# Bode Plot & Coding in MATLAB

In this tutorial, the aim is to explain Gain Margin, Phase Margin & Crossover Frequency that defines the system's stability. First of all, the terms will be explained. Then, it is going to be coded and plotted in MATLAB.

## 1. Crossover Frequency ($w_C$)

It is the frequency where the magnitude (dB) of the system is equal to 0.

$|G(jw_c)| = 0\ dB$

For example, $G(s) = \frac{100}{s^3+10.1s^2+s}$

The bode plot of $G(s)$ is

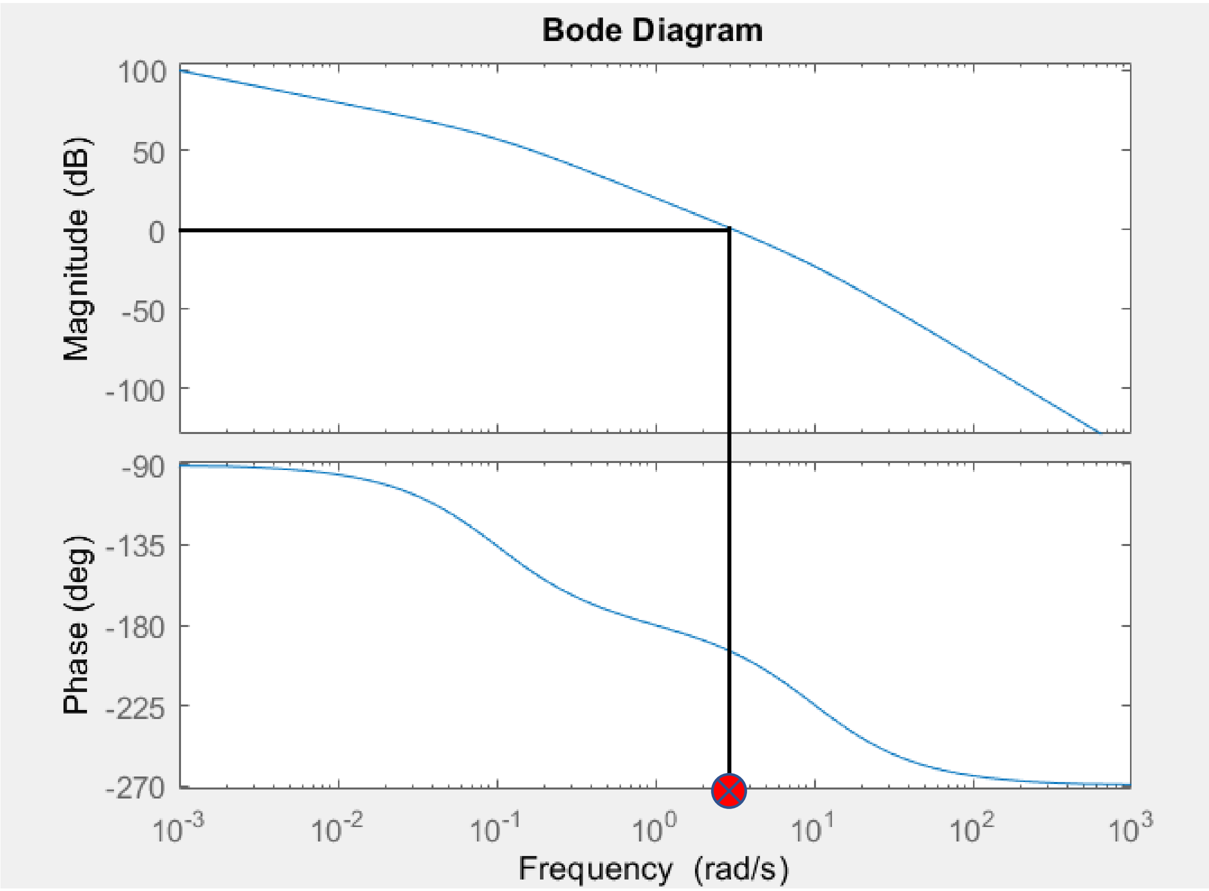



*Figure 1. Bode Plot of G(s)*

It can be seen on the graph that red circle with cross is the crossover frequency.

