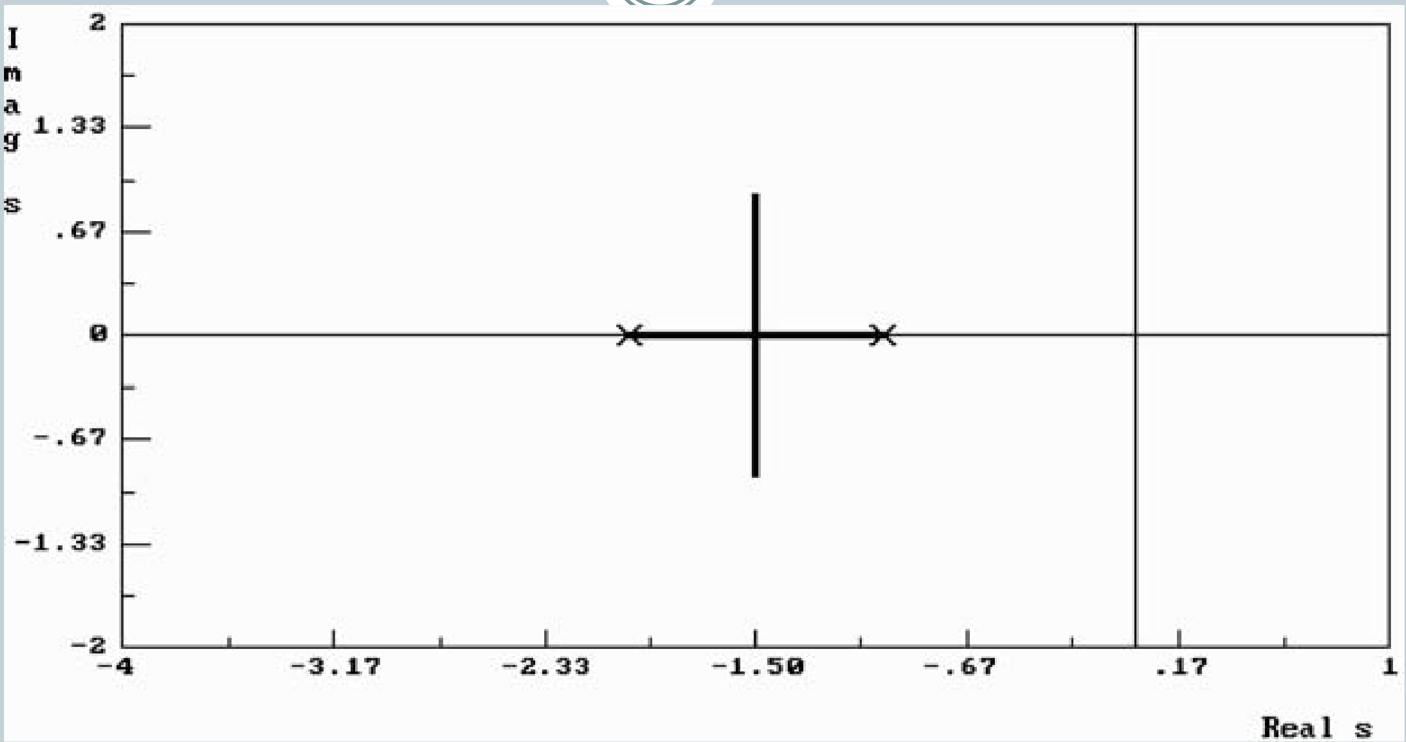


Time response characteristics with and without the lead compensator

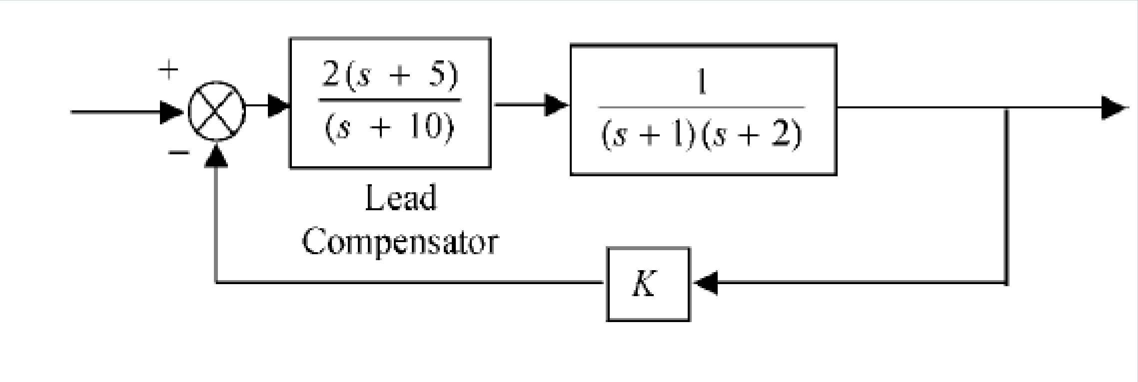
Example 2

- Design a forward-path lead compensator for the following system that will shift the root locus to the left.



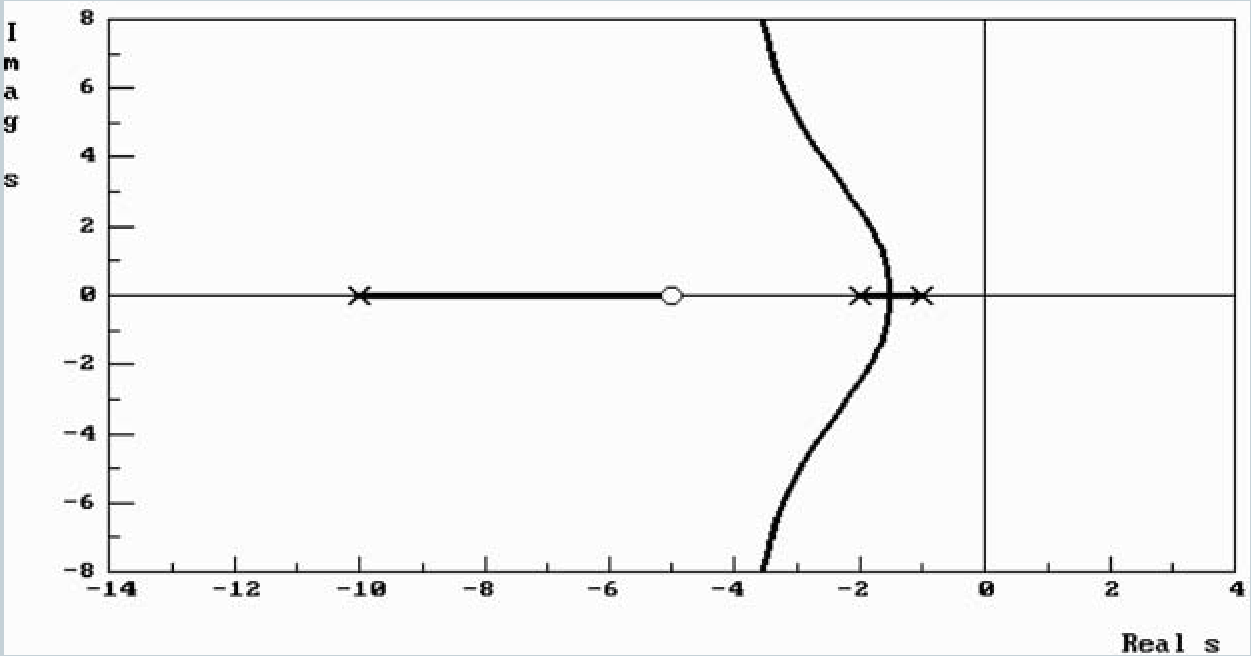


- We add a forward-path compensator that will place a pole and zero to the left of the two open-loop poles. The root locus is attracted to the compensator zero at s=- 5.



+
−
$\frac{2(s+5)}{(s+10)}$
Lead
Compensator
$\frac{1}{(s+1)(s+2)}$
K

- The compensated root locus is presented next. Notice that the vertical branches have shifted to the left.

