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ELEN 100 Lab

February 17, 2023

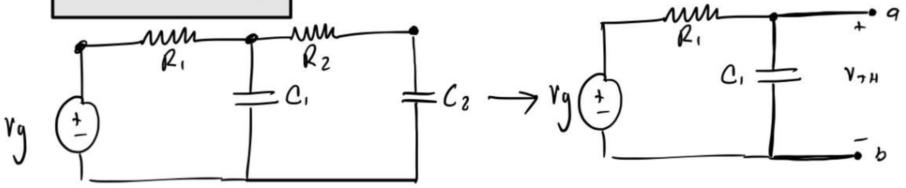
Project 1 Lab Report

Problem 1:

<u>Transfer Function Calculation:</u>

Problem 1

Find transfer function:



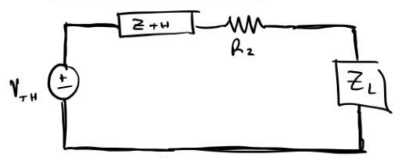
Voltage Divider:

$$V_{TH} = \frac{V_g (C_1)}{R_1 + C_1} \rightarrow V_{TH} = (V_g)\frac{\frac{1}{jwC_1}}{R_1 + \frac{1}{jwC_1}}$$

$$\Rightarrow \frac{\frac{1}{jwC_1}}{\frac{R_1 jwC_1}{jwC_1} + \frac{1}{jwC_1}} \Rightarrow \frac{\frac{1}{jwC_1}}{\frac{1 + R_1 jwC_1}{jwC_1}}$$

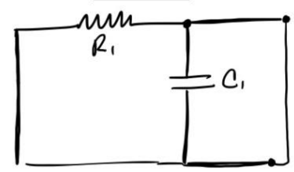
$$\Rightarrow \boxed{\left(\frac{1}{1 + R_1 jwC_1}\right) V_g = V_{TH}}$$

Thevenin Circuit



$$V_{TH} = \frac{V_g}{1 + R_1 jwC_1}$$

Z_{TH}



Parallel components

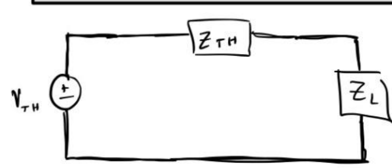
$$a \| b = \frac{a \cdot b}{a + b}$$

$$Z_{TH} = R_1 \| C_1$$

$$= \frac{(R_1)\left(\frac{1}{jwC_1}\right)}{R_1 + \frac{1}{jwC_1}}$$

$$\boxed{Z_{TH} = \frac{R_1 / jwC_1}{R_1 + \frac{1}{jwC_1}}}$$

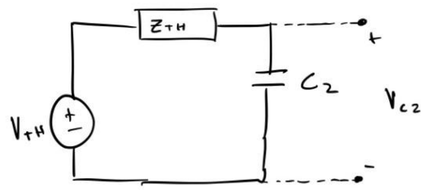
Thevenin Circuit w/ R_2 combined



$$Z_{TH} = Z_{TH} + 2$$

$$\boxed{Z_{TH} = \frac{R_1 + R_2 + jwC_1 R_1 R_2}{1 + jwC_1 R_1}}$$

Problem 1 continued...



$$\left(\frac{j\omega C_2}{j\omega C_2}\right)$$

$$= \frac{R_1 + R_2 + j\omega C_1 R_1 R_2}{1 + j\omega C_1 R_1} + \frac{1}{j\omega C_2}\left(\frac{1 + j\omega C_1 R_1}{1 + j\omega C_1 R_1}\right)$$

$$= \frac{(j\omega C_2)(R_1 + R_2 + j\omega C_1 R_1 R_2)}{(j\omega C_2)(1 + j\omega C_1 R_1)} + \frac{1 + j\omega C_1 R_1}{(j\omega C_2)(1 + j\omega C_1 R_1)}$$

$$\frac{(j\omega C_2)(R_1 + R_2 + j\omega C_1 R_1 R_2) + (1 + j\omega C_1 R_1)}{(j\omega C_2)(1 + j\omega C_1 R_1)}$$

Voltage Divider:

$$Z_{TH} = \frac{R_1 + R_2 + j\omega C_1 R_1 R_2}{1 + j\omega C_1 R_1}$$

$$V_{c2} = \frac{\frac{1}{j\omega C_2}}{\frac{R_1 + R_2 + j\omega C_1 R_1 R_2}{1 + j\omega C_1 R_1} + \frac{1}{j\omega C_2}} \cdot V_{TH}$$

$$= \frac{\frac{1}{j\omega C_2}}{\frac{R_1 + R_2 + j\omega C_1 R_1 R_2}{1 + j\omega C_1 R_1} + \frac{1}{j\omega C_2}} \cdot \frac{V_g}{1 + R_1 j\omega C_1}$$

$$= \frac{\frac{1}{j\omega C_2}}{\frac{(j\omega C_2)(R_1 + R_2 + j\omega C_1 R_1 R_2) + (1 + j\omega C_1 R_1)}{(j\omega C_2)(1 + j\omega C_1 R_1)}} \cdot \frac{V_g}{1 + R_1 j\omega C_1}$$

$$V_{c2} = \frac{\cancel{(j\omega C_2)}(1 + j\omega C_1 R_1)}{\cancel{j\omega C_2}\left[(j\omega C_2)(R_1 + R_2 + j\omega C_1 R_1 R_2) + (1 + j\omega C_1 R_1)\right]} \cdot \frac{V_g}{1 + R_1 j\omega C_1}$$

$$V_{c2} = \frac{\cancel{(1 + j\omega C_1 R_1)}}{(j\omega C_2)(R_1 + R_2 + j\omega C_1 R_1 R_2) + (1 + j\omega C_1 R_1)} \cdot \frac{V_g}{\cancel{1 + R_1 j\omega C_1}}$$

$$V_{c2} = \frac{V_g}{(j\omega C_2)(R_1 + R_2 + j\omega C_1 R_1 R_2) + (1 + j\omega C_1 R_1)}$$

$$\frac{V_{c2}}{V_g} = \frac{1}{(j\omega C_2)(R_1 + R_2 + j\omega C_1 R_1 R_2) + (1 + j\omega C_1 R_1)}$$

