LINEAR CONTROL SYSTEMS

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Lecture 9

Controller design in the frequency domain

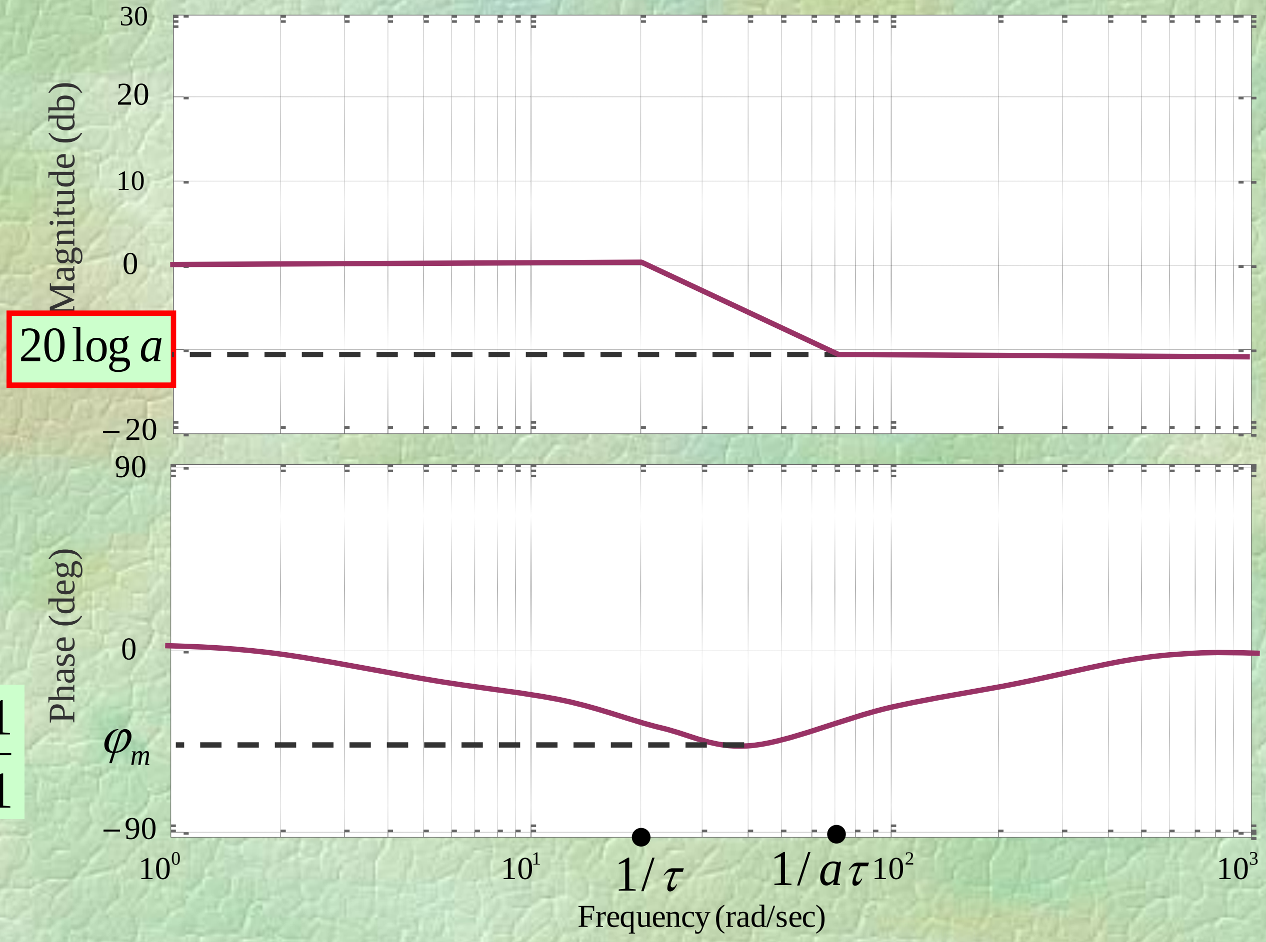
Topics to be covered include:

- Phase-lag controller design.
- Phase-lead controller design

A phase-lag controller

$$G(s)=\frac{a\tau s+1}{\tau s+1}$$

$Let\quad a<1$

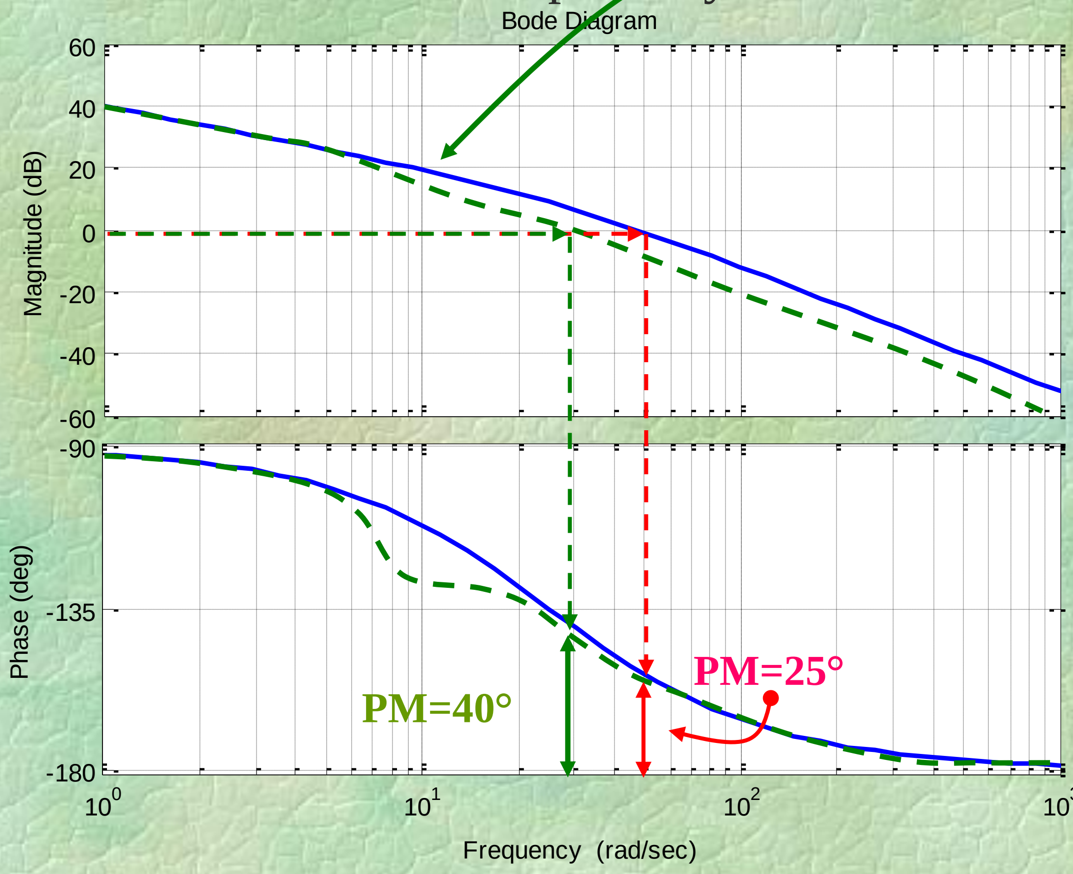


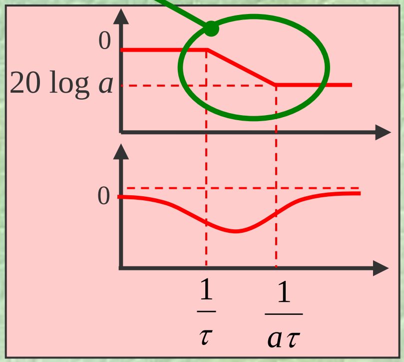
$$\sin\varphi_m=\frac{a-1}{a+1}$$

Design fundamental of a lag controller

Analysis Design

Consider a minimum phase system.





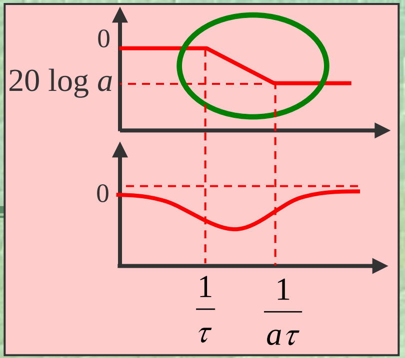
How can the lag controller help us?

Is it different from a Proportional controller?

What is the effect of a lag controller on BW? Speed of system?

What is the effect of a lag controller on noise effect?

Design procedure of a phase-lag controller in the frequency domain



Step 1: Consider $G_c(s) = k\dfrac{a\tau s+1}{\tau s+1}$ with $a<1$ as a phase-lag controller.

Note: If the plant has another gain *k*, let $G_c(s) = \dfrac{a\tau s+1}{\tau s+1}$

Step 2: Try to fix *k* according to the performance request, otherwise let *k*=1 ✓

Step 3: Sketch the Bode plot of the system (with the fixed *k*) without controller.

Step 4: According to desired PM (GM) choose the new gain crossover frequency (Phase crossover frequency). (reduce it a little). ?

Step 5: Find the required gain by lag controller and derive the parameter a.

$$20\log(a) = ... \qquad \Rightarrow \qquad a = \checkmark$$

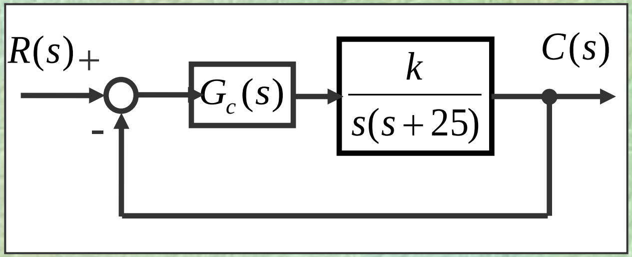
Step 6: Put the right corner of the controller sufficiently far from crossover frequency.

$$\frac{1}{a\tau} = \frac{\omega_{cross}^{new}}{10} \qquad \Rightarrow \qquad \tau = \checkmark$$

Step 7: Check the designed controller.

Phase-lag controller design in the frequency domain

Example 1: Design a lag controller for the following system such that the phase margin be 45° and the ramp error constant be 100. Find the M_p of overall system.



Step 1: Consider $G_c(s) = k\dfrac{a\tau s+1}{\tau s+1}$ with $a<1$ as a phase-lag controller.

Note: If the plant has another gain *k*, let $G_c(s) = \dfrac{a\tau s+1}{\tau s+1}$

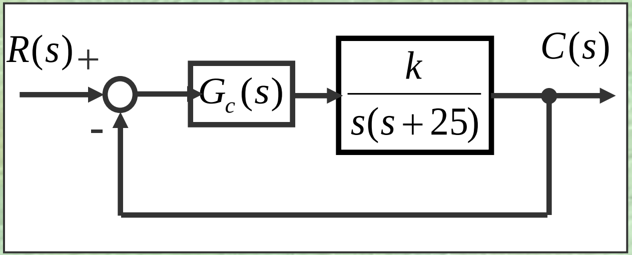
$$\Rightarrow \quad G_c(s) = \frac{a\tau s+1}{\tau s+1} \qquad a<1$$

Step 2: Try to fix *k* according to the performance request, otherwise let *k*=1

$$k_v = \lim_{s\to 0} sG_c(s)\frac{k}{s(s+25)} = 100 \quad \Rightarrow \quad k = 2500$$

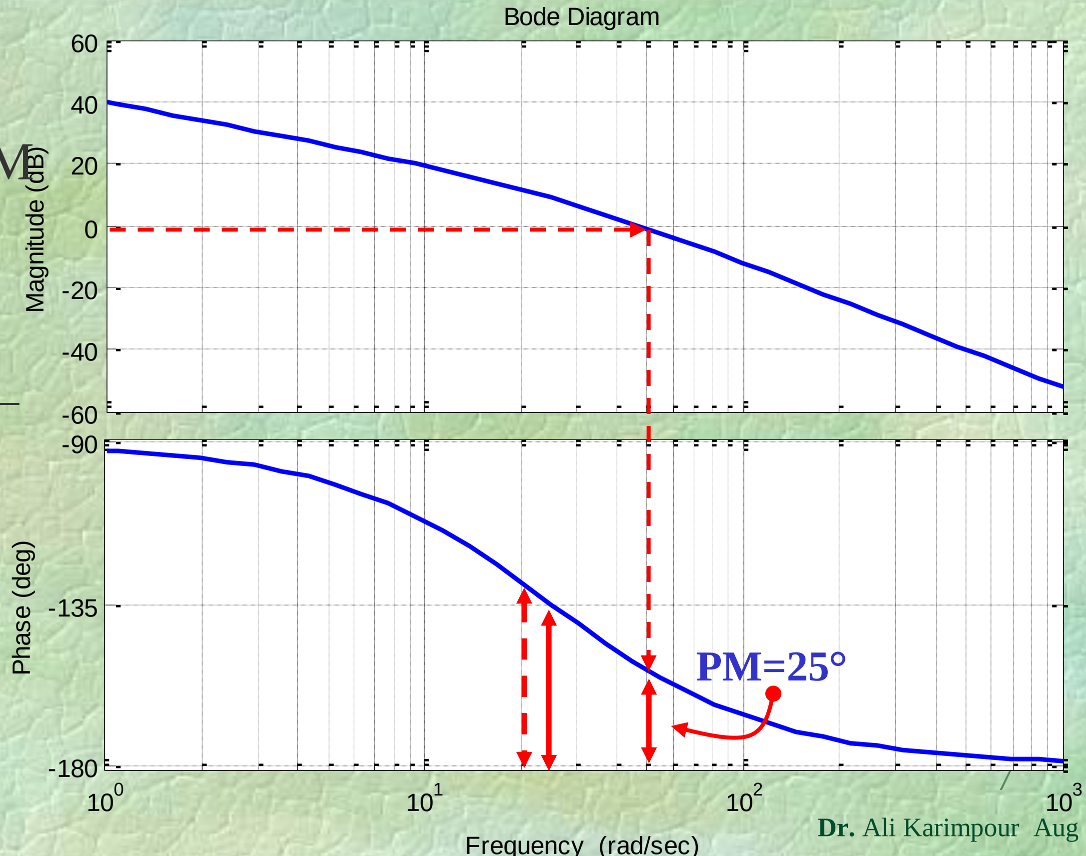
Phase-lag controller design in the frequency domain

Step 3: Sketch the Bode plot of the system (with the fixed k) without controller.



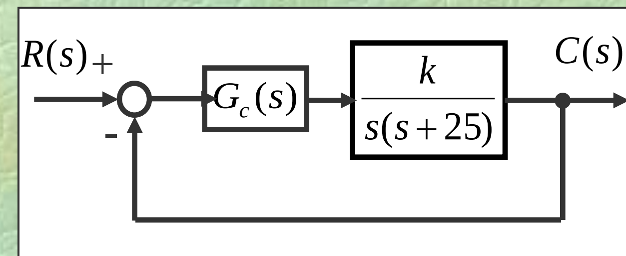
$$G(s)=\frac{2500}{s(s+25)}=\frac{100}{s(s/25+1)}$$

Step 4: According to desired PM (GM) choose the new gain crossover frequency (Phase crossover frequency). (reduce it a little).



$\omega_{croos}^{new}=25$ $\omega_{cross}^{new}=20$

Phase-lag controller design in the frequency domain



Step 5: Find the required gain by lag controller and derive the parameter a.

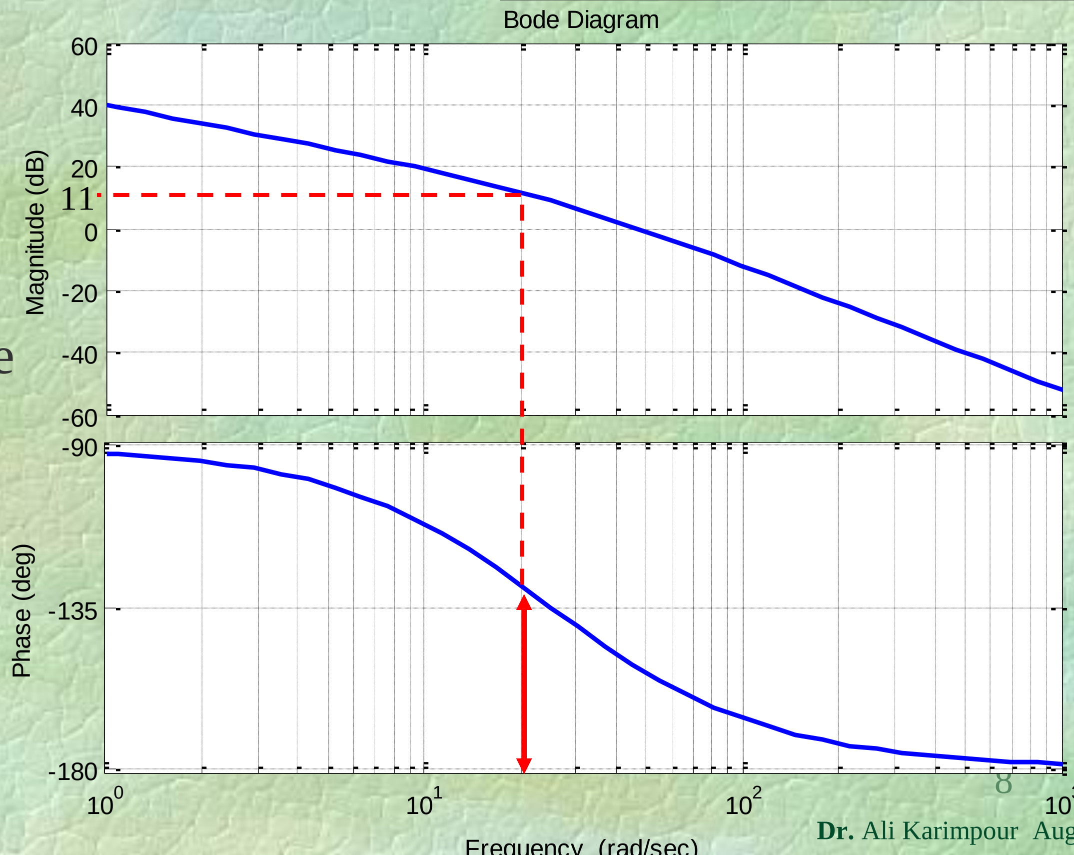
$$20\log(a) = -11$$

$$a = 10^{-\frac{11}{20}} = 0.28$$

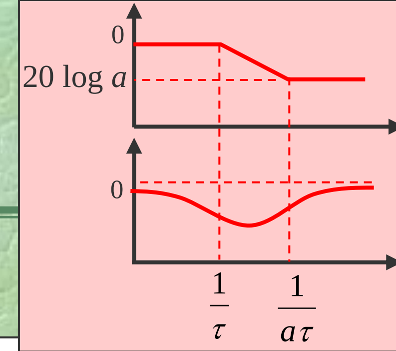
Step 6: Put the right corner of the controller sufficiently far from crossover frequency.

$$\frac{1}{a\tau} = \frac{\omega_{cross}^{new}}{10} = 2 \qquad \tau = 1.79$$

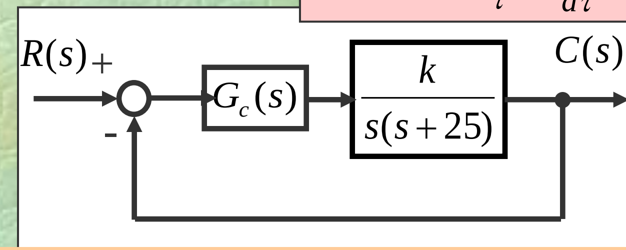
$$G_c(s) = \frac{a\tau s + 1}{\tau s + 1} = \frac{0.5s + 1}{1.79s + 1}$$

