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Part 1 & 2: Pa9 and Transient Circuit Simulation

The goal of this assignment is to use nodal analysis techniques to analyse circuits. In Part 1 we are given a circuit to simulate that contains resistors, inductors, capacitors, voltage sources and current sources. To effectively model these components the KCL equations were written for the 5 voltage nodes and an 8x8 matrix for the real and imaginary values of the components was created. (G & C matrices)

The first set of testing conditions were a DC voltage sweep from -10V to 10V while recording the circuit gain. An AC frequency sweep of 0 to 50Hz, with random pertubations on the Capacitance while recording the circuit gain.

The next set of testing conditions was to perform transient analysis on the circuit which involved applying three distinct input signals to the circuit and monitoring the frequency and time domain response of the circuit. The three signals were:

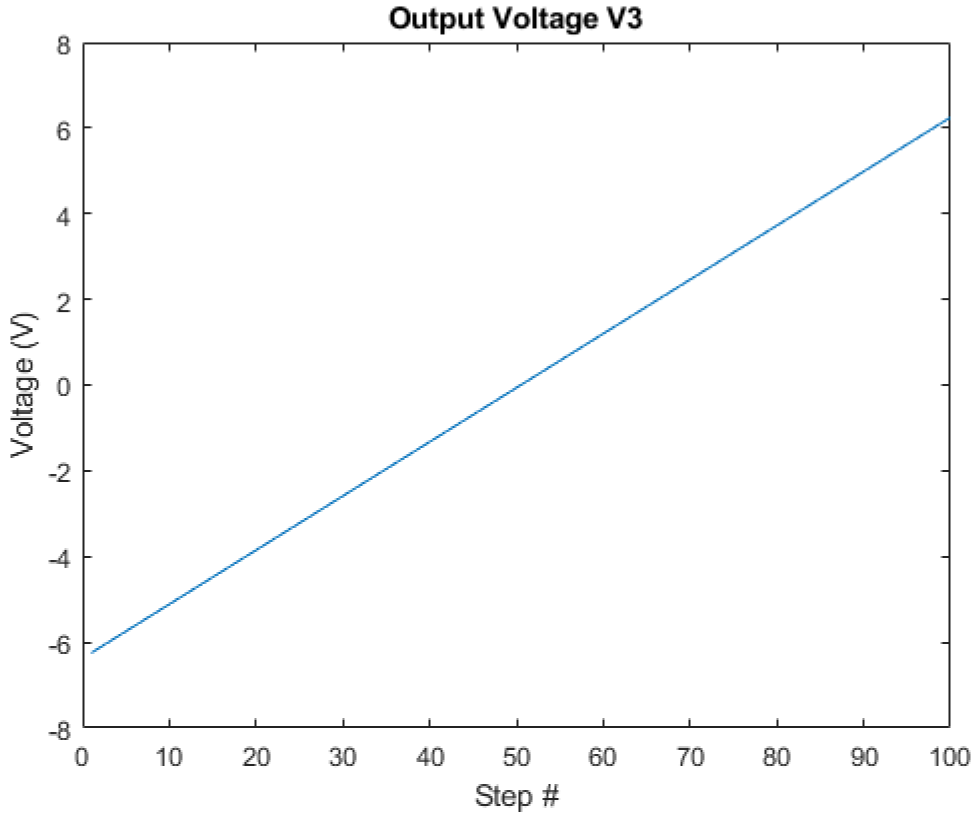
1. A step that transistions from 0 to 1 at 0.03s. 2. A sin(2pif t) function with f = 1/(0.03) 1/s 3. A guassian pulse with a magnitude of 1, std dev. of 0.03s and a delay of 0.06s

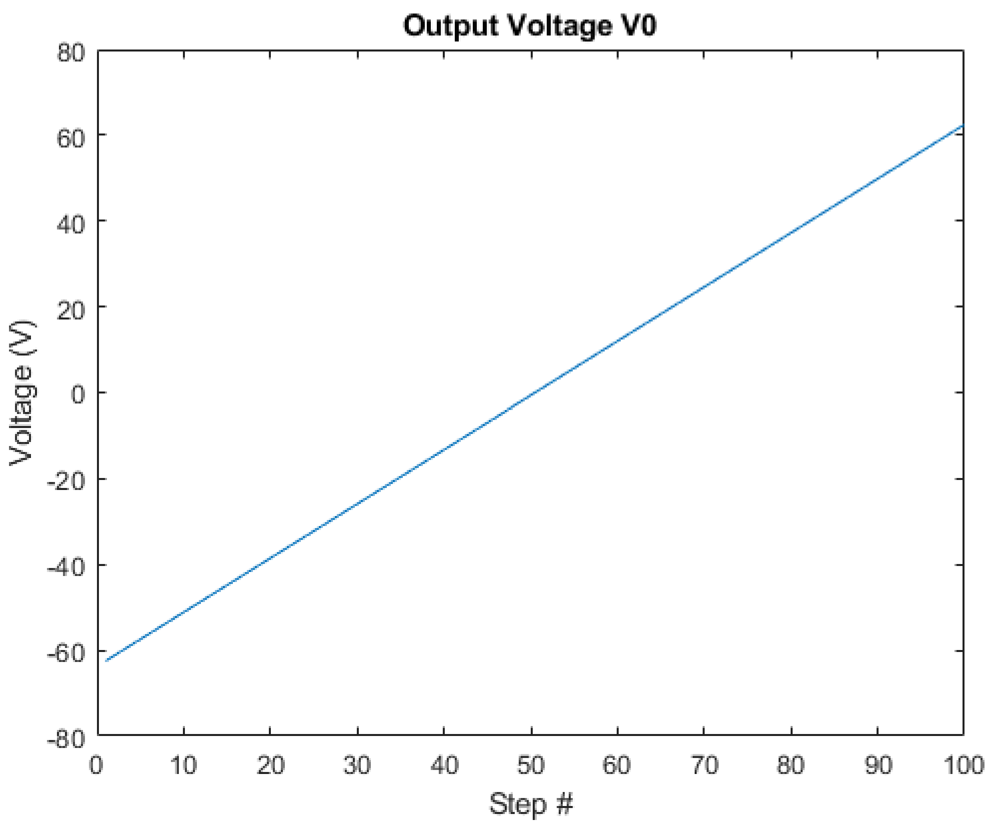
The results displayed in this section are: C and G matrices, Plot of DC sweep, Plots from AC case of gain (Vout/Vin), Plot of Vin and Vout from numerical solution in time domain, Fourier Transform plots of Frequency response

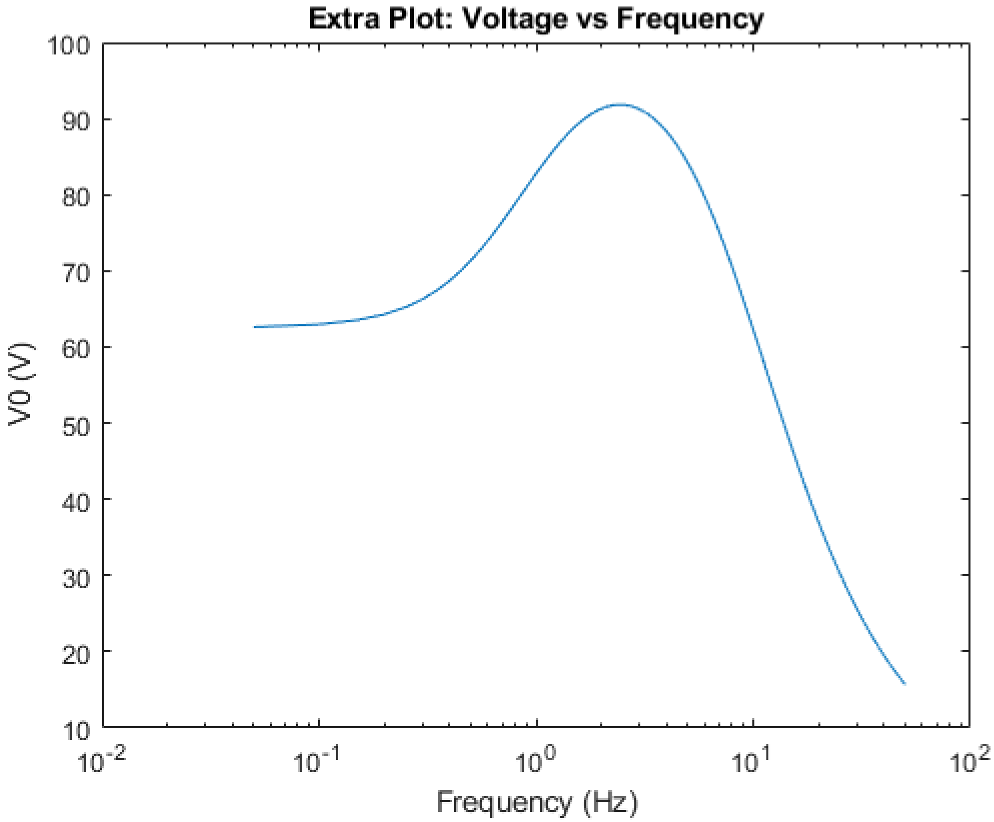
```
close all
clear all
Part1F()
Part2T()
```

