



Introduction

Frequency-Response Analysis



MATLAB and Simulink

Create Transfer Function

Transfer function is

$$G(s) = \frac{num}{den}$$

Example

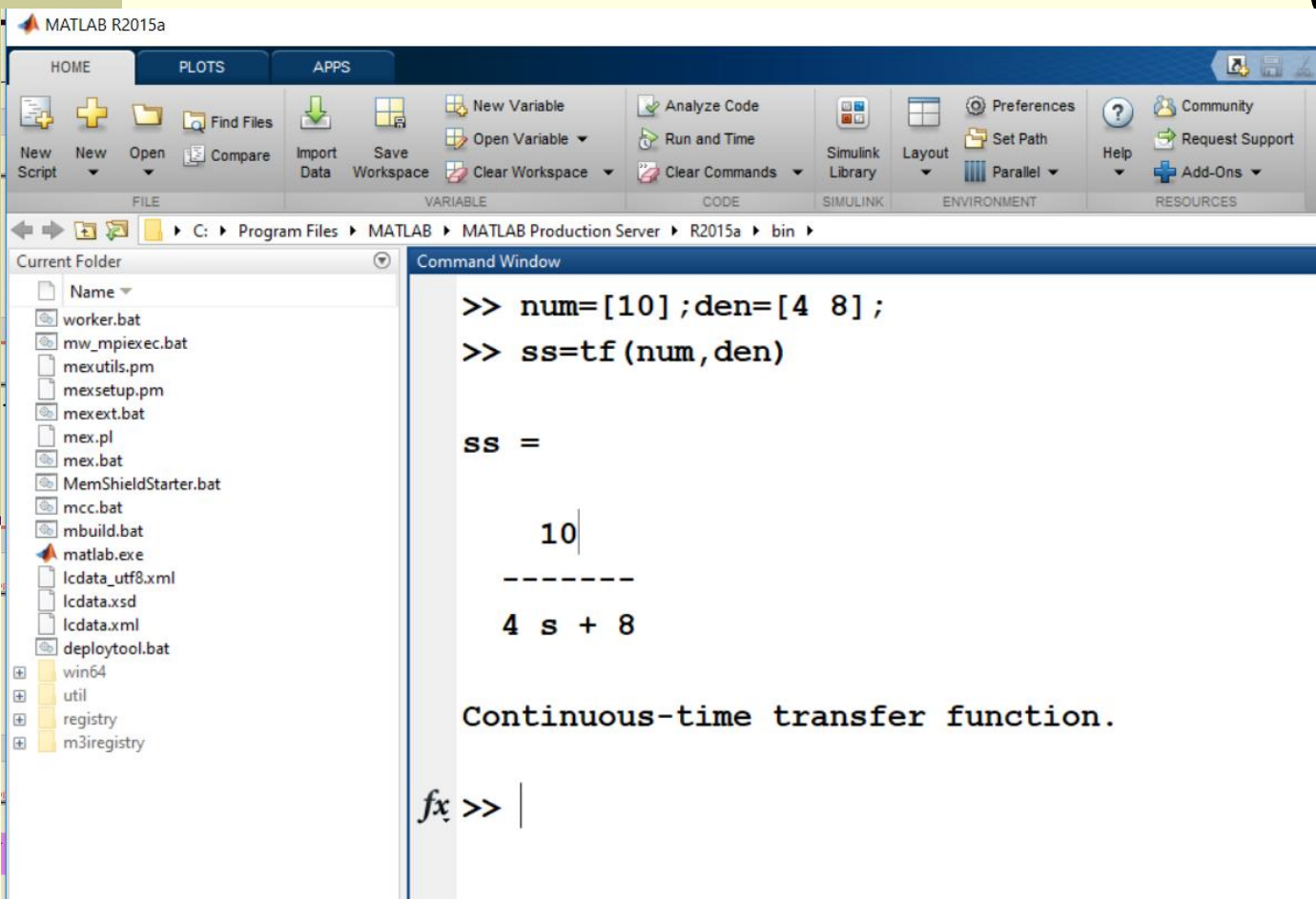
$$G(s) = \frac{10}{4s + 8}$$

```
>> num=[10];den=[4 8];  
>> ss=tf(num,den)
```

Create Transfer Function

Example Transfer function is

$$G(s) = \frac{10}{4s + 8}$$



The image shows a screenshot of the MATLAB R2015a Command Window. The window title is "MATLAB R2015a". The Command Window displays the following code and output:

```
>> num=[10];den=[4 8];
>> ss=tf(num,den)

ss =

    10
-----
   4 s + 8

Continuous-time transfer function.

fx >> |
```

The Command Window also shows the current folder path: C:\Program Files\MATLAB\MATLAB Production Server\R2015a\bin. The left pane shows the file explorer with various files and folders, including worker.bat, mw_mpiexec.bat, mexutils.pm, mexsetup.pm, mexext.bat, mex.pl, mex.bat, MemShieldStarter.bat, mcc.bat, mbuild.bat, matlab.exe, lcdata_utf8.xml, lcdata.xsd, lcdata.xml, deploytool.bat, win64, util, registry, and m3iregistry.

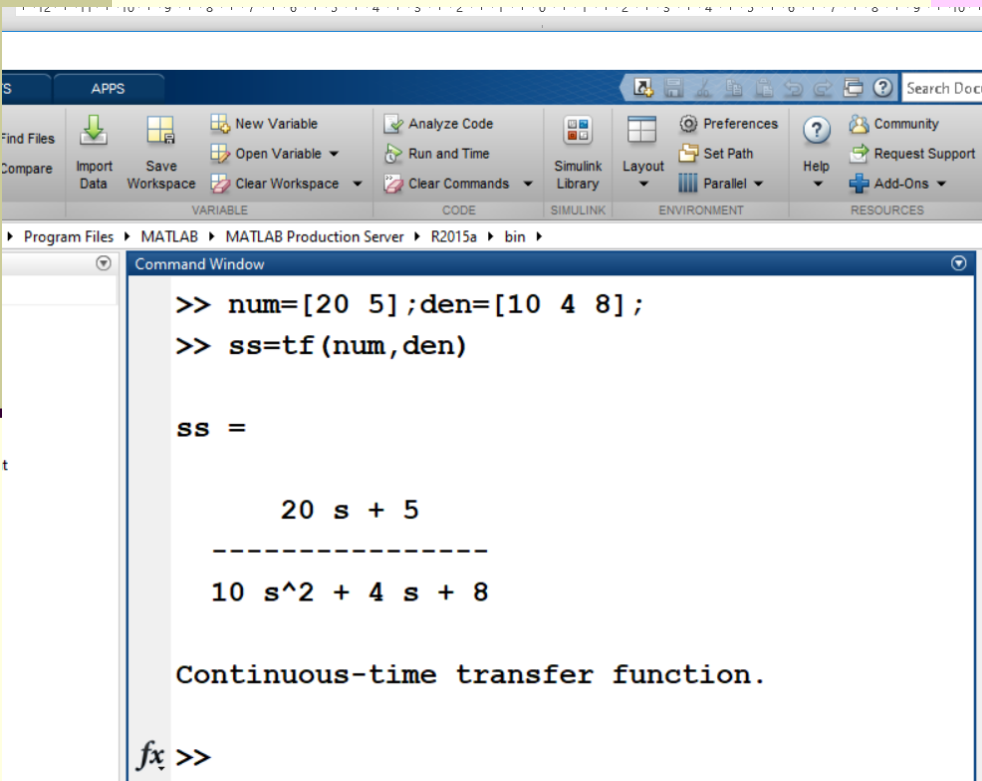
Create Transfer Function

Example

Transfer function is

$$G(s) = \frac{20s + 5}{10s^2 + 4s + 8}$$

```
>> num=[20 5];den=[10 4 8];  
> ss=tf(num,den)
```



The screenshot shows the MATLAB Command Window with the following code and output:

```
>> num=[20 5];den=[10 4 8];  
>> ss=tf(num,den)  
  
ss =  
  
      20 s + 5  
-----  
    10 s^2 + 4 s + 8  
  
Continuous-time transfer function.  
  
fx >>
```