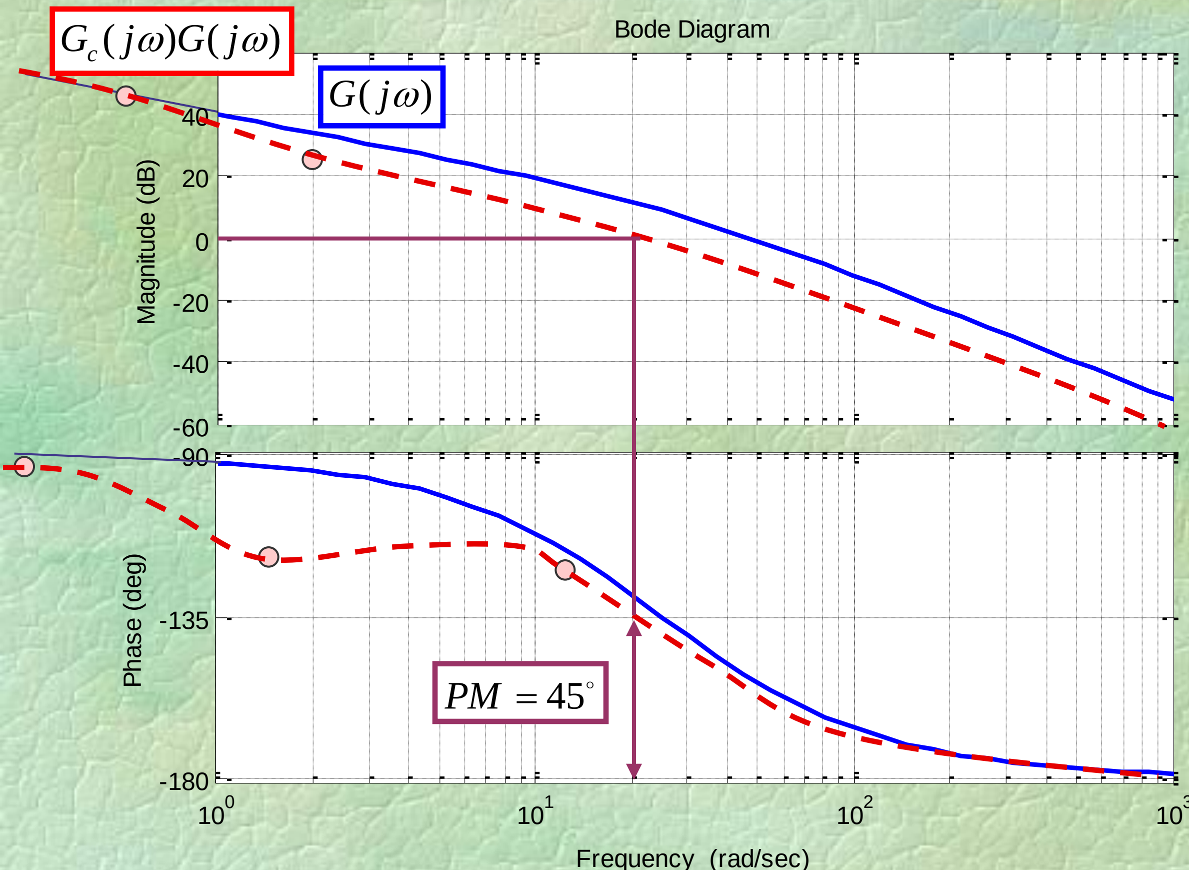


Phase-lag controller design in the frequency domain



Step 7: Check the designed controller.





$$G_c(s)=\frac{a\tau s+1}{\tau s+1}=\frac{1.79\times 0.28s+1}{1.79s+1}$$

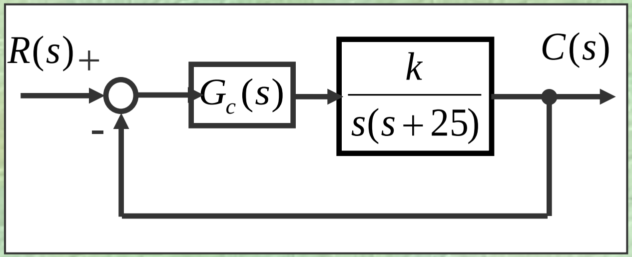
$$1/\tau=0.55,\ 1/a\tau=2$$

$$20\log a=-11db$$

$$1/\sqrt{a\tau}=1.05$$

$$\sin\varphi_m=\frac{0.28-1}{0.28+1}\Rightarrow\varphi_m=-34^\circ$$

Phase-lag controller design in the frequency domain

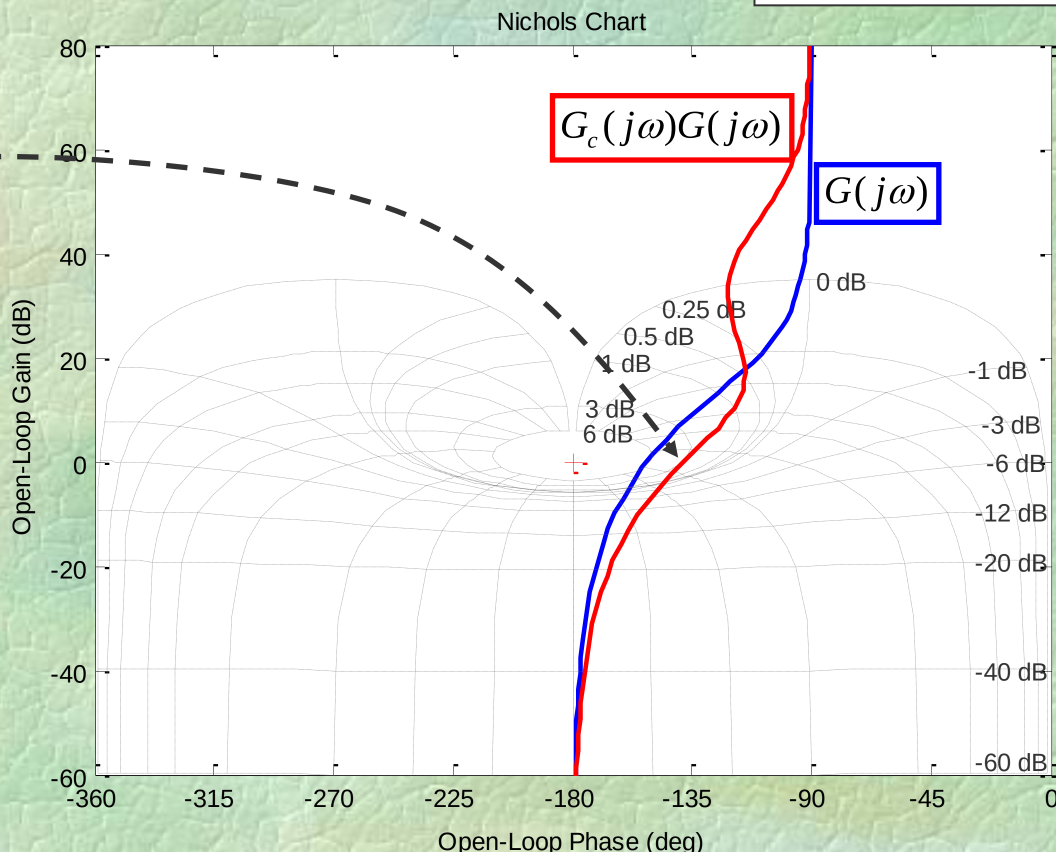


Finding M_p

Without controller M_p=6 db

After applying controller

M_p=3 db



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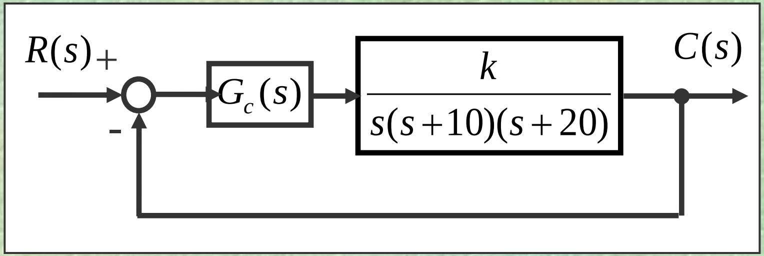
Phase-lag controller design in the frequency domain

Example 2: Design a lag controller for the following system such that the phase margin be 45° and the ramp error constant be 100.



Step 1: Consider $G_c(s) = k\dfrac{a\tau s+1}{\tau s+1}$ with $a<1$ as a phase-lag controller.

Note: If the plant has another gain *k*, let $G_c(s) = \dfrac{a\tau s+1}{\tau s+1}$

$$G_c(s) = \frac{a\tau s+1}{\tau s+1} \qquad a<1$$

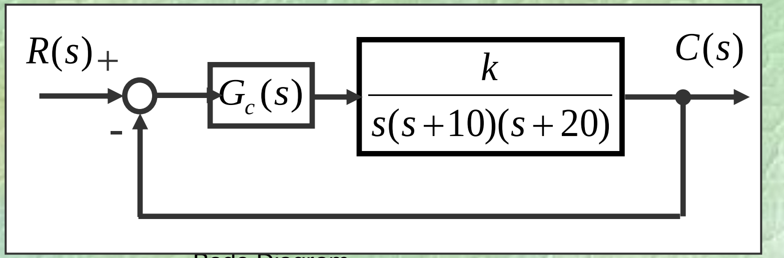
Step 2: Try to fix *k* according to the performance request, otherwise let *k*=1

$$k_v = \lim_{s\to 0} sG_c(s)\frac{k}{s(s+10)(s+20)} = 100$$

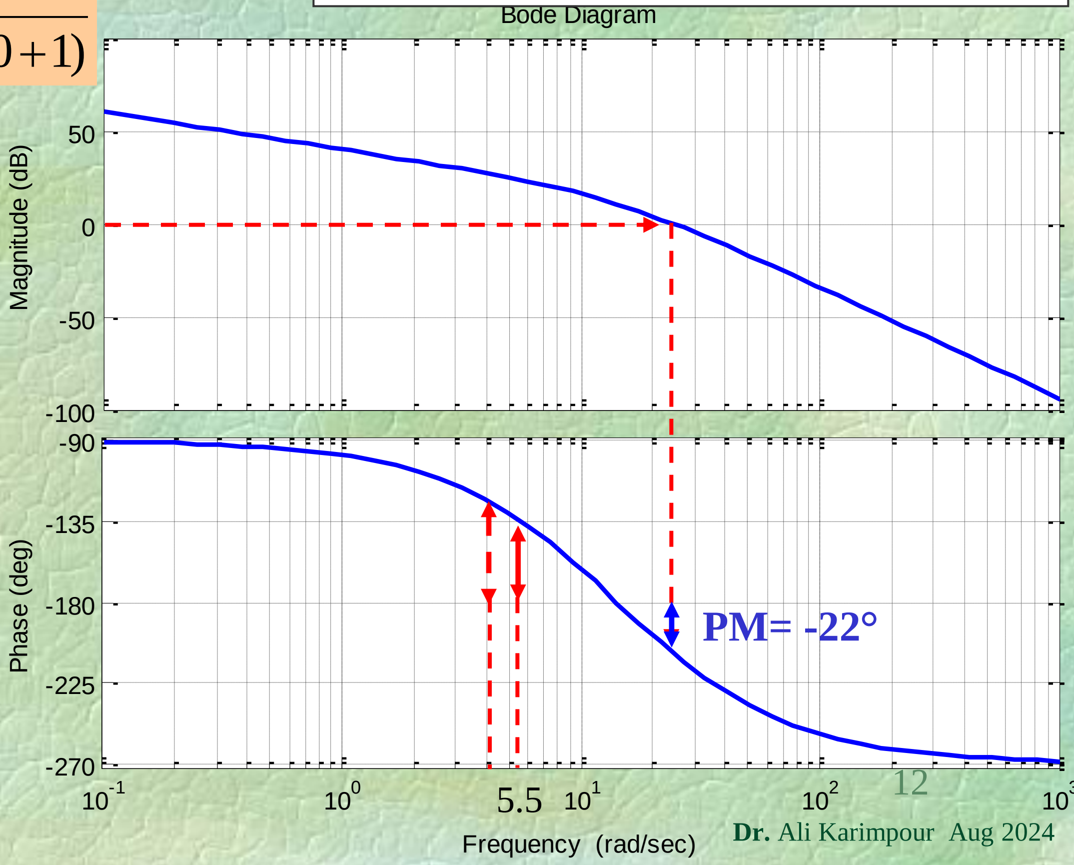
$$k = 20000$$

Phase-lag controller design in the frequency domain

Step 3: Sketch the Bode plot of the system (with the fixed k) without controller.



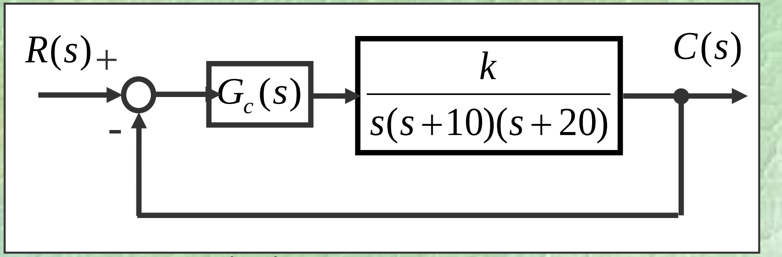
$$G(s)=\frac{20000}{s(s+10)(s+20)}=\frac{100}{s(s/10+1)(s/20+1)}$$



Step 4: According to desired PM (GM) choose the new gain crossover frequency (Phase crossover frequency). (reduce it a little).

~~$\omega_{cross}^{new}=5.5$~~ $\omega_{cross}^{new}=4$

Phase-lag controller design in the frequency domain



Step 5: Find the required gain by lag controller and derive the parameter a.

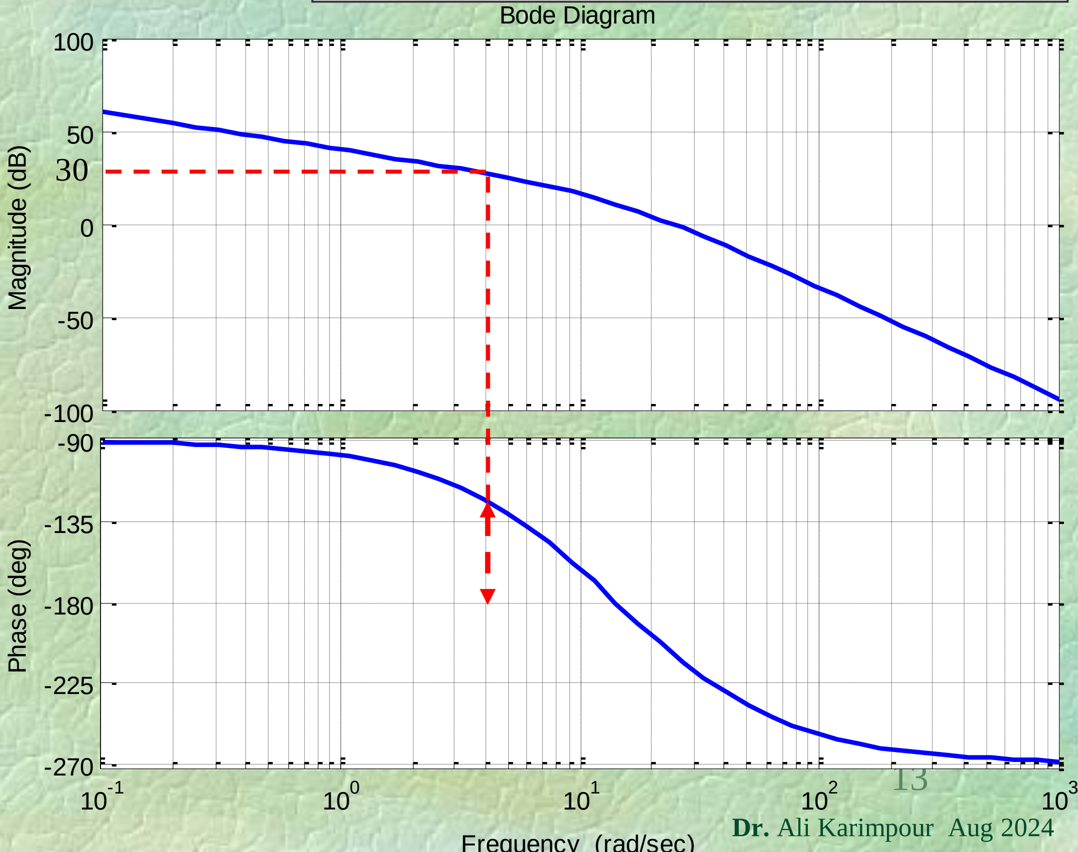
$$20\log(a) = -30$$

$$a = 10^{-\frac{30}{20}} = 0.0316$$

Step 6: Put the right corner of the controller sufficiently far from crossover frequency.

$$\frac{1}{a\tau} = \frac{\omega_{cross}^{new}}{10} = 0.4 \qquad \tau = 79$$

$$G_c(s) = \frac{a\tau s + 1}{\tau s + 1} = \frac{2.5s + 1}{79s + 1}$$



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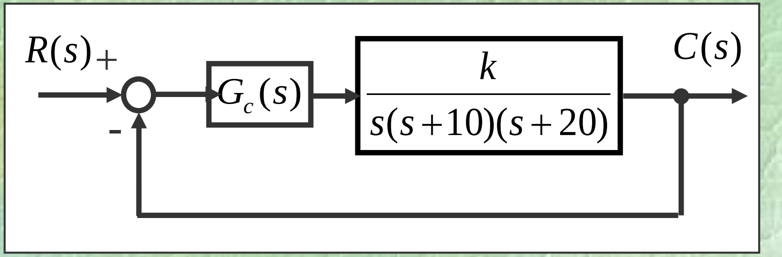
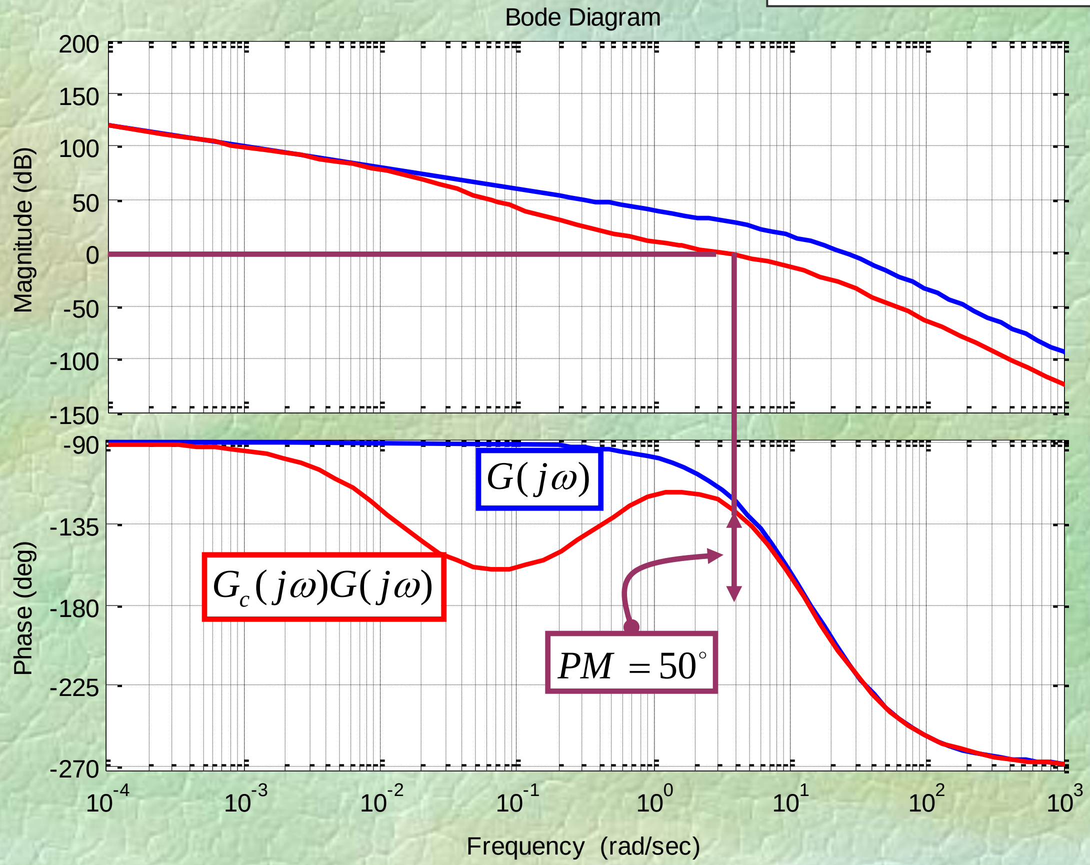
Phase-lag controller design in the frequency domain

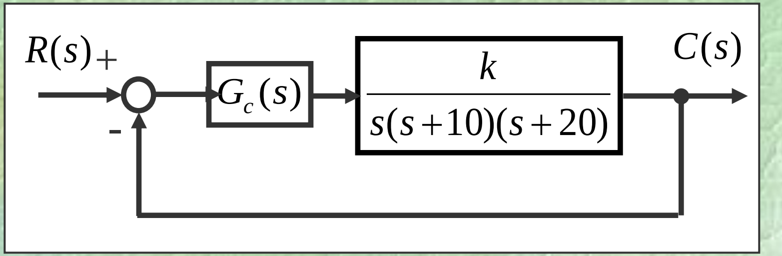
Step 7: Check the designed controller.