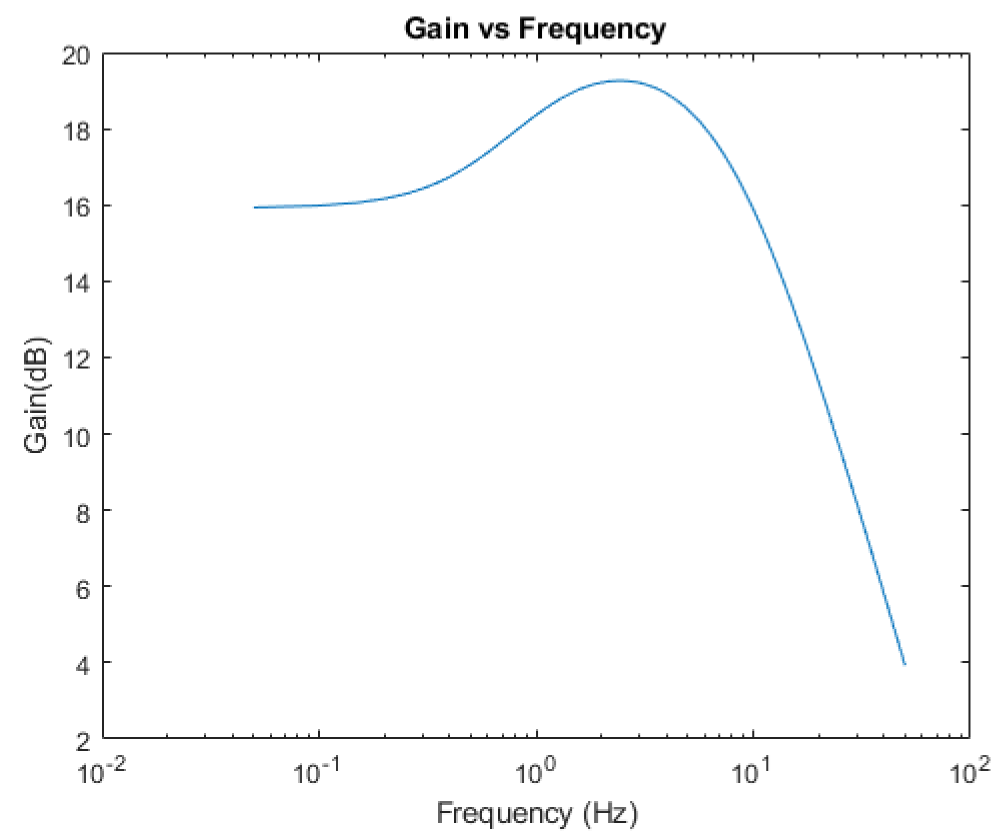
```

C =

  Columns 1 through 7

    0.2500   -0.2500         0         0         0         0         0
   -0.2500    0.2500         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0   -0.2000
         0         0         0         0         0         0         0

  Column 8

         0
         0
```

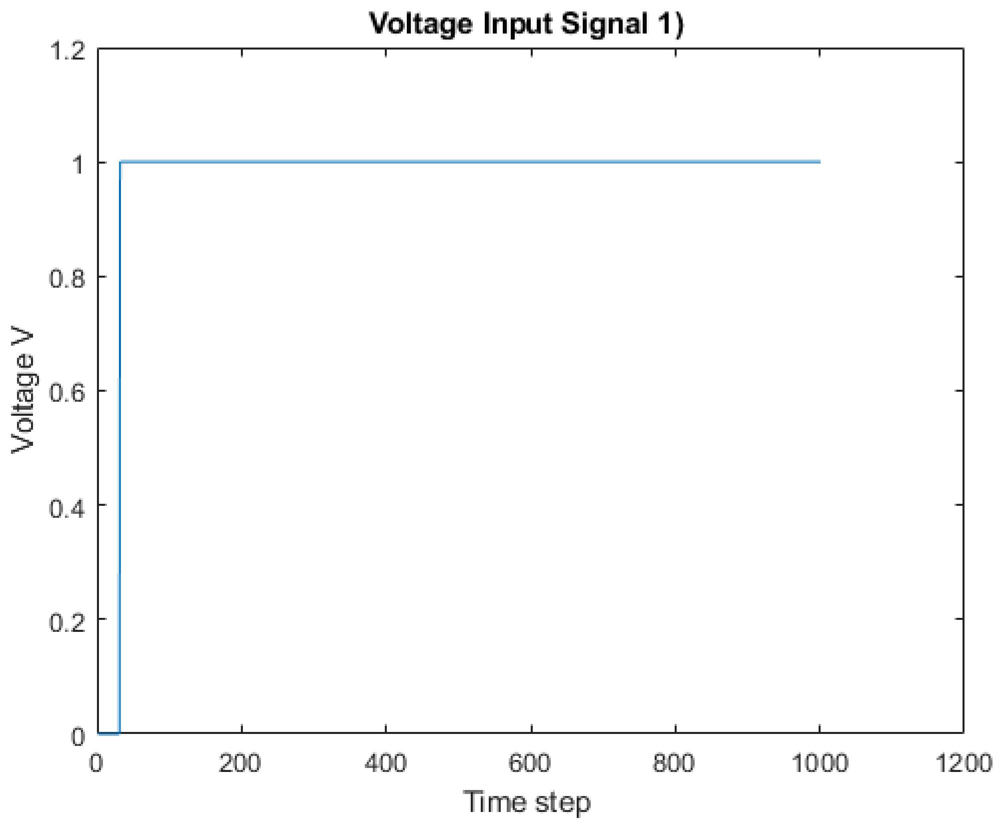
```
         0
         0
         0
         0
         0
         0


G =

  Columns 1 through 7

    1.0000   -1.0000         0         0         0    1.0000         0
   -1.0000    1.5000         0         0         0         0    1.0000
         0         0    0.1000         0         0         0   -1.0000
         0         0         0   10.0000  -10.0000         0         0
         0         0         0   10.0000   10.0010         0         0
    1.0000         0         0         0         0         0         0
         0    1.0000   -1.0000         0         0         0         0
         0         0  -10.0000    1.0000         0         0         0

  Column 8

         0
         0
         0
    1.0000
         0
         0
         0
         0
```

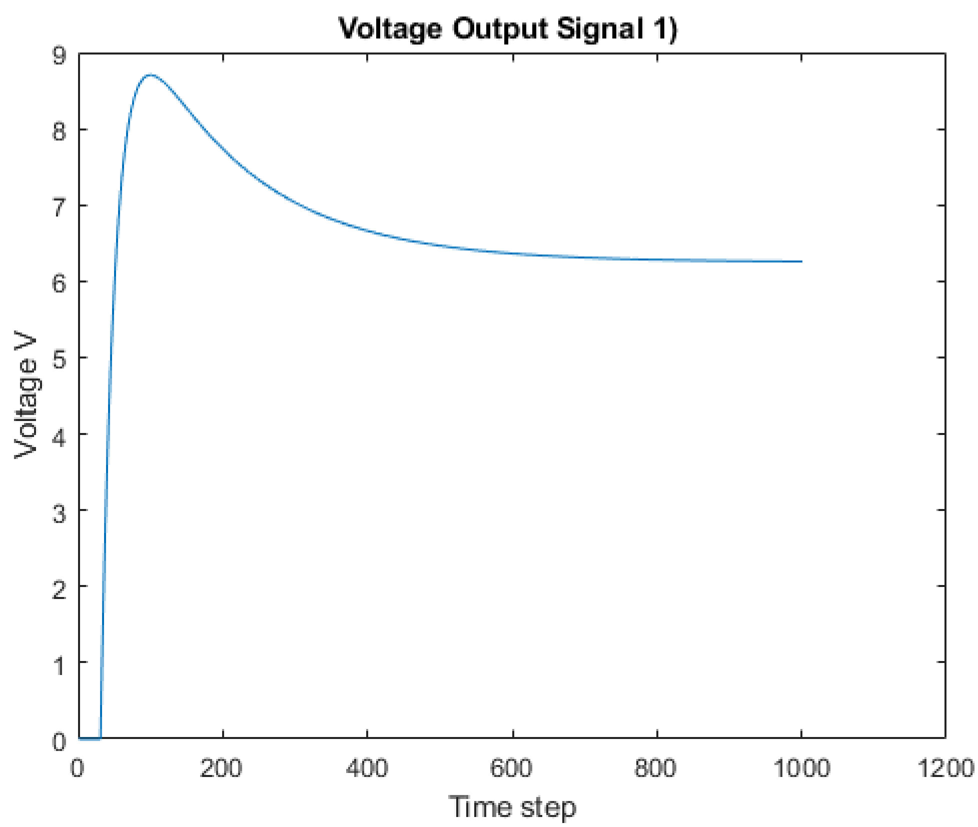

Output Voltage V3
Voltage (V)
Step #
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
70
80
90
100

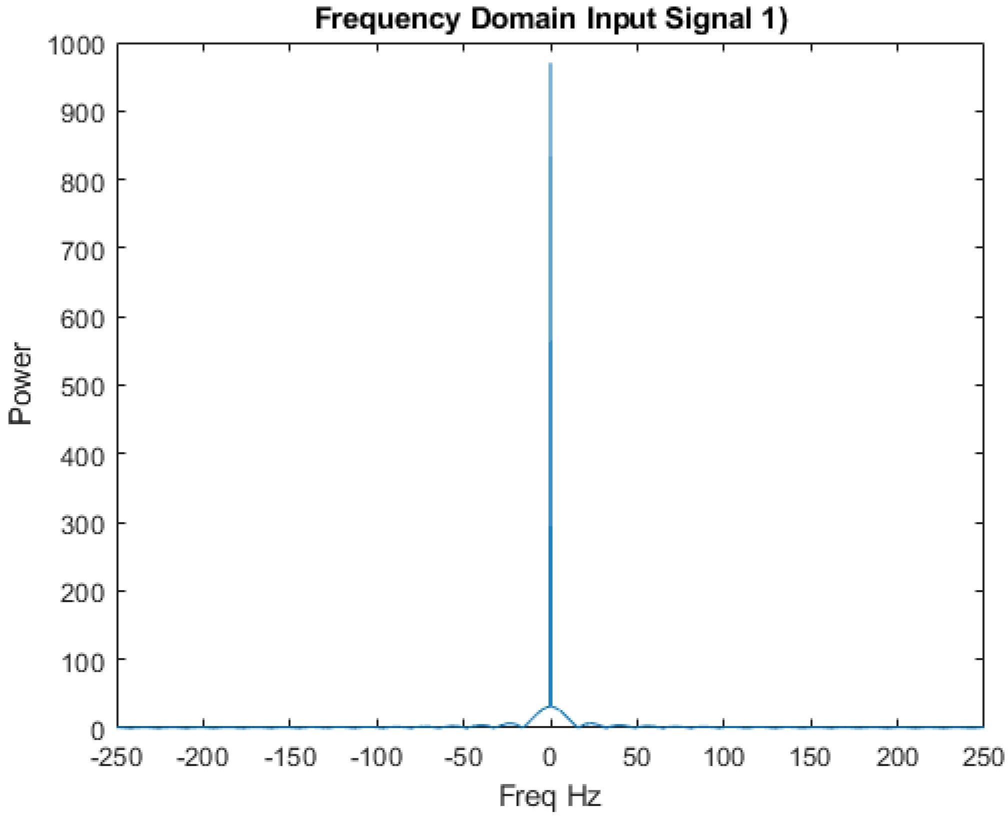

Output Voltage V0
Voltage (V)
Step #
80
60
40
20
0
-20
-40
-60
-80
0
10
20
30
40
50
60
70
80
90
100