Plot Bode Diagram

Example No.1

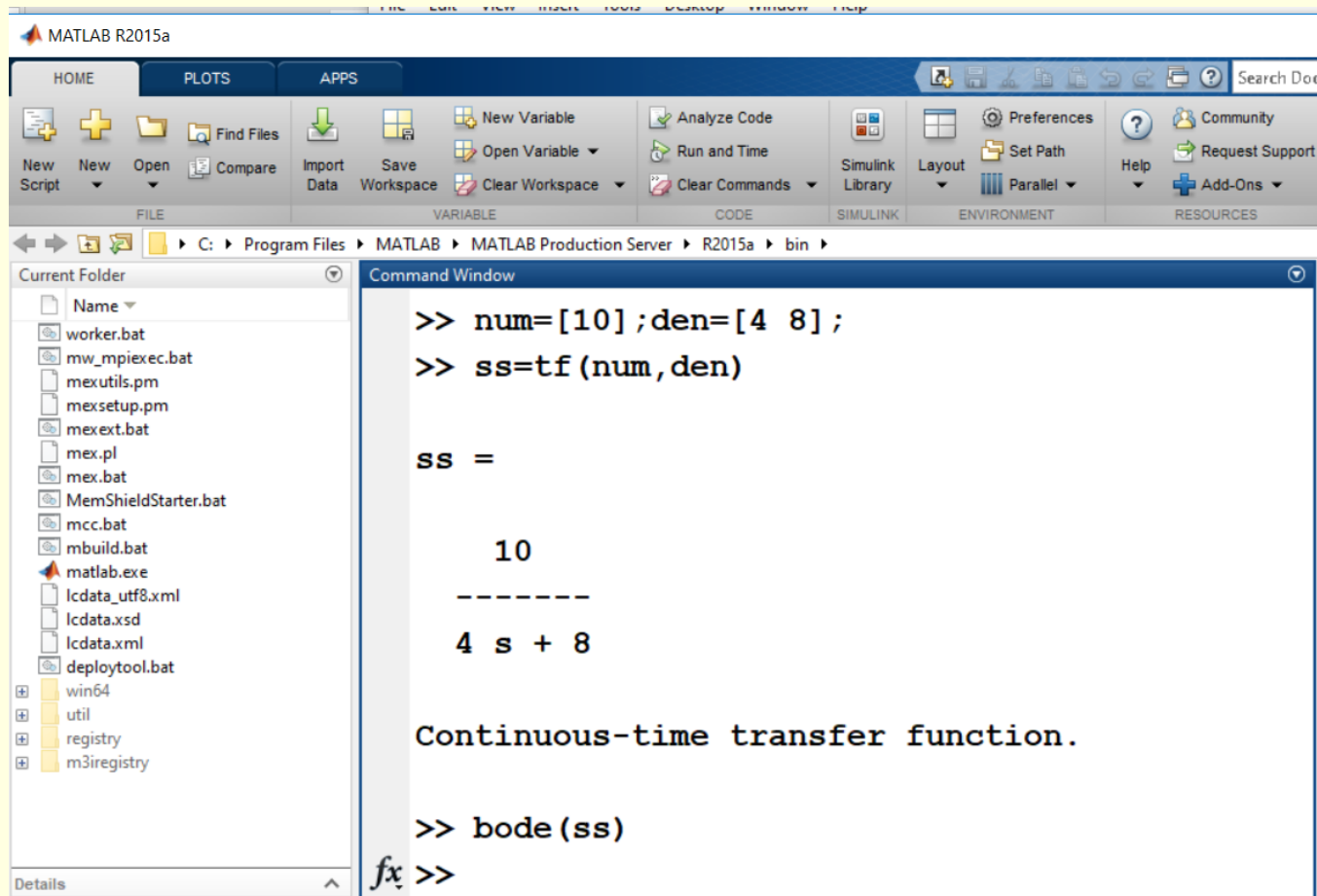
$$G(s) = \frac{10}{4s + 8}$$

```
>> num=[10];den=[4 8];  
>> ss=tf(num,den)  
>> bode(ss)
```

Plot Bode Diagram

Example

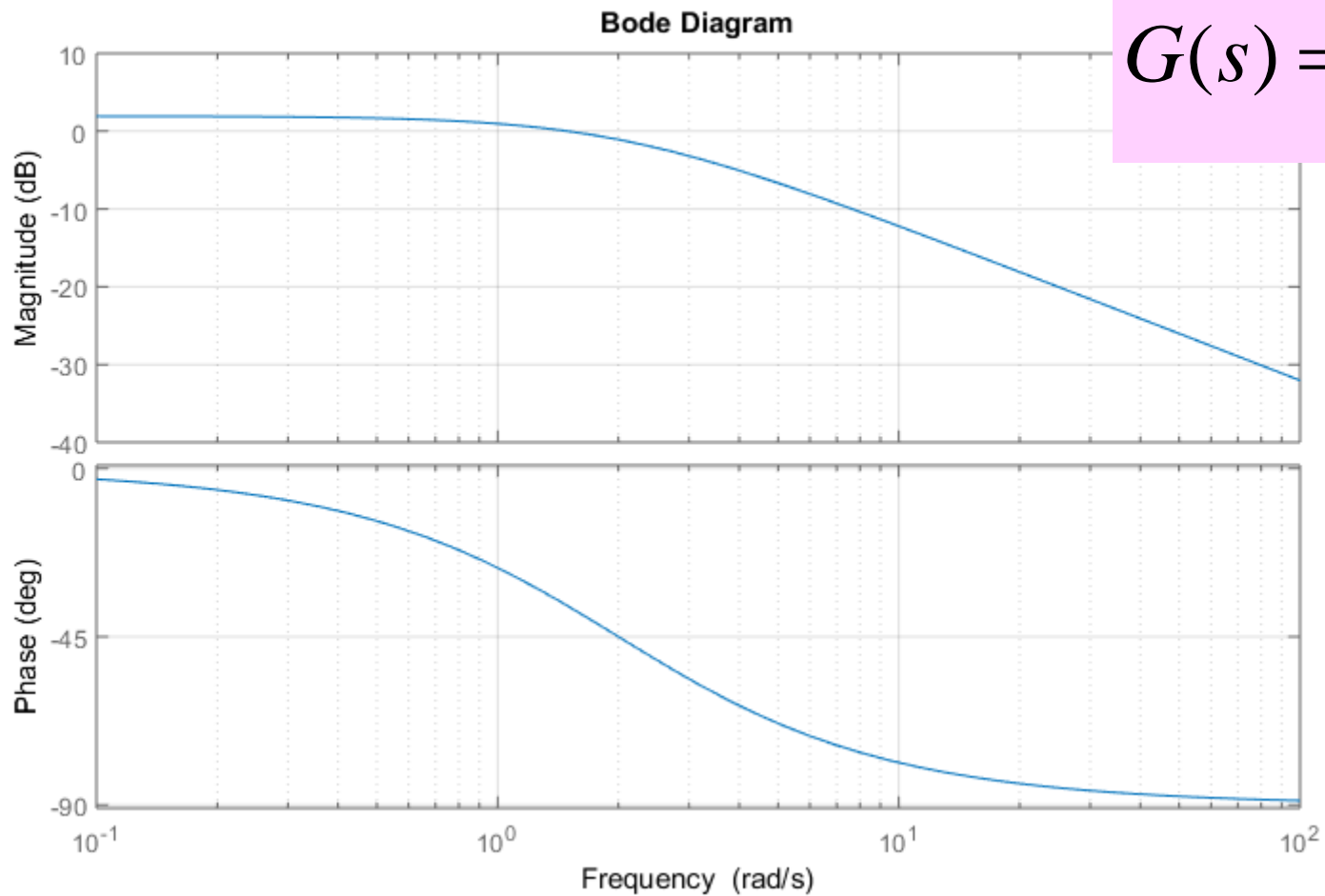
$$G(s) = \frac{10}{4s + 8}$$



The image shows a screenshot of the MATLAB R2015a Command Window. The window title is "MATLAB R2015a". The current folder is "C:\Program Files\MATLAB\MATLAB Production Server\R2015a\bin". The Command Window contains the following code and output:

```
>> num=[10];den=[4 8];  
>> ss=tf(num,den)  
  
ss =  
  
      10  
-----  
    4 s + 8  
  
Continuous-time transfer function.  
  
>> bode(ss)  
fx >>
```

Plot Bode Diagram



$$G(s) = \frac{10}{4s + 8}$$

Plot Bode Diagram

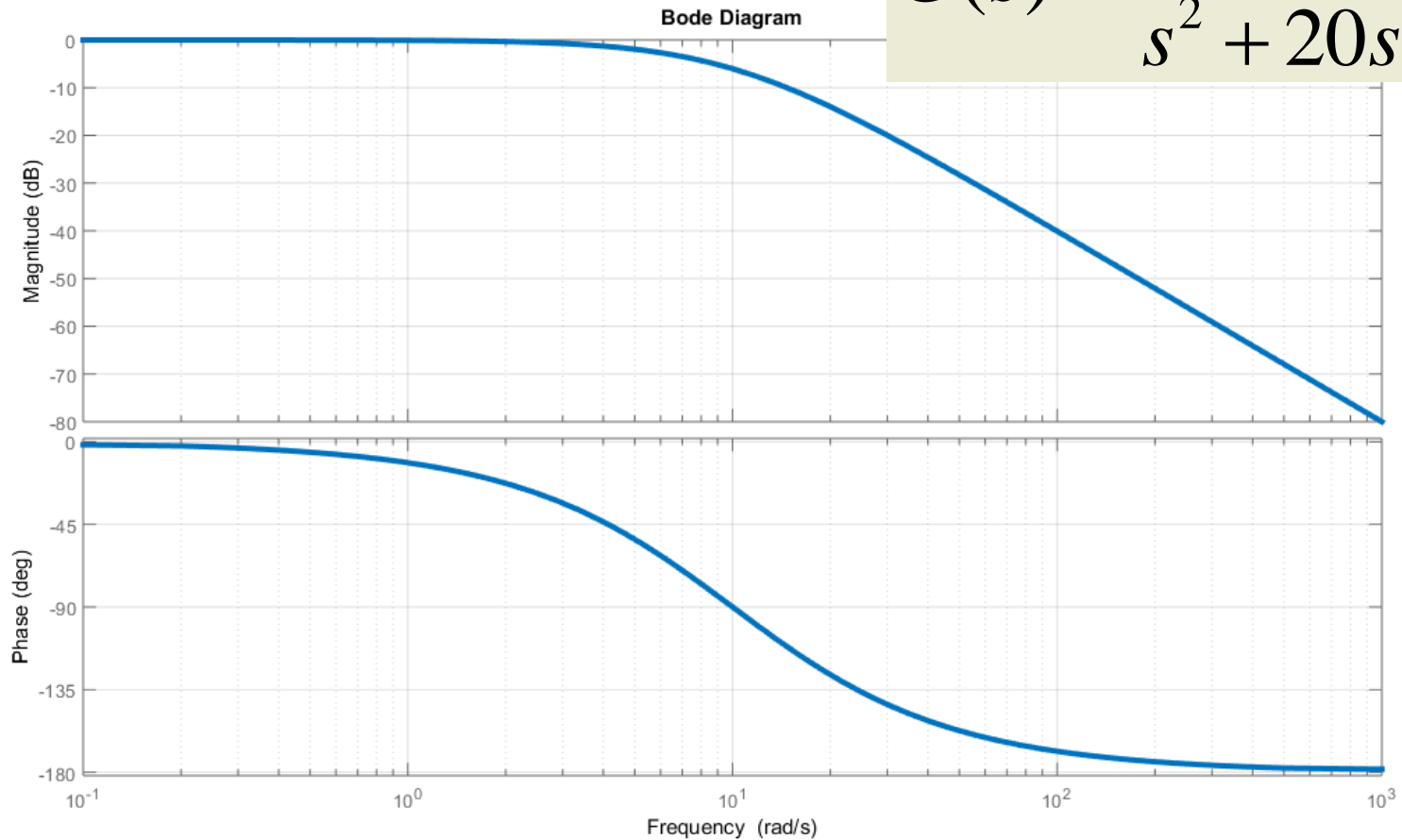
Example No.II

$$G(s) = \frac{100}{s^2 + 20s + 100}$$

```
>> num=[100];den=[1 20 100];  
>> ss=tf(num,den);  
>> bode(ss)
```