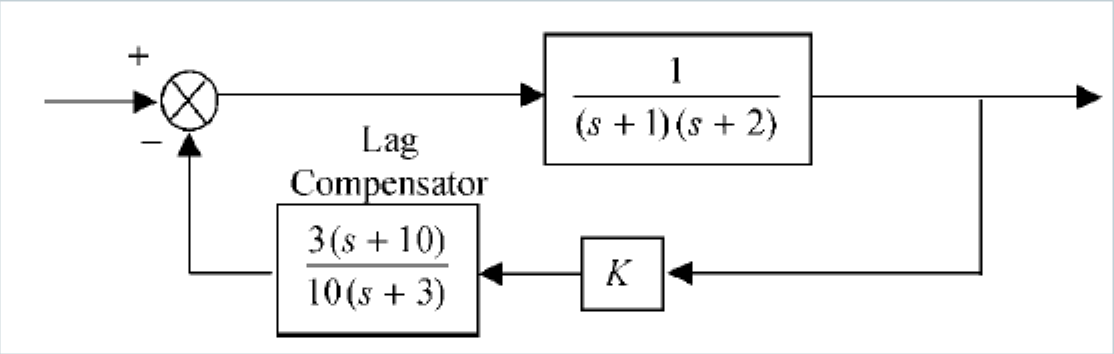


Lag compensator

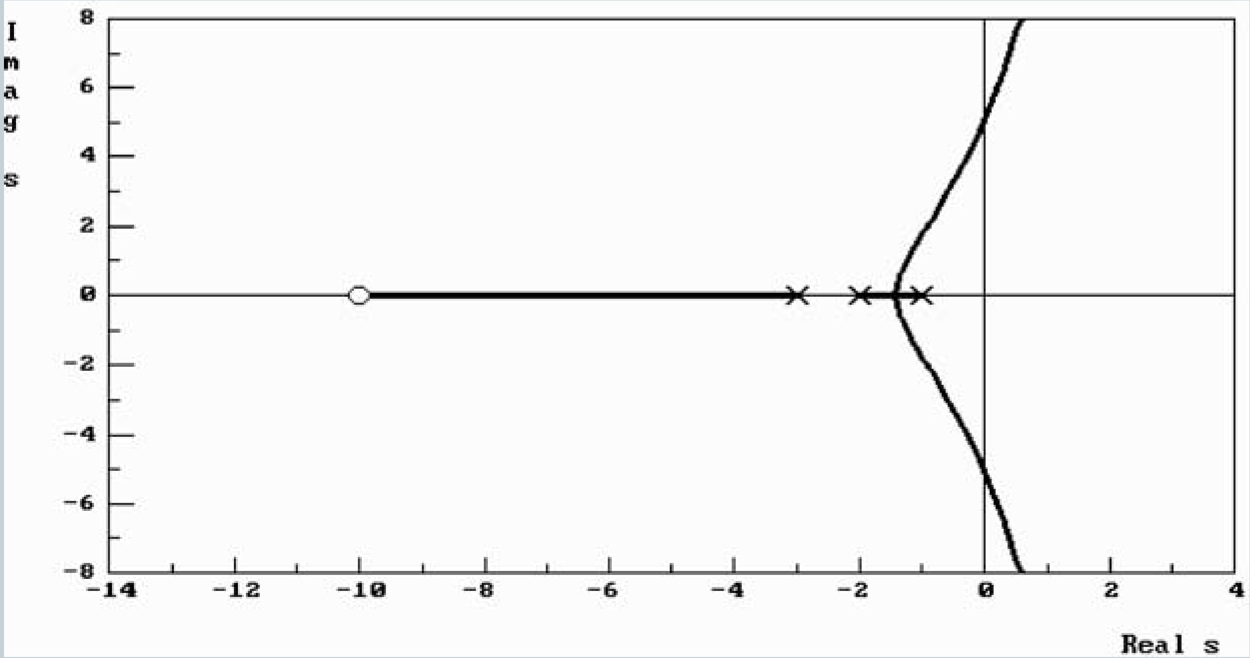
- Lag compensator shift the root locus towards the right hand side of the complex s plane.
- It help to decrease the stability of the system as well as to reduce speed of response(aircraft response).
- It also helps to increases steady state accuracy. Increasing steady state accuracy helps to induce instability.
- With lag compensation, a pole is added to the right of a zero. The pole may be used to cancel a zero, or it may be used to shift the root locus to the right.
- Lag compensation may also reduce the steady-state error of a system.

$$TF_{\substack{\text{lag}\\ \text{compensator}}} = \frac{b(s+a)}{a(s+b)} \quad a > b$$

- The lag compensator pole is placed at s=-3 to repel the root locus to the right.