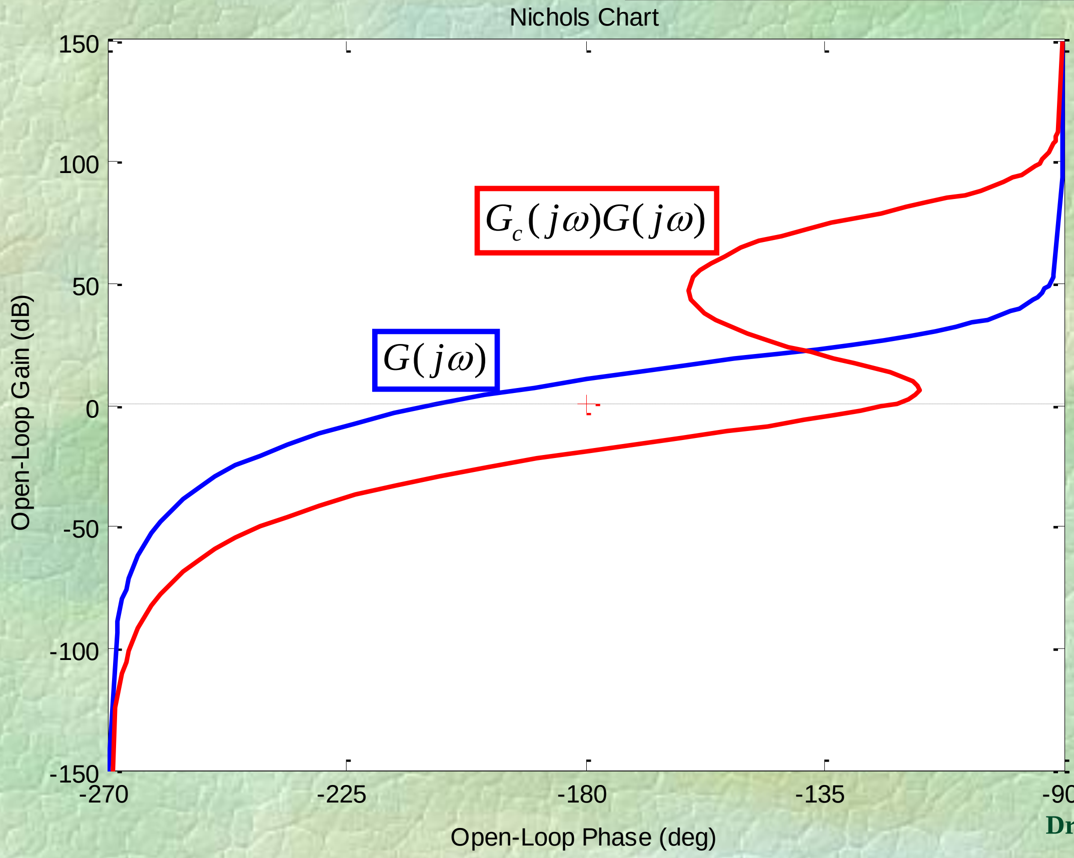




Phase-lag controller design in the frequency domain

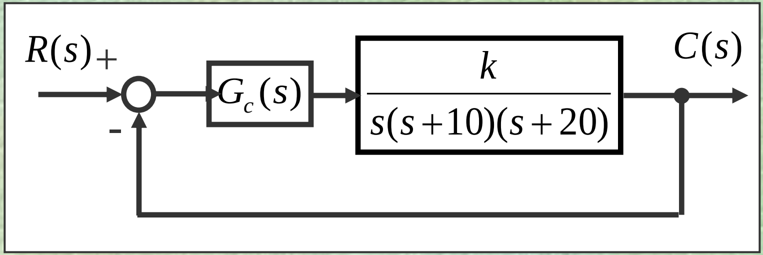
Step 7: Check the designed controller.





Phase-lag controller design in the frequency domain

Example 3: Design a lag controller for the following system such that the gain margin be 10 db and the ramp error constant be 100.



Step 1: Consider $G_c(s) = k\dfrac{a\tau s+1}{\tau s+1}$ with $a<1$ as a phase-lag controller.

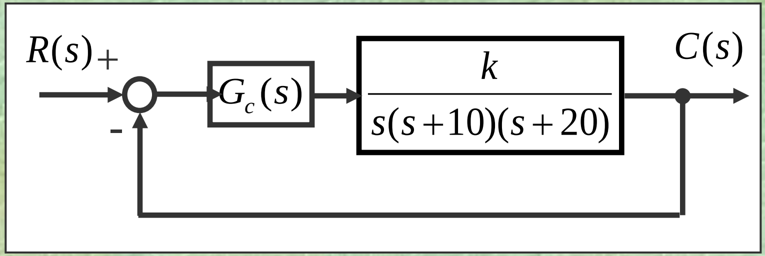
Note: If the plant has another gain *k*, let $G_c(s) = \dfrac{a\tau s+1}{\tau s+1}$

$$\Rightarrow \quad G_c(s) = \frac{a\tau s+1}{\tau s+1} \qquad a<1$$

Step 2: Try to fix *k* according to the performance request, otherwise let *k*=1

$$k_v = \lim_{s\to 0} sG_c(s)\frac{k}{s(s+10)(s+20)} = 100 \quad \Rightarrow \quad k = 20000$$

Phase-lag controller design in the frequency domain



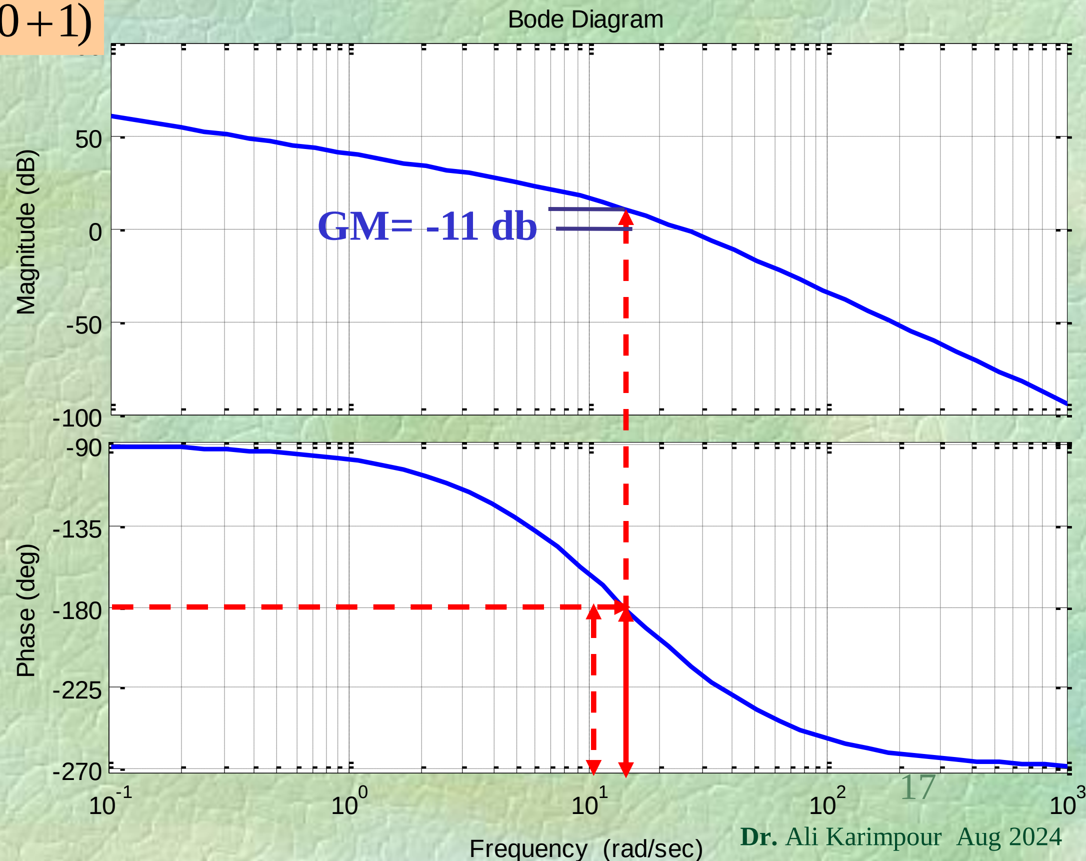
Step 3: Sketch the Bode plot of the system (with the fixed k) without controller.

$$G(s)=\frac{20000}{s(s+10)(s+20)}=\frac{100}{s(s/10+1)(s/20+1)}$$

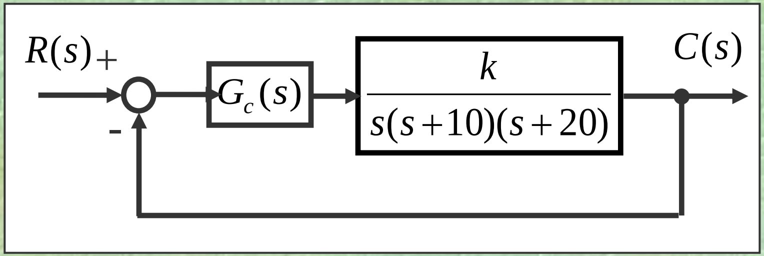
Step 4: According to desired PM (GM) choose the new gain crossover frequency (Phase crossover frequency). (reduce it a little).

~~$\omega_{cross}^{new}=15$~~

$$\omega_{cross}^{new}=10$$



Phase-lag controller design in the frequency domain



Step 5: Find the required gain by lag controller and derive the parameter a.

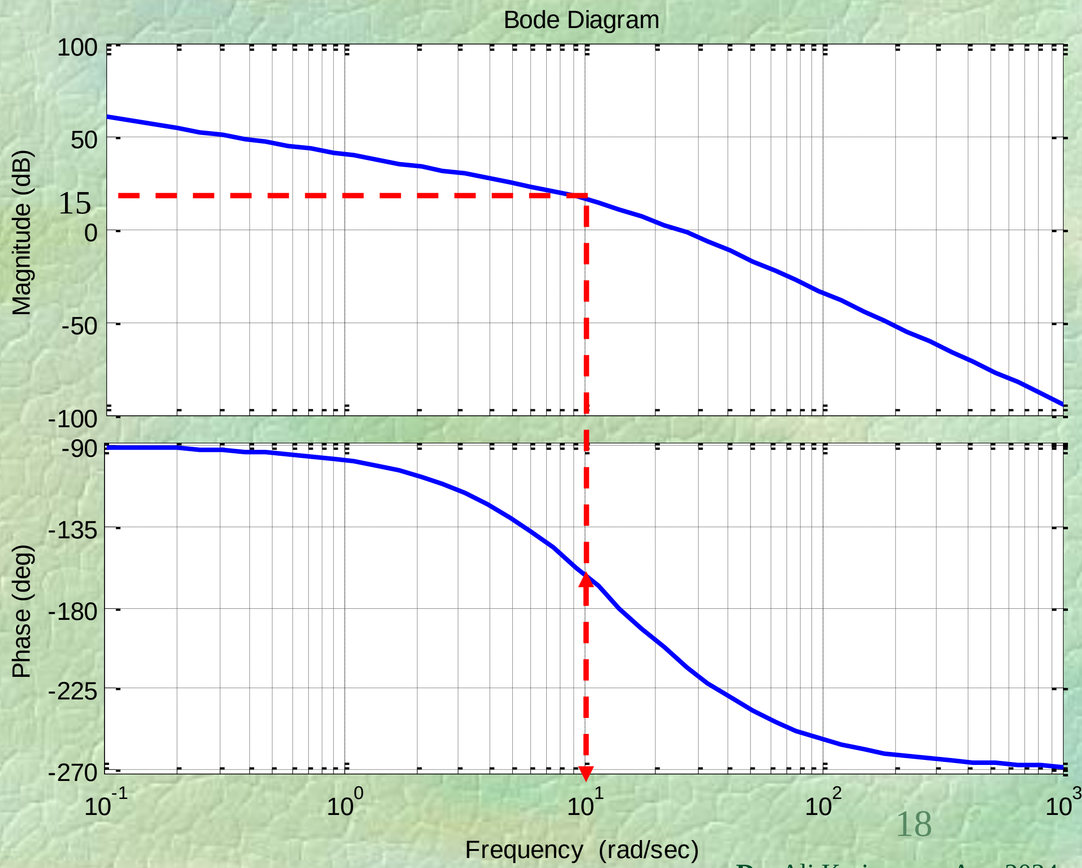
$$20\log(a) = -25$$

$$a = 10^{-\frac{25}{20}} = 0.056$$

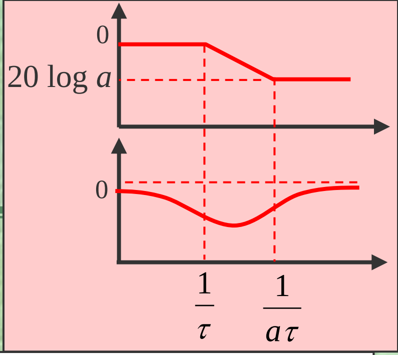
Step 6: Put the right corner of the controller sufficiently far from crossover frequency.

$$\frac{1}{a\tau} = \frac{10}{10} = 1 \qquad \tau = 17.9$$

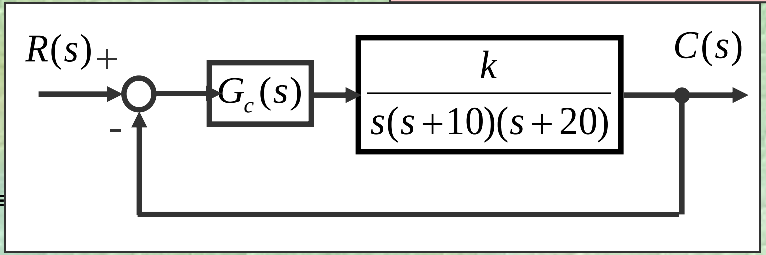
$$G_c(s) = \frac{a\tau s+1}{\tau s+1} = \frac{s+1}{17.9s+1}$$

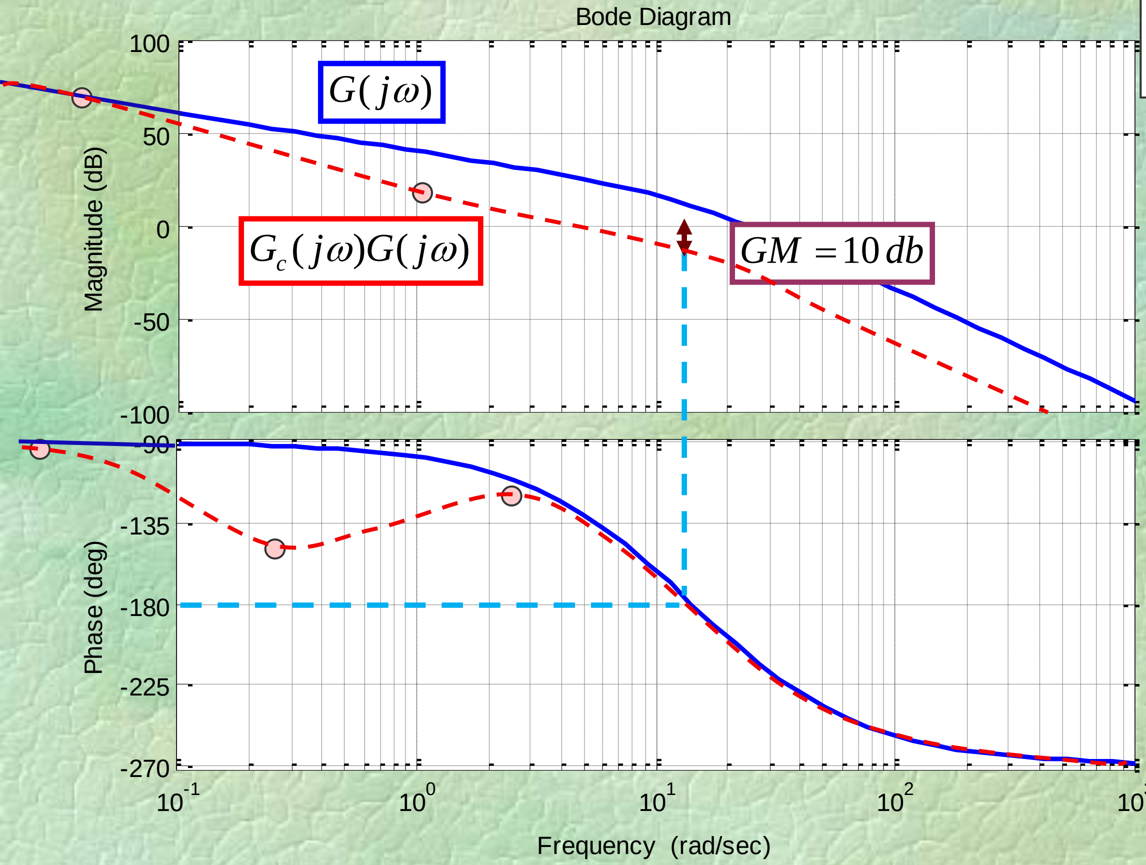


Phase-lag controller design in the frequency domain



Step 7: Check the designed controller.





$$G_c(s)=\frac{a\tau s+1}{\tau s+1}=\frac{0.056\times 17.9s+1}{17.9s+1}$$

$$1/\tau=0.06,\ 1/a\tau=1$$

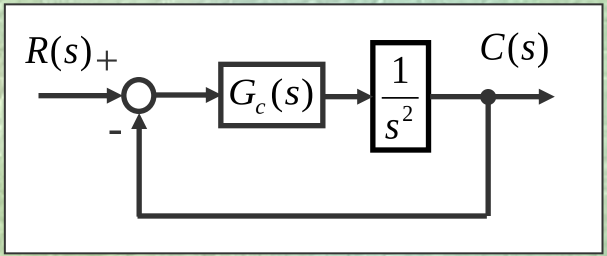
$$20\log a=-25db$$

$$1/\sqrt{a\tau}=0.25$$

$$\sin\varphi_m=\frac{0.056-1}{0.056+1}\Rightarrow\varphi_m=-63^\circ$$

Phase-lag controller design in the frequency domain

Example 4: Design a lag controller for the following system such that the phase margin be 45° and the open loop bandwidth be 10 rad/sec



It is not possible explain why?