Plot Bode Diagram

$$G(s) = \frac{100}{s^2 + 20s + 100}$$





Introduction

Frequency-Response Analysis



MATLAB and Simulink

Frequency-Response Analysis

First-order transfer function(Closed-loop TF)

$$G(s) = \frac{K}{Ts + 1}$$

Example

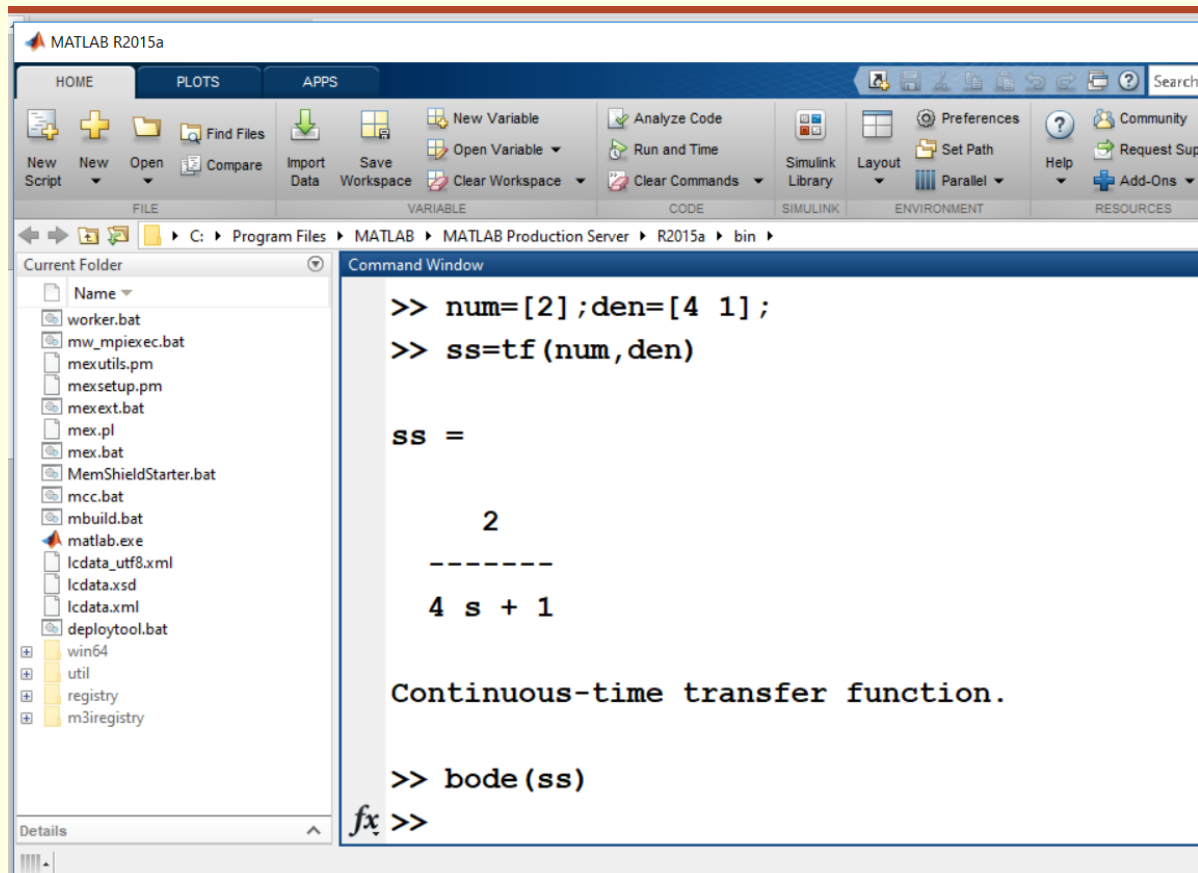
$$G(s) = \frac{2}{4s + 1}; \quad K = 2 \text{ and } T = 4$$

```
>> num=[2];den=[4 1];  
>> ss=tf(num,den);  
>> bode(ss)
```

Frequency-Response Analysis

First-order transfer function

$$G(s) = \frac{2}{4s + 1}; \quad K = 2 \text{ and } T = 4$$



The image shows the MATLAB R2015a software interface. The Command Window displays the following code and output:

```
>> num=[2];den=[4 1];
>> ss=tf(num,den)

ss =

      2
-----
    4 s + 1

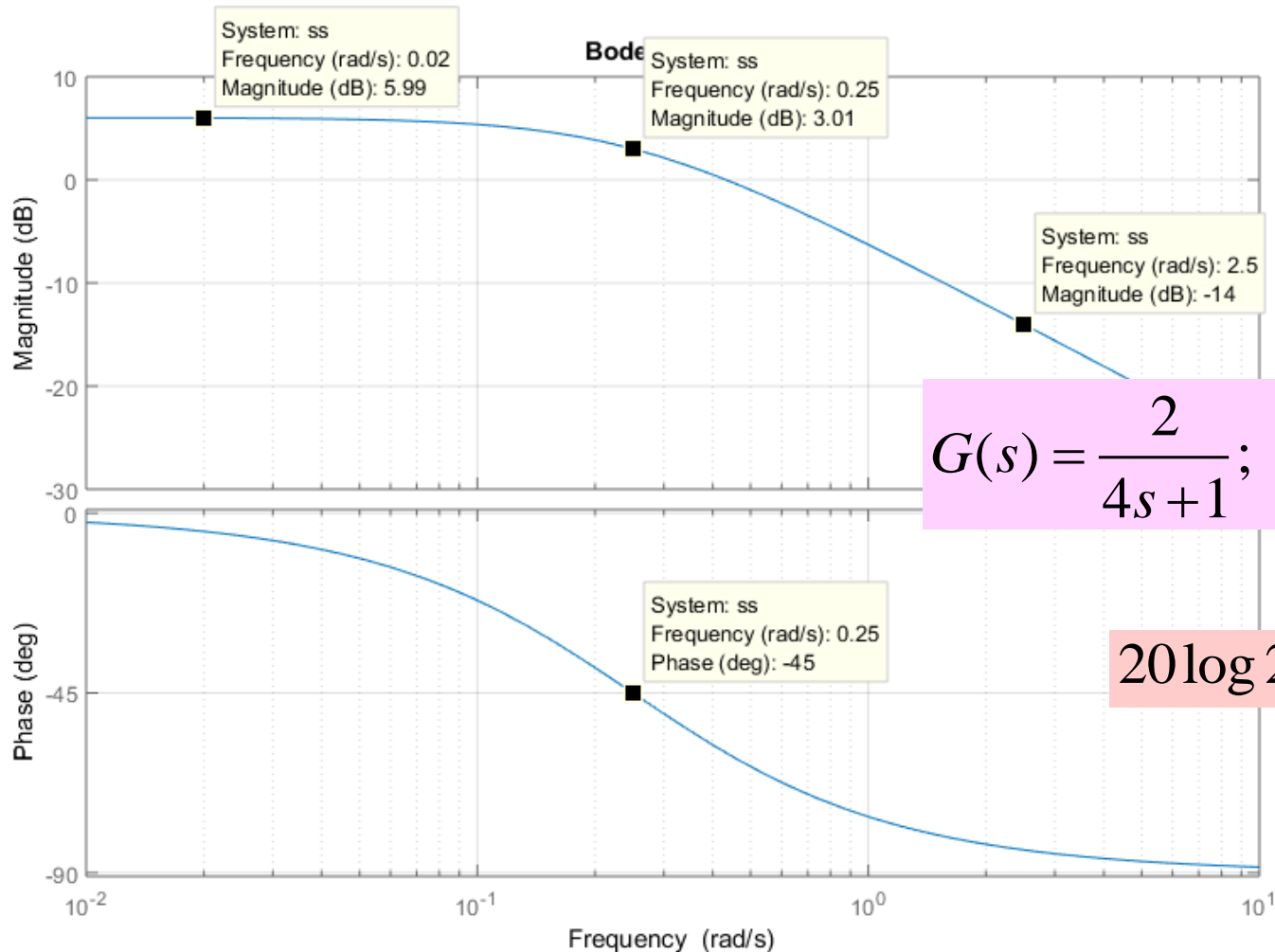
Continuous-time transfer function.

>> bode(ss)
fx >>
```

The interface also shows the current folder containing various files and subfolders, including 'win64', 'util', 'registry', and 'm3iregistry'.