- The root locus for the compensated system is presented next. Notice that the root locus branches have shifted to the right.



Lead-Lag Compensator

- A lead-lag compensator normally adds two zeros that are fairly close together and that provide a powerful attraction for root locus branches.

- In many cases, the useful gain range (before a system goes unstable) can be increased using a lead-lag compensator.

- Another common use of lead-lag compensators is the attenuation of a specific frequency range (sometimes called a notch filter).

- For example, an aircraft structural resonant frequency can be filtered out with a lead-lag compensator if a feedback sensor is erroneously affected by that frequency

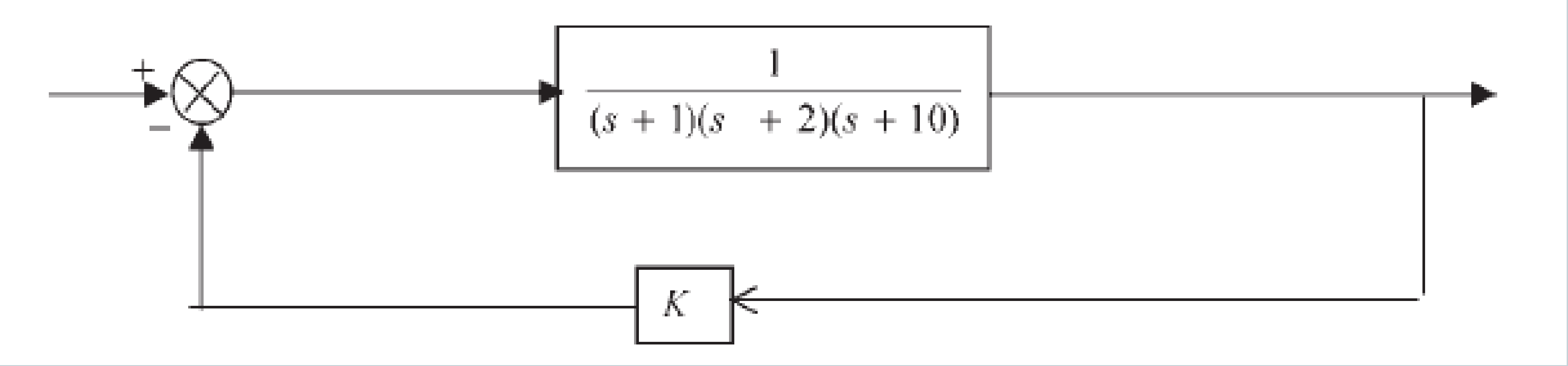
- A lead-lag compensator has the general form