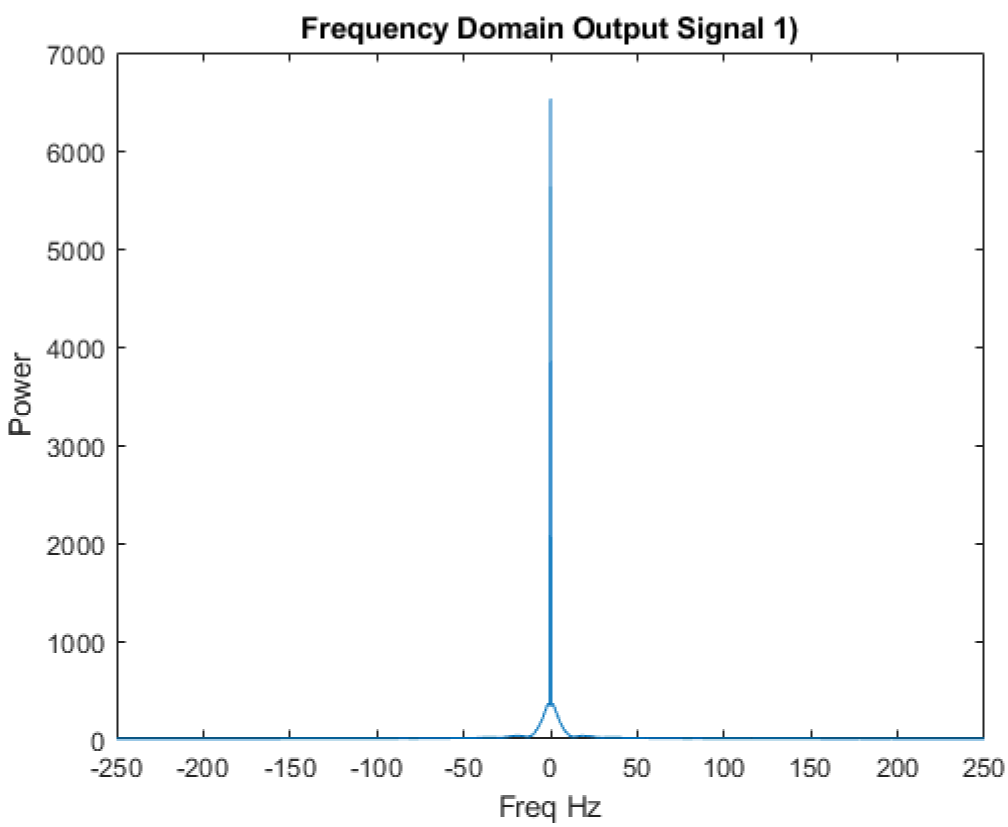

Extra Plot: Voltage vs Frequency
V0 (V)
Frequency (Hz)
100
90
80
70
60
50
40
30
20
10
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

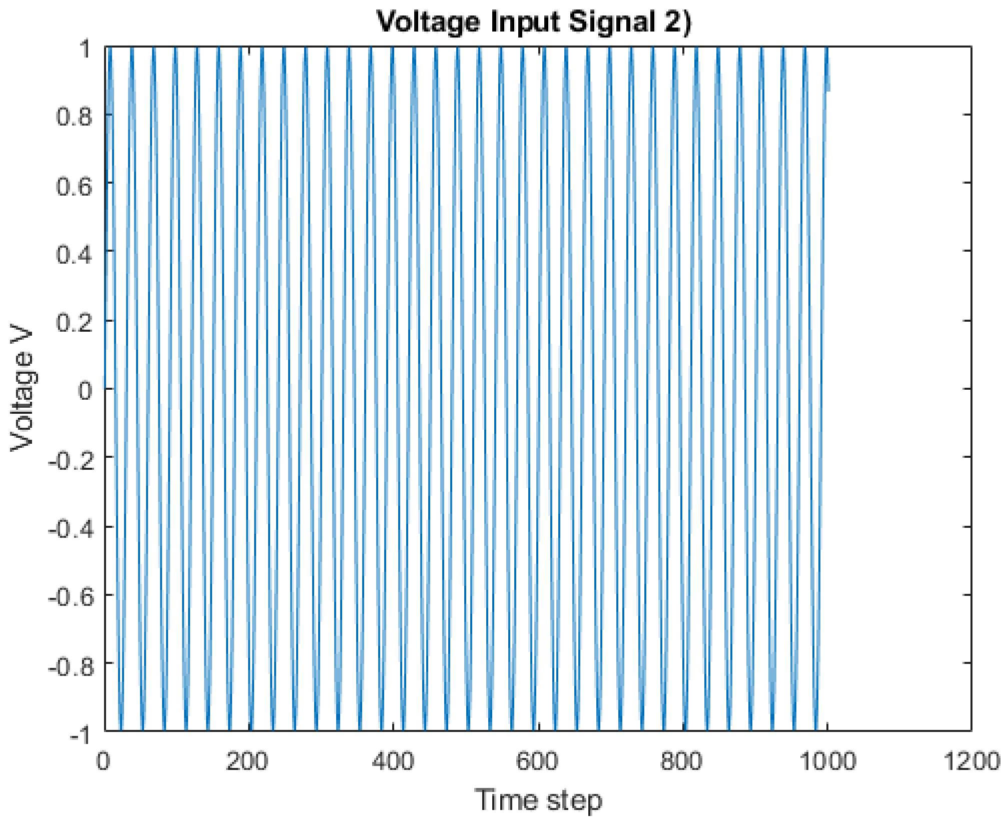

Gain vs Frequency
Gain(dB)
Frequency (Hz)
20
18
16
14
12
10
8
6
4
2
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

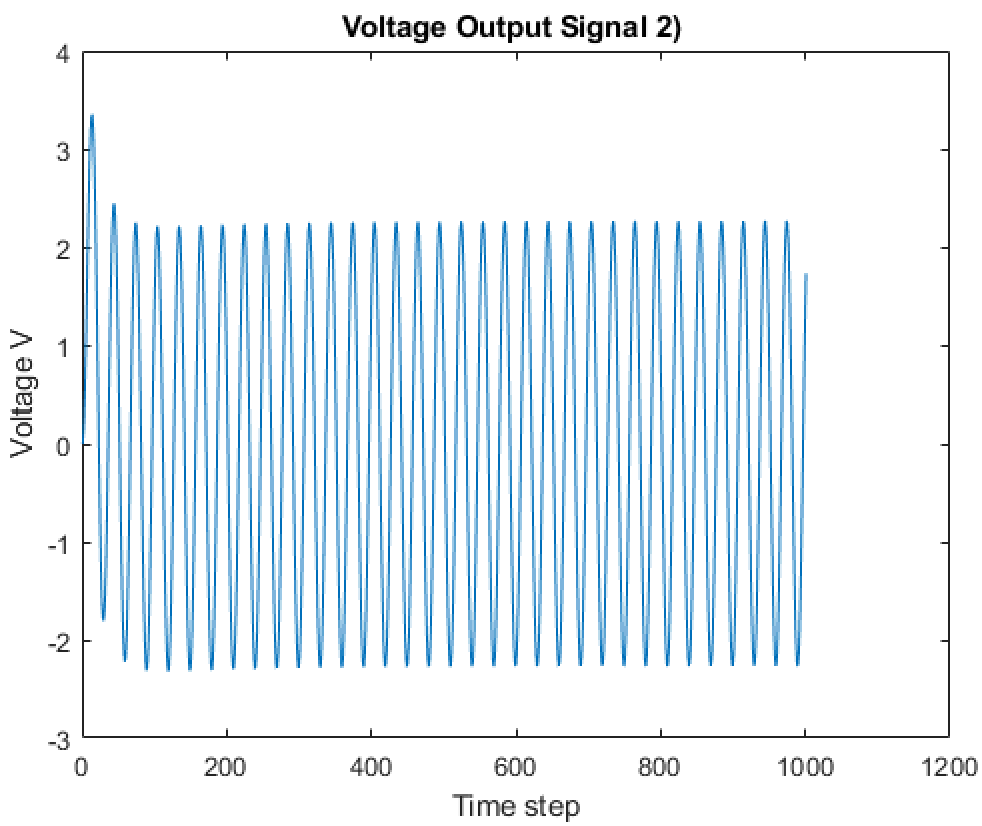

Voltage Input Signal 1)
Voltage V
Time step
0
0.2
0.4
0.6
0.8
1
1.2
0
200
400
600
800
1000
1200