Frequency-Response Analysis

First-order transfer function



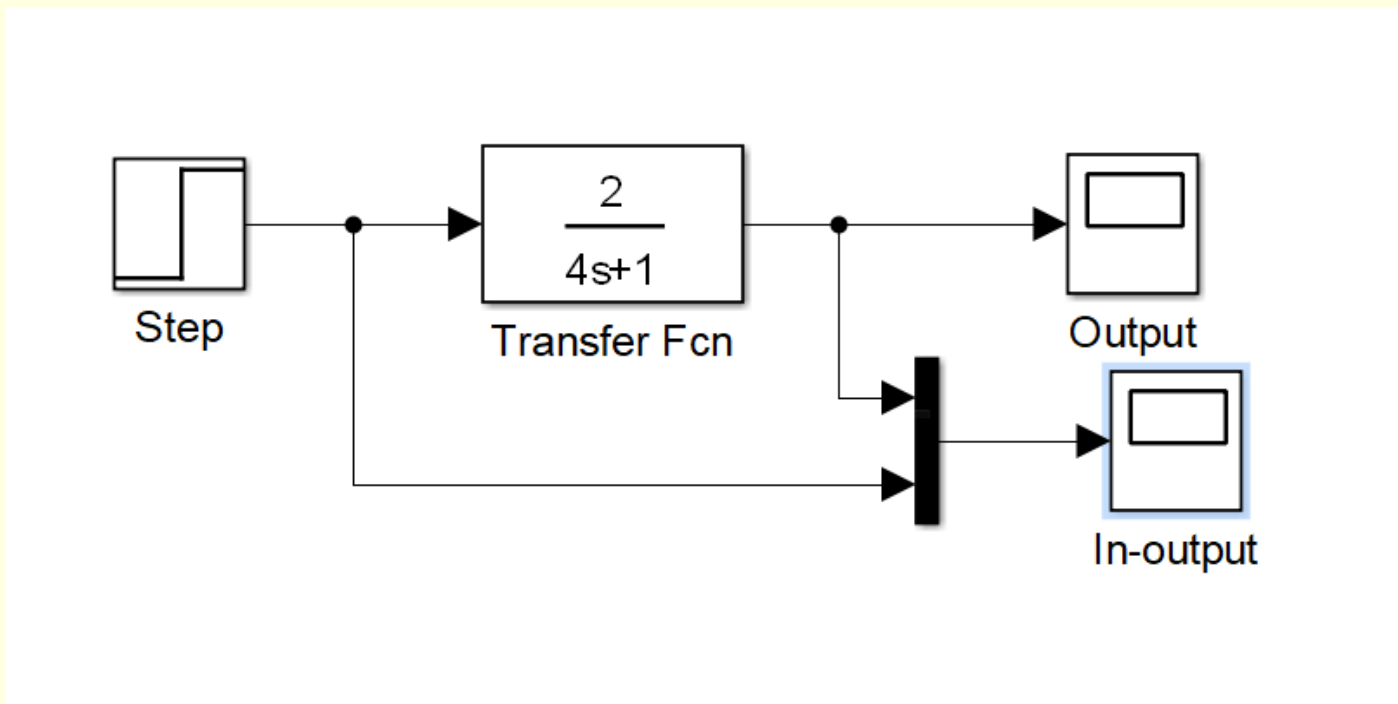
$$G(s) = \frac{2}{4s + 1}; \quad K = 2 \text{ and } T = 4$$

$$20 \log 2 = 6 \text{ dB}$$

Frequency-Response Analysis

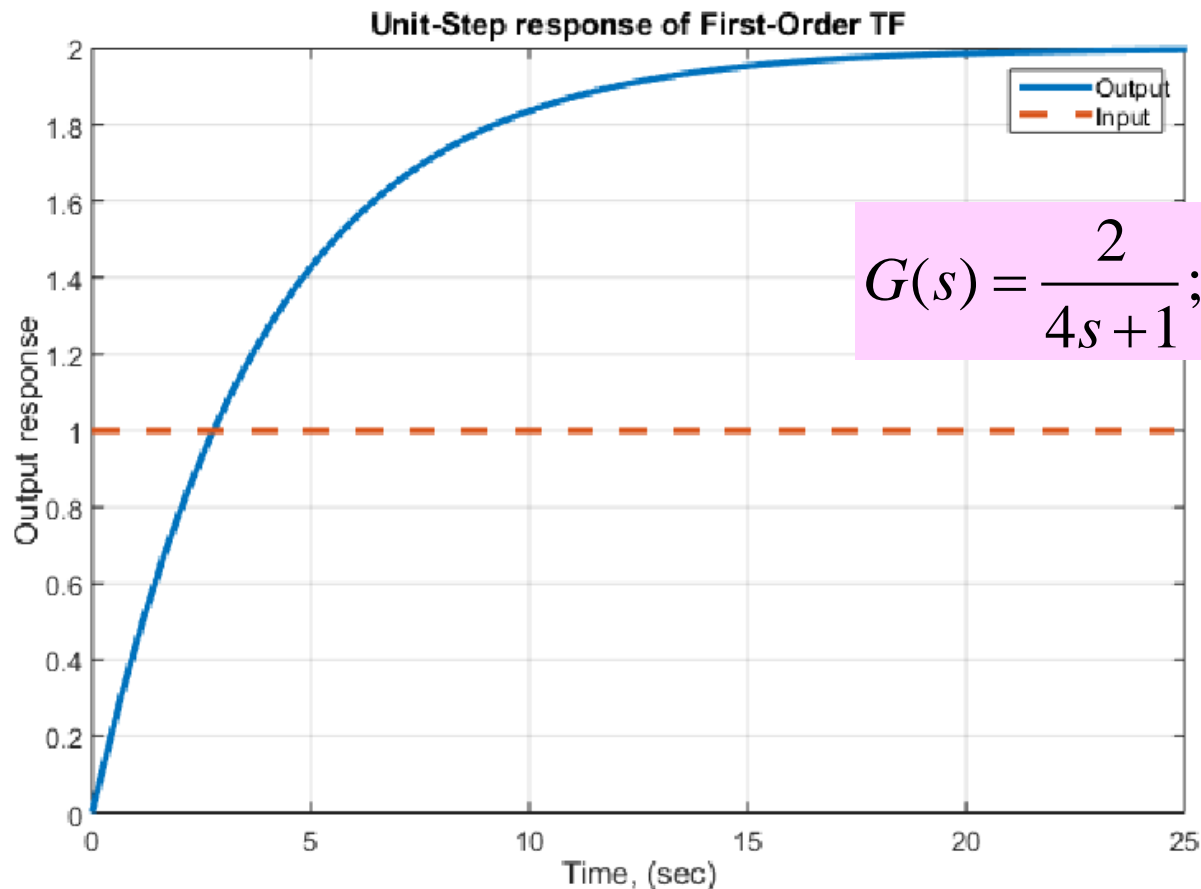
First-order transfer function - Time domain

$$G(s) = \frac{2}{4s+1}; \quad K = 2 \text{ and } T = 4$$



Frequency-Response Analysis

First-order transfer function - Time domain



$$G(s) = \frac{2}{4s + 1}; \quad K = 2 \text{ and } T = 4$$

Frequency-Response Analysis

Second-order transfer function(Closed-loop TF)