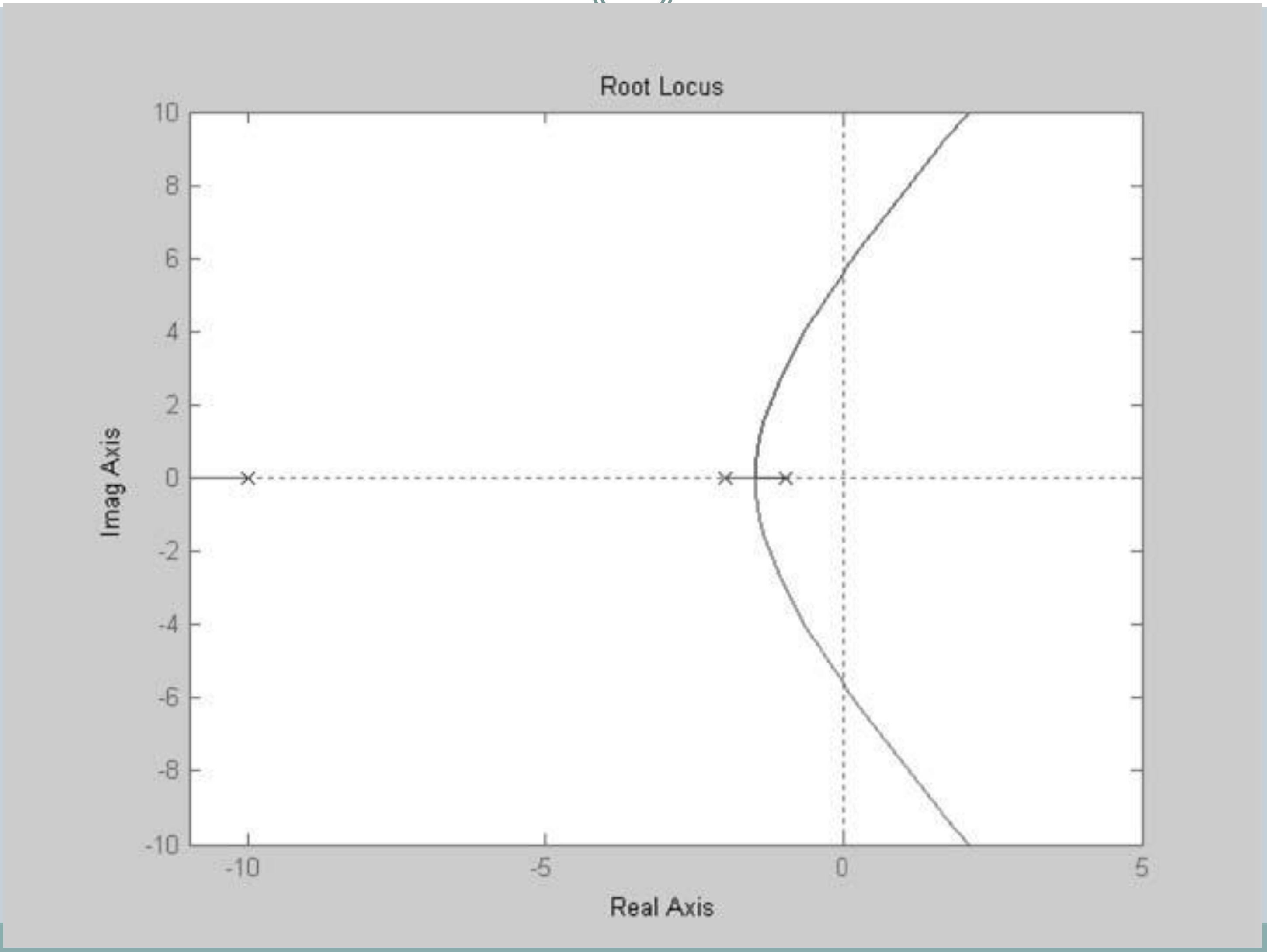
$$TF_{lead\ lag\ compensator} = \frac{bd(s+a)(s+c)}{AC(s+b)(s+d)} \qquad a > b, a < c, c < d$$

$$\frac{(s+a)}{(s+b)} component\ represent\ lag\ filter$$

$$\frac{(s+c)}{(s+d)} component\ represent\ lead\ filter$$

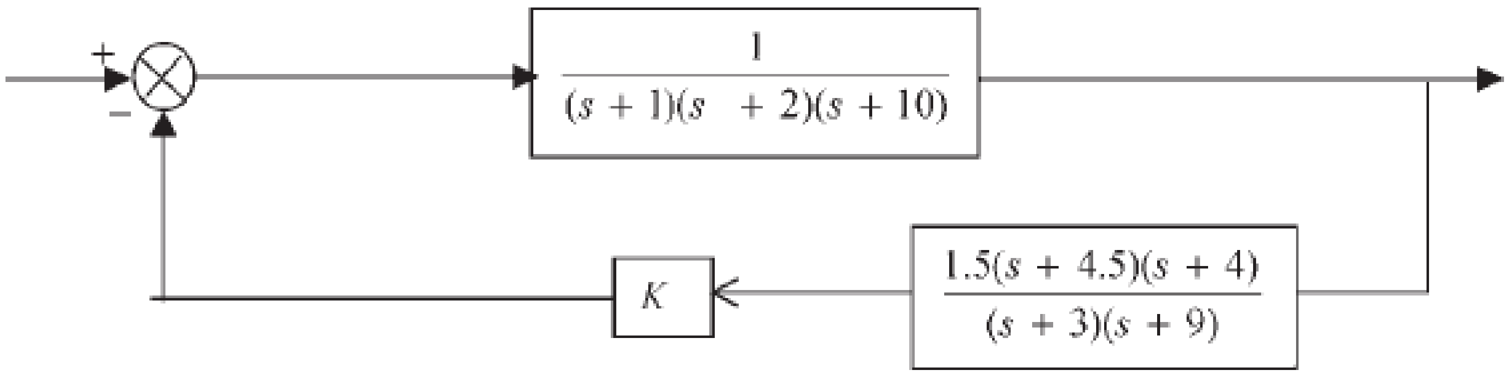
- Starting with the following system, design a lead-lag feedback path compensator that will provide for stable roots at higher values of K.