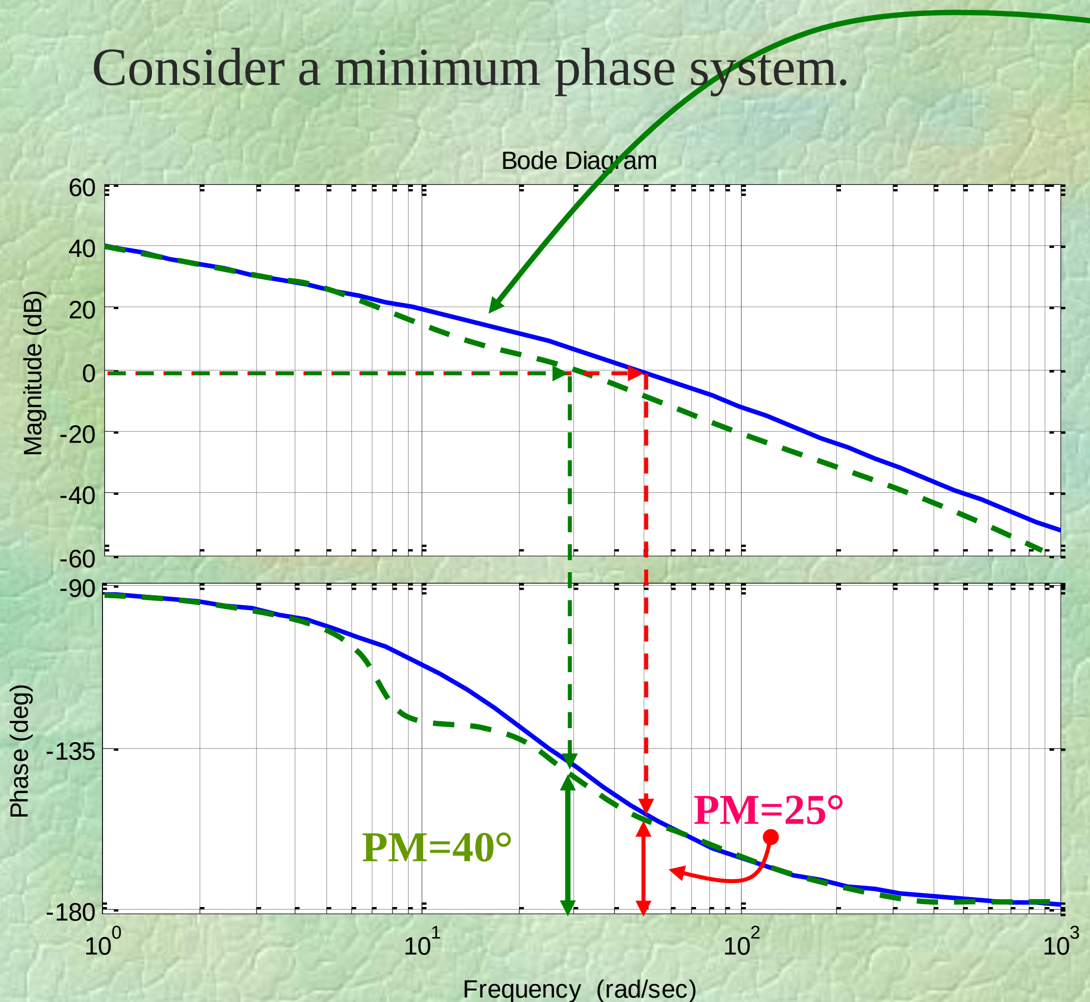
Controller design in the frequency domain

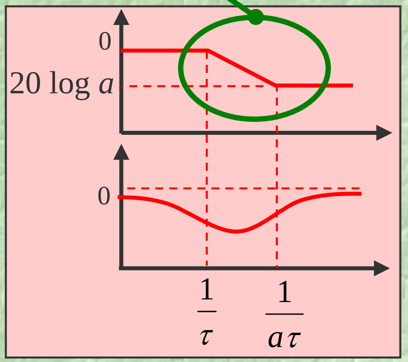
Topics to be covered include:

- Phase-lag controller design.
- Phase-lead controller design

Design fundamental of a lag controller (remember)

Consider a minimum phase system.





BW reduced.

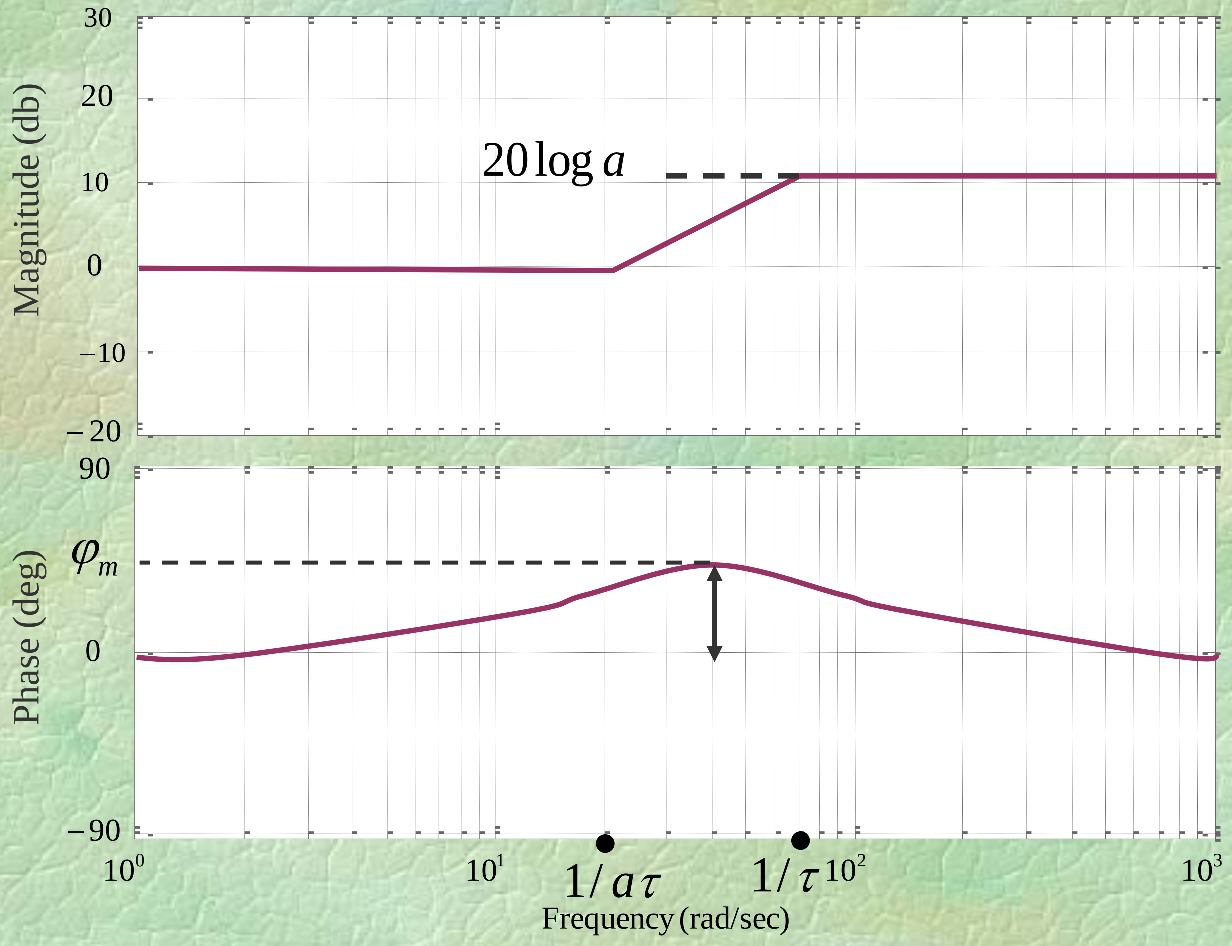
Speed of system reduced.

Effect of the noise is reduced.

A phase-lead controller

$$G(s)=\frac{a\tau s+1}{\tau s+1}$$

Let $a>1$



$$\sin\varphi_m=\frac{a-1}{a+1}$$

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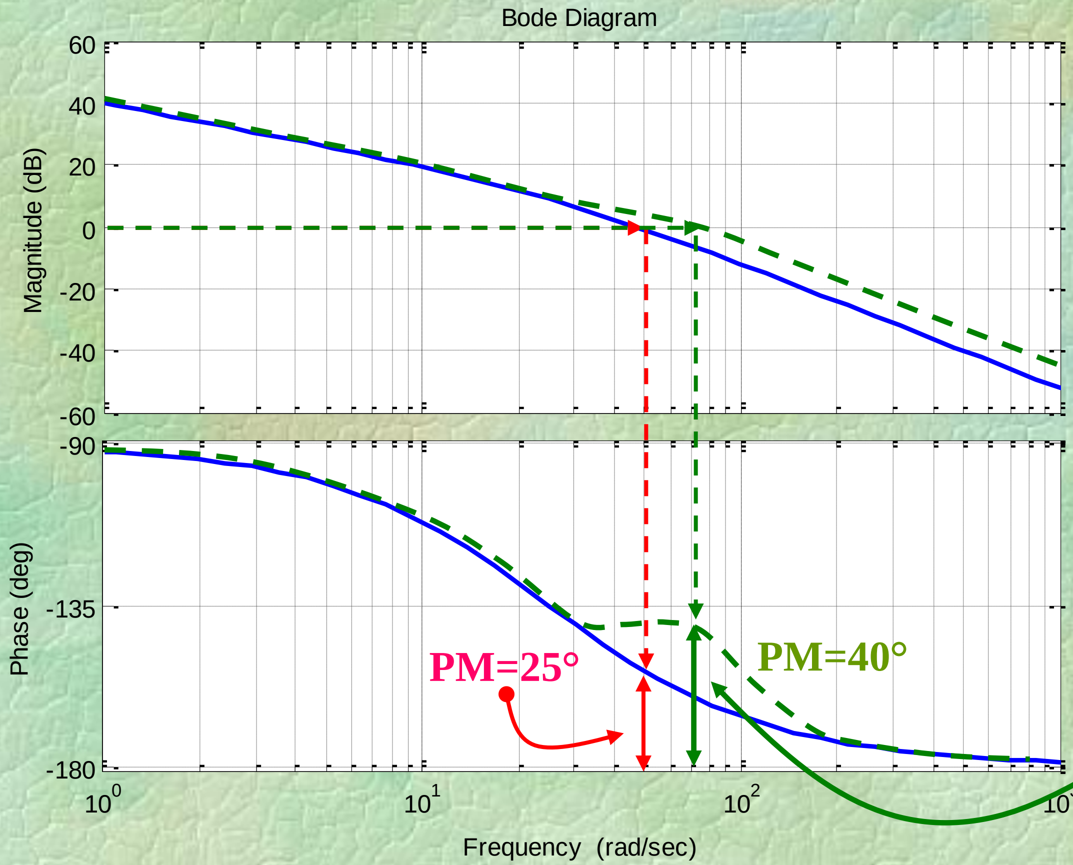
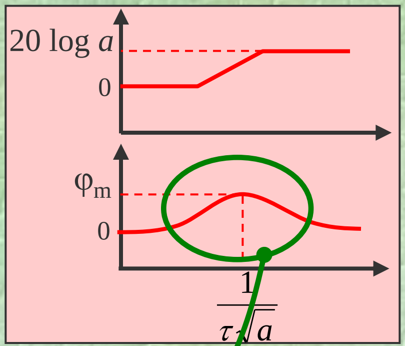
Design fundamental of the lead controller

Analysis Design

Consider a minimum phase system.



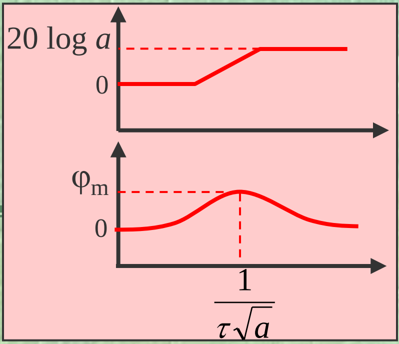


How can the lead controller help us?

What is the effect of a lead controller on BW? Speed of system?

What is the effect of a lead controller on noise effect?

Design procedure of the phase-lead controller in the frequency domain



Step 1: Consider $G_c(s) = k\dfrac{a\tau s+1}{\tau s+1}$ with $a>1$ as a phase lead controller.

Note: If the plant has another gain *k*, let $G_c(s) = \dfrac{a\tau s+1}{\tau s+1}$

Step 2: Try to fix *k* according to the performance request, otherwise let *k*=1

Step 3: Sketch the Bode plot of the system (with the fixed *k*) without controller.

Step 4: Find the system PM and if it is not sufficient choose the required phase by:

$$\varphi_m = \text{Desired PM - Existed PM} + \Delta \quad ? \qquad \sin\varphi_m = \frac{a-1}{a+1} \quad \Rightarrow \quad a =$$

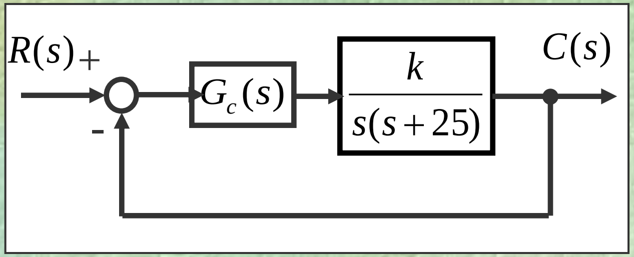
Step 5: Put the center of the controller in the new gain crossover frequency:

$$20\log\left|G(j\omega)\right|_{\omega=\omega_c^{new}} + 10\log(a) = 0 \qquad \omega_c^{new} = \qquad \omega_c^{new} = \frac{1}{\tau\sqrt{a}} \quad \Rightarrow \quad \tau =$$

Step 6: Check the controller.

Phase-lead controller design in the frequency domain

Example 5: Design a lead controller for the following system such that the phase margin be 45° and the ramp error constant be 100. Find the M_p of overall system.



Step 1: Consider $G_c(s) = k\dfrac{a\tau s+1}{\tau s+1}$ with $a>1$ as a phase-lead controller.

Note: If the plant has another gain *k*, let $G_c(s) = \dfrac{a\tau s+1}{\tau s+1}$

$$G_c(s) = \frac{a\tau s+1}{\tau s+1} \qquad a>1$$

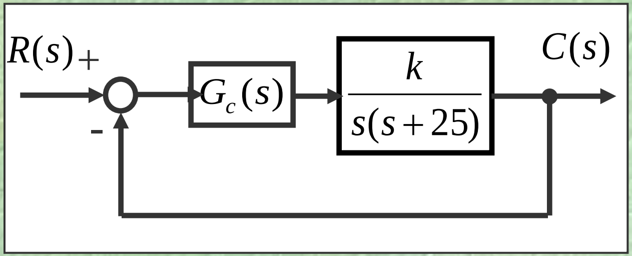
Step 2: Try to fix *k* according to the performance request, otherwise let *k*=1

$$k_v = \lim_{s\to 0} sG_c(s)\frac{k}{s(s+25)} = 100$$

$$k = 2500$$

Phase-lead controller design in the frequency domain

Step 3: Sketch the Bode plot of the system (with the fixed k) without controller.



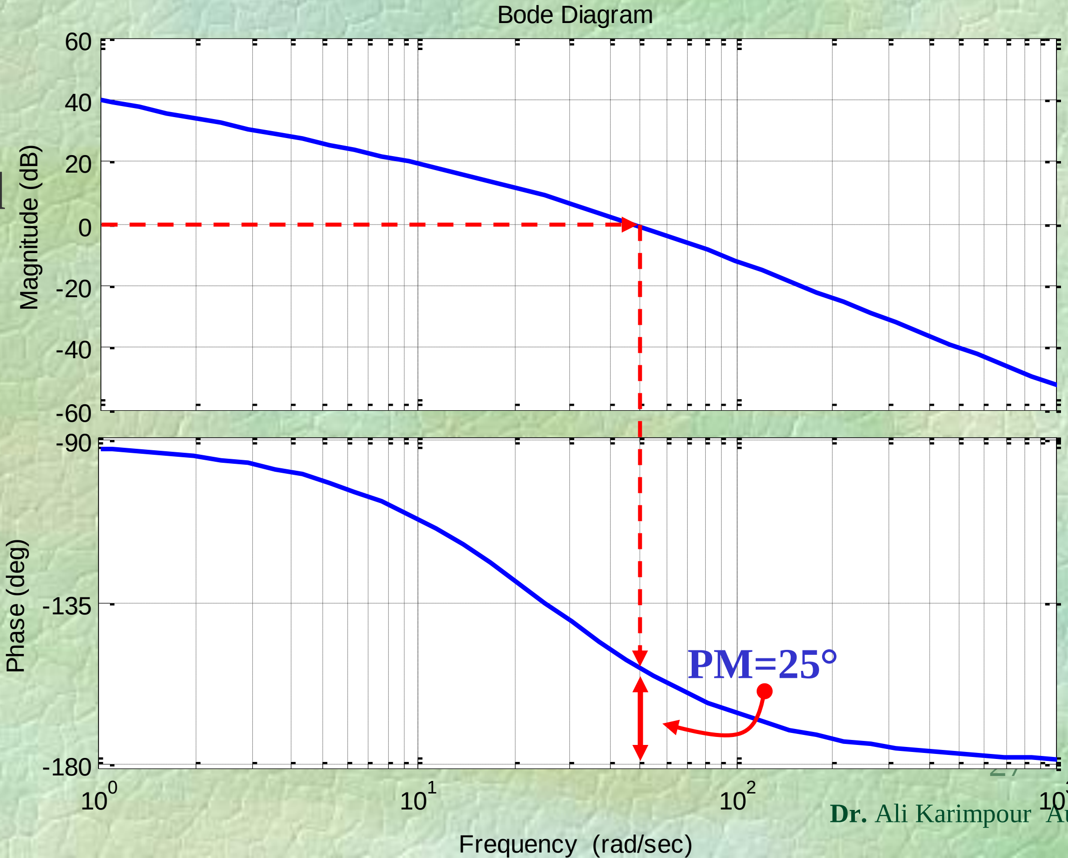
$$G(s)=\frac{2500}{s(s+25)}=\frac{100}{s(s/25+1)}$$

Step 4: Find the system PM and if it is not sufficient choose the required phase by:

$$\varphi_m = \text{Desired PM - Existed PM} + \Delta$$

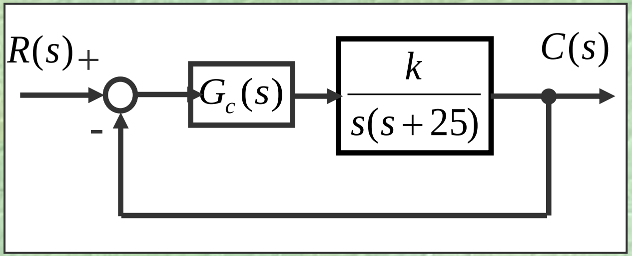
$$\varphi_m = 45^\circ - 25^\circ + 5^\circ = 25^\circ$$

$$\sin 25 = \frac{a-1}{a+1} \quad \Rightarrow \quad a = 2.46$$



Phase-lead controller design in the frequency domain

Step 5: Put the center of the controller in the new gain crossover frequency:



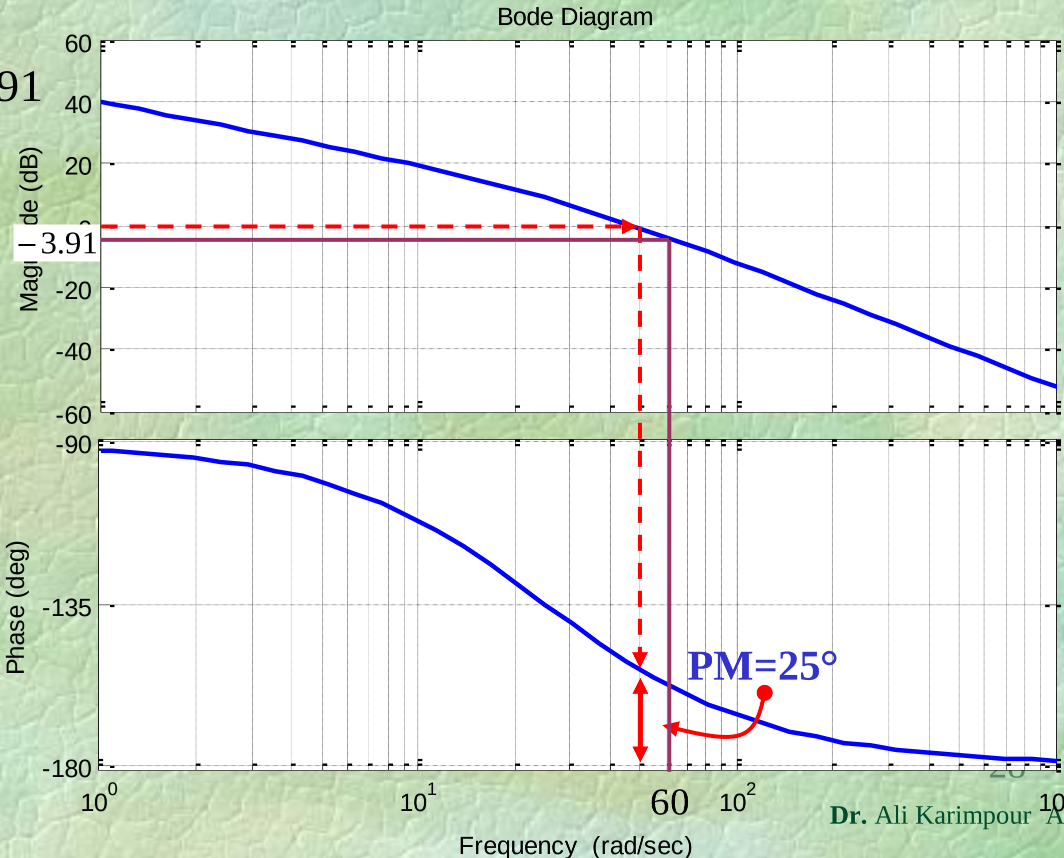
$$20\log\left|G(j\omega)\right|_{\omega=\omega_c^{new}} + 10\log(a) = 0$$

$$20\log\left|G(j\omega)\right|_{\omega=\omega_c^{new}} = -10\log(a) = -3.91$$

$$\omega_c^{new} = 60$$

$$\omega_c^{new} = \frac{1}{\tau\sqrt{a}} \Rightarrow \qquad \tau = 0.0106$$

$$G_c(s) = \frac{a\tau s + 1}{\tau s + 1} = \frac{0.0261s + 1}{0.0106s + 1}$$



Phase-lead controller design in the frequency domain

Step 6: Check the controller.