$$\frac{V_{c2}}{V_g} = \frac{1}{(R_1 j\omega C_2 + R_2 j\omega C_2 + j\omega C_1 R_1 R_2 j\omega C_2) + (1 + j\omega C_1 R_1)}$$

$$= \frac{1}{R_1 j\omega C_2 + R_2 j\omega C_2 + j\omega C_1 R_1 R_2 \cancel{j\omega} C_2 + 1 + j\omega C_1 R_1}$$

$$\frac{V_{c2}}{V_g} = \frac{1}{j\omega\left(R_1 C_2 + R_2 C_2 + j\omega C_1 R_1 R_2 C_2 + C_1 R_1\right) + 1}$$

$$\frac{1}{j\omega R_1 C_2 + j\omega R_2 C_2 + (j\omega)^2 C_1 C_2 R_1 R_2 + j\omega C_1 R_1 + 1}$$

$$H(j\omega) = \frac{V_{c2}}{V_g} = \boxed{\frac{1}{1 + j\omega(R_1 C_2 + R_2 C_2 + C_1 R_1) + (j\omega)^2 C_1 R_1 C_2 R_2}}$$

Problem 2:

Resistor Value Calculations:

$\boxed{\text{Problem \#2}}$

$$\frac{V_{c2}}{V} = \frac{1}{j\omega(R_1C_2 + R_1C_1 + R_2C_2) + j\omega^2(C_1C_2R_1R_2) + 1}$$

All Components

$$\boxed{\begin{array}{l} C_1 = C_2 = 10^{-6}\ F \\ R_1 = 65.93\ \Omega \\ R_2 = 252.79\ \Omega \end{array}}$$

$$\frac{1}{b} + \frac{1}{a} = R_1C_2 + R_1C_1 + R_2C_2$$

$$\frac{3000 + 20000}{3000 \cdot 20000} = R_1C_2 + R_1C_1 + R_2C_2$$

$$\frac{23}{60000} = R_1C_2 + R_1C_1 + R_2C_2$$

$$= R_1C_1 + R_1C_1 + R_2C_1$$

$$= C_1(R_1 + R_1 + R_2)$$

$$\frac{23}{60000} = C_1(2R_1 + R_2)$$

$$\frac{1}{ab} = C_1C_2R_1R_2$$

$$\frac{1}{3000 \cdot 20000} = (10^{-6})^2 R_1R_2$$

$$R_1 = \frac{1}{3000 \cdot 20000 \cdot (10^{-6})^2 \cdot R_2}$$

$$R_1 = 16666.67 \cdot \frac{1}{R_2}$$

$$\frac{23}{60000} = 10^{-6}\left(\frac{2 \cdot 16666.67}{R_2} + R_2\right)$$

$$\frac{23}{60000} = \frac{.033}{R_2} + (R_2 \times 10^{-6})$$

$$\frac{23}{60000} \cdot R_2 = .033 + (R_2^2 \times 10^{-6})$$

$$0 = (10^{-6})R_2^2 - \left(\frac{23}{60000}\right)R_2 + (0.033)$$

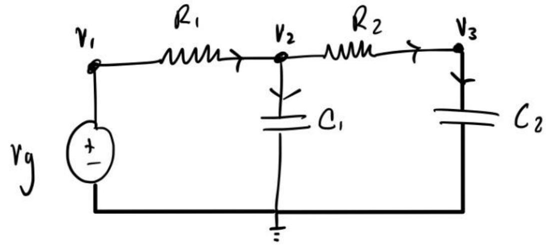
$$\boxed{\begin{array}{l} R_2 = 252.79\ \Omega\ ;\ 130.54\ \Omega \\ R_1 = 65.93\ \Omega\ ;\ 127.67\ \Omega \end{array}}$$

Problem 3:

Nodal Analysis for MATLAB Matrix input:

$\boxed{\text{Problem \#3}}$

NODE voltage circuit :



$V_1)\quad V_1 = V_g$

$V_2)\quad -\frac{(V_1-V_2)}{R_1} + \frac{(V_2-0)}{C_1} + \frac{(V_2-V_3)}{R_2} = 0$

$V_3)\quad -\frac{(V_2-V_3)}{R_2} + \frac{(V_3-0)}{C_2} = 0$

$-\frac{V_1}{R_1} + \frac{V_2}{R_1} + \frac{V_2}{C_1} + \frac{V_2}{R_2} - \frac{V_3}{R_2} = 0$

$V_1\left(-\frac{1}{R_1}\right) + V_2\left(\frac{1}{R_1} + \frac{1}{C_1} + \frac{1}{R_2}\right) + V_3\left(-\frac{1}{R_2}\right) = 0$

$-\frac{1}{R_1} \;\Big|\; \frac{1}{R_1} + j\omega C_1 + \frac{1}{R_2} \;\Big|\; -\frac{1}{R_2} \;\Big|\; 0$

$-\frac{V_2}{R_2} + \frac{V_3}{R_2} + \frac{V_3}{C_2} = 0$

$V_2\left(-\frac{1}{R_2}\right) + V_3\left(\frac{1}{R_2} + \frac{1}{C_2}\right) = 0$