$$G(s) = \frac{K \omega_n^2}{s^2 + 2\zeta \omega_n s + \omega_n^2}$$

Example

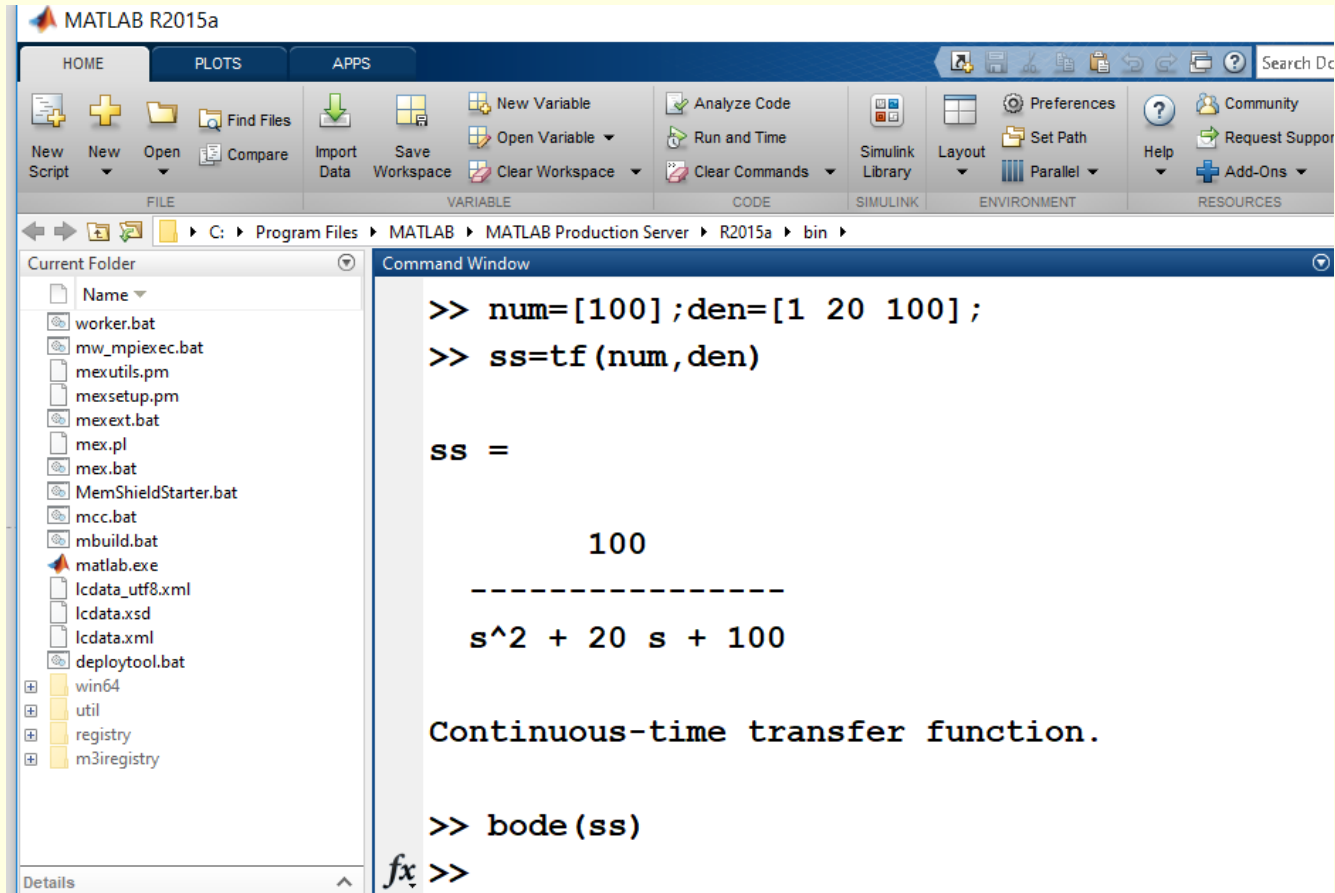
$$G(s) = \frac{100}{s^2 + 20s + 100}; \quad K = 100, \zeta = 1 \text{ and } \omega_n = 10 \text{ rad/sec}$$

```
>> num=[100];den=[1 20 100];  
>> ss=tf(num,den);  
>> bode(ss)
```


Frequency-Response Analysis

Second-order transfer function

$$G(s) = \frac{100}{s^2 + 20s + 100}; \quad K = 100, \zeta = 1 \text{ and } \omega_n = 10 \text{ rad/sec}$$



The image shows the MATLAB R2015a interface. The Command Window displays the following code and output:

```
>> num=[100];den=[1 20 100];
>> ss=tf(num,den)

ss =

          100
-----
s^2 + 20 s + 100

Continuous-time transfer function.

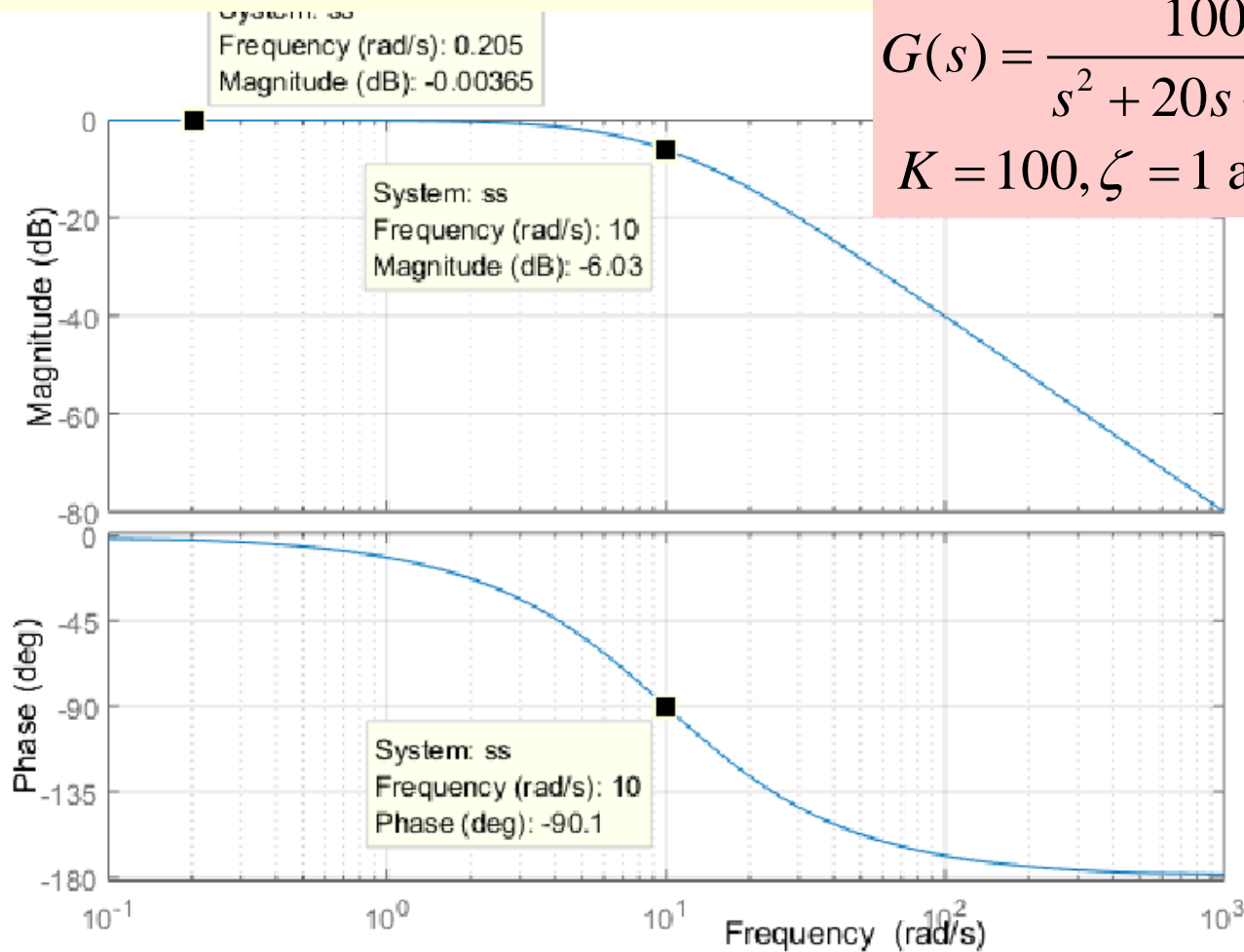
>> bode(ss)
fx >>
```

Frequency-Response Analysis

Second-order transfer function

$$G(s) = \frac{100}{s^2 + 20s + 100};$$

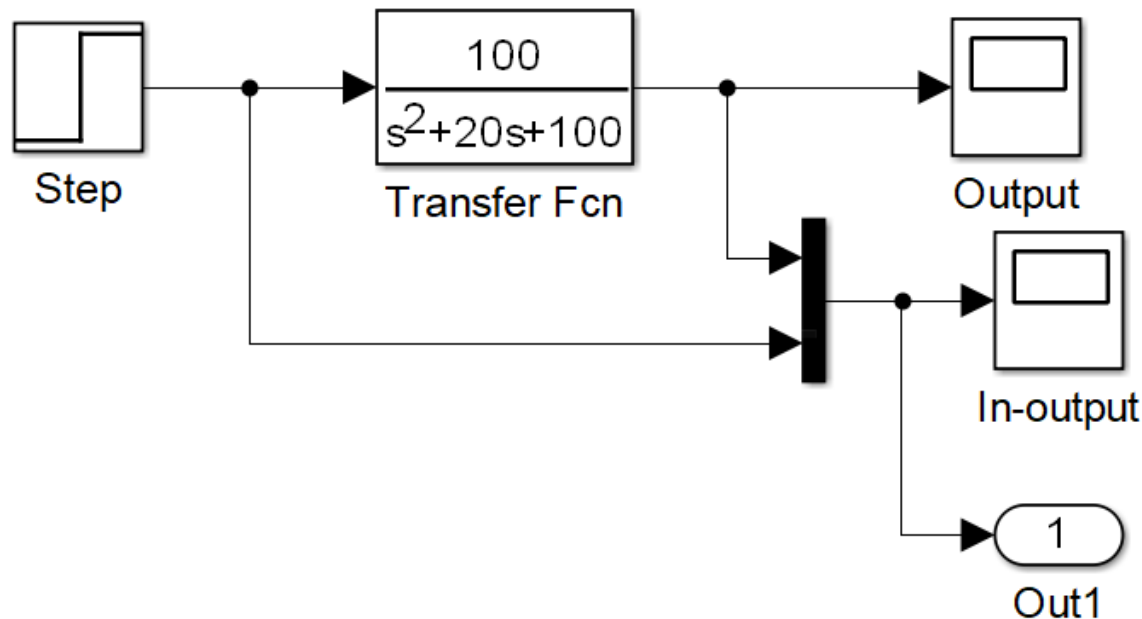
$$K = 100, \zeta = 1 \text{ and } \omega_n = 10 \text{ rad/sec}$$