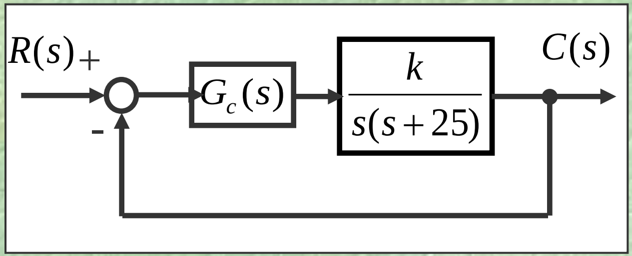
$$G_c(s)=\frac{0.0261s+1}{0.0106s+1}$$

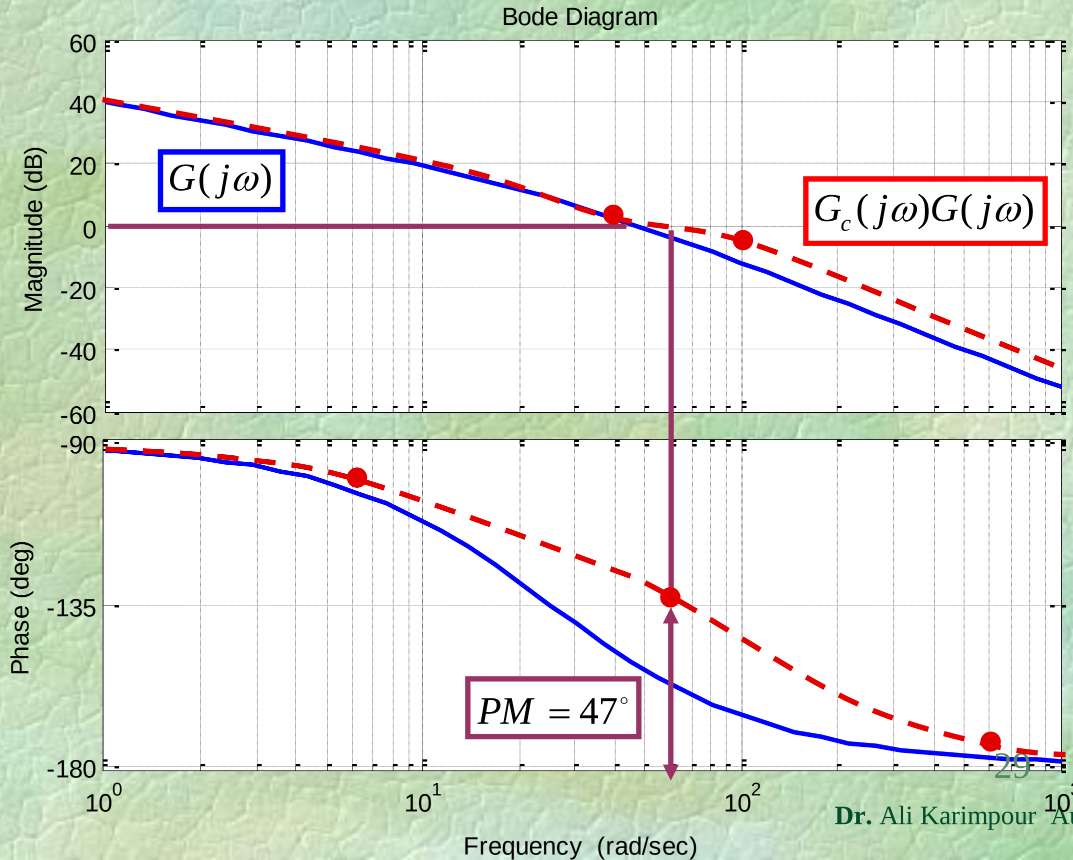
$$1/\tau=94.33,\ 1/a\tau=38.3$$

$$20\log a=7.8$$

$$1/\sqrt{a}\tau=60$$

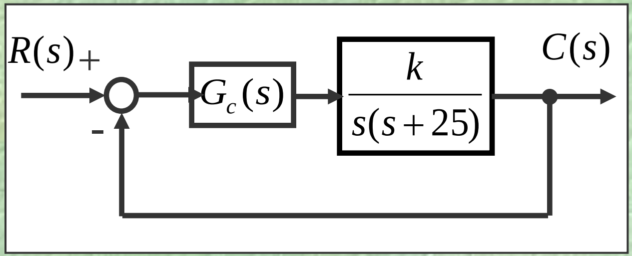
$$\varphi_m=25^\circ$$



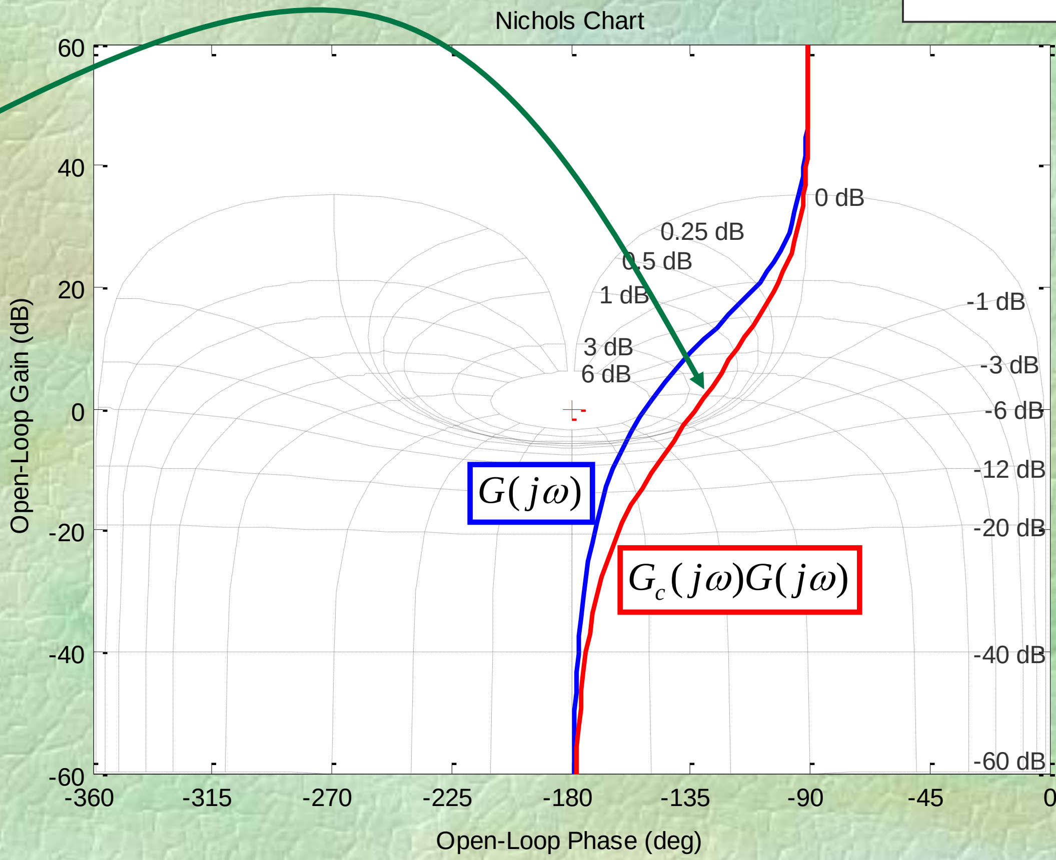


Phase-lead controller design in the frequency domain

Find M_p

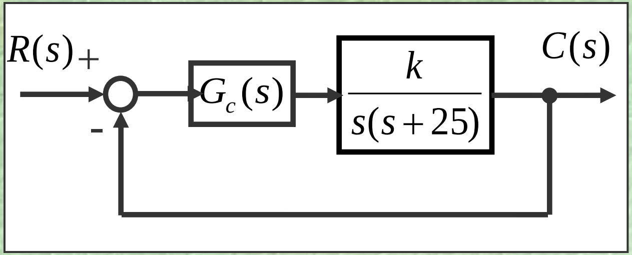


M_p= 2 db



Phase-lead controller design in the frequency domain

Example 6: Find the step response of example 5 and compare it with lag design in example 1.



$$G_{clead}(s)=\frac{0.0261s+1}{0.0106s+1}$$ Lead controller of example 5

$$G_{clag}(s)=\frac{0.5s+1}{1.79s+1}$$ Lag controller of example 1

$$M_1(s)=\frac{G(s)}{1+G(s)}=\frac{2500}{s^2+25s+2500}$$ Closed loop transfer function without controller

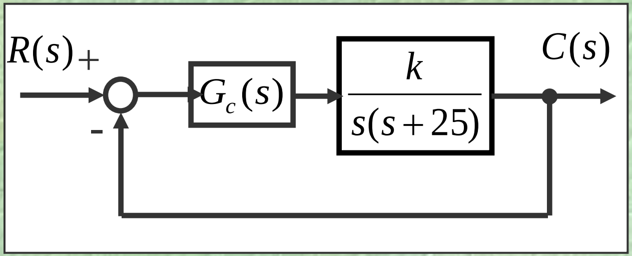
$$M_2(s)=\frac{G_{clead}(s).G(s)}{1+G_{clead}(s).G(s)}=\frac{6156s+235800}{s^3+119.3s^2+8514s+235800}$$ Closed loop transfer function with a phase-lead controller

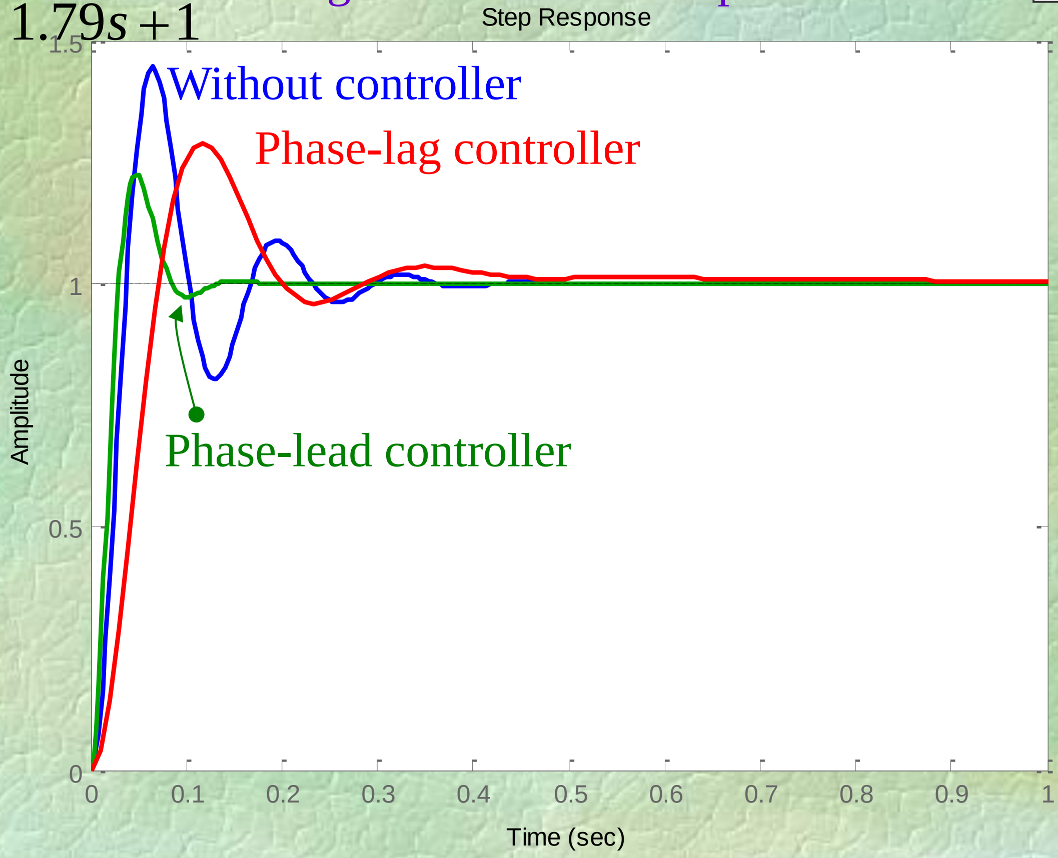
$$M_3(s)=\frac{G_{clag}(s).G(s)}{1+G_{clag}(s).G(s)}=\frac{698.3s+1397}{s^3+25.6s^2+712.3s+1397}$$ Closed loop transfer function with a phase-lag controller

Phase-lead controller design in the frequency domain

$$G_{clead}(s) = \frac{0.0261s + 1}{0.0106s + 1}$$ Lead controller of example 5

$$G_{clag}(s) = \frac{0.5s + 1}{1.79s + 1}$$ Lag controller of example 1

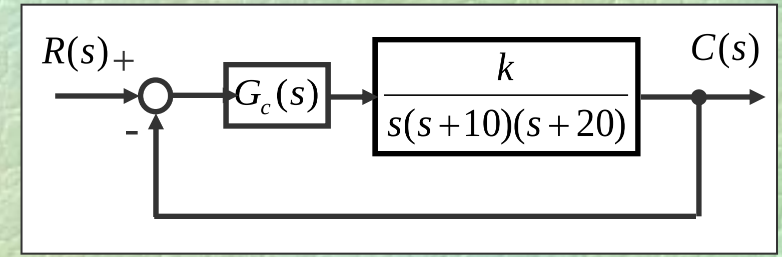




Check the speed of different controllers and compare it ??

Phase-lead controller design in the frequency domain

Example 7: Design a lead controller for the following system such that the phase margin be 45° and the ramp error constant be 100.



Step 1: Consider $G_c(s) = k\dfrac{a\tau s+1}{\tau s+1}$ with $a>1$ as a phase-lead controller.

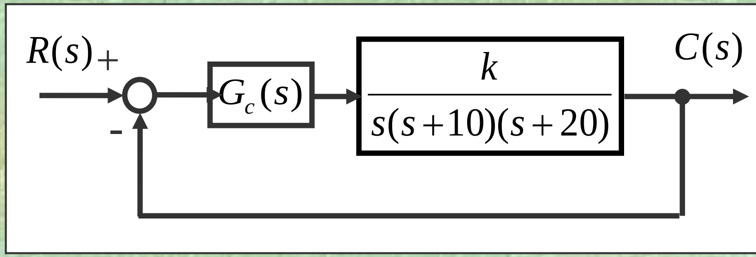
Note: If the plant has another gain k, let $G_c(s) = \dfrac{a\tau s+1}{\tau s+1}$

$$\Rightarrow \quad G_c(s) = \frac{a\tau s+1}{\tau s+1} \qquad a>1$$

Step 2: Try to fix k according to performance request, otherwise let k=1

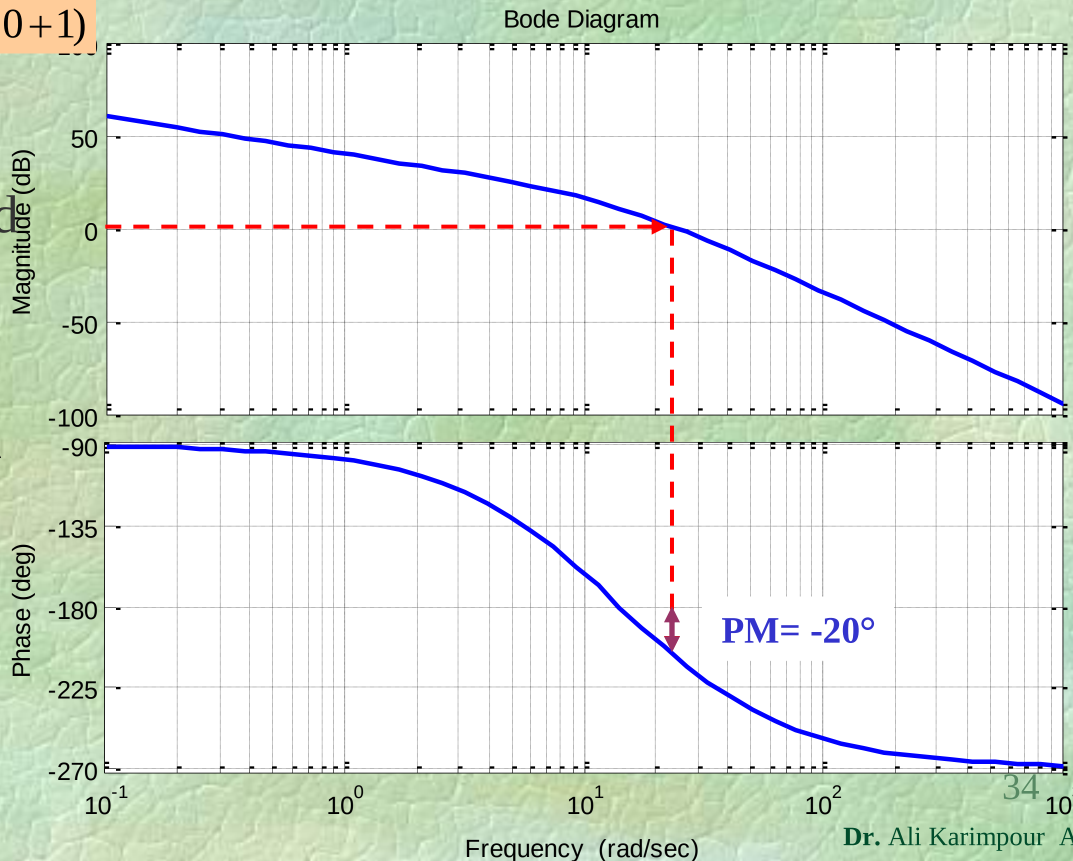
$$k_v = \lim_{s\to 0} sG_c(s)\frac{k}{s(s+10)(s+20)} = 100 \quad \Rightarrow \quad k = 20000$$