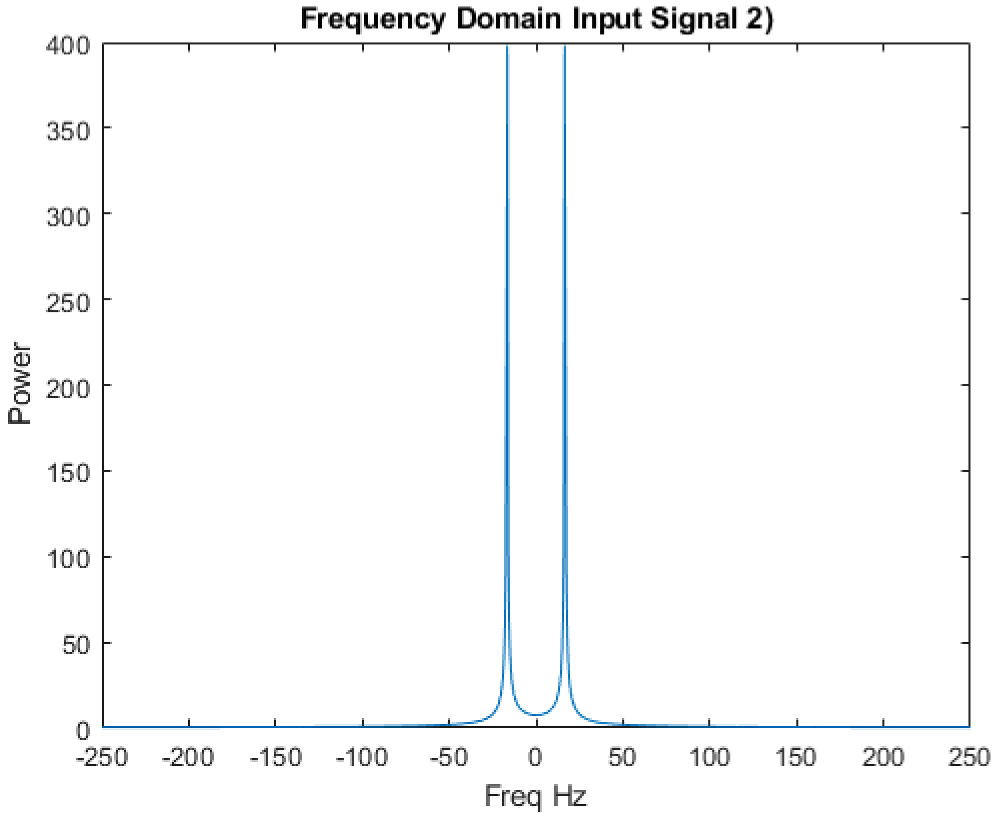

Voltage Output Signal 1)
Voltage V
Time step
0
1
2
3
4
5
6
7
8
9
0
200
400
600
800
1000
1200

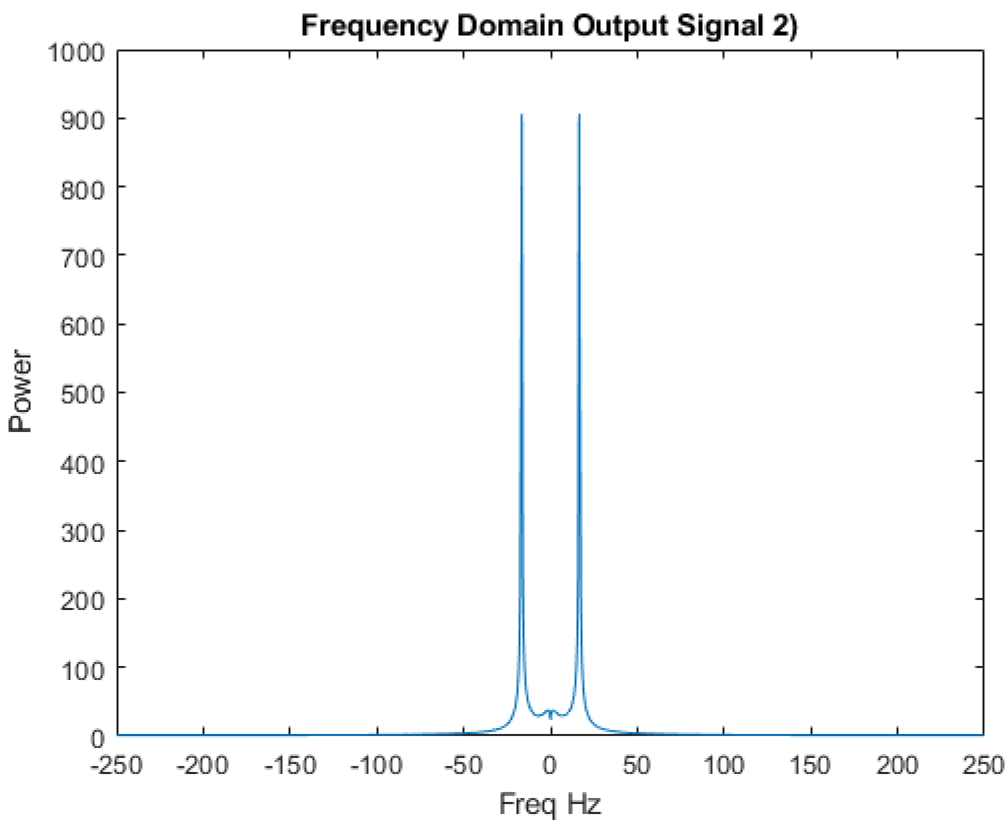

Frequency Domain Input Signal 1)
Power
Freq Hz
1000
900
800
700
600
500
400
300
200
100
0
-250
-200
-150
-100
-50
0
50
100
150
200
250

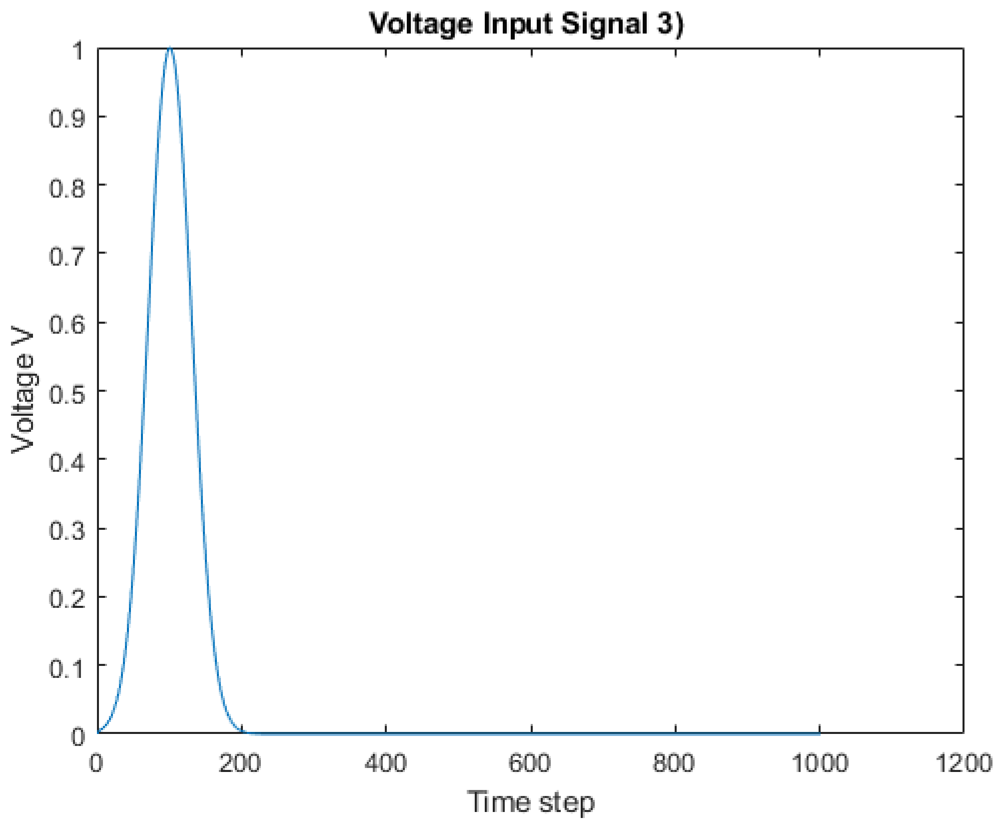

Frequency Domain Output Signal 1)
Power
Freq Hz
7000
6000
5000
4000
3000
2000
1000
0
-250
-200
-150
-100
-50
0
50
100
150
200
250


Voltage Input Signal 2)
Voltage V
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
200
400
600
800
1000
1200
Time step