Frequency-Response Analysis

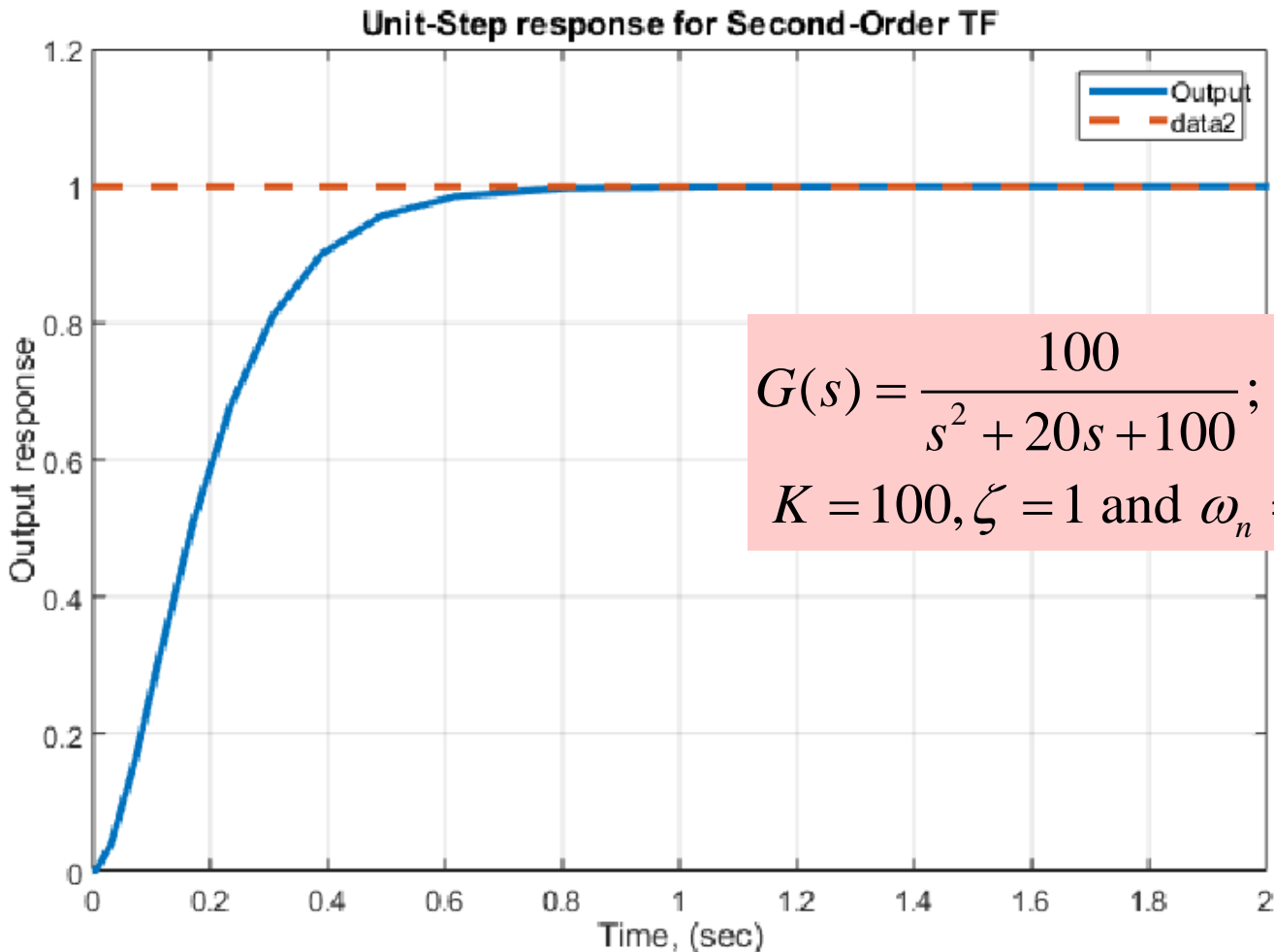
Second-order transfer function - Time domain

$$G(s) = \frac{100}{s^2 + 20s + 100}; \quad K = 100, \zeta = 0.5 \text{ and } \omega_n = 10 \text{ rad/sec}$$



Frequency-Response Analysis

Second-order transfer function - Time domain



$$G(s) = \frac{100}{s^2 + 20s + 100};$$

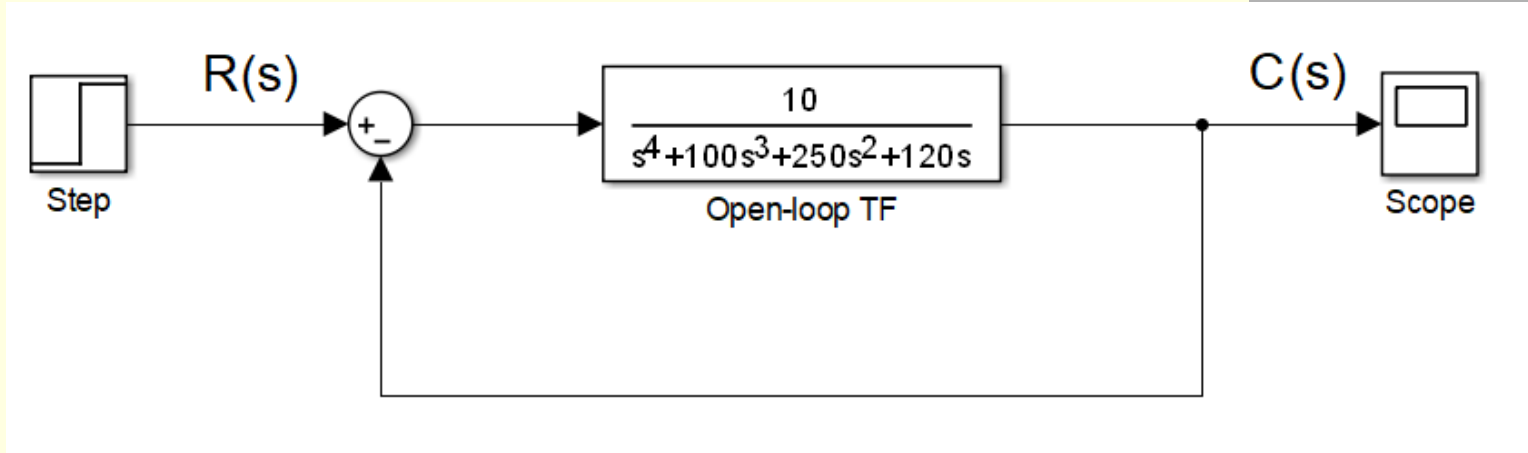
$K = 100, \zeta = 1$ and $\omega_n = 10$ rad/sec

Stability Analysis by FRA

- Unity feedback system
- Open-loop transfer function via Bode Diagram
 - Gain Margin(GM)
 - Phase Margin(PM)
 - Percent overshoot and damping ratio

Gain Margin(GM) and Phase Margin(PM)

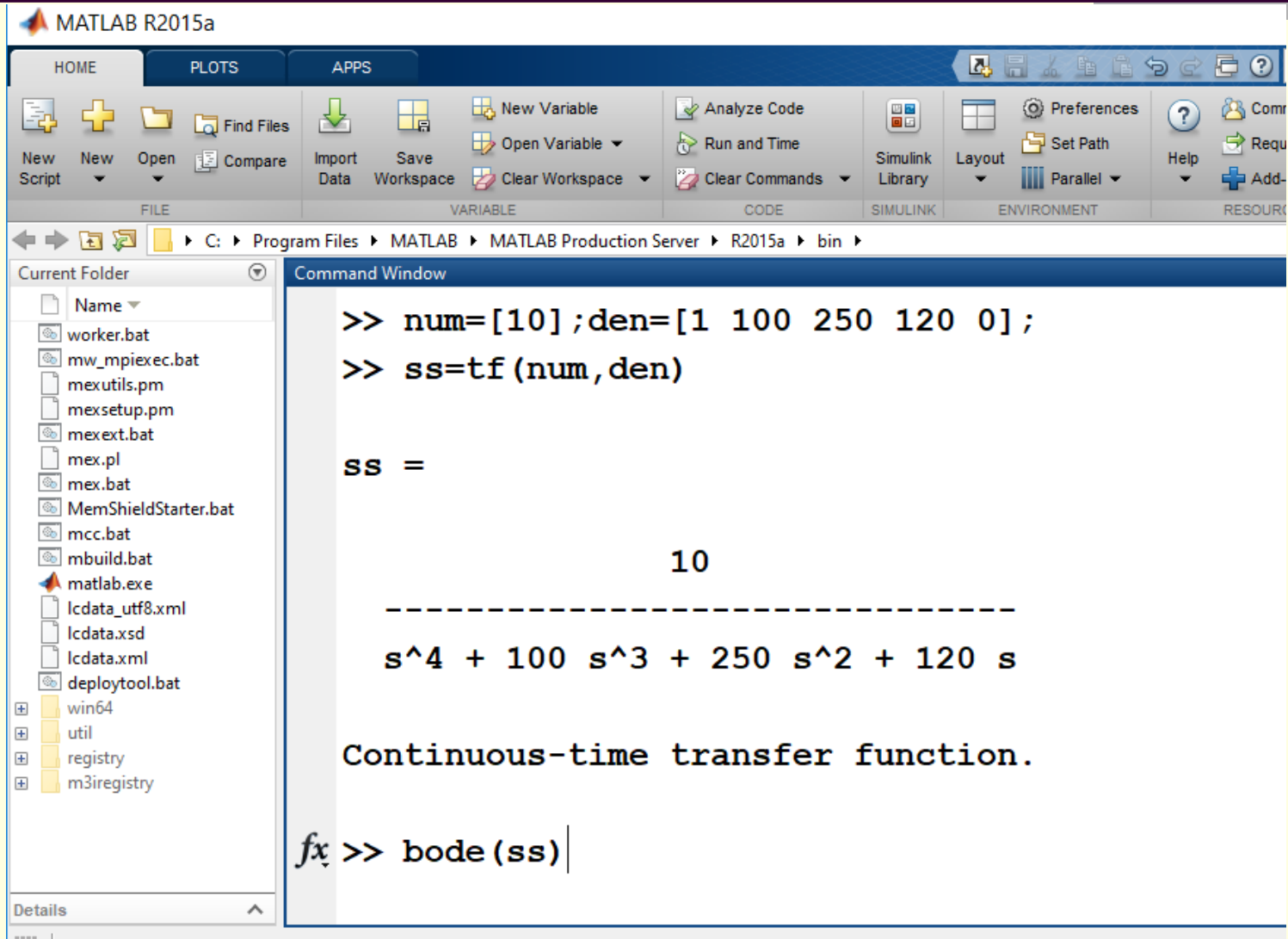
Stable system



```
>> num=[10];den=[1 100 250 120 0];  
>> ss=tf(num,den);  
>> bode(ss)
```