## 2. Phase Margin

It is the difference between the phase lag ϕ (< 0) and -180°

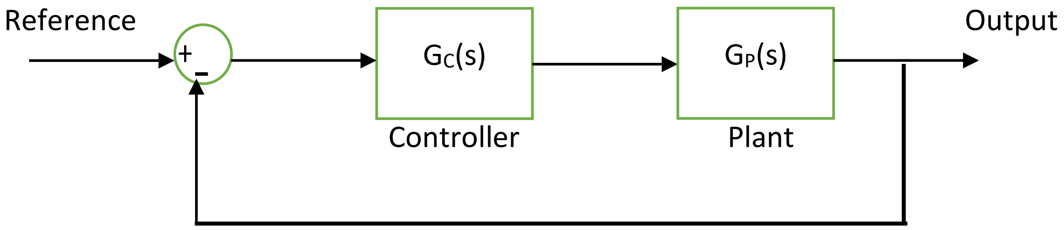
$\angle G(jw_C) + 180°$

## 3. Gain Margin

It is the gain needed to increase magnitude to 0 dB when phase is -180°.

## 4. Stabilization with Bode Plot

Bode plot is the frequency response of $G(s)$




We may or may not add some sort of controller, so we look at the bode plot & all the stability analysis we are doing where we seeing phase margin & gain margin and how far it is from $-180°$ & 1 (0 dB) (magn.) We are looking at those things that's all because we want to see what happens when we connect it in this type of feedback above. If we find that the system $G_P(s)$ is not stable if it has a negative phase margin. That means its phase goes past $-180°$ at crossover frequency, so we need to add controller to try stabilize the system.

Let's get into the MATLAB code

To find exact value of the crossover frequency from MATLAB

First of all we need to define the function $G(s) = \frac{100}{s^3+10.1s^2+s}$

```
Gs = tf([100],[1 10.1 1 0])
```

The output will be:

```
>> G = tf([100],[1 10.1 1 0])

G =

        100
  ------------------
  s^3 + 10.1 s^2 + s
```

To plot bode diagram we use the command

```
bode(Gs)
```

MATLAB will plot the bode diagram with 'bode()' command

For our transfer function, the bode diagram will be plotted as

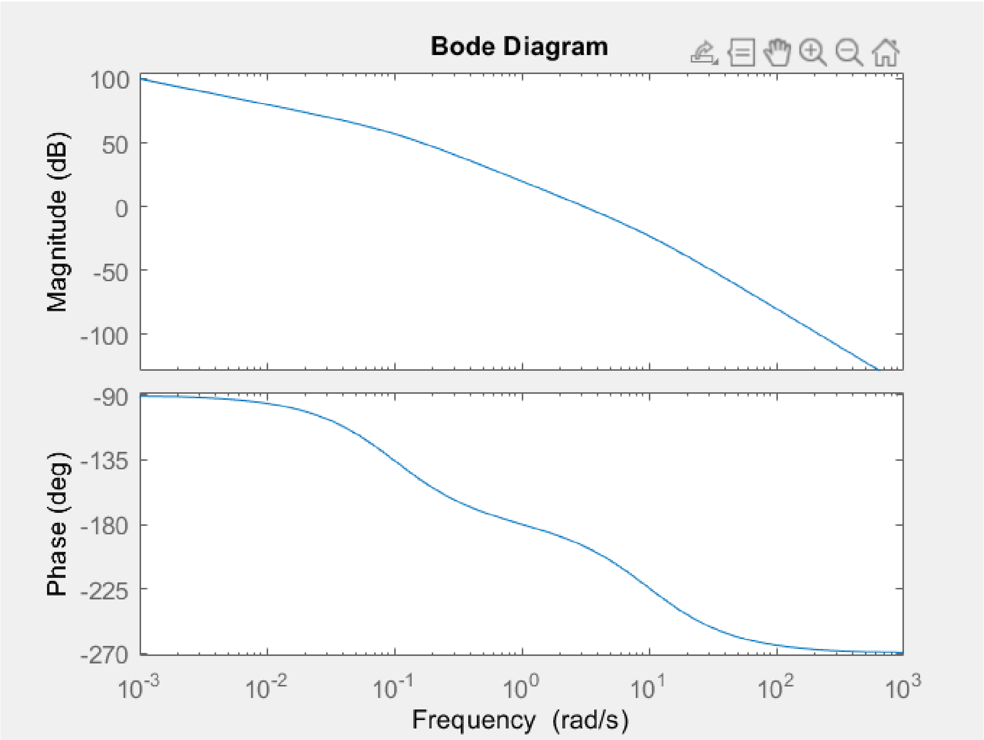



*Figure 2. Bode Plot of Gs*

To grid enable to get results more clear

Enter the following command:

```
grid on
```

The graph will have grid:

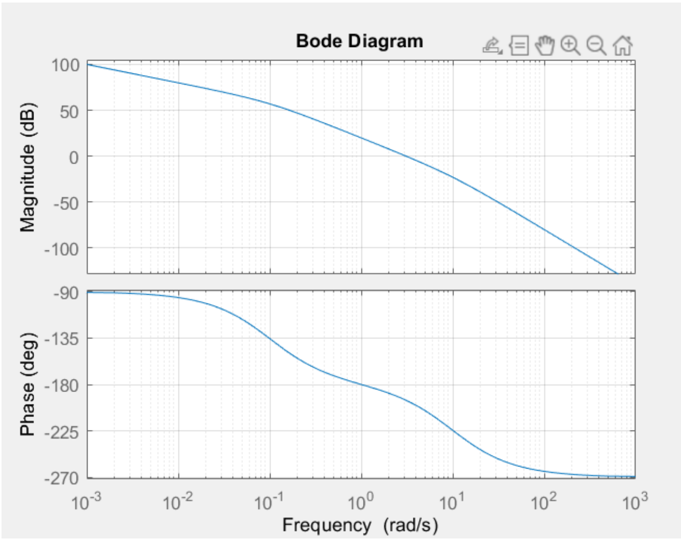



*Figure 3. Bode plot of Gs with Grid Enable*

To get Gain Margin, Phase Margin, Angle of Gain & Phase Margin, we use the code following:

```
[Gm, Pm, PhiGM, PhiPM] = margin(G)
```

```
>> [Gm, Pm, PhiGM, PhiPM] = margin(G)
Warning: The closed-loop system is unstable.
> In DynamicSystem/margin (line 77)

Gm =

    0.1010


Pm =

  -15.3186


PhiGM =

    1.0000


PhiPM =

    3.0902
```

From the results, it can be said that to reach stability we need to multiply our system by the value which is lesser than Gm value which is equal to 0.1010.

For example $G_1 = 0.05$

Let's multiply G by $G_1$ and get the bode plot. Following code shows how to do that.

```
Bode(G)
hold on
G1 = 0.5
bode(G*G1)
```

```
>> bode(G)
>> hold on
>> G1 = 0.05

G1 =

    0.0500

>> bode(G*G1)
```