Phase-lead controller design in the frequency domain



Step 3: Sketch the Bode plot of system (with the fixed k) without controller.

$$G(s)=\frac{20000}{s(s+10)(s+20)}=\frac{100}{s(s/10+1)(s/20+1)}$$



Step 4: Find the system PM and if it is not sufficient choose the required phase by:

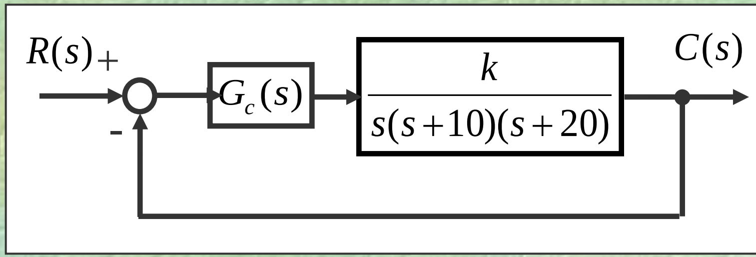
$$\varphi_m = \text{Desired PM - Existed PM} + \Delta$$

$$\varphi_m = 45^\circ - (-20) + 5^\circ = 70^\circ$$

$$\sin 70 = \frac{a-1}{a+1} \quad \Rightarrow \quad a = 32$$

Phase-lead controller design in the frequency domain

Step 5: Put the center of controller in the new gain crossover frequency:



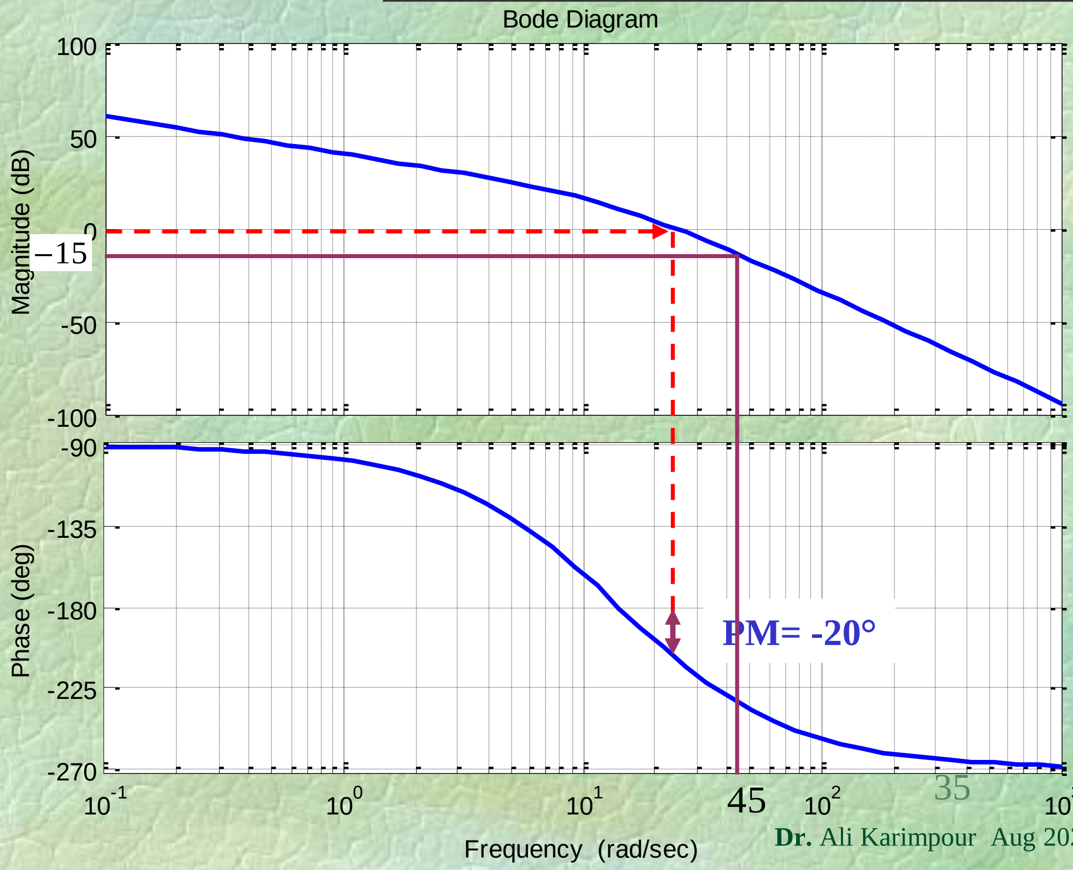
$$20\log|G(j\omega)|_{\omega=\omega_c^{new}} + 10\log(a) = 0$$

$$20\log|G(j\omega)|_{\omega=\omega_c^{new}} = -10\log(a) = -15$$

$$\omega_c^{new} = 45$$

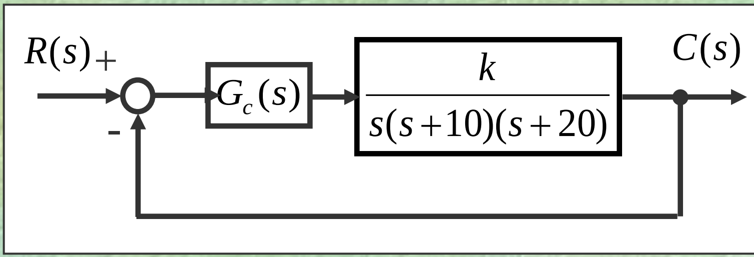
$$\omega_c^{new} = \frac{1}{\tau\sqrt{a}} \quad \Rightarrow \quad \tau = 0.0039$$

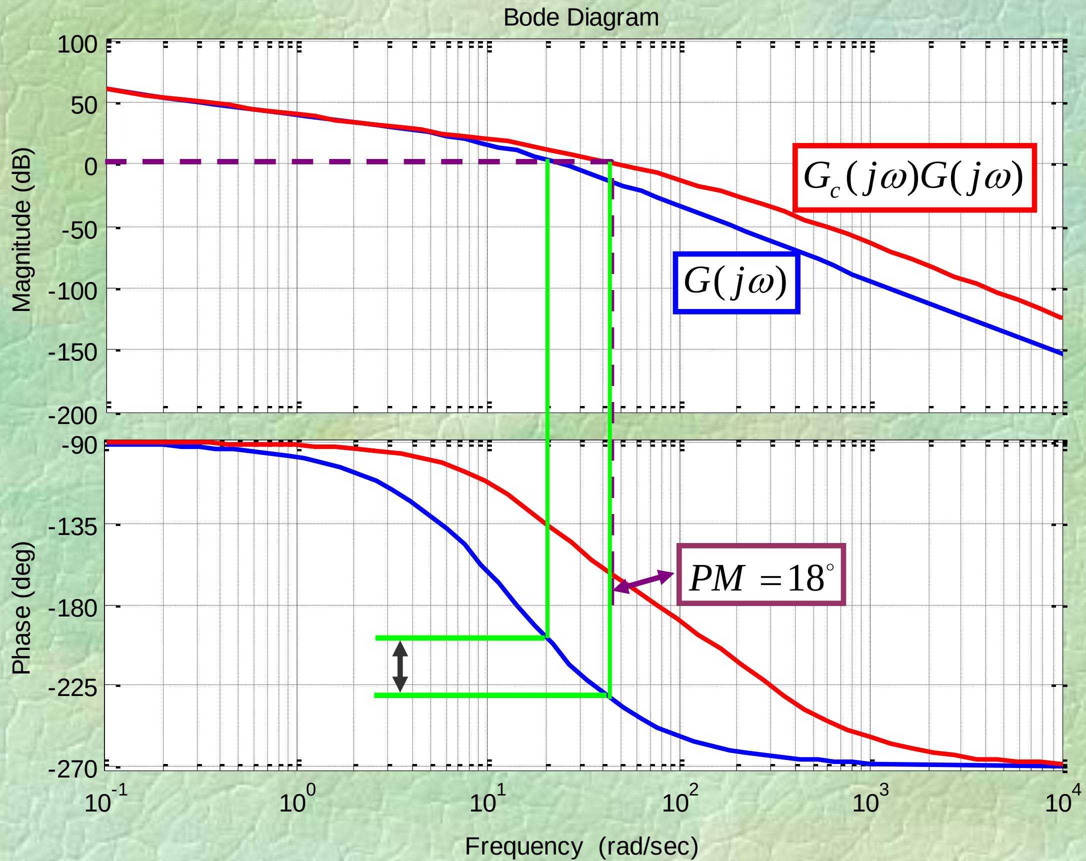
$$G_c(s) = \frac{a\tau s+1}{\tau s+1} = \frac{0.1248s+1}{0.0039s+1}$$



Phase-lead controller design in the frequency domain

Step 6: Check the controller.



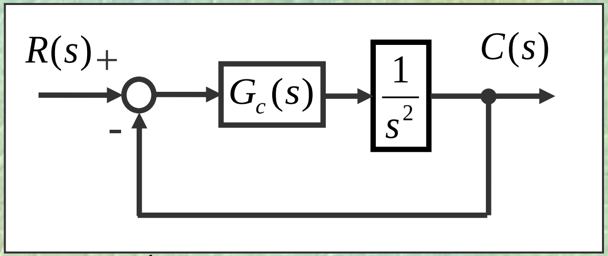


Note: Design is not possible!

Why?

Phase-lead controller design in the frequency domain

Example 8: Design a lead controller for the following system such that the phase margin be 45° and the open loop bandwidth be 10 rad/sec



Step 1: Consider $G_c(s) = k\dfrac{a\tau s+1}{\tau s+1}$ with $a>1$ as a phase-lag controller.

Note: If the plant has another gain k, let $G_c(s) = \dfrac{a\tau s+1}{\tau s+1}$

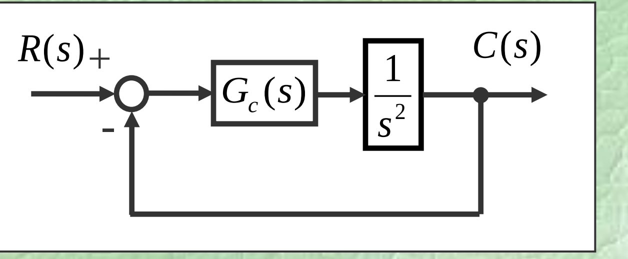
$$\Rightarrow \quad G_c(s) = k\frac{a\tau s+1}{\tau s+1} \qquad a>1$$

Step 2: Try to fix k according to performance request, otherwise let k=1

$$20\log\left|\frac{k}{\omega^2}\right|_{\omega=5} = -3 \quad \Rightarrow \quad k = 17.7$$

Why?

Phase-lead controller design in the frequency domain



Step 3: Sketch the Bode plot of system (with the fixed k) without controller.

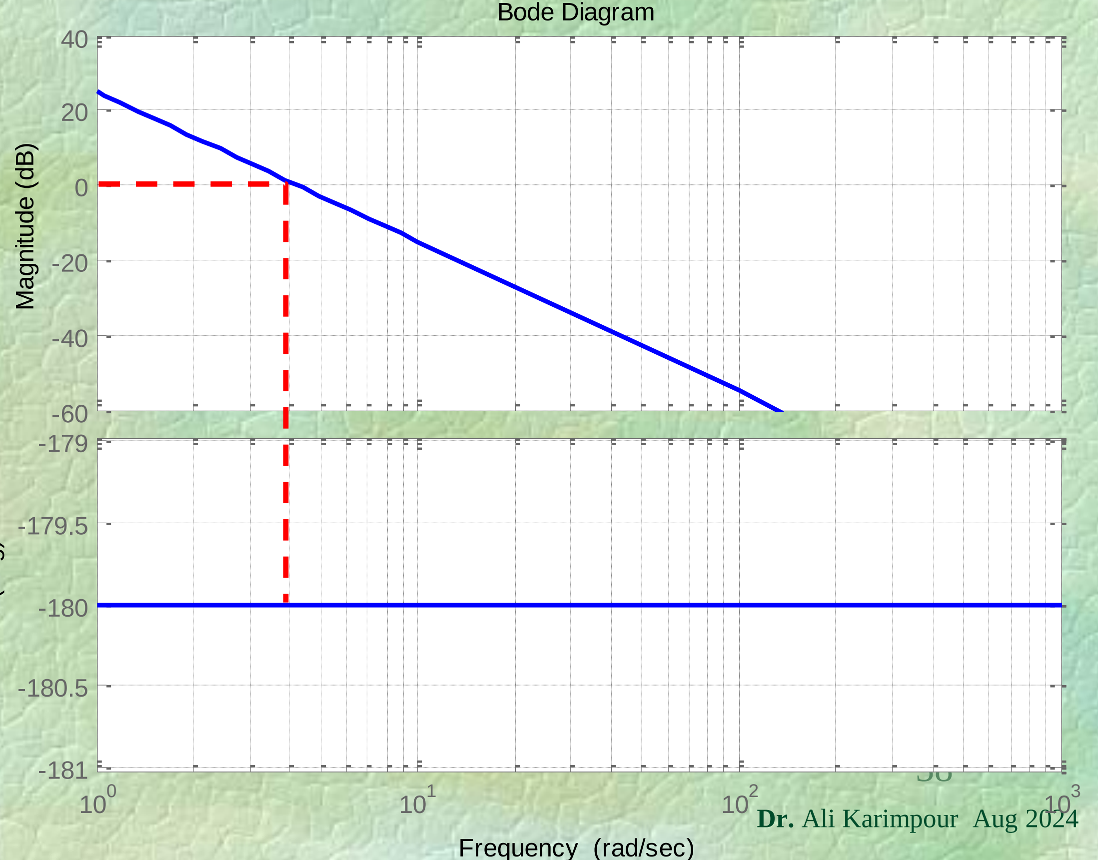
$$G(s) = \frac{17.7}{s^2}$$

Step 4: Find the system PM and if it is not sufficient choose the required phase by:

$$\varphi_m = \text{Desired PM - Existed PM} + \Delta$$

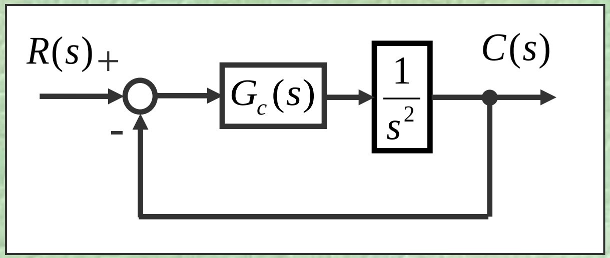
$$\varphi_m = 45^\circ - (0) + 0^\circ \;\; = 45^\circ$$

$$\sin 45^\circ = \frac{a-1}{a+1} \quad \Rightarrow \quad a = 5.8$$



Phase-lead controller design in the frequency domain

Step 5: Put the center of controller in the new gain crossover frequency:



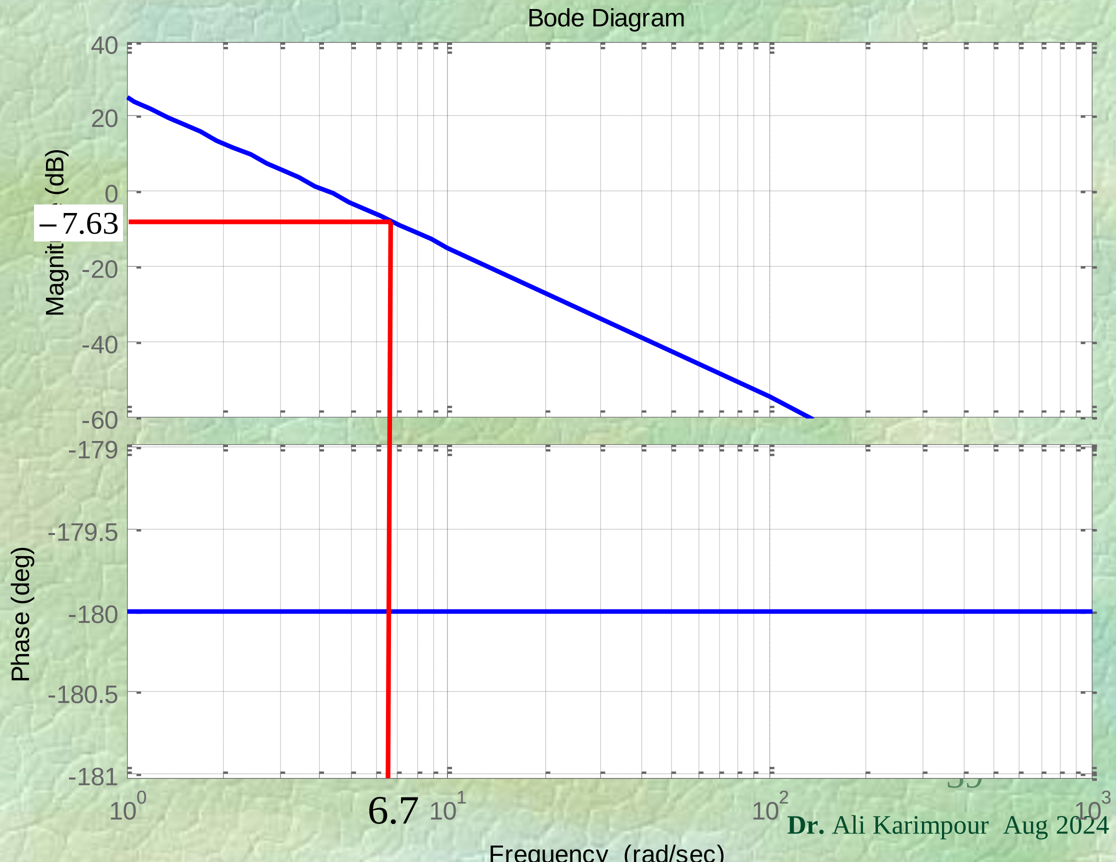
$$20\log\left|G(j\omega)\right|_{\omega=\omega_c^{new}} + 10\log(a) = 0$$

$$20\log\left|G(j\omega)\right|_{\omega=\omega_c^{new}} = -10\log(a) = -7.63$$

$$\omega_c^{new} = 6.7$$

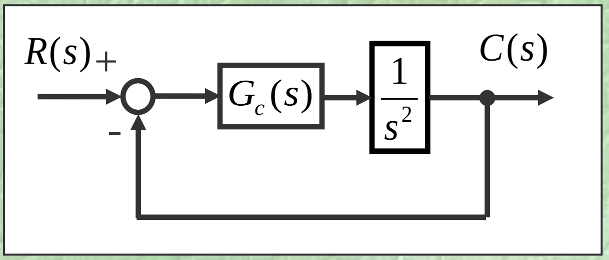
$$\omega_c^{new} = \frac{1}{\tau\sqrt{a}} \quad \Rightarrow \quad \tau = 0.062$$

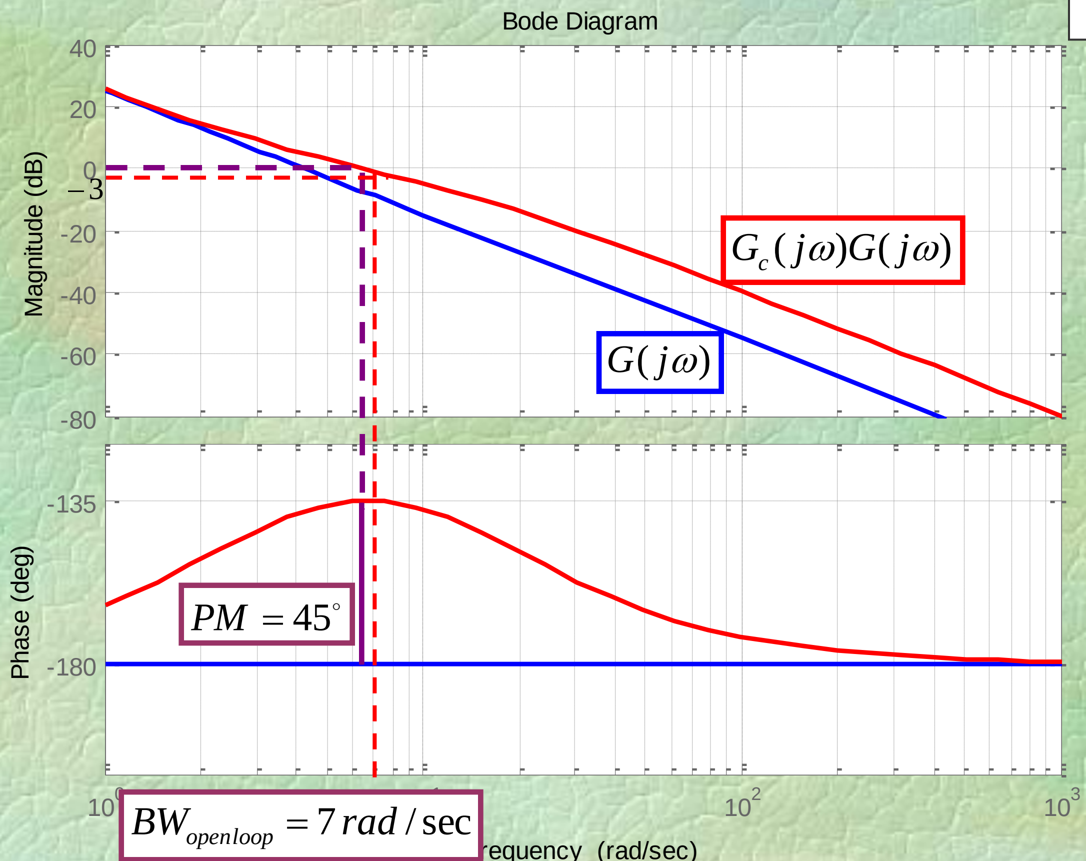
$$G_c(s) = \frac{a\tau s+1}{\tau s+1} = 17.7\,\frac{0.3596s+1}{0.062s+1}$$



Phase-lead controller design in the frequency domain

Step 6: Check the controller.