Gain Margin(GM) and Phase Margin(PM)

Stable system



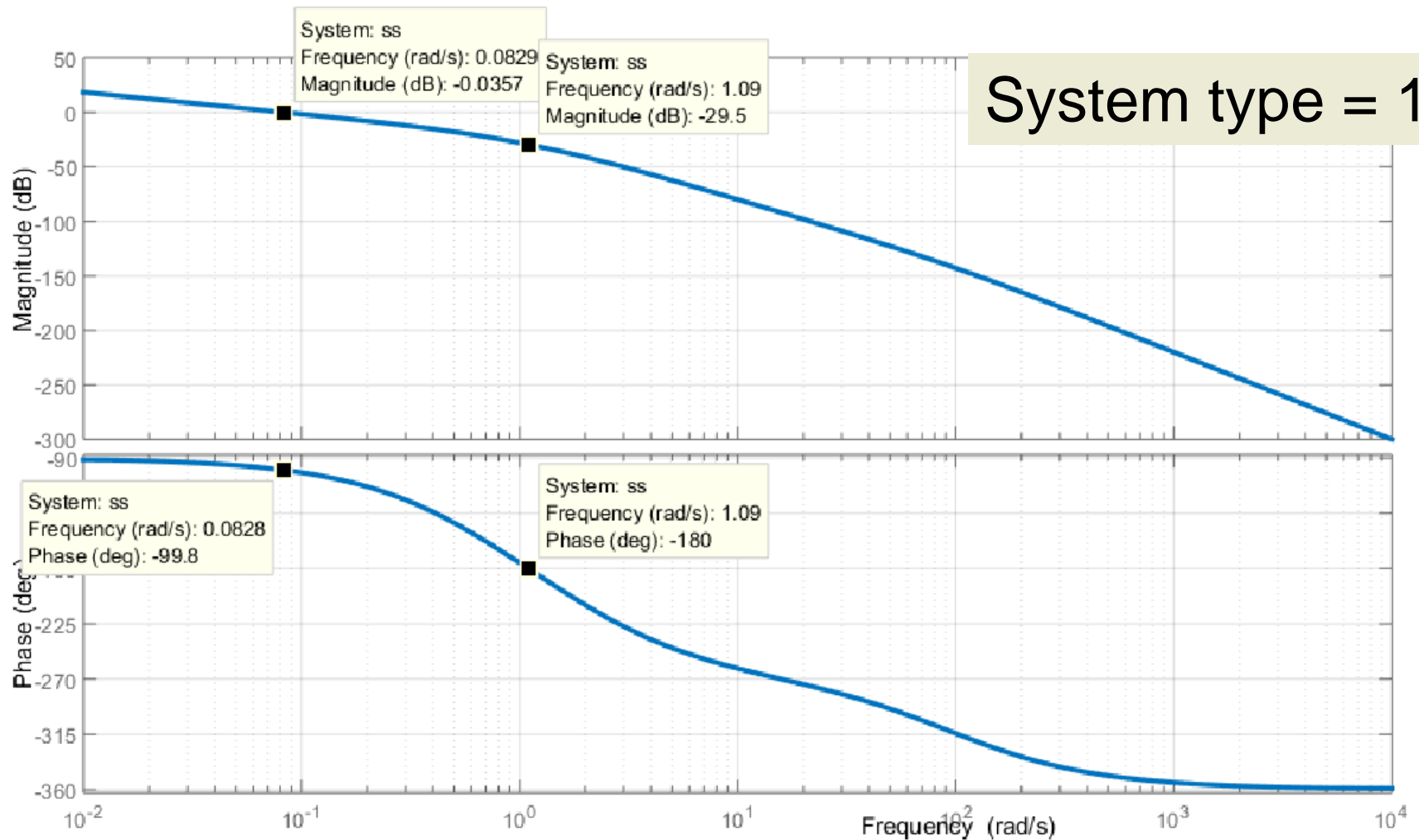
The image shows the MATLAB R2015a interface. The Command Window contains the following code and output:

```
>> num=[10];den=[1 100 250 120 0];  
>> ss=tf(num,den)  
  
ss =  
  
          10  
-----  
s^4 + 100 s^3 + 250 s^2 + 120 s  
  
Continuous-time transfer function.  
  
fx >> bode(ss)
```

Gain Margin(GM) and Phase Margin(PM)

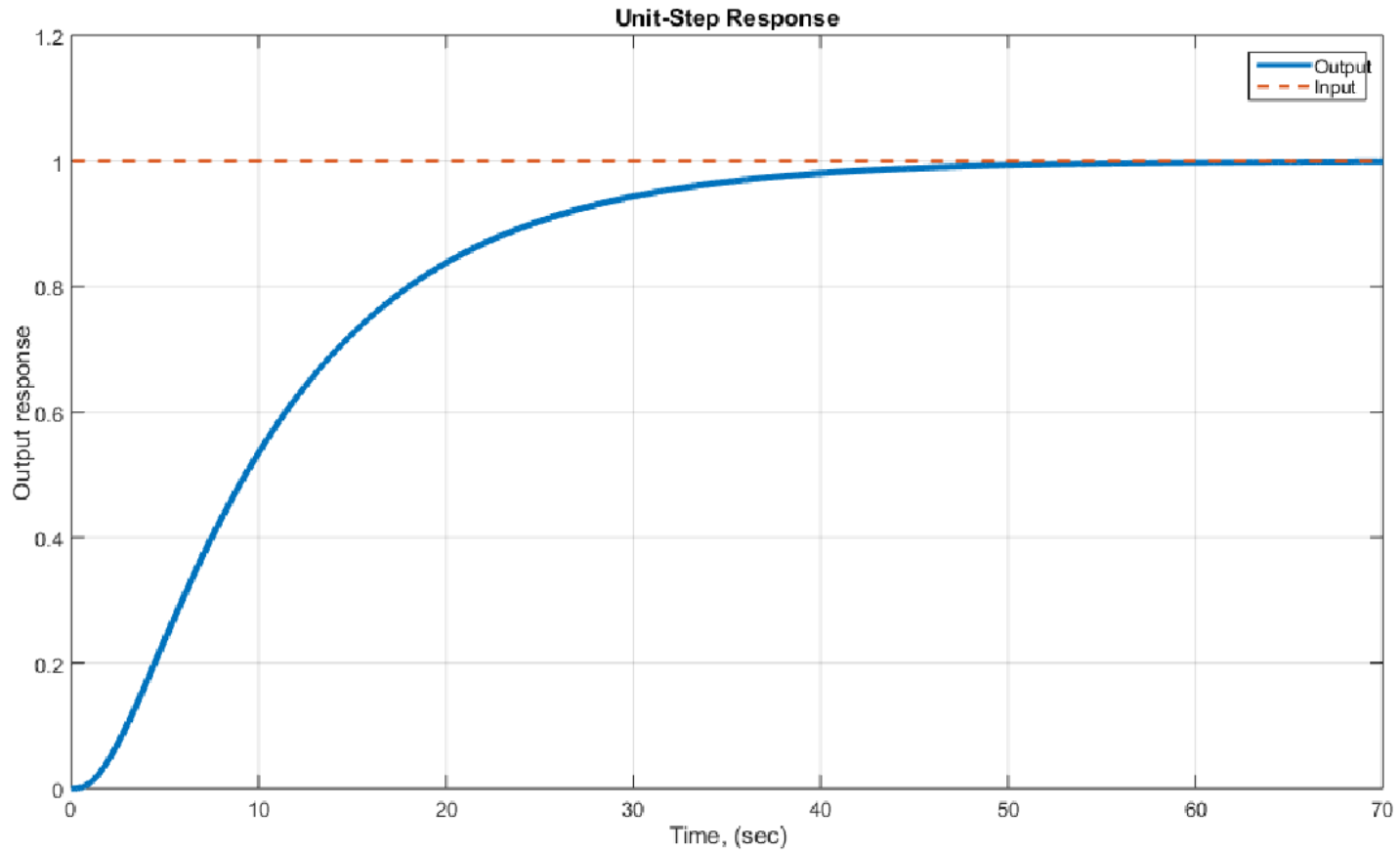
Stable system

System type = 1

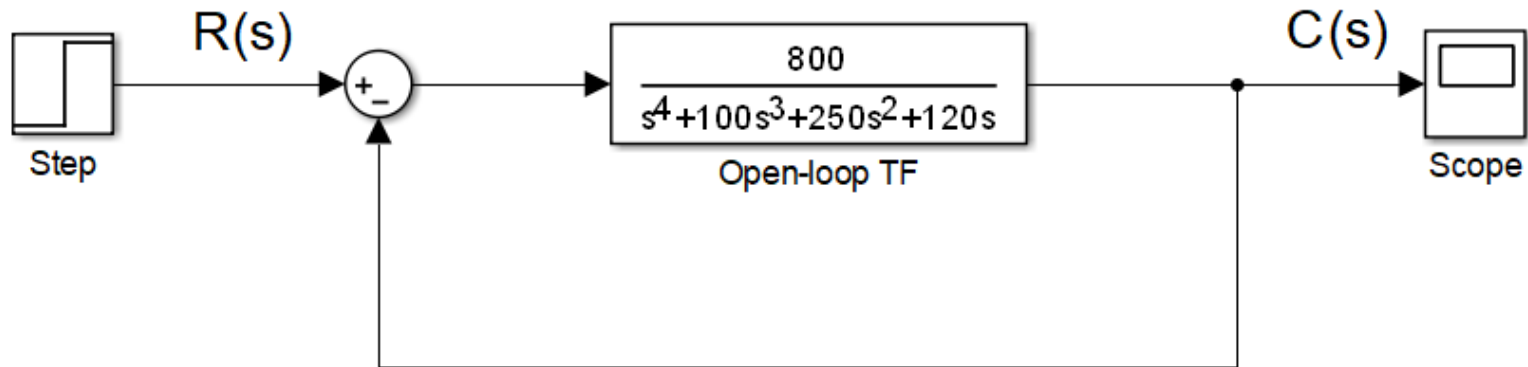


Gain Margin(GM) and Phase Margin(PM)