The bode plot will be like

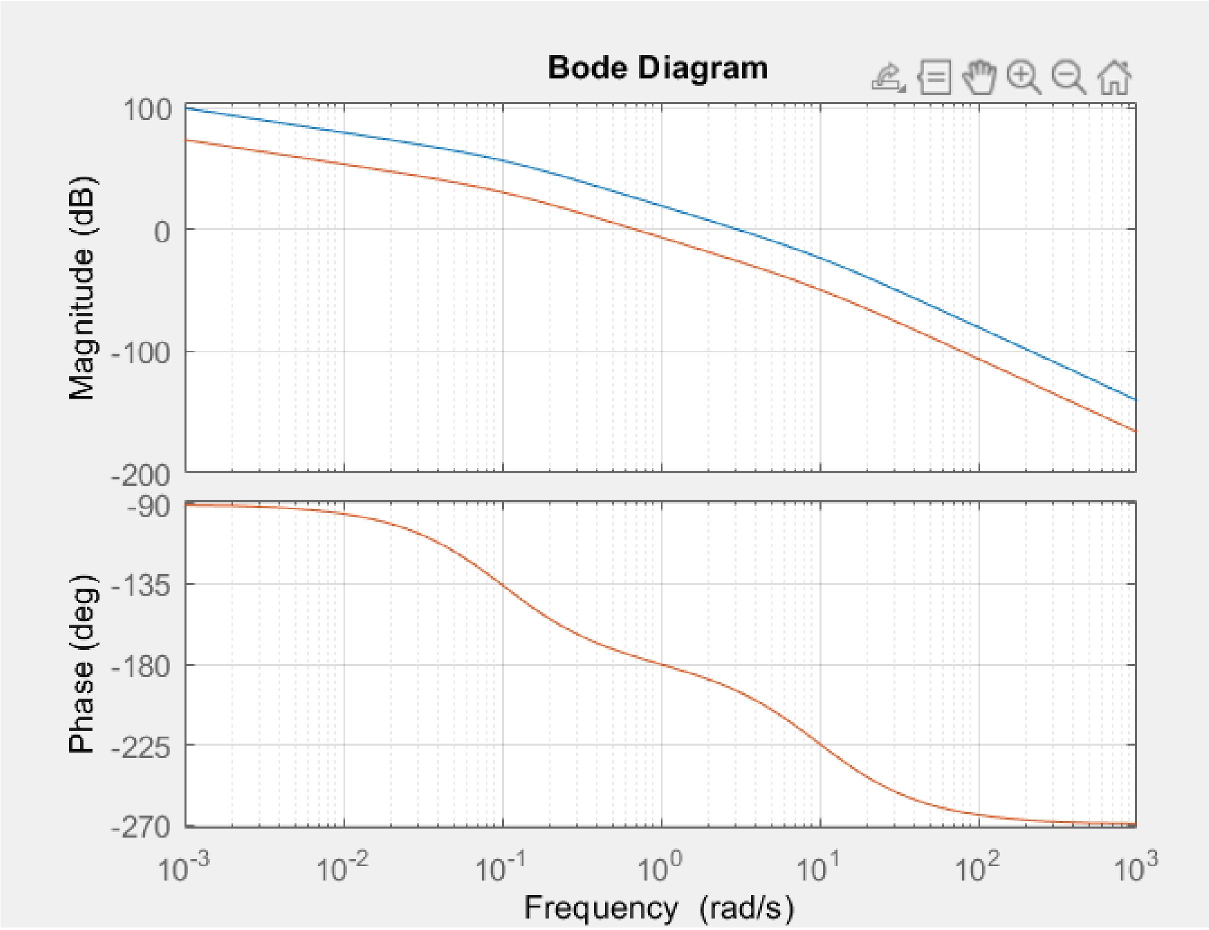



*Figure 4. Bode plot of Gs and G1*Gs*

*Blue one is the new one.

Let’s check our new Gm, Pm, PhiGM, PhiPM values

```
[Gm, Pm, PhiGM, PhiPM] = margin(G*G1)
```

```
>> [Gm, Pm, PhiGM, PhiPM] = margin(G*G1)

Gm =

    2.0200


Pm =

    4.0826


PhiGM =

    1.0000


PhiPM =

    0.7025
```

As we can see our new Pm = 4.08 (it is positive value) so our system became stable now.

## 5. Lag Compensation

Another way to stabilize our system is lag controller.

Lag controller is the way to stabilize our system without shift all the curve. Instead, we just shift specific area to reach stability.

For example, let's add new controller:

```
G2 = tf([0.02 0.0005],[1 0.0005])
bode(G2)
```

The bode plot of G2 is

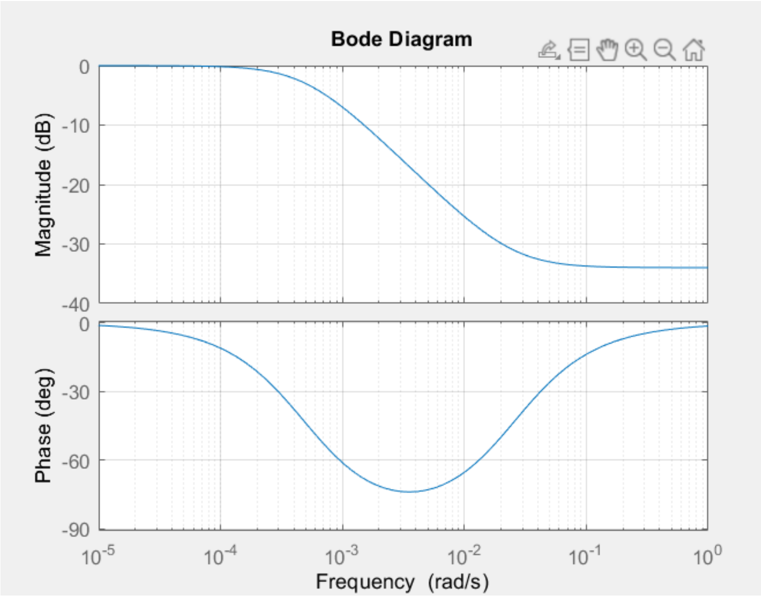



*Figure 5. Bode Plot of G2*

It can be said that we decreased the gain at higher frequencies without changing phase not much.