$-\frac{1}{R_2} \;\Big|\; \frac{1}{R_2} + j\omega C_2 \;\Big|\; 0$

Final Matrix

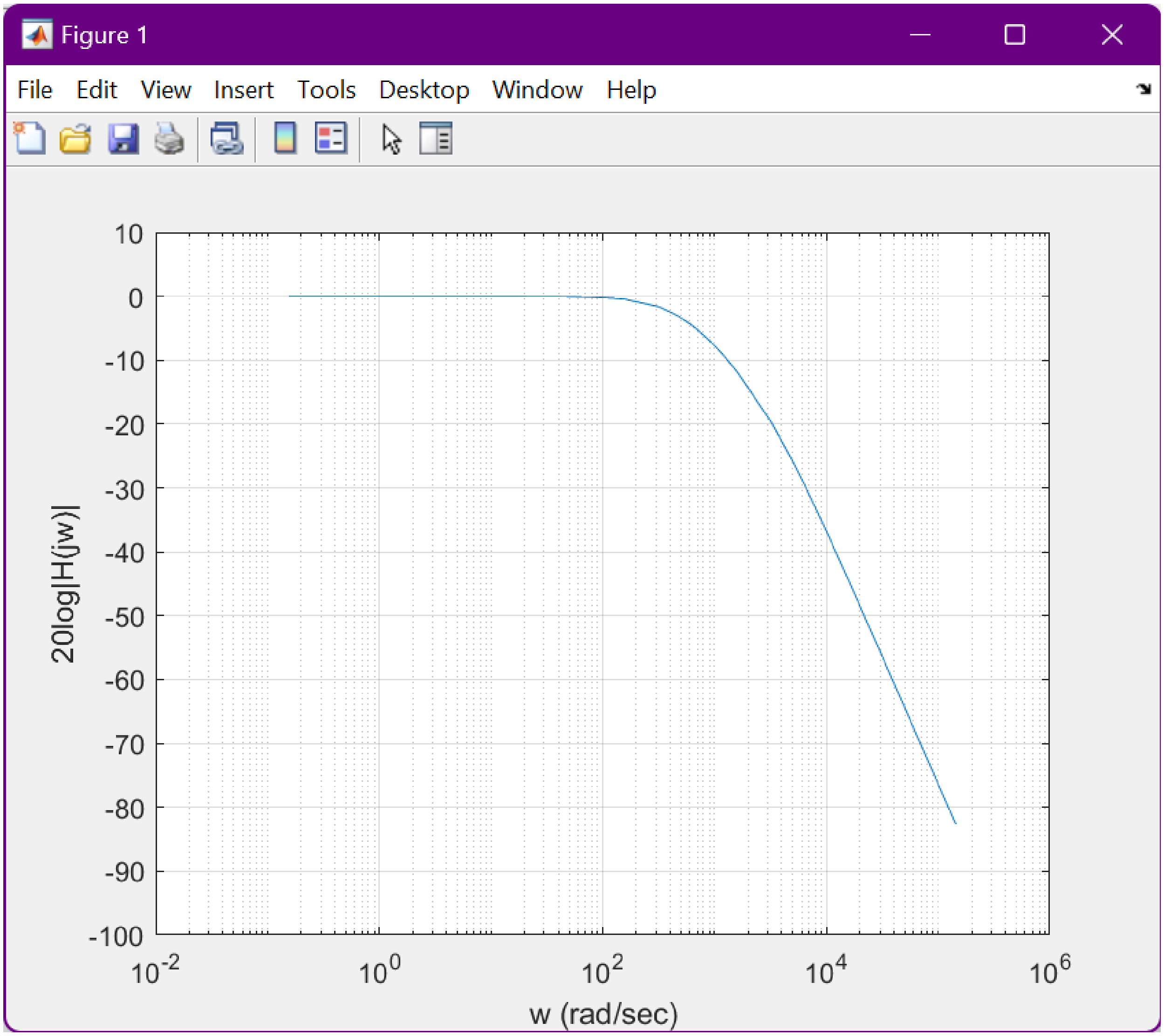
$$\begin{pmatrix} 1 & 0 & 0 \\ -\frac{1}{R_1} & \frac{1}{R_1} + j\omega C_1 + \frac{1}{R_2} & -\frac{1}{R_2} \\ 0 & -\frac{1}{R_2} & \frac{1}{R_2} + j\omega C_2 \end{pmatrix} = \begin{pmatrix} V_1 \\ V_2 \\ V_3 \end{pmatrix} \begin{pmatrix} V_g \\ 0 \\ 0 \end{pmatrix}$$

* matrix plugged into matlab

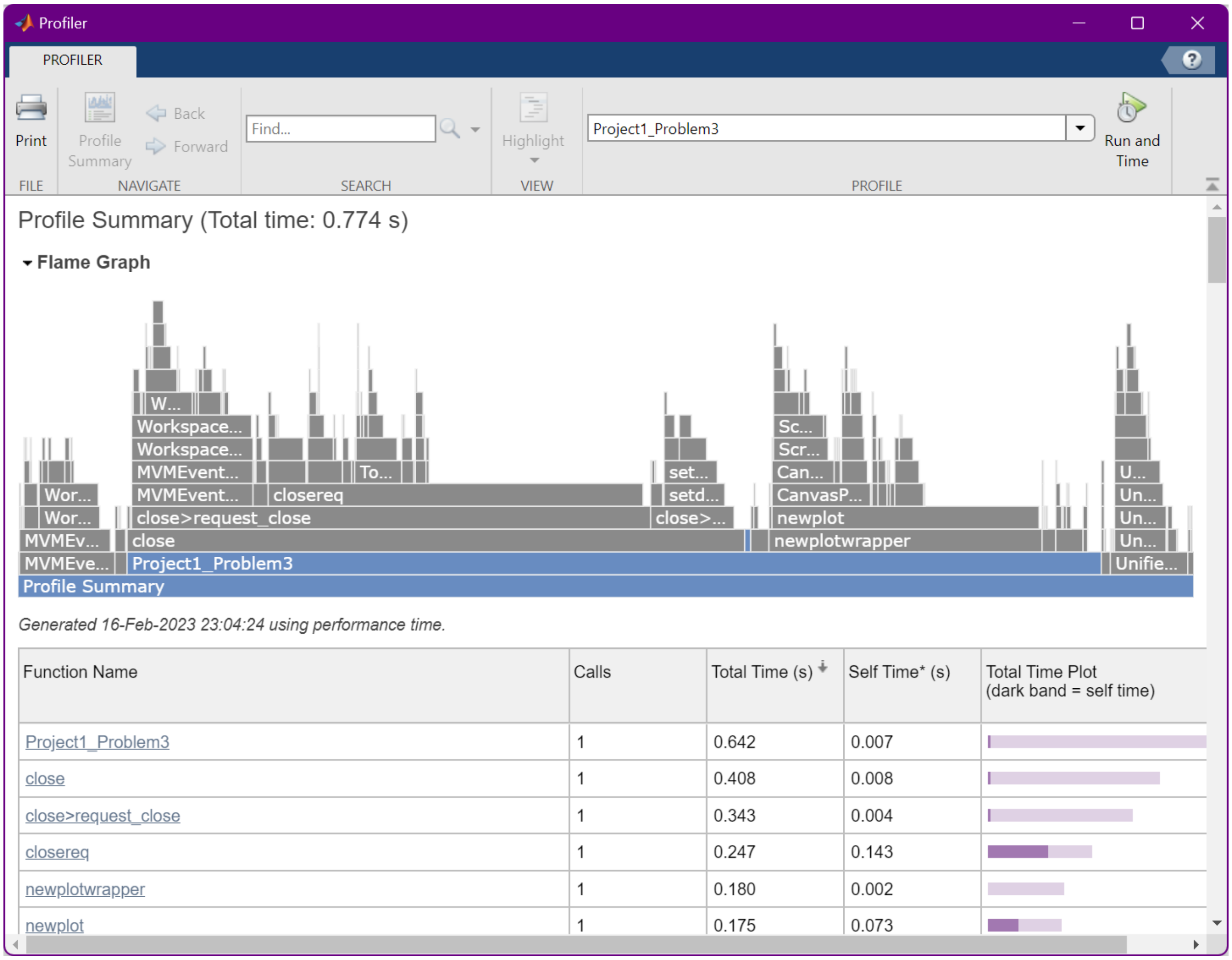
MATLAB Script:

```
close all;
clear;
clc;

%Variabble declarations
R1 = 65.93;
R2 = 252.79;
C1 = 10^-6;
C2 = 10^-6;

%Matrix declarations
G = [1,0,0;(-1/R1),(1/R1+1/R2),-1/R2;0,(-1/R2),(1/R2)];
C = [0,0,0;0,(C1),0;0,0,C2];
b = [1;0;0];

%Varying frequencies
r = [1 2 3 4 5 6 7 8 9];
w = [r,(10*r),(1e2*r),(1e3*r),(1e4*r),(1e5*r)];
freq = (w/(2*pi));

%Calling graphing functions with the parameters
semilogx(freq,freqresp4(G,C,b,w))
grid
ylim([-100,10]);
ylabel('20log|H(jw)|');
xlabel('w (rad/sec)');

hold on
```