Stable system

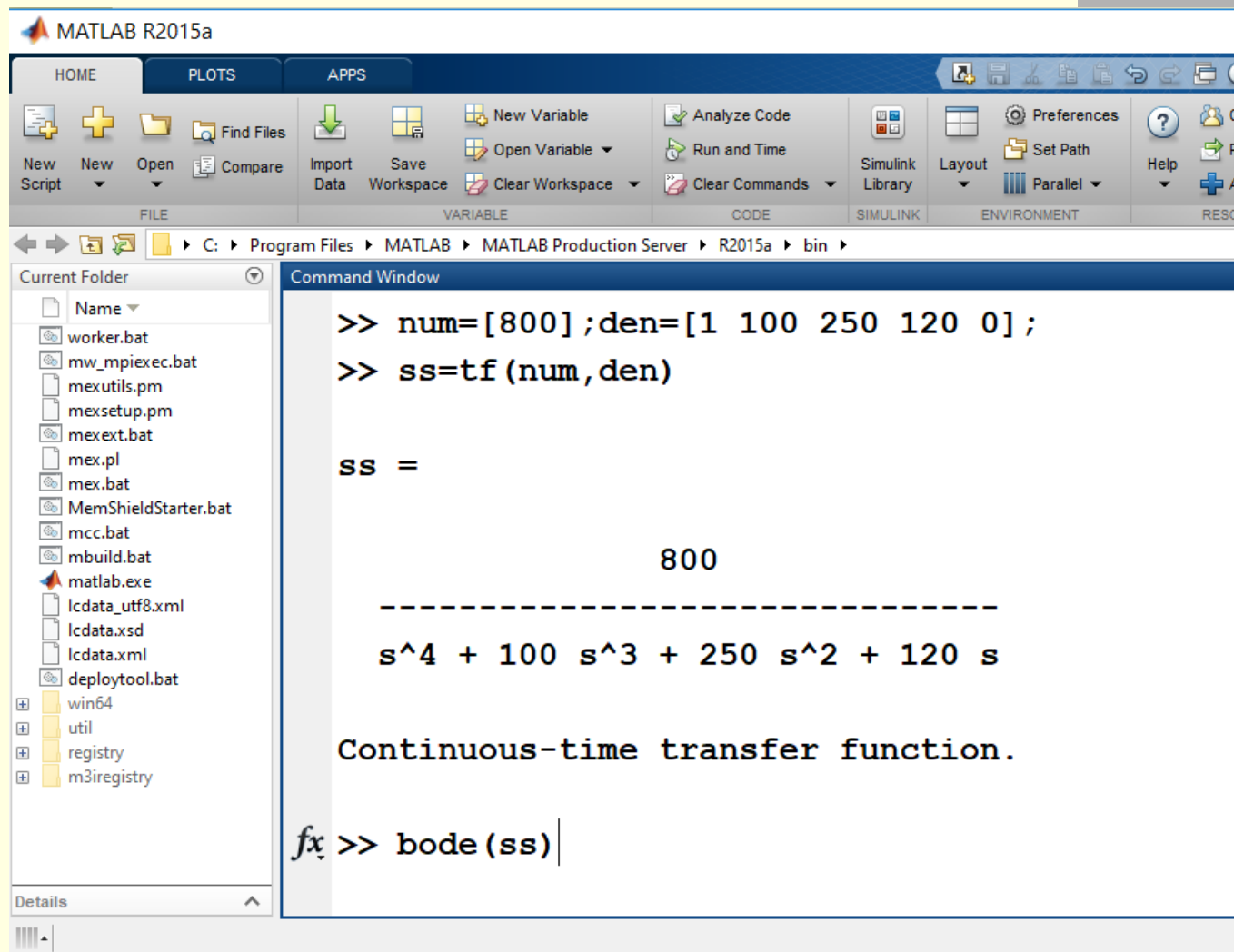


Gain Margin(GM) and Phase Margin(PM)



```
>> num=[800];den=[1 100 250 120 0];  
>> ss=tf(num,den);  
>> bode(ss)
```

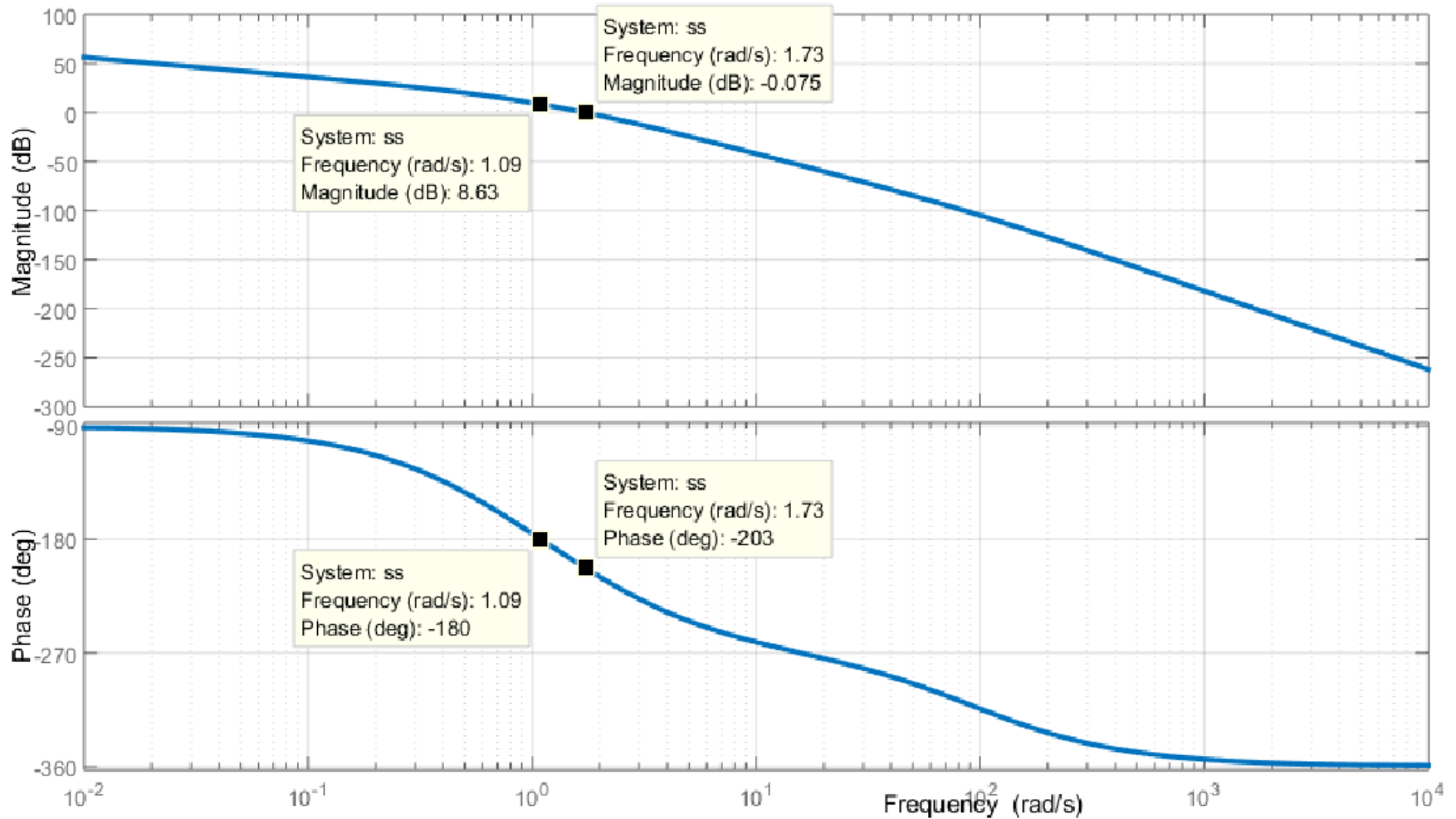
Gain Margin(GM) and Phase Margin(PM)



The image shows the MATLAB R2015a interface. The Command Window contains the following code and output:

```
>> num=[800];den=[1 100 250 120 0];  
>> ss=tf(num,den)  
  
ss =  
  
          800  
-----  
s^4 + 100 s^3 + 250 s^2 + 120 s  
  
Continuous-time transfer function.  
  
fx >> bode(ss)
```

Gain Margin(GM) and Phase Margin(PM)



Gain Margin(GM) and Phase Margin(PM)

Unstable system