Adding following commands

```
bode(G)
hold on
bode(G*G2)
grid on
```

```
bode(G)
hold on
bode(G*G2)
grid on
```

The bode plot will be

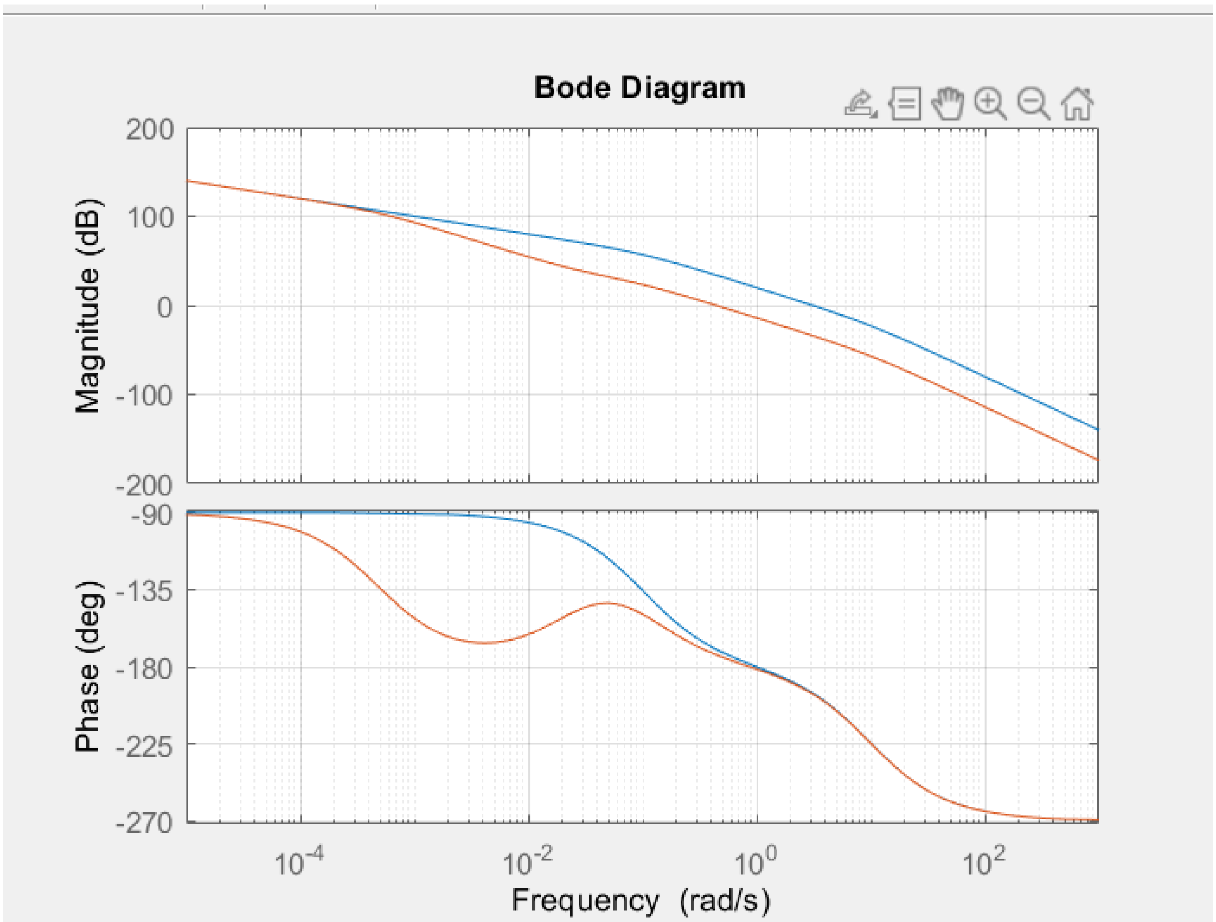



*Figure 6. Bode Plot with New Controller*

Let’s check our values again with following code

```
[Gm, Pm, PhiGM, PhiPM] = margin(G*G2)
```

```
Gm =

    3.8003


Pm =

    7.0503


PhiGM =

    0.8675


PhiPM =

    0.4418
```

We have positive phase margin that system is stable.