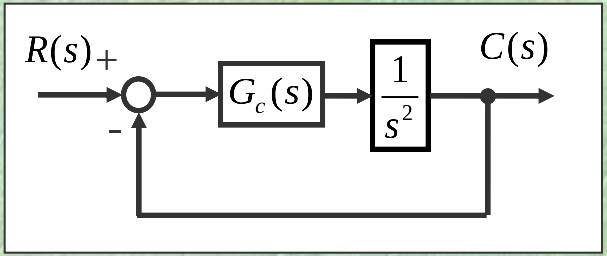




Controller is not ok

Try again

Phase-lead controller design in the frequency domain



Step 2: Try to fix *k* according to performance request, otherwise let *k*=1

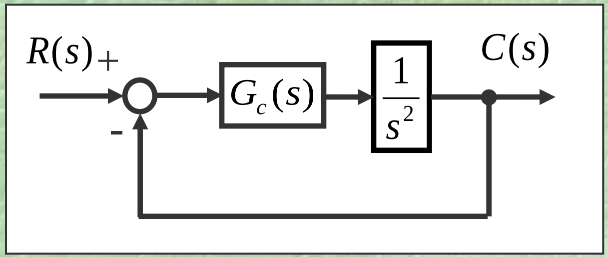
Open loop bandwidth is near to gain crossover frequency so:

$$20\log\left|\frac{k}{\omega^2}\right|_{\omega=5} = -3 \quad \Rightarrow \quad k = 17.7$$

$$20\log\left|\frac{k}{\omega^2}\right|_{\omega=7} = -3 \quad \Rightarrow \quad k = 35.7$$

Phase-lead controller design in the frequency domain

Step 3: Sketch the Bode plot of system (with the fixed k) without controller.



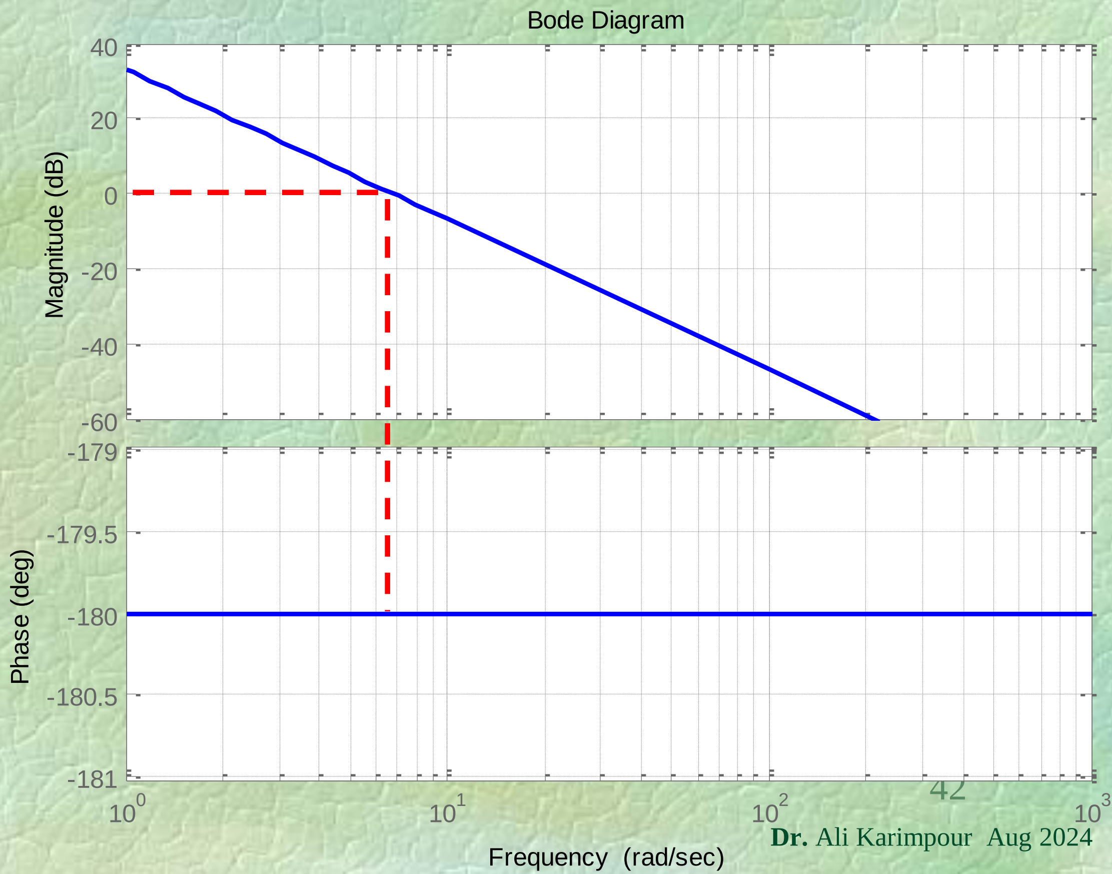
$$G(s) = \frac{35.7}{s^2}$$

Step 4: Find the system PM and if it is not sufficient choose the required phase by:

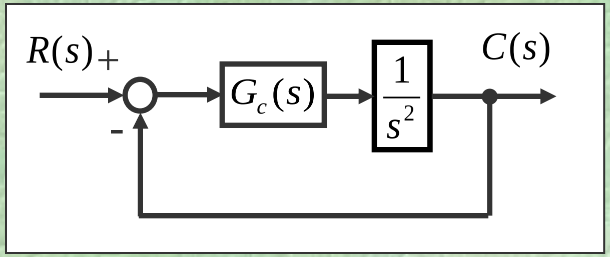
$$\varphi_m = \text{Desired PM - Existed PM} + \Delta$$

$$\varphi_m = 45^\circ - (0) + 0^\circ \quad = 45^\circ$$

$$\sin 45^\circ = \frac{a-1}{a+1} \quad \Rightarrow \quad a = 5.8$$



Phase-lead controller design in the frequency domain



Step 5: Put the center of controller in the new gain crossover frequency:

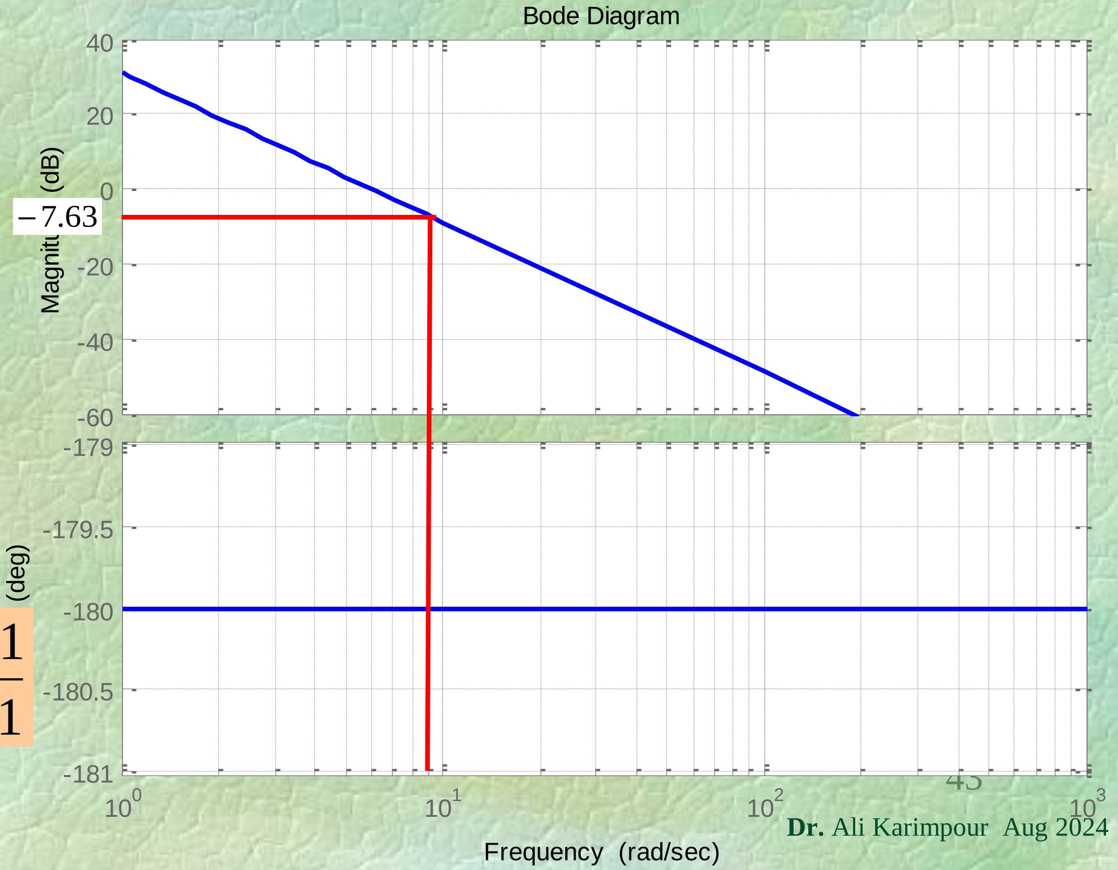
$$20\log|G(j\omega)|_{\omega=\omega_c^{new}} + 10\log(a) = 0$$

$$20\log|G(j\omega)|_{\omega=\omega_c^{new}} = -10\log(a) = -7.63$$

$$\omega_c^{new} = 9$$

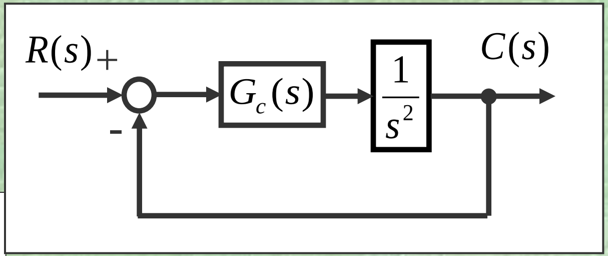
$$\omega_c^{new} = \frac{1}{\tau\sqrt{a}} \quad \Rightarrow \quad \tau = 0.0461$$

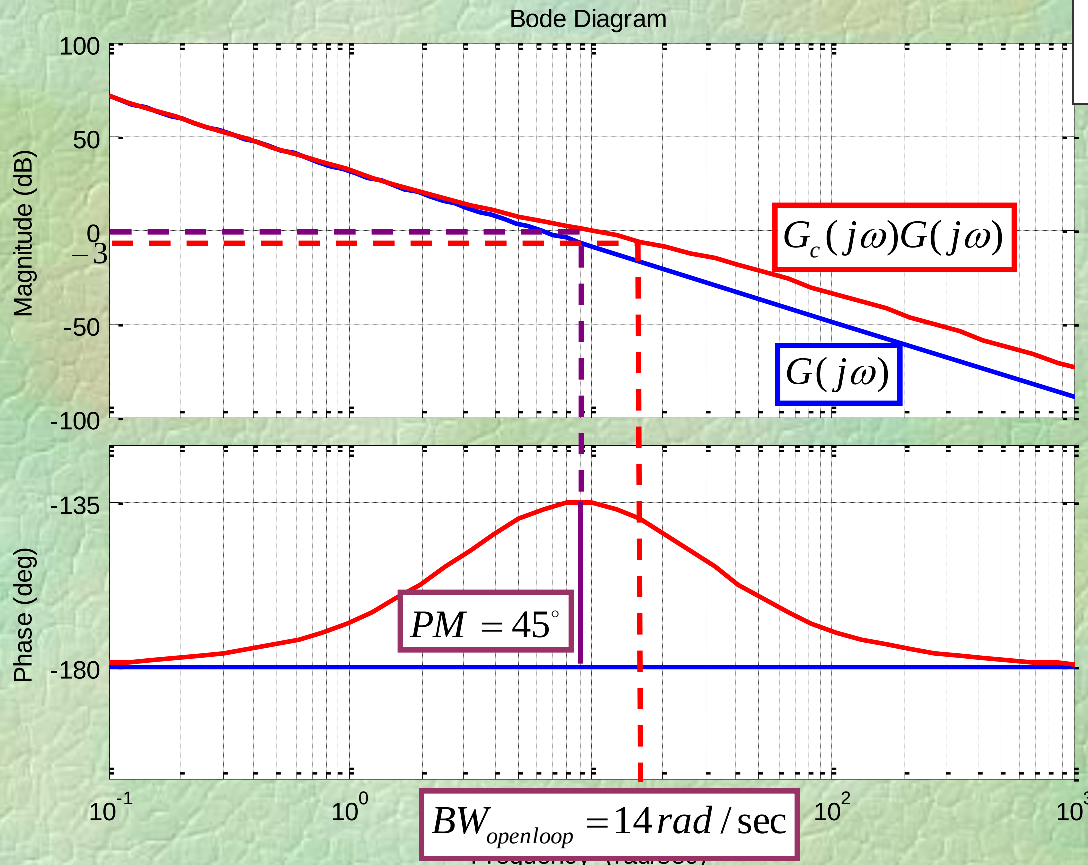
$$G_c(s) = k\frac{a\tau s+1}{\tau s+1} = 35.7\frac{0.2674s+1}{0.0461s+1}$$



Phase-lead controller design in the frequency domain

Step 6: Check the controller.

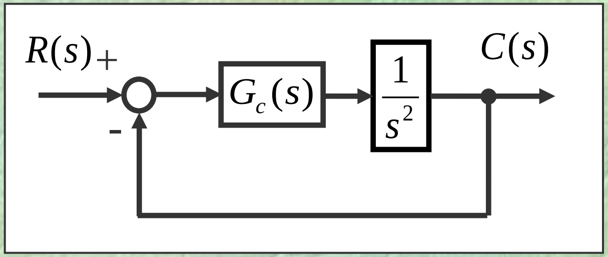




Controller is not ok

Try again

Phase-lead controller design in the frequency domain



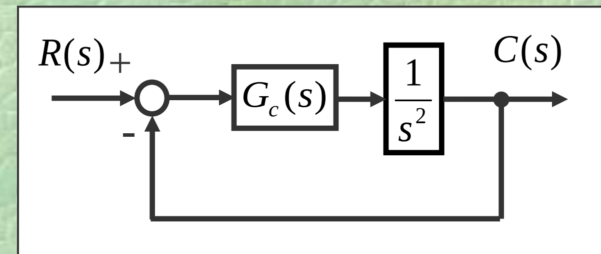
Step 2: Try to fix *k* according to performance request, otherwise let *k*=1

Open loop bandwidth is near to gain crossover frequency so:

$$20\log\left|\frac{k}{\omega^2}\right|_{\omega=7}=-3 \quad\Rightarrow\quad k=35.7$$

$$20\log\left|\frac{k}{\omega^2}\right|_{\omega=6}=-3 \quad\Rightarrow\quad k=25.5$$

Phase-lead controller design in the frequency domain



Step 3: Sketch the Bode plot of system (with the fixed *k*) without controller.