MATLAB Simulation Result:

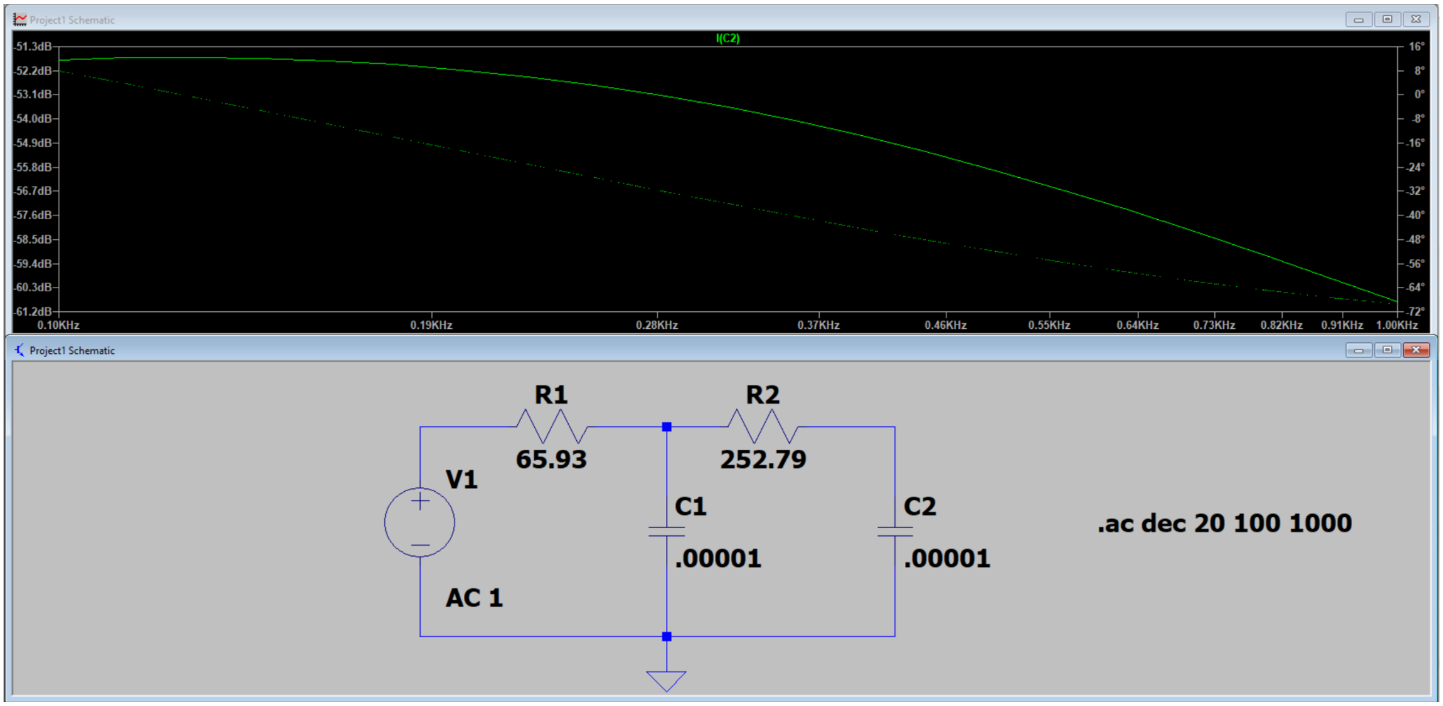


MATLAB Run-time Results:



Problem 4:

SPICE Simulation Results:

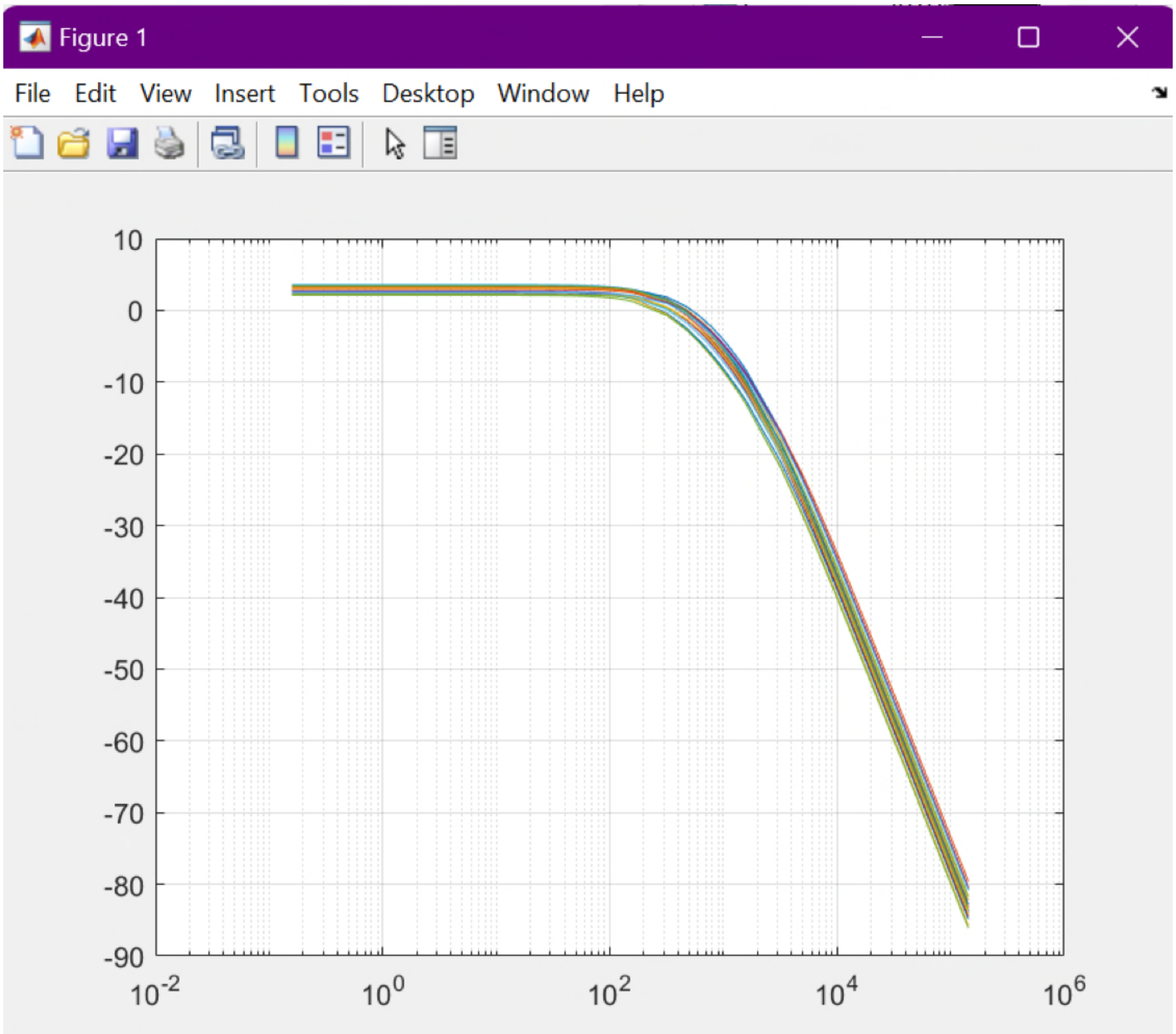


Problem 5:

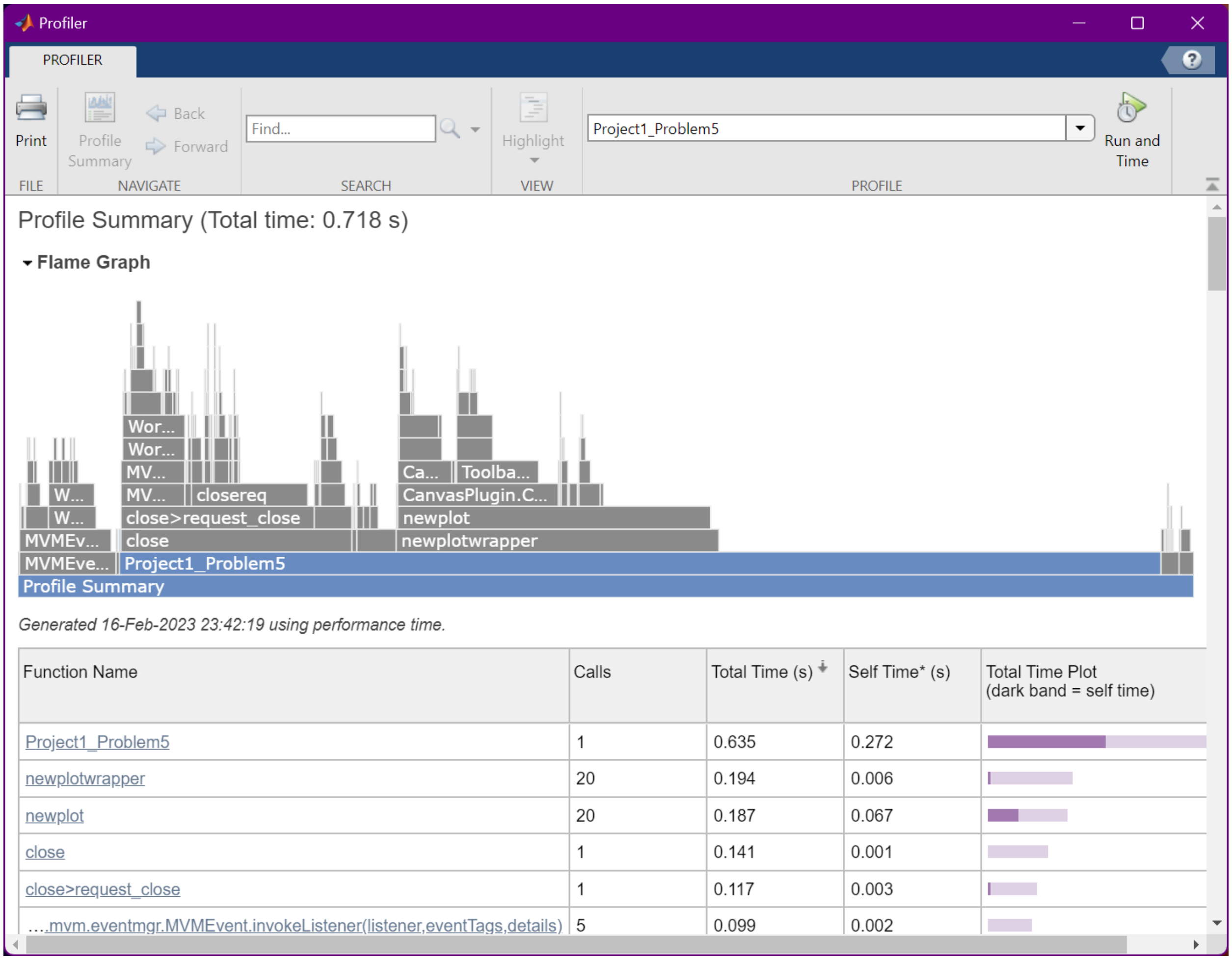
MATLAB Script:

```
close all;
clear all;
clc;

%All Resistor and Capacitor Declarations
R1 = 110;
R2 = 120;
C1 = 10^-6;
C2 = 10^-6;

%Count of graphs being produced.
num = 20;

QX = [R1 R2 C1 C2];

b = [1;0;0];
r = [1 2 3 4 5 6 7 8 9];
w = [r,(10*r),(1e2*r),(1e3*r),(1e4*r),(1e5*r)];
freq = (w/(2*pi));

for s = 1:num
 Q = variation(QX);
   % This function produces random variables of the element values, which are
 within 20% of the nominal ones.

 G = zeros(3,3); C = zeros(3,3);
   %This line saves us some time, since we now need to enter only the nonzero
 elements in G and C.

   G(1,1) = 1;
   G(2,1) = -1/Q(1);
   G(2,2) = 1/Q(1);
   G(2,3) = -1/Q(2);
   G(3,2) = -1/Q(2);
   G(3,3) = 1/Q(2);

   C(2,2) = Q(3);
   C(3,3) = Q(4);
   %For each new set of elements values, matrices G, C and L must be
 recomputed.

   mag = zeros(3,1);
   %vector mag is initialized

   for k = 1: length(w)
    omega = w(k);
       % omega is the next frequency

       A = G+i*omega* C;
       x = A\b;
       %Vector X contains the solution of the node voltage equation in complex
 form
```