## 6. Lead Compensation

Let’s add new controller

```
G3 = tf([1 2],[1 4])
```

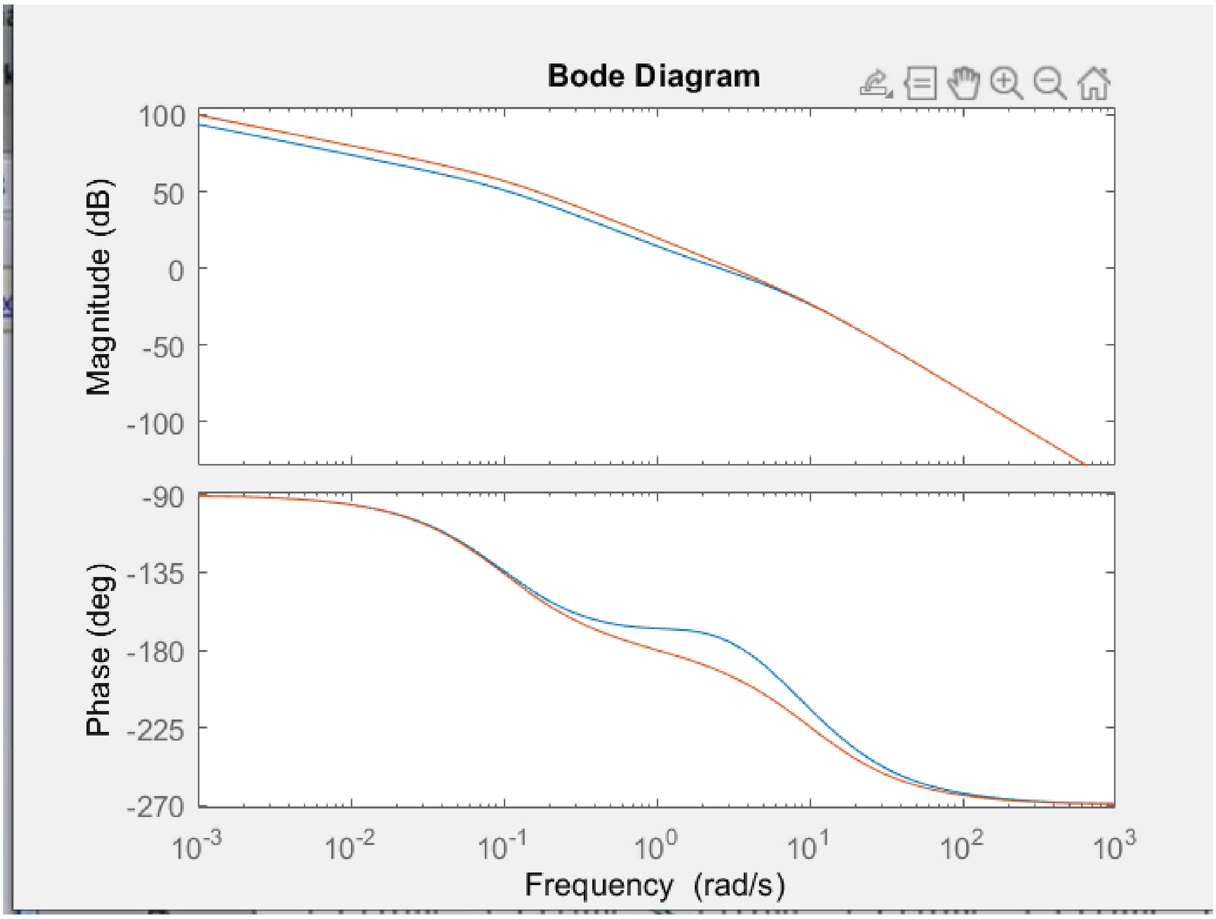
```
G3 =

  s + 2
  -----
  s + 4

Continuous-time transfer function.
```

With new controller, our bode plot will be

```
bode(G)
hold on
bode(G*G3)
```




*blue is the new one (G*G3)

As we can see on the graph, magnitude is around same but phase is shifted towards up (blue one).

Let’s check our values.

```
[Gm, Pm, PhiGM, PhiPM] = margin(G*G3)
```

```
Gm =

    1.9030


Pm =

    7.1744


PhiGM =

    3.7122


PhiPM =

    2.5753
```

As we can see above, Phase Margin is positive, our system became stable.

## 7. Things we can do to stabilize a closed-loop system based on the open-loop bode plot:

1. Change the gain (apply proportional control to shift the crossover frequency)
2. Lag compensation control to decrease gain above a certain frequency.
3. Lead compensation control to boost gain at crossover frequency.