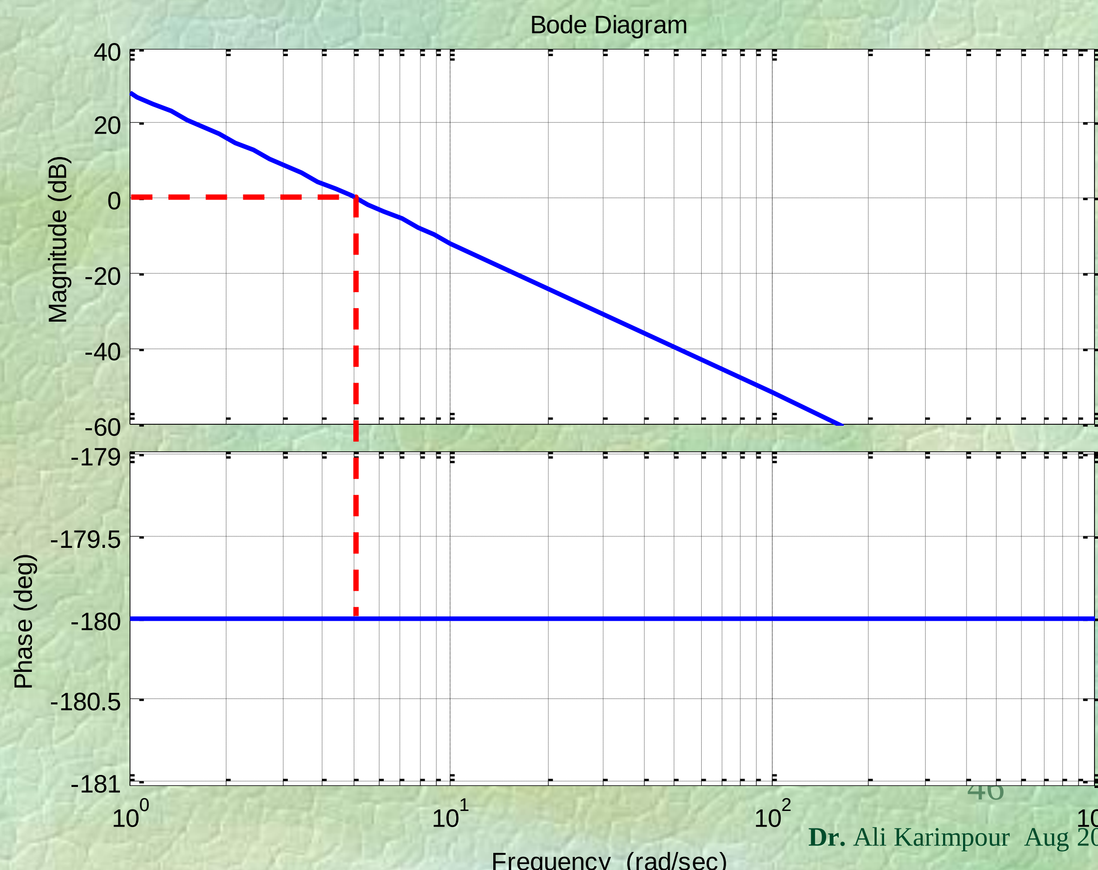
$$G(s)=\frac{25.5}{s^2}$$

Step 4: Find the system PM and if it is not sufficient choose the required phase by:

$$\varphi_m = \text{Desired PM - Existed PM} + \Delta$$

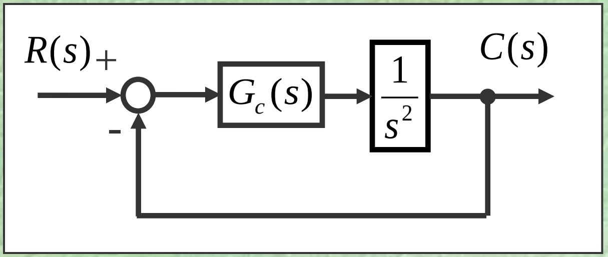
$$\varphi_m = 45^\circ - (0) + 0^\circ = 45^\circ$$

$$\sin 45^\circ = \frac{a-1}{a+1} \quad \Rightarrow \quad a = 5.8$$



Phase-lead controller design in the frequency domain

Step 5: Put the center of controller in the new gain crossover frequency:



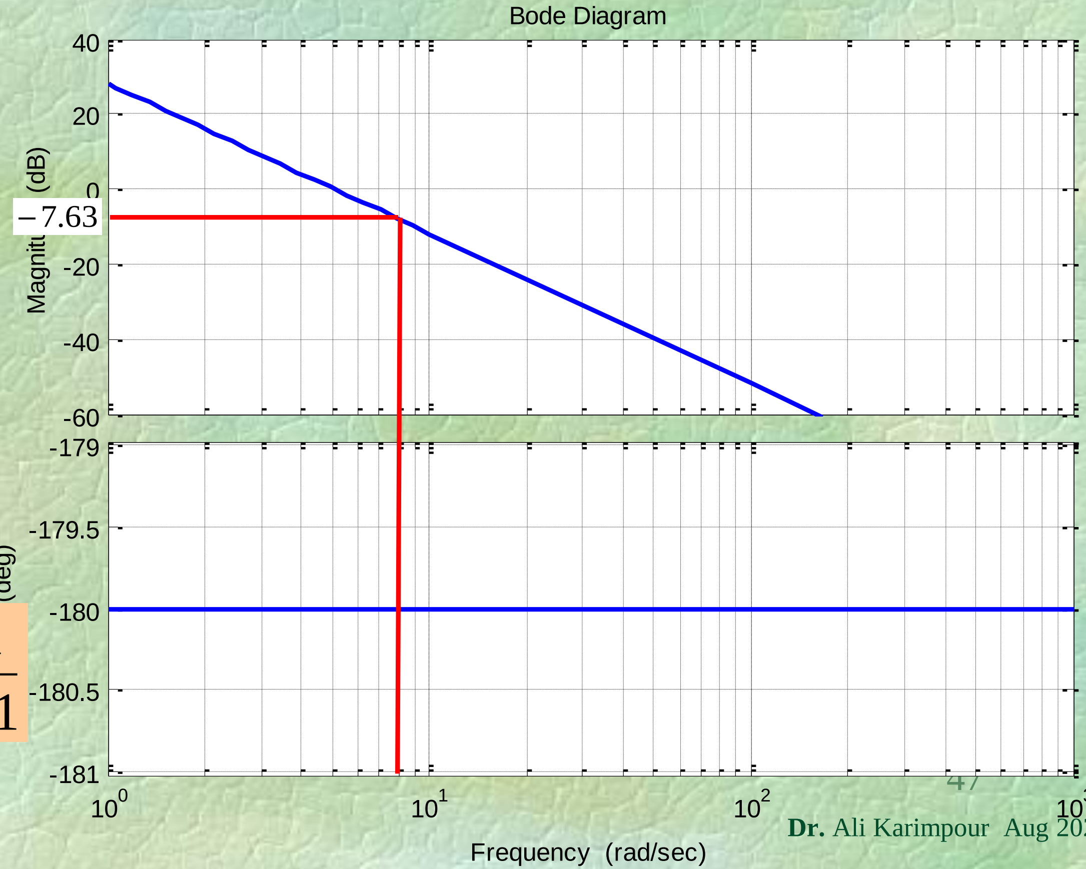
$$20\log\left|G(j\omega)\right|_{\omega=\omega_c^{new}} + 10\log(a) = 0$$

$$20\log\left|G(j\omega)\right|_{\omega=\omega_c^{new}} = -10\log(a) = -7.63$$

$$\omega_c^{new} = 8$$

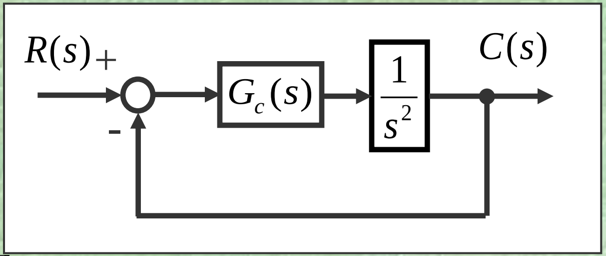
$$\omega_c^{new} = \frac{1}{\tau\sqrt{a}} \quad \Rightarrow \quad \tau = 0.0519$$

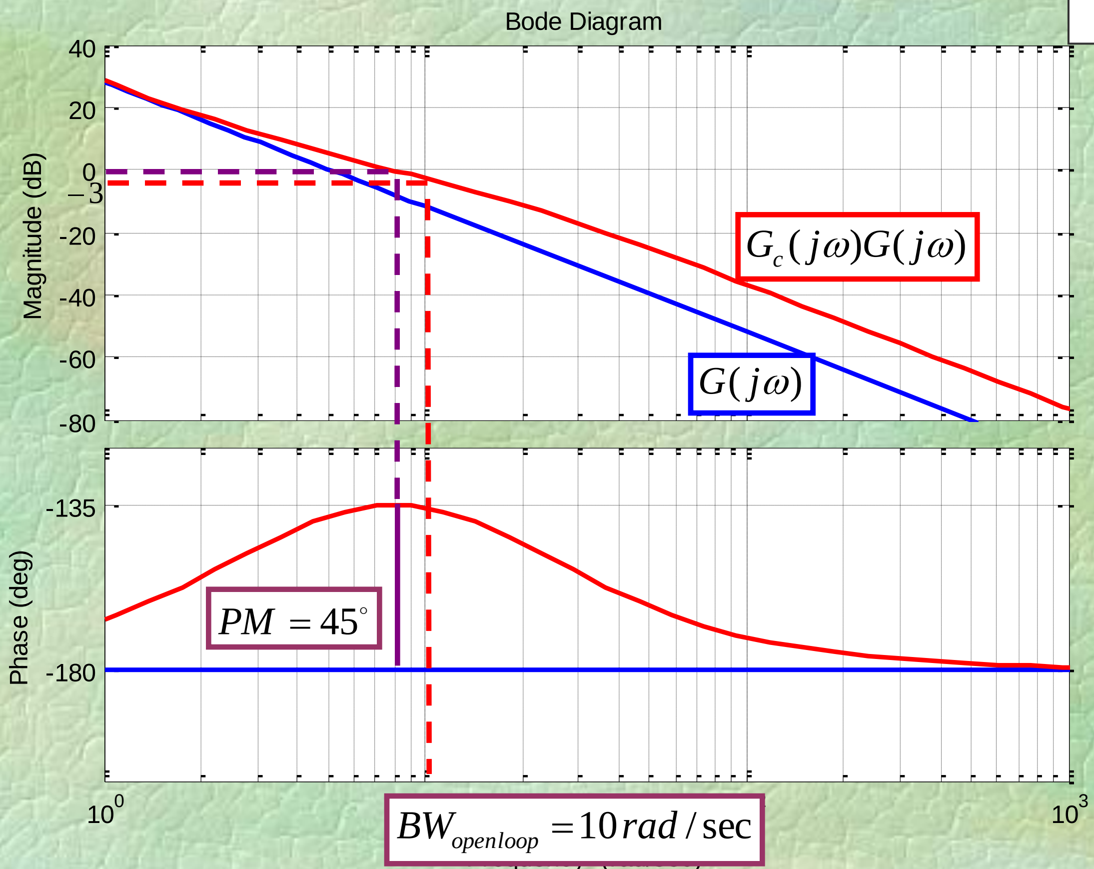
$$G_c(s) = k\,\frac{a\tau s+1}{\tau s+1} = 25.5\,\frac{0.301s+1}{0.0519s+1}$$



Phase-lead controller design in the frequency domain

Step 6: Check the controller.





Controller is ok

It can be solved by a very better method without trial and error. Try to find it.

Exercises

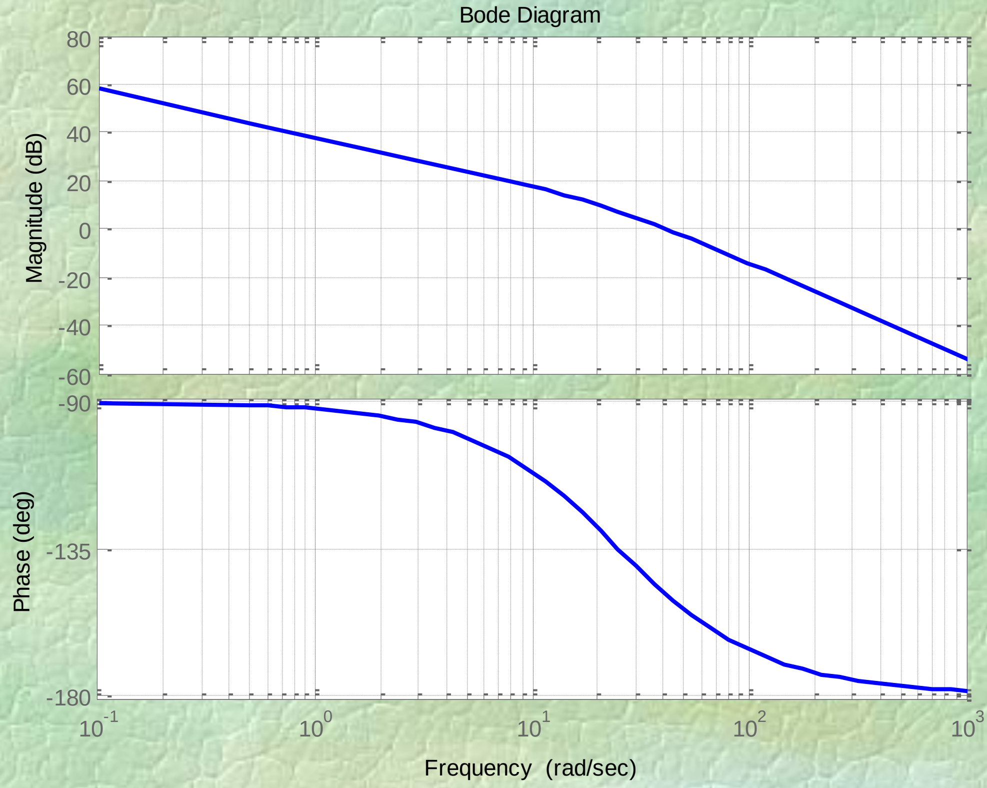
1- Following is the open loop transfer function of a system.

a) What is the velocity error constant. (answer 80)

b) Design lag controller such that PM=45°. (answer $G_c(s)=(0.5s+1)/(1.56s+1)$)

c) Design lag controller such that PM=45° and the velocity error constant be 200.

(answer $G_c(s)=(0.49s+1)/(3.75s+1)$)

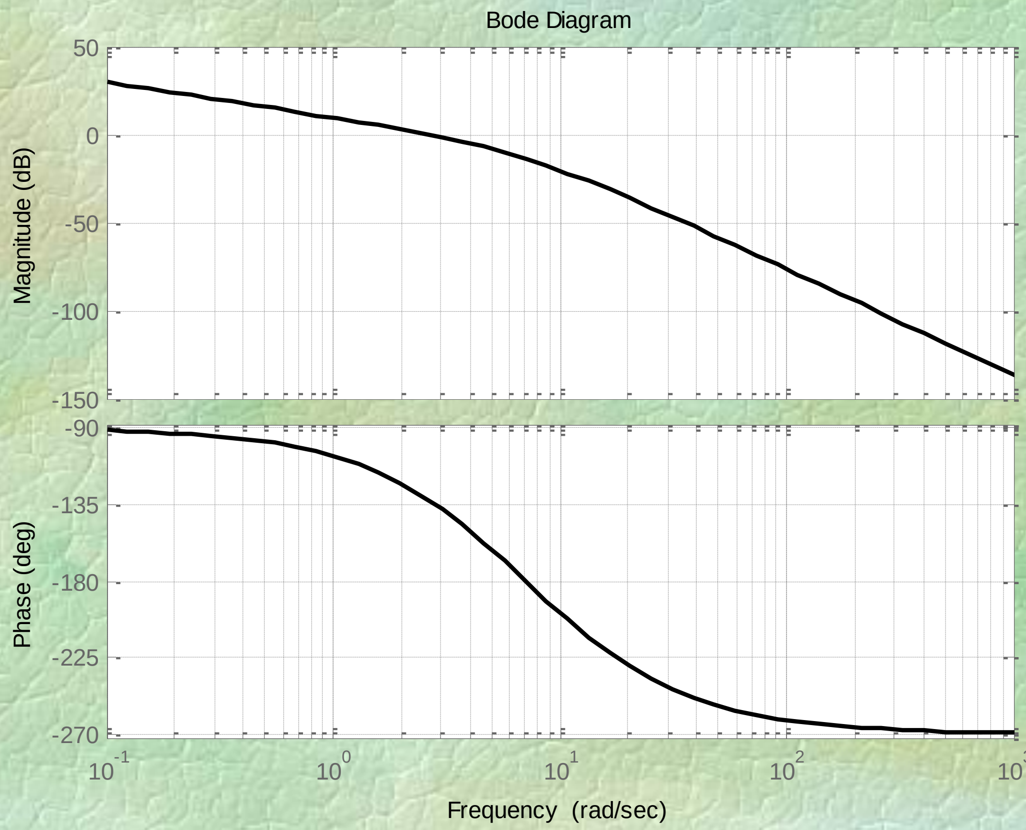


Exercises

2- Following is the open loop transfer function of a system.

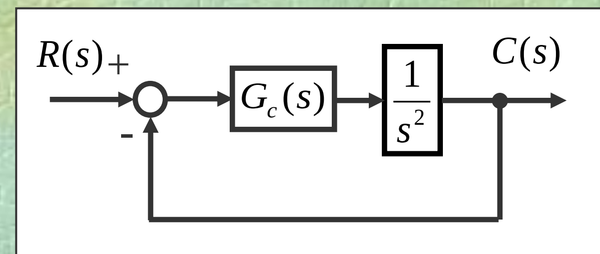
a) Design a controller that the GM of system be 50 db.

b) Design lag controller such that PM=45° and the velocity error constant be 30.

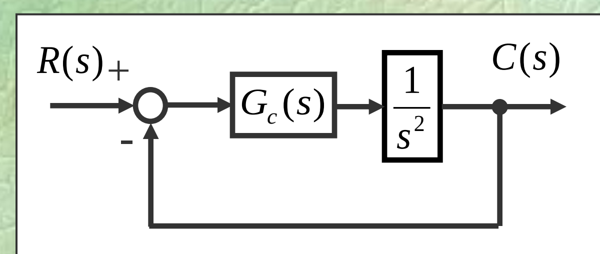


Exercises

3- Design a lead controller for the following system such that the phase margin be 40° and the open loop bandwidth be 23 rad/sec



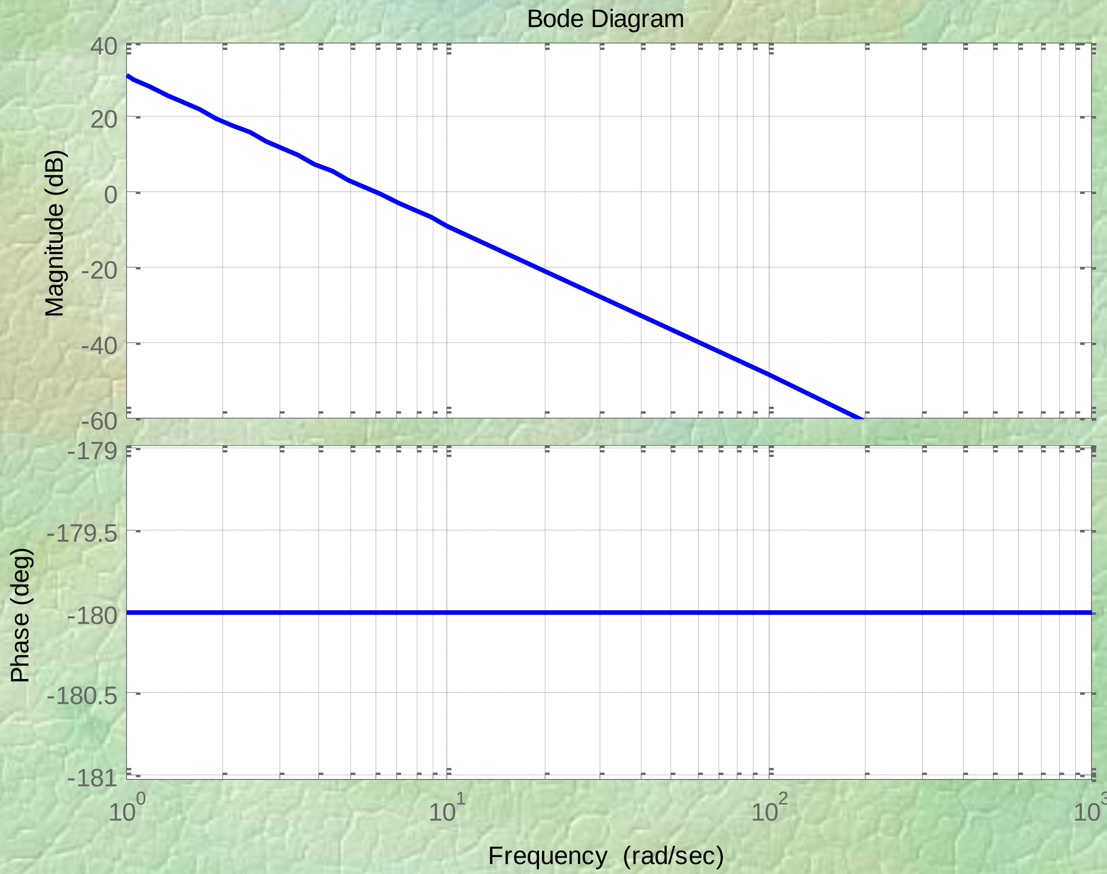
4- Design a lead controller for the following system such that the phase margin be 40° and the acceleration constant be 25.



$$\text{Answer}: G_c(s) = k\frac{0.301s+1}{0.0519s+1}$$

Exercises

5- Following is the open loop transfer function of a system. Design a lead controller such that PM=45°. Draw the bode plot of compensated system.



$$\text{Answer}: G_c(s) = k\frac{0.2674s+1}{0.0461s+1}$$

Exercises

6- Following is the open loop transfer function of a system.

a) What is the velocity error constant. (answer 80)

b) Design a lead controller such that PM=50°. (answer $G_c(s)=(0.0315s+1)/(0.0126s+1)$)

c) Design a lead controller such that PM=50° and the velocity error constant be 200. (answer $G_c(s)=2.5(0.0192s+1)/(0.0052s+1)$)