Figure 10.1 Types of compensation

(a) Cascade compensation
(b) Feedback compensation
(c) Output, or load, compensation
(d) Input compensation
Figure 10.2  Pole-zero diagram of the phase-lead network
Figure 10.3 Bode diagram of the phase-lead network
Figure 10.7  Pole-zero diagram of the phase-lag network
Figure 10.8 Bode diagram of the phase-lag network
\begin{equation}
R(s) + G_c(s) \frac{1}{s(s+5)(s+10)} - Y(s)
\end{equation}

Figure 10.24  (a) Rotor winder control system  (b) Block diagram

Copyright © 1998 by Addison Wesley Longman. All rights reserved.
Figure 10.25 Root locus for lead compensator for rotor winder
Figure 10.26  (a) Step response and (b) ramp response for rotor winder system
$K = [50 \ 100 \ 200 \ 500]$;
numg=[1]; deng=[1 15 50 0];
t=[0:0.1:5];

for i=1:4
[nums,dens]=series(K(i),1,numg,deng);
[num,den]=cloop(nums,dens);
[y,x]=step(num,den,t);
Ys(:,i)=y;
end

plot(t,Ys(:,1),'-',t,Ys(:,2),'-',t,Ys(:,3),'-',t,Ys(:,4),'-')
xlabel('Time (sec)'), ylabel('y(t)

Figure 10.30 (a) Transient response for simple gain controller (b) MATLAB script
Figure 10.31  (a) Bode diagram  (b) MATLAB script

K=500; numg=[1]; deng=[1 15 50 0];
[num,den]=series(K,1,numg,deng);
w=logspace(-1,2,200);
[mag,phase,w]=bode(num,den,w);
[Gm,Pm,Wcg,Wcp]=margin(mag,phase,w);

% Phi=(60-Pm)*pi/180;
% alpha=(1+sin(Phi))/(1-sin(Phi))
% M=-10*log10(alpha)*ones(length(w),1);

[mag,phase,w]=bode(num,den,w);
semilogx(w,20*log10(mag),w,M), grid
xlabel('Frequency (rad/sec)'), ylabel('mag (dB)')
K = 1800;
numg = [1];
deng = [1 15 50 0];
numgc = K*[1 3.5];
dengc = [1 25];
[num, den] = series(numgc, dengc, numg, deng);
w = logspace(-1, 2, 200);
[mag, phase, w] = bode(num, den, w);
[Gm, Pm, Wcg, Wcp] = margin(mag, phase, w);

% bode(num, den)
title(['Gain margin = ', num2str(Gm), ...]
' Phase margin = ', num2str(Pm))

Increase $K$ to account for attenuation of $1/\alpha$.
Lead compensator

Figure 10.32 Lead compensator
(a) Compensated Bode diagram  (b) MATLAB script

Copyright © 1998 by Addison Wesley Longman. All rights reserved.
K = 1800;
numg = [1]; deng = [1 15 50 0];
numgc = K * [1 3 5]; dengc = [1 25];
[nums, dens] = series(numgc, dengc, numg, deng);
[num, den] = cloop(nums, dens);
t = [0:0.01:2];
step(num, den, t)
ylabel ('y(t)')

Figure 10.33 Lead compensator
(a) Step response  (b) MATLAB script
numg=[1]; deng=[1 15 50 0];
axis([-15,1,-10,10]);
clg; rlocus(numg,deng); hold on
% 
zeta=0.5912; wn=2.2555;
% 
x=[-10:0.1:-zeta*wn]; y=-(sqrt(1-zeta^2)/zeta)*x;
xc=[-10:0.1:-zeta*wn]; c=sqrt(wn^2-xc.^2); 
% 
plot(x,y,':',x,-y,':',xc,c,':',xc,-c,':')

Figure 10.34  Lag compensator
(a) Uncompensated root locus  (b) MATLAB script
numg=[1]; deng=[1 15 50 0];
numgc=[1 0.1]; dengc=[1 0.01];
[num,den]=series(numgc,dengc,numg,deng);
axis([-15,1,-10,10]);
clg; rlocus(num,den); hold on
zeta=0.5912; wn=2.2555;
x=[-10:0.1:-zeta*wn]; y=-(sqrt(1-zeta^2)/zeta)*x;
xc=[-10:0.1:-zeta*wn]; c=sqrt(wn^2-xc.^2);
plot(x,y,':',x,-y,':',xc,c,':',xc,-c,':')

Figure 10.35  Lag compensator
(a) Compensated root locus  (b) MATLAB script
\( K = 100; \)
\[
\text{numg} = [1]; \quad \text{deng} = [1 \ 15 \ 50 \ 0];
\]
\[
\text{numgc} = K \times [1 \ 0.1]; \quad \text{dengc} = [1 \ 0.01];
\]
\[
\text{[nums, dens]} = \text{series(nums, dengc, numg, deng);}
\]
\[
\text{[num, den]} = \text{clloop(nums, dens);}
\]
\[
\text{step(num, den)}
\]

**Figure 10.36**  Lag compensator  
(a) Step response  (b) MATLAB script
TABLE 10.6  Disk Drive Control System Specifications and Actual Performance

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Desired Value</th>
<th>Actual Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent overshoot</td>
<td>Less than 5%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Settling time</td>
<td>Less than 150 ms</td>
<td>40 ms</td>
</tr>
<tr>
<td>Maximum response to a unit disturbance</td>
<td>Less than $5 \times 10^{-3}$</td>
<td>$6.9 \times 10^{-5}$</td>
</tr>
</tbody>
</table>
Figure 10.37 Disk drive control system with PD controller (second-order model)
### TABLE 10.7 A Summary of the Characteristics of Phase-Lead and Phase-Lag Compensation Networks

<table>
<thead>
<tr>
<th></th>
<th>Phase-Lead</th>
<th>Phase-Lag</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Approach</strong></td>
<td>Addition of phase-lead angle near crossover frequency on Bode diagram. Add lead network to yield desired dominant roots in ( s )-plane</td>
<td>Addition of phase-lag to yield an increased error constant while maintaining desired dominant roots in ( s )-plane or phase margin on Bode diagram</td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td>1. Increases system bandwidth</td>
<td>1. Decreases system bandwidth</td>
</tr>
<tr>
<td></td>
<td>2. Increases gain at higher frequencies</td>
<td></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>1. Yields desired response</td>
<td>1. Suppresses high-frequency noise</td>
</tr>
<tr>
<td></td>
<td>2. Improves dynamic response</td>
<td>2. Reduces steady-state error</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>1. Requires additional amplifier gain</td>
<td>1. Slows down transient response</td>
</tr>
<tr>
<td></td>
<td>2. Increases bandwidth and thus susceptibility to noise</td>
<td>2. May require large values of components for ( RC ) network</td>
</tr>
<tr>
<td></td>
<td>3. May require large values of components for ( RC ) network</td>
<td></td>
</tr>
<tr>
<td><strong>Applications</strong></td>
<td>1. When fast transient response is desired</td>
<td>1. When error constants are specified</td>
</tr>
<tr>
<td><strong>Not applicable</strong></td>
<td>1. When phase decreases rapidly near crossover frequency</td>
<td>1. When no low-frequency range exists where phase is equal to desired phase margin</td>
</tr>
</tbody>
</table>

Table 10.7 A summary of the characteristics of phase-lead and phase-lag compensation networks
Figure DP10.3  Shuttle mast flight system