MATLAB Simulation Result:



<u>MATLAB Run-time Results</u>:



Problem 6:

Measured Resistor and Capacitor Values:

R1: .109k

R2: .119k

C1: 96.3nF

C2: 1.035µF

Measured Results from Assembled Circuit:

#	Frequency	Amplitude	Gain (dB)	Phase (°)
1	500	1	-1.87	-36.73
2	596.6	1	-2.45	-41.72
3	711.8	1	-3.17	-46.98
4	849.3	1	-4.03	-52.08
5	1013.4	1	-4.98	-57.1
6	1209.1	1	-6.08	-61.96
7	1442.7	1	-7.27	-66.48
8	1721.4	1	-8.57	-70.65
9	2053.9	1	-9.91	-74.5
10	2450.6	1	-11.3	-78.01
11	2924	1	-12.72	-81.28
12	3488.8	1	-14.19	-84.36
13	4162.8	1	-15.68	-87.3
14	4966.9	1	-17.19	-90.21
15	5926.3	1	-18.71	-93.13
16	7071.1	1	-20.3	-96.17
17	8437	1	-21.9	-99.33
18	10066.7	1	-23.53	-102.7
19	12011.2	1	-25.2	-106.35
20	14331.4	1	-26.96	-110.35
21	17099.8	1	-28.82	-114.62
22	20402.9	1	-30.73	-119.23
23	24344	1	-32.73	-124.04
24	29046.4	1	-34.87	-129.03
25	34657.2	1	-37.16	-133.96
26	41351.9	1	-39.55	-138.83
27	49339.6	1	-42.16	-143.57
28	58870.4	1	-44.83	-147.74
29	70242.2	1	-47.57	-151.65
30	83810.6	1	-50.46	-155.54
31	100000	1	-53.42	-159.14
32	119316.6	1	-56.53	-162.48
33	142364.6	1	-59.73	-166.58
34	169864.6	1	-62.98	187.67
35	202676.8	1	-66.32	180.56
36	241827.1	1	-69.68	167
37	288540	1	-72.34	148.68
38	344276.2	1	-73.78	120.16
39	410778.8	1	-72.31	101.21
40	490127.4	1	-70.5	92.4
41	584803.5	1	-68.92	82.27
42	697767.9	1	-67.06	82.89
43	832553.2	1	-65.25	79.9
44	993374.5	1	-63.66	79.41
45	1185261	1	-62.02	78.59
46	1414214	1	-60.95	77.46
47	1687392	1	-59.07	77.43
48	2013339	1	-57.72	73.65
49	2402249	1	-56.25	76.36
50	2866283	1	-54.63	74.01
51	3419952	1	-52.96	73.54
52	4080572	1	-51.31	70.85
53	4868801	1	-49.73	65.37
54	5809289	1	-47.99	61.77
55	6931448	1	-46.12	58.33
56	8270371	1	-44.12	52.19
57	9867929	1	-41.75	45.67
58	11774080	1	-38.91	37.92
59	14048437	1	-35.42	28.25
60	16762122	1	-30.12	16.03
61	20000000	1	-19.92	-1.32

MATLAB Script:

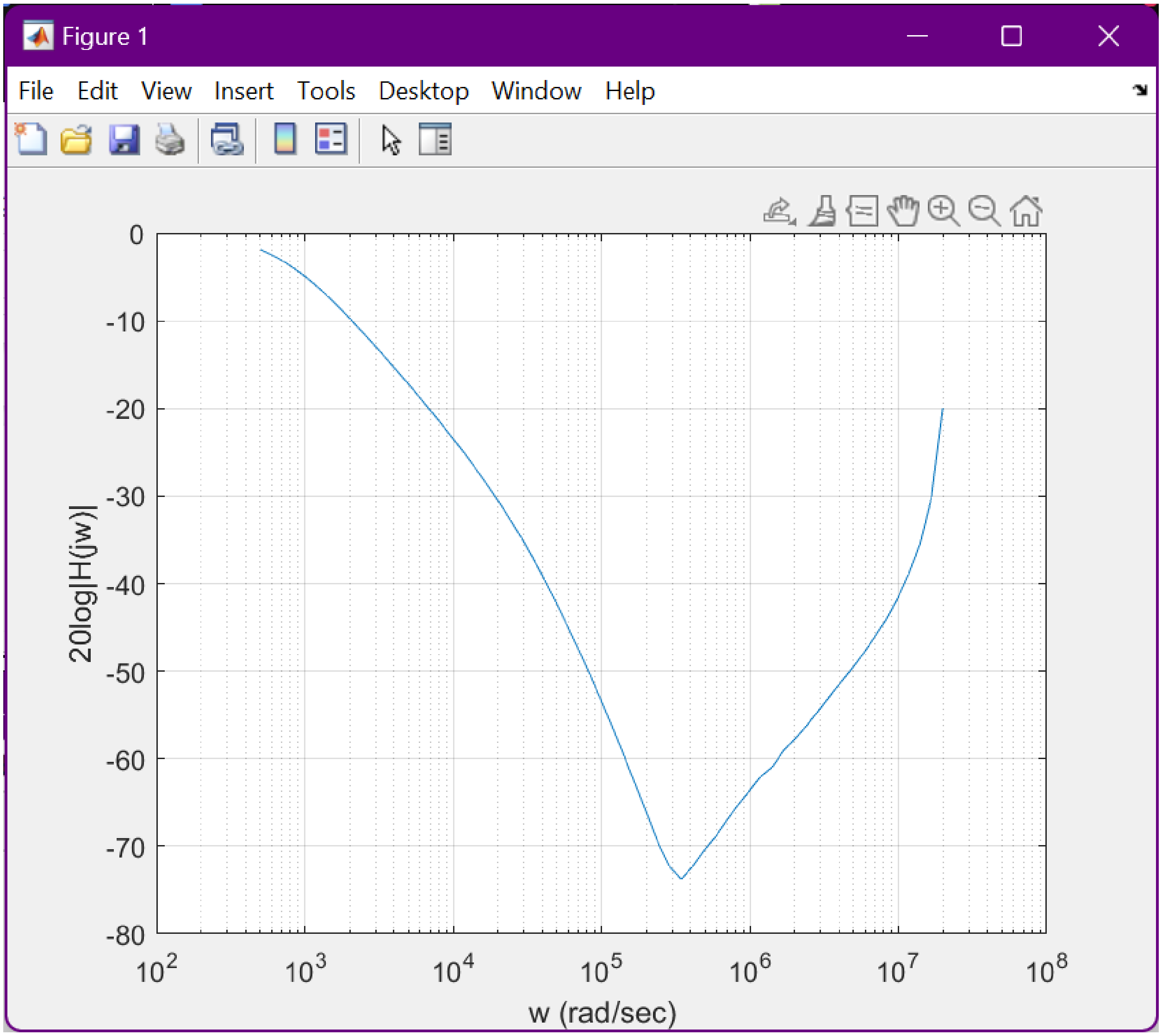
Set up the Import Options and import the data

```
opts = delimitedTextImportOptions("NumVariables", 5);

% Specify range and delimiter
opts.DataLines = [2, Inf];
opts.Delimiter = ",";

% Specify column names and types
opts.VariableNames =
 ["VarName1", "FrequencyHz", "AmplitudeVpp", "GaindB", "Phase"];
opts.VariableTypes = ["double", "double", "double", "double", "double"];

% Specify file level properties
opts.ExtraColumnsRule = "ignore";
opts.EmptyLineRule = "read";

% Import the data
MeasuredResults = readtable("C:\Users\purin\Documents\SCU\2022-2023\ELEN
 100\ELEN 100 Lab\ELEN 100 Project 1 Deliverables\Measured Results.csv",
 opts);
```