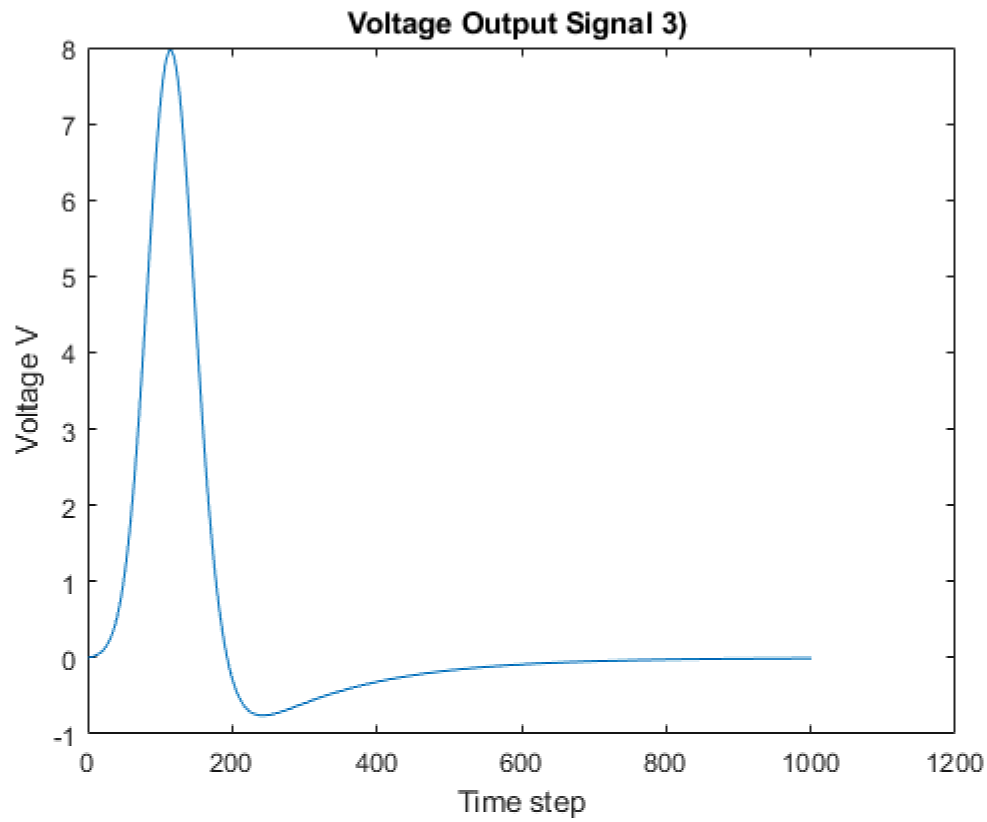

Voltage Output Signal 2)
Voltage V
4
3
2
1
0
-1
-2
-3
0
200
400
600
800
1000
1200
Time step


Frequency Domain Input Signal 2)
Power
Freq Hz
400
350
300
250
200
150
100
50
0
-250
-200
-150
-100
-50
0
50
100
150
200
250

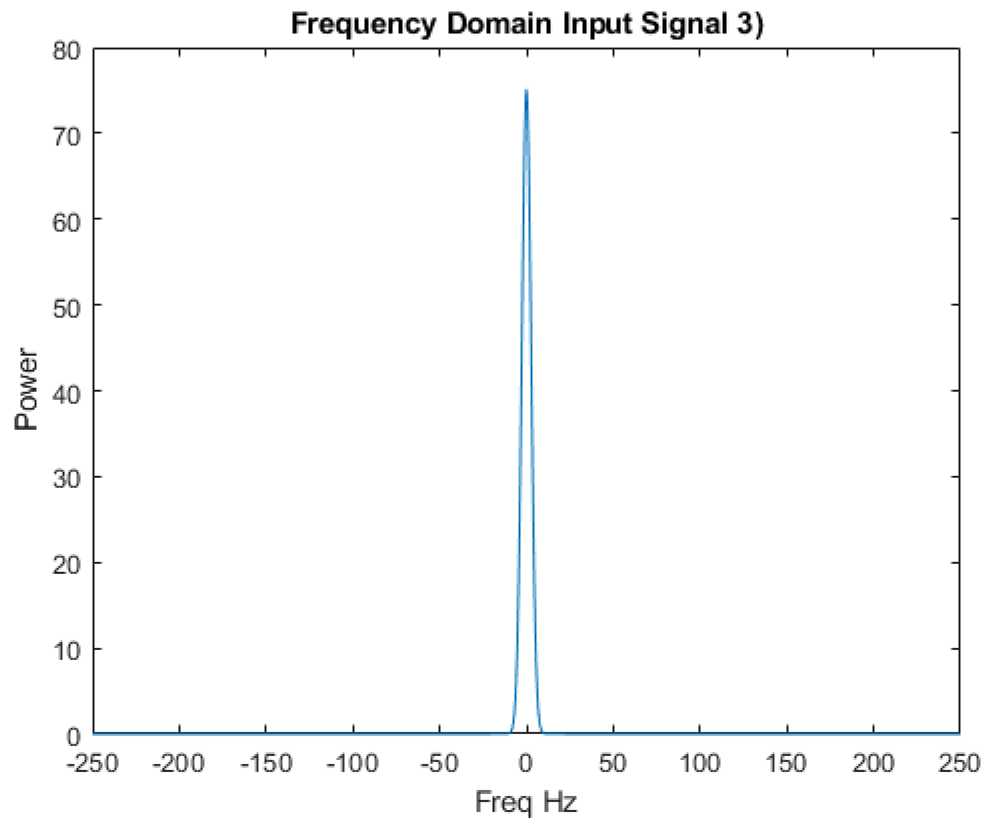

Frequency Domain Output Signal 2)
Power
Freq Hz
1000
900
800
700
600
500
400
300
200
100
0
-250
-200
-150
-100
-50
0
50
100
150
200
250

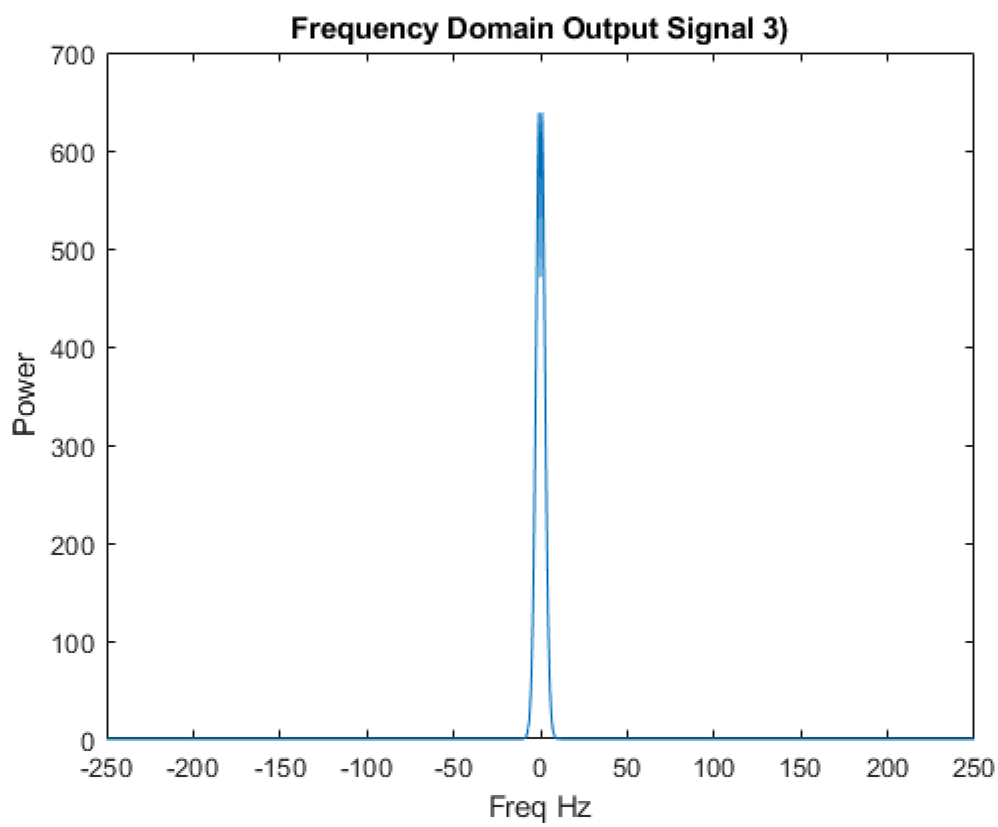


Voltage Input Signal 3)
Voltage V
Time step



Voltage Output Signal 3)
Voltage V
Time step


Frequency Domain Input Signal 3)
Power
Freq Hz
80
70
60
50
40
30
20
10
0
-250
-200
-150
-100
-50
0
50
100
150
200
250


Frequency Domain Output Signal 3)
Power
Freq Hz
700
600
500
400
300
200
100
0
-250
-200
-150
-100
-50
0
50
100
150
200
250

The circuit is linear and this is demonstrated by the DC sweep. We see that the Vout is a linear function of the input voltage Vin.

Inspecting the frequency sweep, the circuit's gain begins to sharply decrease around 10Hz. What this means is that the circuit is operating like a low pass filter. Lower frequencies are allowed to pass but higher frequencies are attenuated.

When we introduced the random perturbations on the capacitance the gain of the circuit is realtively consistent. This is a benefit because if the circuit were to be manufactured there would surely be unexpected parasitic capacitances and manufacturing variations. The fact that the circuit is not overly sensitve is a valuable characteristic of the circuit.

Part 3: Circuit with Noise

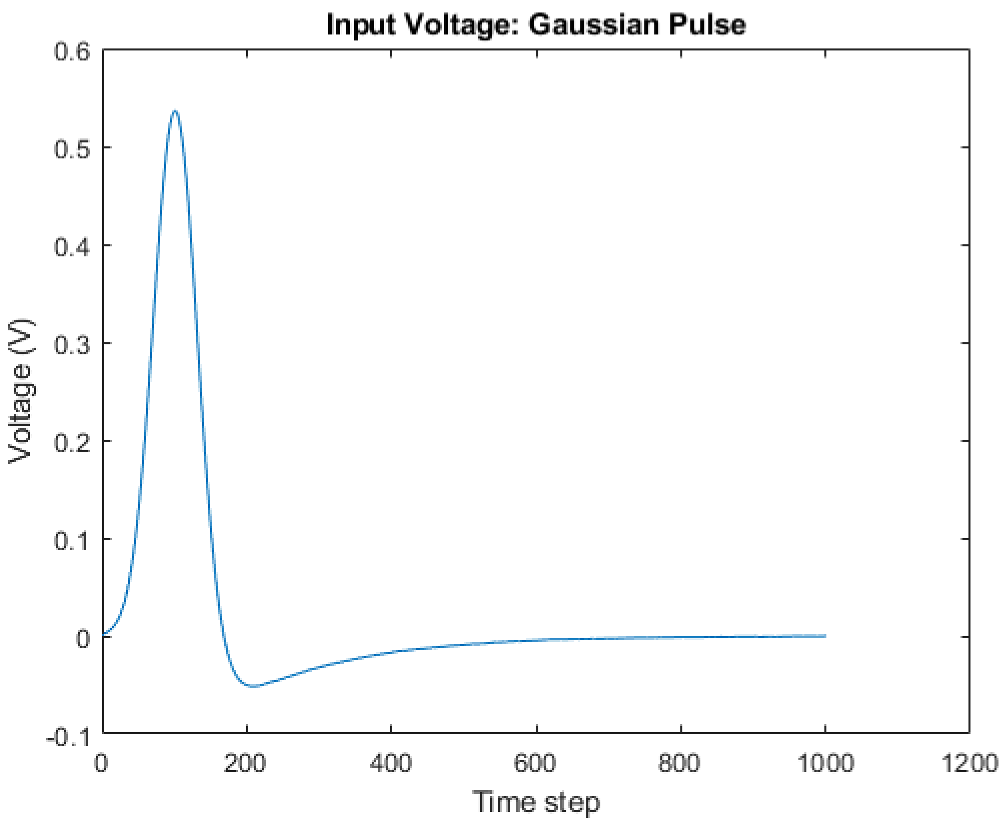
In ths section of the assignment we try to model random thermal noise on a resistor by inserting a current source to inject the noise and a capcitor to limit the bandwidth of the noise. The capacitor value used was as given Cn=0.00001 and the noise distribution was gaussian with a maximum value of 0.001.

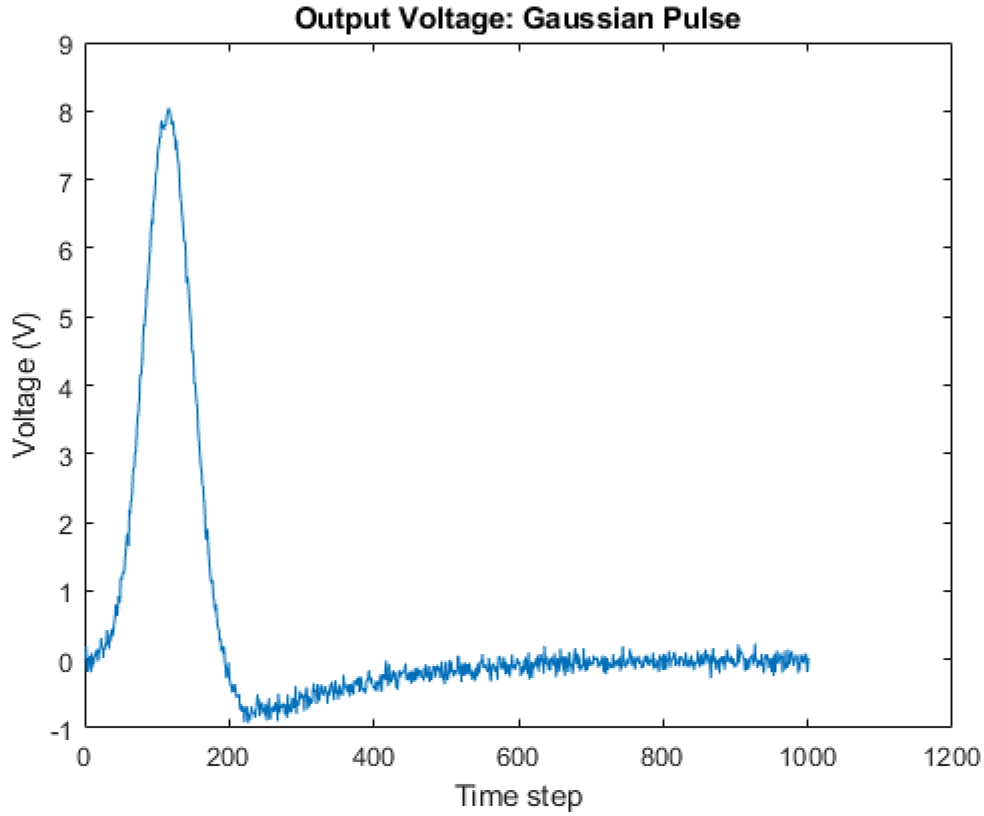
The student performed analysis by recording the output of the circuit in the time and frequncy domain (fft). Then the student varied the value of Cn to observe how the bandwidth of the noise affects the circuits operation. Finally the student varied granularity of the time steps to observe how to it affected circuit operation.

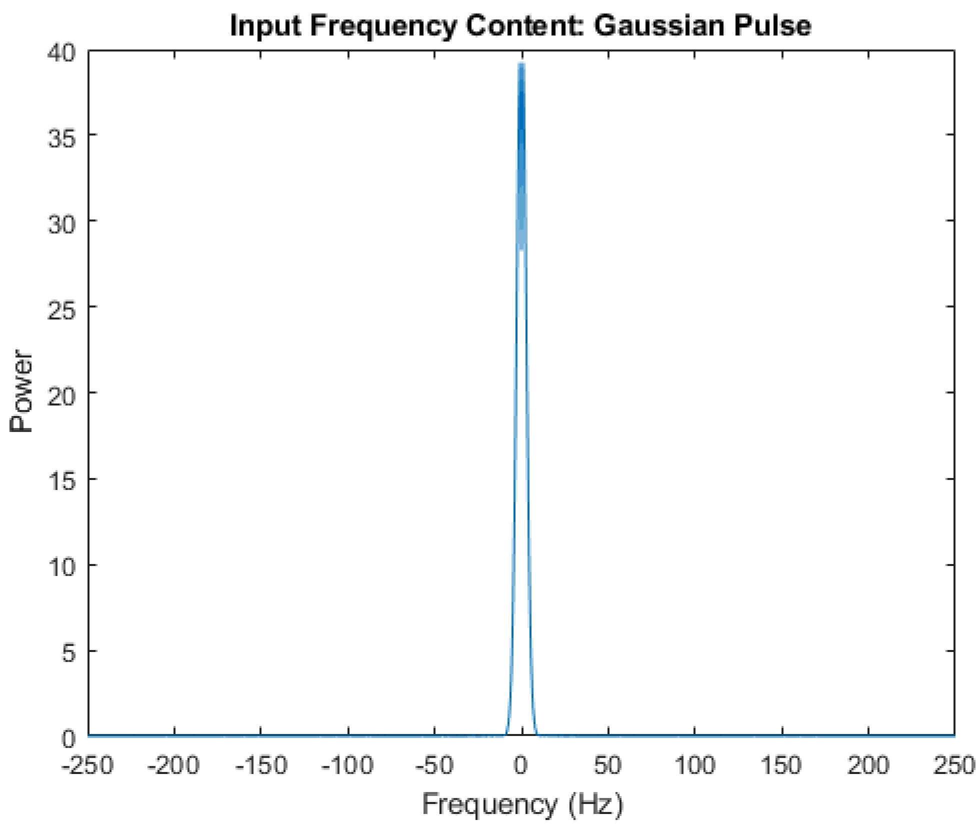
```
Part3a()
Part3b()
```

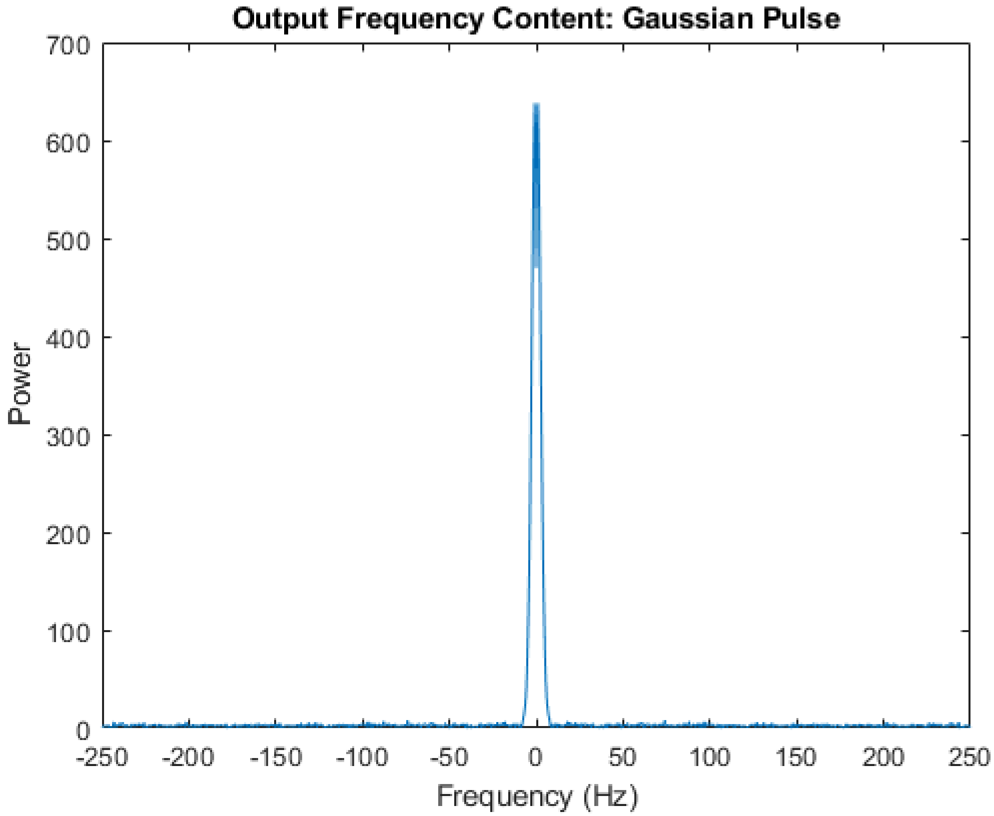
```

G =

  Columns 1 through 7

    1.0000   -1.0000         0         0         0    1.0000         0
   -1.0000    1.5000         0         0         0         0    1.0000
         0         0    0.1000         0         0         0   -1.0000
         0         0         0   10.0000  -10.0000         0         0
         0         0         0   10.0000   10.0010         0         0
    1.0000         0         0         0         0         0         0
         0    1.0000   -1.0000         0         0         0         0
         0         0  -10.0000    1.0000         0         0         0

  Column 8

         0
         0
         0
    1.0000
         0
         0
         0
         0


C =
```

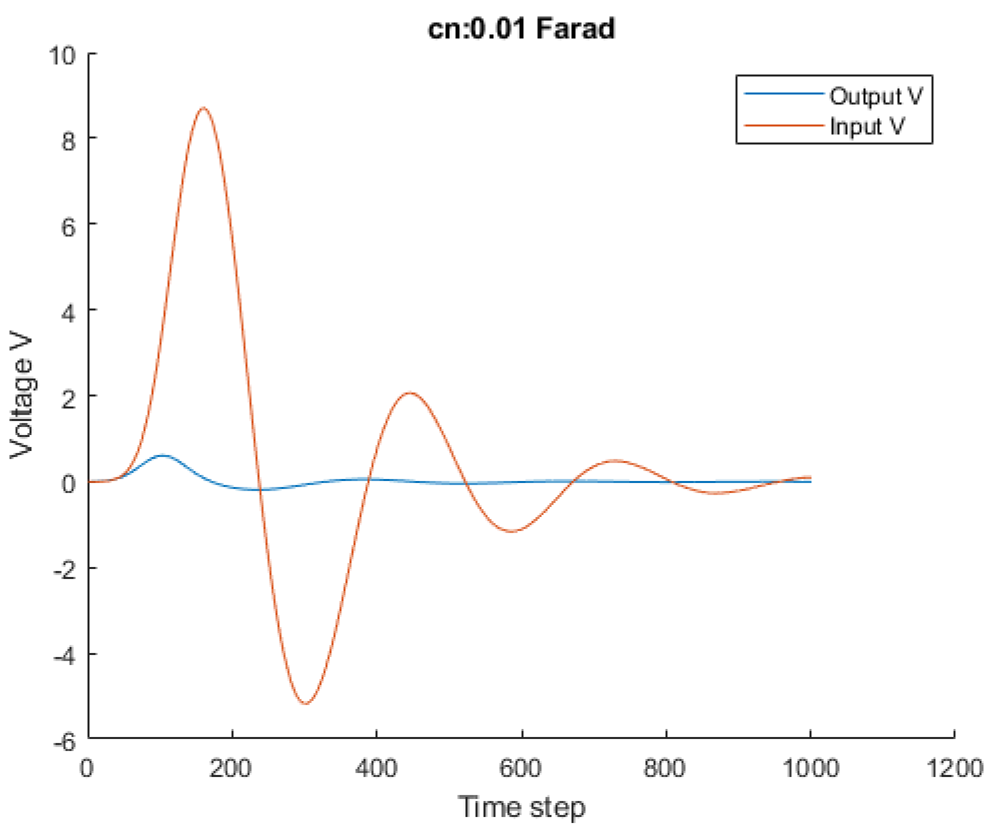
```
Columns 1 through 7

  0.2500   -0.2500         0         0         0         0         0
 -0.2500    0.2500         0         0         0         0         0
       0         0    0.0000         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0   -0.2000
       0         0         0         0         0         0         0

Column 8

       0
       0
       0
       0
       0
       0
       0
       0
```

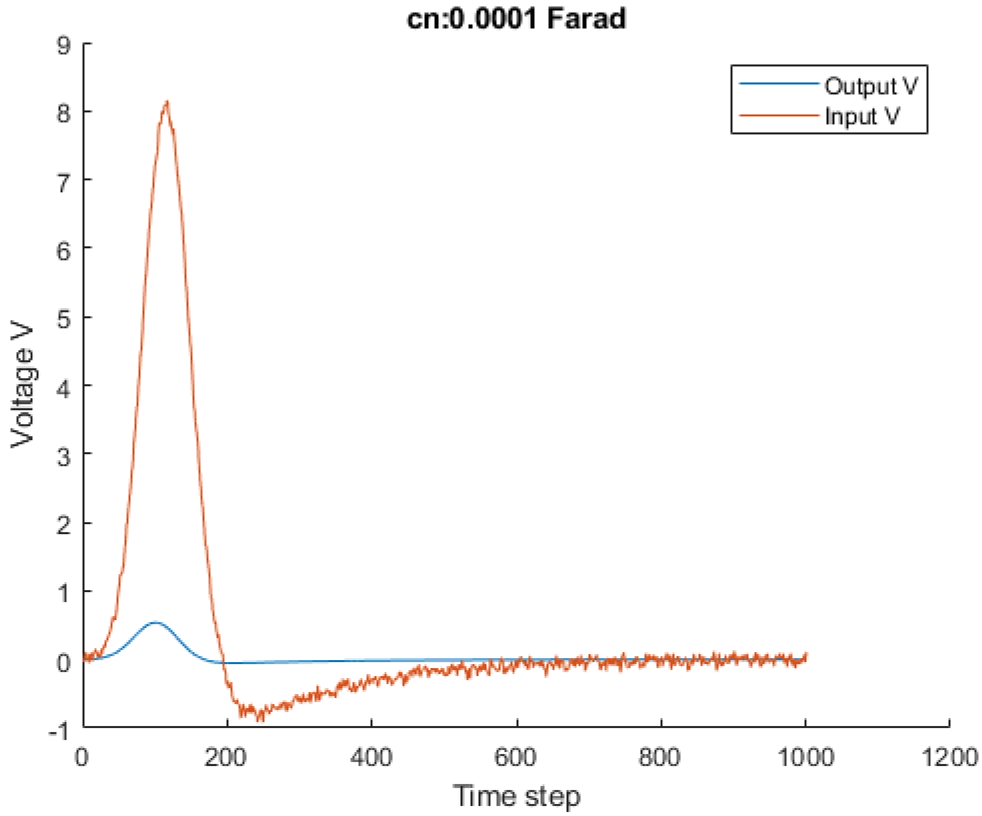


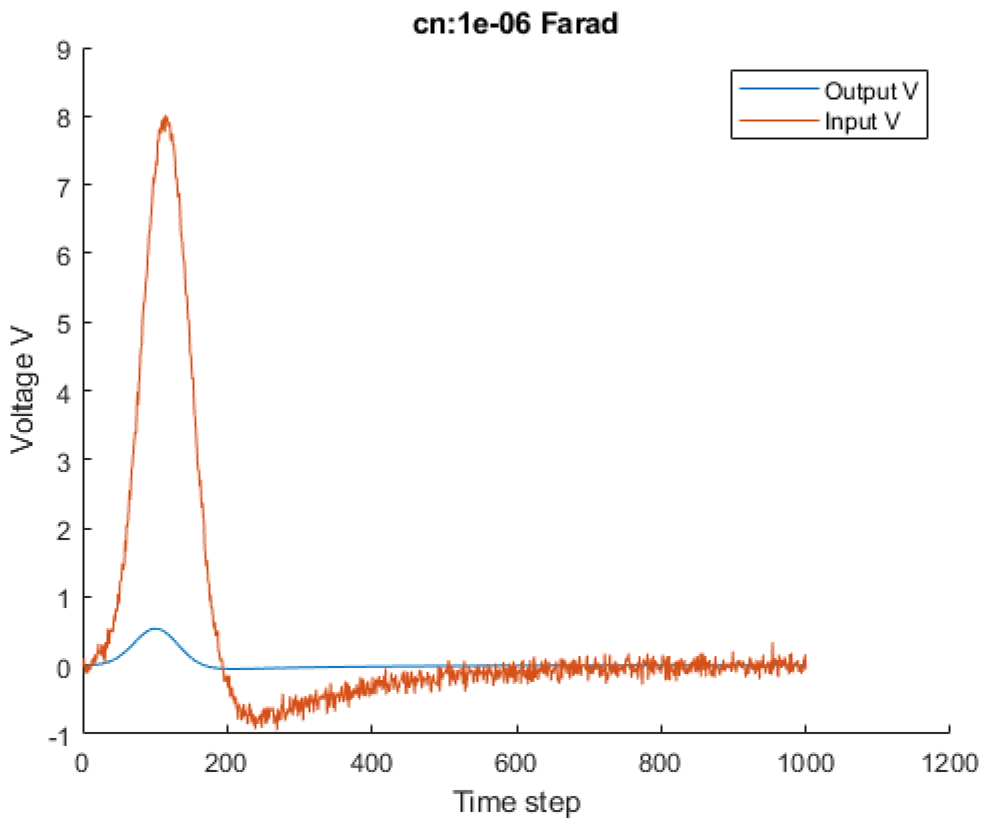

Output Voltage: Gaussian Pulse
Voltage (V)
Time step
9
8
7
6
5
4
3
2
1
0
-1
0
200
400
600
800
1000
1200

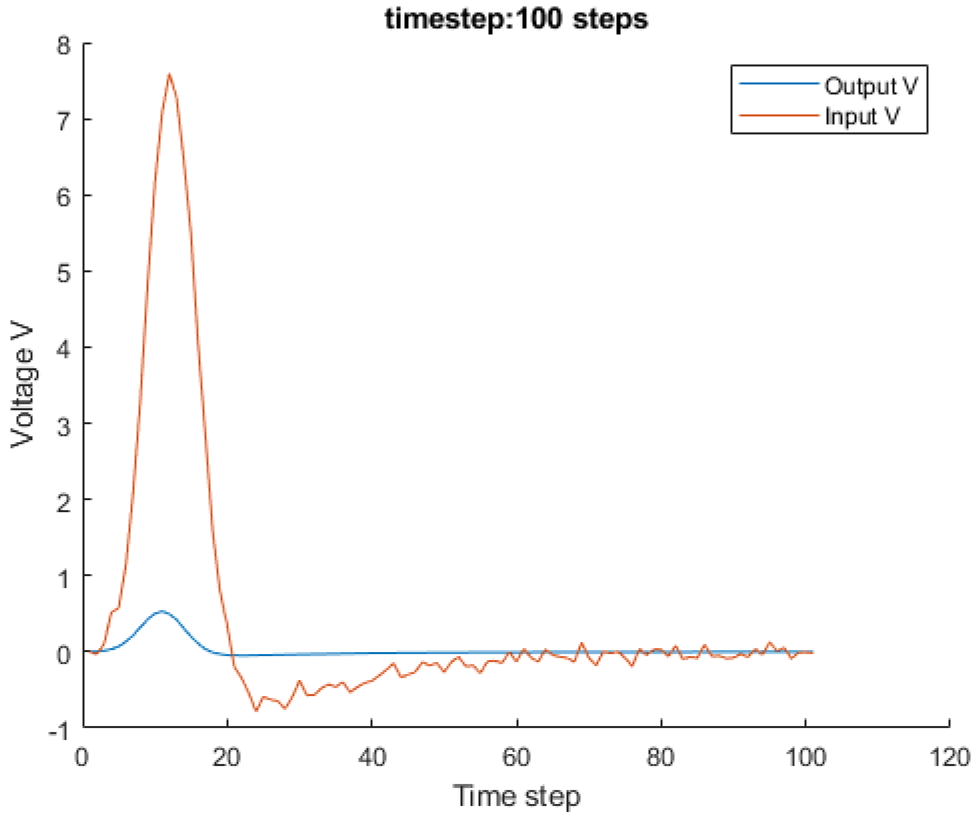

Input Frequency Content: Gaussian Pulse
Power
Frequency (Hz)
40
35
30
25
20
15
10
5
0
-250
-200
-150
-100
-50
0
50
100
150
200
250

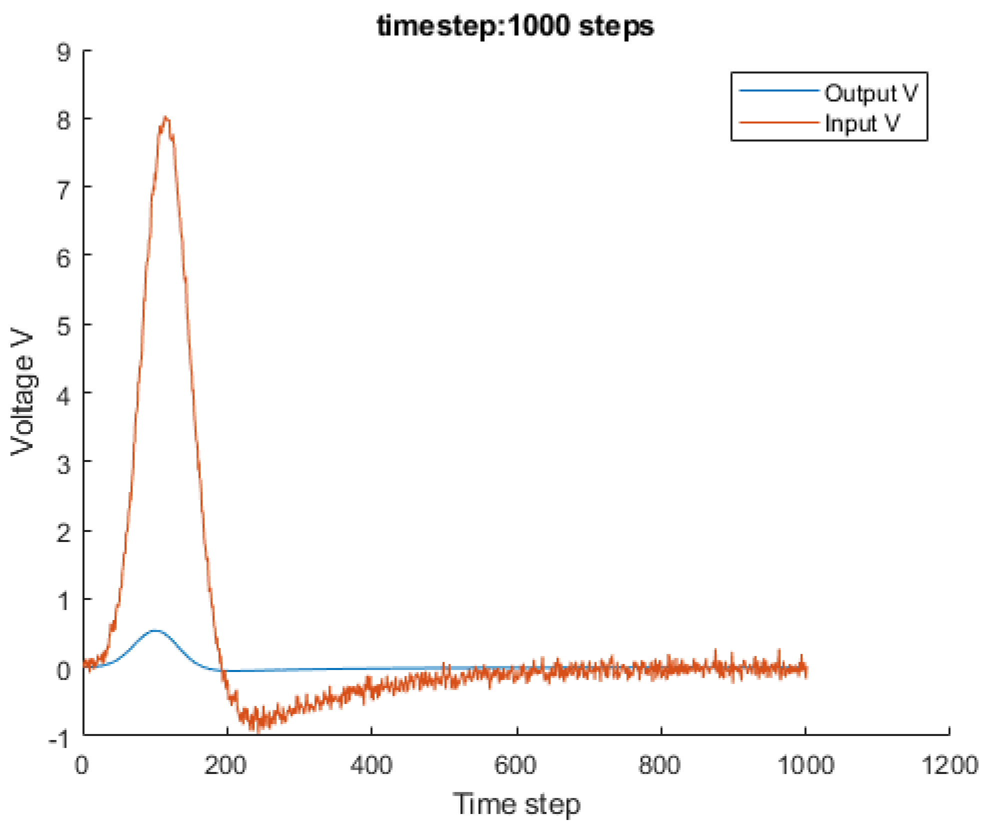

Output Frequency Content: Gaussian Pulse
700
600
500
400
300
200
100
0
Power
-250
-200
-150
-100
-50
0
50
100
150
200
250
Frequency (Hz)

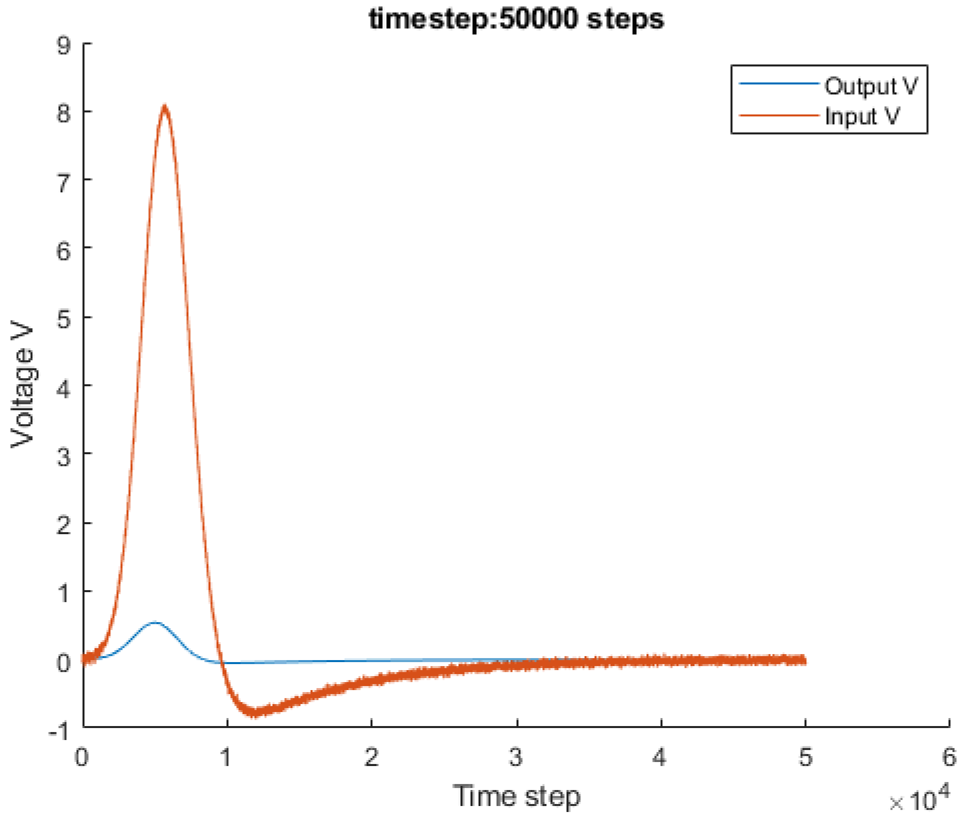

cn:0.01 Farad
Output V
Input V
10
8
6
4
2
0
-2
-4
-6
Voltage V
0
200
400
600
800
1000
1200
Time step


cn:0.0001 Farad
Output V
Input V
Voltage V
Time step


cn:1e-06 Farad
Output V
Input V
Voltage V
Time step


timestep:100 steps
Output V
Input V
Voltage V
Time step
8
7
6
5
4
3
2
1
0
-1
0
20
40
60
80
100
120


timestep:1000 steps
Output V
Input V
Voltage V
Time step
9
8
7
6
5
4
3
2
1
0
-1
0
200
400
600
800
1000
1200



In figure 17 and 18, the noticeable addition of thermal noise can be seen. The effects of varying the Cn capictor were noticeable as increasing the value allowed for larger noise variations on the signal. This makes sense because the capacitor should limit noise bandwidth similarly to how an RC circuit dampens abrupt changes in an electrical system. A larger capacitor rsulted in larger noise variations and smaller capacitor values reduced the noise bandwidth.

As the the granularity of the time steps was increased I saw better resolution of the signal. The noise injected on the signal was easier to see at a smaller time step. Thus for maximum analysis resolution the time step should be small.

Part 4 Non Linearity

Since we now have a non linear circuit response we need to modify our analysis methods. As seen in lecture of week 10 Circuits and MNA we briefly covered some non linear analysis.

Now that we have non linear components we will need to construct the equation from slide 20, week 10.

$$\hat{C}\frac{d\hat{V}}{d\hat{t}} + \hat{G}\hat{V} + \hat{B}(\hat{V}) = \hat{F}(t)$$

The B term will contain the non linear components. Since our equation is non linear we have to find the solution iteratively. We can do this by re-formulating it as a "root" finding problem and use the Newton Raphson Method.

Netwon Raphson Method : $x_{n+1} = x_n - \frac{f(x_n)}{\frac{df}{dx}(x_n)}$

We also need to form the Jacobian which contains partial derivatives of the each equation in B.

Finally we can constuct the equation from slide 23, week 10.

$$(\frac{C}{\Delta t})V_n - \frac{C}{\Delta t}V_{n-1} - B(V) - F(t) = 0$$

With the above equation, we will expand around Vn, form the Jacobian, apply the newton raphson method and and iterate for each time step to find the voltage.

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