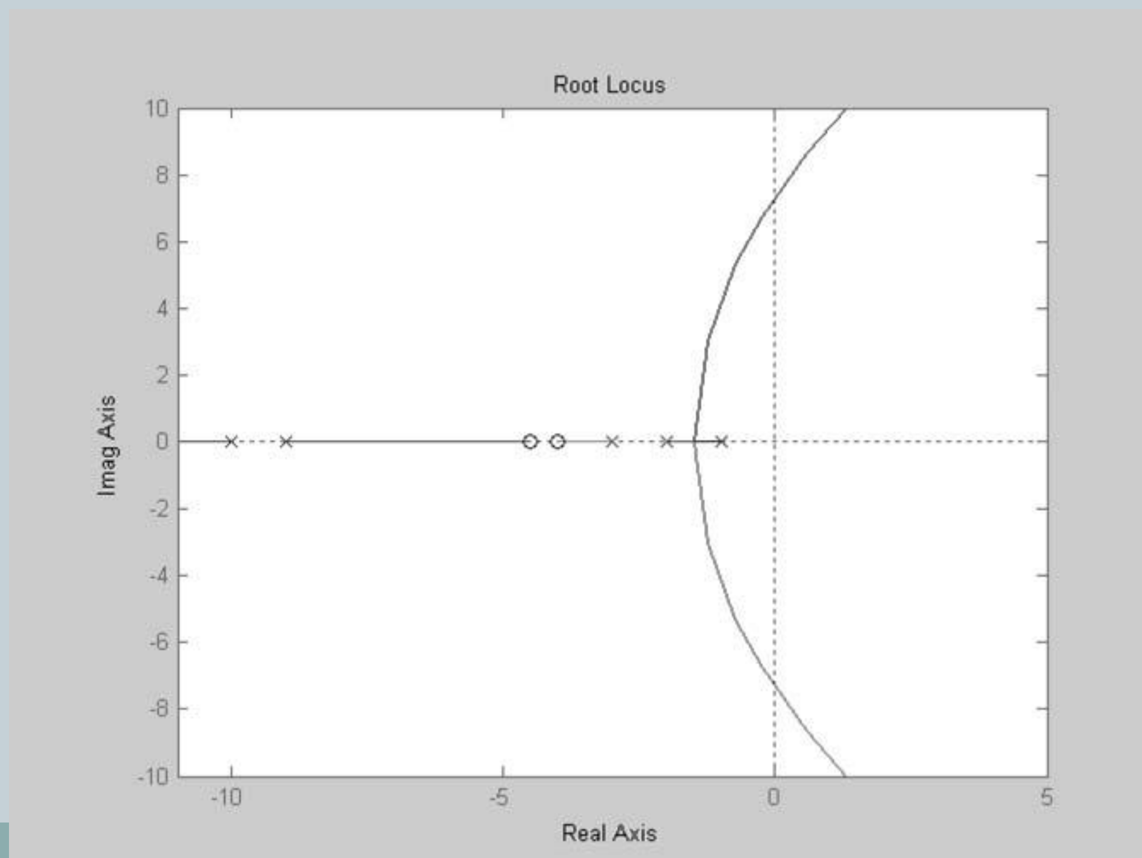

Root Locus
10
8
6
4
2
0
-2
-4
-6
-8
-10
Imag Axis
-10
-5
0
5
Real Axis

- The two complex branches of the root locus go unstable for values of K greater than 391. To allow for a larger range of stable gain values, we add the feedback path lead-lag compensator that places two zeros to the left of the pole at 2.

$$\frac{1.5(s+4.5)(s+4)}{(s+3)(s+9)}$$



+
−
1
(s + 1)(s + 2)(s + 10)
K
1.5(s + 4.5)(s + 4)
(s + 3)(s + 9)



Root Locus
Imag Axis
Real Axis
10
8
6
4
2
0
-2
-4
-6
-8
-10
-10
-5
0
5

- The two complex branches of the compensated root locus now go unstable for K values greater than 600. Thus, we have gained a larger range of stable values of K.

Thank you