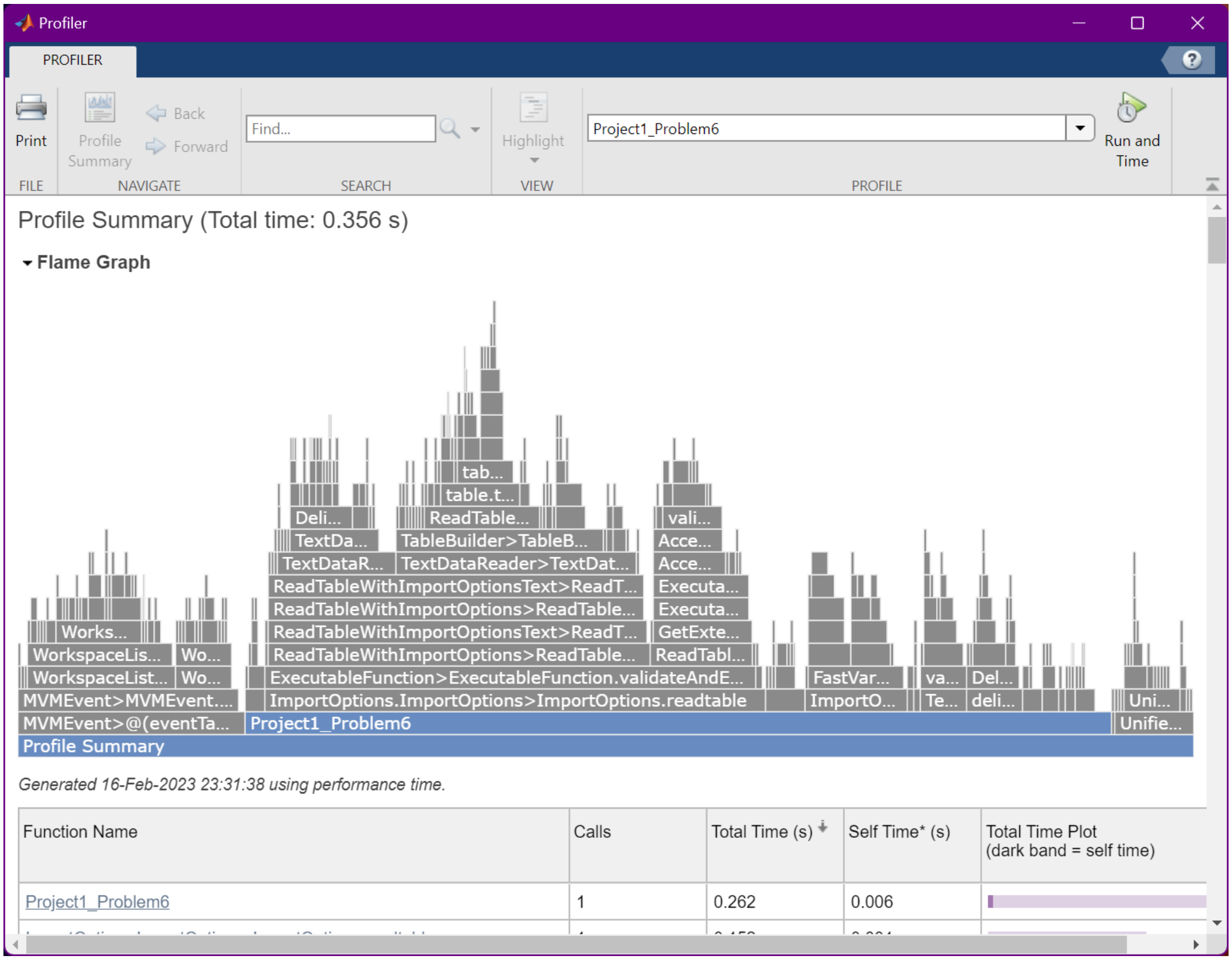
Clear temporary variables

```
clear opts

x = MeasuredResults.FrequencyHz;
y = MeasuredResults.GaindB;

semilogx(x,y)
grid
ylabel('20log|H(jw)|');
xlabel('w (rad/sec)');
```

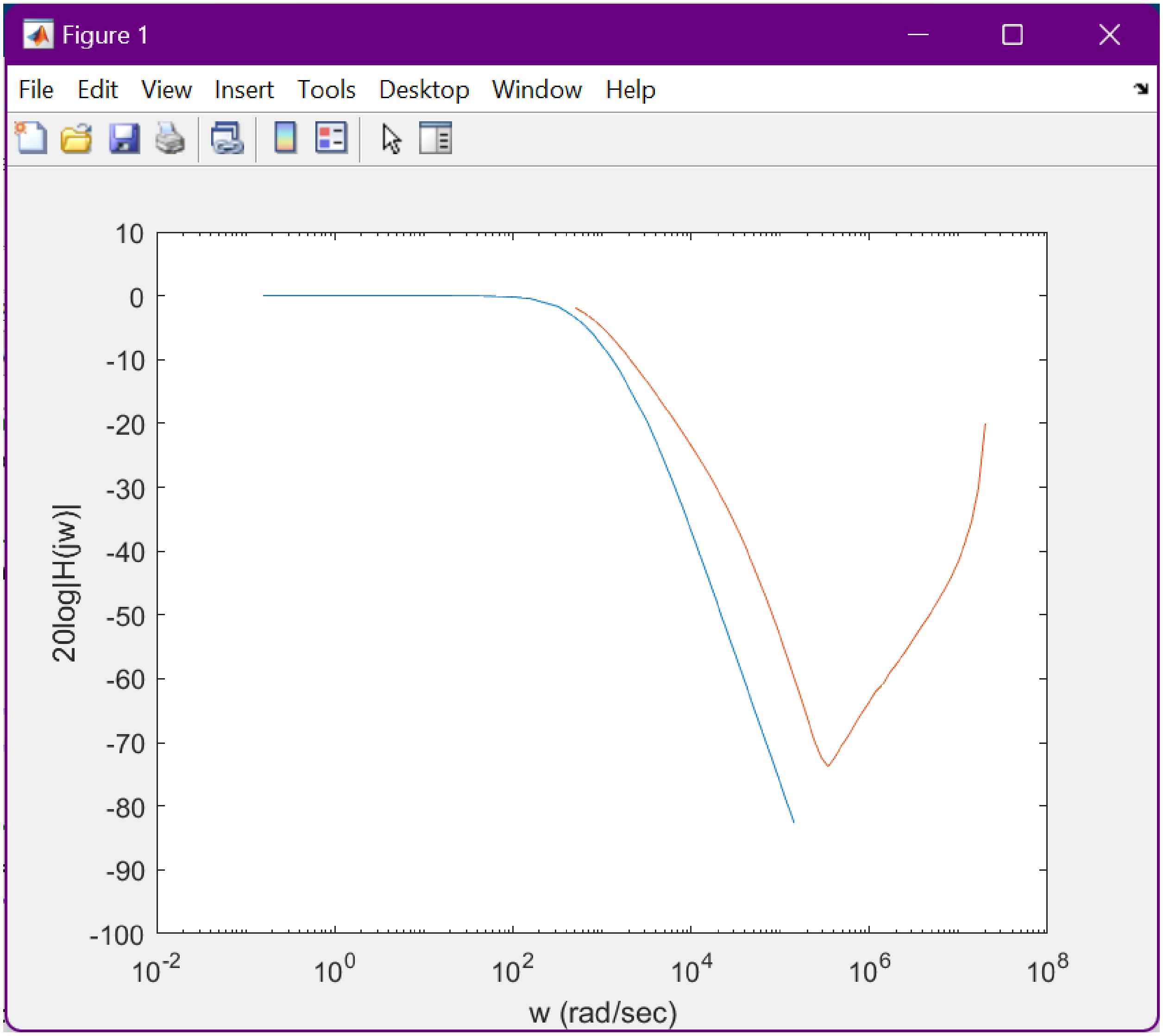
MATLAB Simulation Result:



MATLAB Run-time Results:



MATLAB Simulation Compared to Problem 3:



MATLAB Simulation Compared to Problem 5: