Carleton University

Course: ELEC 4700 Modelling of Integrated Device

Assignment No: 4

Circuit Modeling

Kwabena Gyasi Bawuah

101048814

Due: 04/11/2021

Table of Contents

Introduction

This report is for ELEC 4700 in response to the call for an assignment report. The assignment was to model given circuits by simulation in different situations and for different outcomes. We are also to report on work completed in PA 9. This report will detail the results from the built simulation, observation of results, discussion of results, answers to specific questions asked in the assignment and conclusions derived. Samples of the code used to perfume these models will also be produced within the sections.

Formulation and Programming:

PA9 reporting

The C, G matrix and F vector were created to describe the circuit network. The input voltage was then DC swept form -10 to 10V with Vo and V3 plotted. Vo as a function of w was then plotted for the AC case. The gain in dB was then plotted. The gain was plotted as a function of random perturbation for AC using a normal distribution generator at w of 3.14 and stf of 0.5. Histograms were then used to plot the gain.

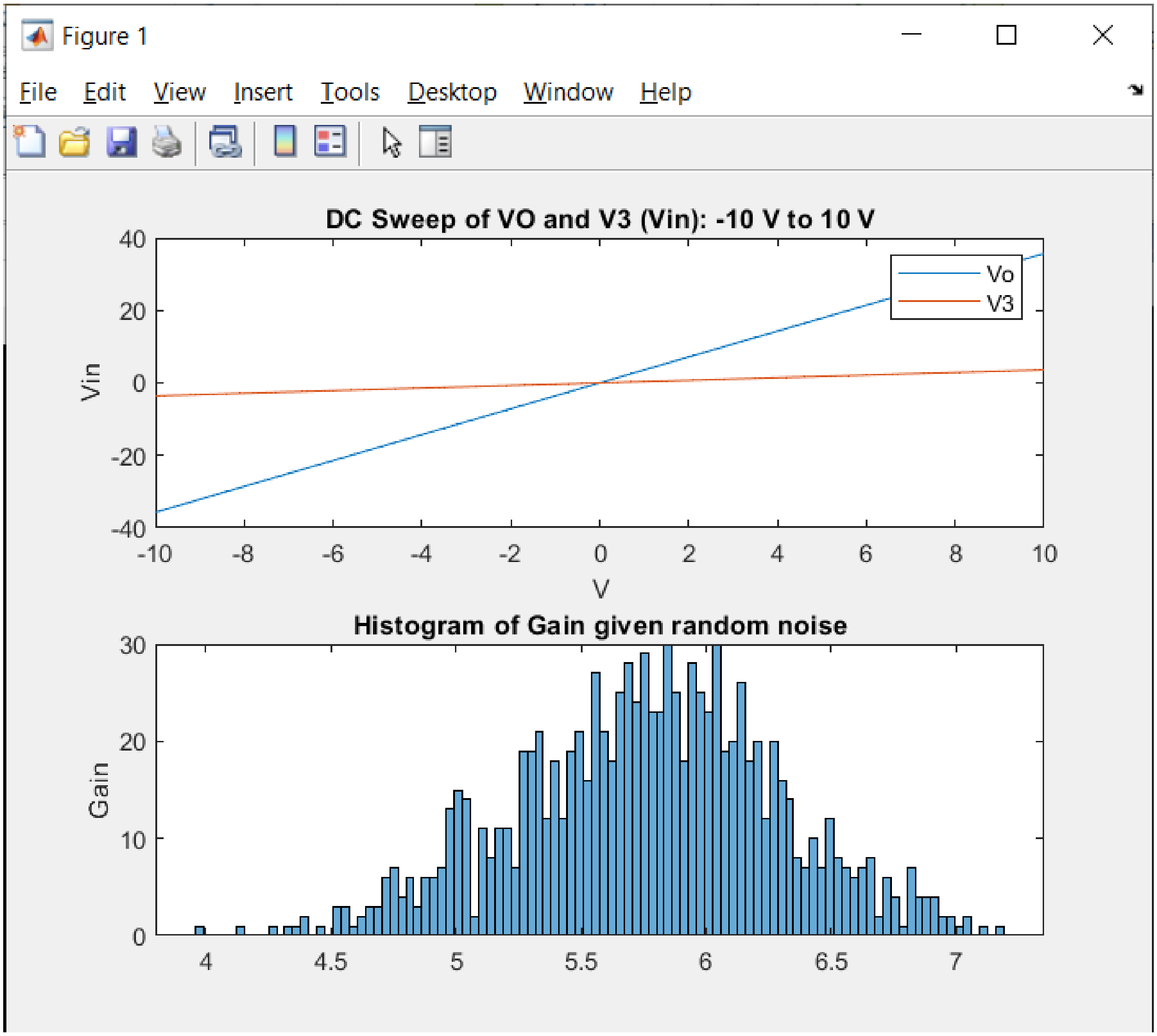
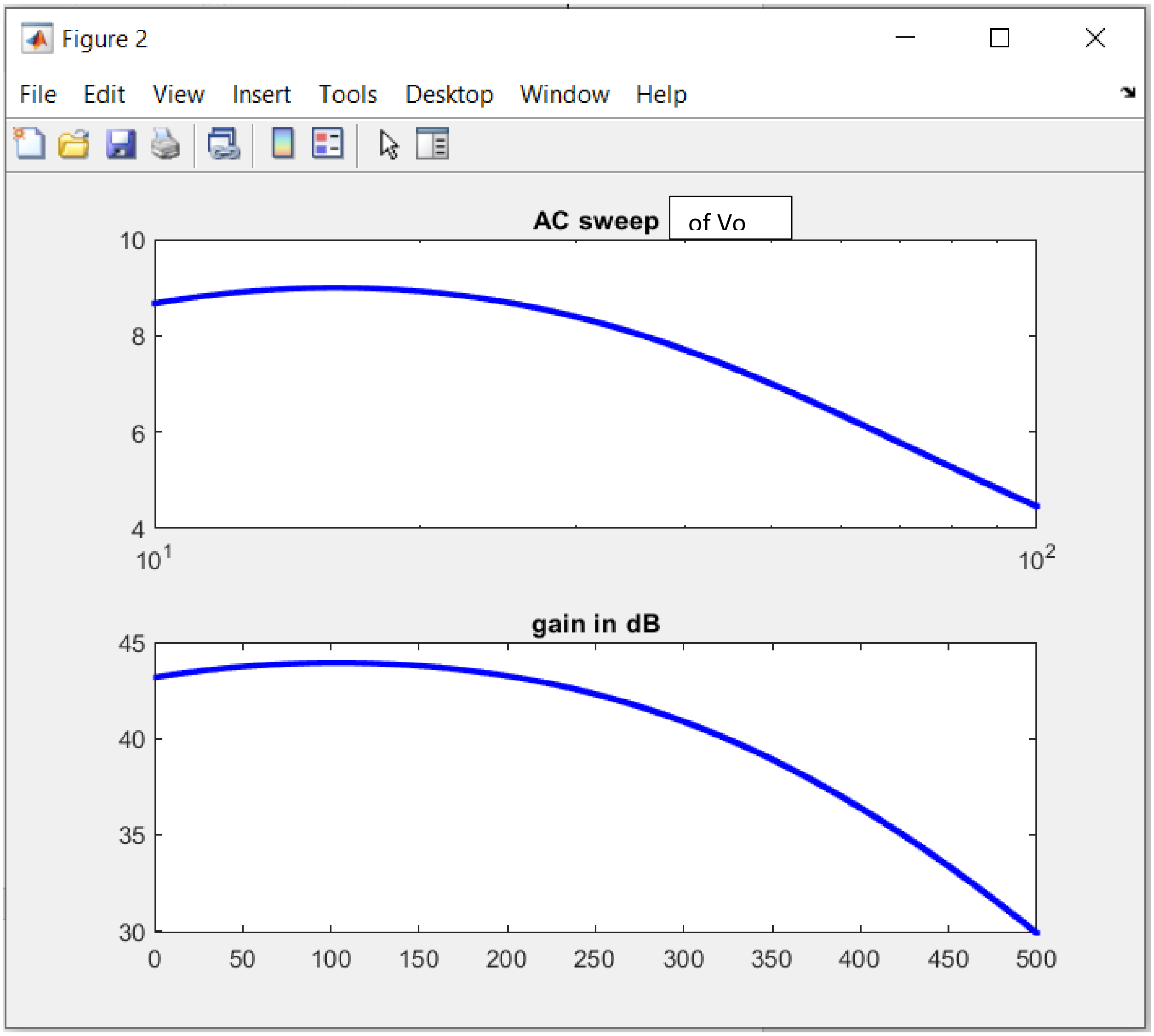


Figure 1
File Edit View Insert Tools Desktop Window Help
DC Sweep of VO and V3 (Vin): -10 V to 10 V
Vo
V3
Vin
V
40
20
0
-20
-40
-10
-8
-6
-4
-2
0
2
4
6
8
10
Histogram of Gain given random noise
Gain
30
20
10
0
4
4.5
5
5.5
6
6.5
7



Code used for section:

```
%Kwabena Gyasi Bawuah
%101048814

close all

global G
global C
global F

%G = zeros(6, 6);
%C = zeros(6, 6);
```

```
F = zeros(7, 1);

vo2 = zeros(1000, 1);
W = zeros(1000, 1);
%part d
CC = zeros(1000,1);
GG = zeros(1000,1);


%Circuit Parameters
%resistances and conductances
R1 = 1;
R2 = 2;
R3 = 10;
R4 = 0.1;
R0 = 1000;
G1 = 1/R1;
G2 = 1/R2;
G3 = 1/R3;
G4 = 1/R4;
G0 = 1/R0;
L = 0.2;
a = 100;
Cap = 0.25;

vi = zeros(100, 1);
vo = zeros(100, 1);
v3 = zeros(100, 1);

% G(1, 1) = 1;
% G(2, 1) = G1; G(2, 2) = -(G1 + G2); G(2, 6) = -1;
% G(3 ,3) = -G3; G(3, 6) = 1;
% G(4, 3) = -a*G3; G(4, 4) = 1;
% G(5, 5) = -(G4+G0); G(5, 4) = G4;
% G(6, 2) = -1; G(6, 3) = 1;

G = [1 0 0 0 0 0 0;
           -G2 G1+G2 -1 0 0 0 0;
            0 1 0 -1 0 0 0;
            0 0 -1 G3 0 0 0;
            0 0 0 0 -a 1 0;
            0 0 0 G3 -1 0 0;
            0 0 0 0 0 -G4 G4+G0];
```

```
% C(2, 1) = Cap; C(2, 2) = -Cap;
% C(6, 6) = L;

C = [0 0 0 0 0 0 0;
           -Cap Cap 0 0 0 0 0;
            0 0 -L 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;];


v = 0;
% [V1 Iin V2 I3 V4 Icc Vo]

%DC Case
%capacitive/inductive effect
s = 0;

for Vin = -10:0.1:10
    v = v + 1;
    F(1) = Vin;

    Vm = G\F
    vi(v) = Vin;
    vo(v) = Vm(6);
    v3(v) = Vm(4);
    %v = v + 1;
end

figure(1)
subplot(2,1,1)
plot(vi, vo);
hold on;
plot(vi, v3);
title('DC Sweep of VO and V3 (Vin): -10 V to 10 V');
xlabel('V')
ylabel('Vin')
legend('Vo','V3')


w = logspace(1,2,500);
F(1) = 1;
```

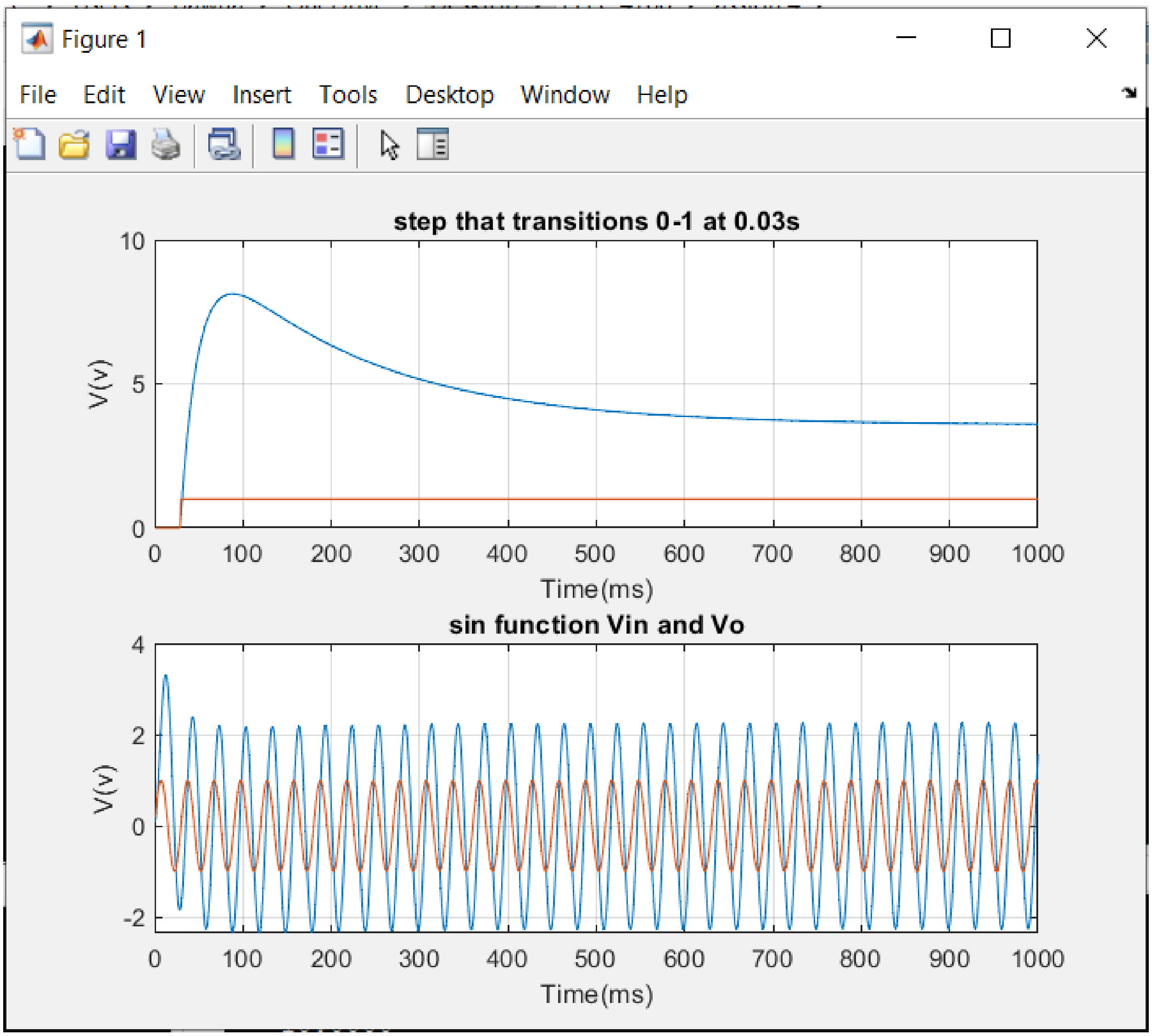
```
for i = 1:length(w)

    Vm2 = (G+C*1j*w(i))\F;


    figure(2)
    subplot(2,1,1)
    semilogx(w(i), abs(Vm2(7,1)),'b.')
    hold on
    title('AC sweep')


    %to get the db
    dBval = 20*log(abs(Vm2(7,1))/F(1));
    subplot(2,1,2)
    plot(i, dBval, 'b.')
    hold on
    title('gain in dB')
end

%using a normal distribution with std = 0.05 and w=?
w = 3.14;

for i = 1:1000
    randp = Cap + 0.05*randn(1,1000);
    C(2, 1) = randp(i);
    C(2, 2) = -randp(i);
    %Vm3 = (G+1i*w*C)\F;
    Vm3 = (G+C*1j*w)\F;
    %CC(i) = randp;
    %for the gain
    %GG(i) = 20*log10(norm(Vm3(5))/10);
    GG(i,1) = abs(Vm3(7,1))/F(1);
end

figure(1)
subplot(2,1,2)
histogram(GG,100)
title('Histogram of Gain given random noise')
ylabel('Gain')
```

Transient Circuit Simulation:

a) This is an RLC circuit due to the presence of capacitors, resistors and inductors which are all linear components. A DC transient response in RLCS can be found when a voltage or current is applied to it.

b) The reactive inductance of the inductor equals the value of the capacitance reactance of the capacitor (xL=xC) at a frequency when the RLC experiences resonance. Gain is low at all frequencies except this specific frequency which it has sharp rises. The circuit therefore has a sharp bandpass response which can then be used as a filter or an amplifier at the frequency.

d)



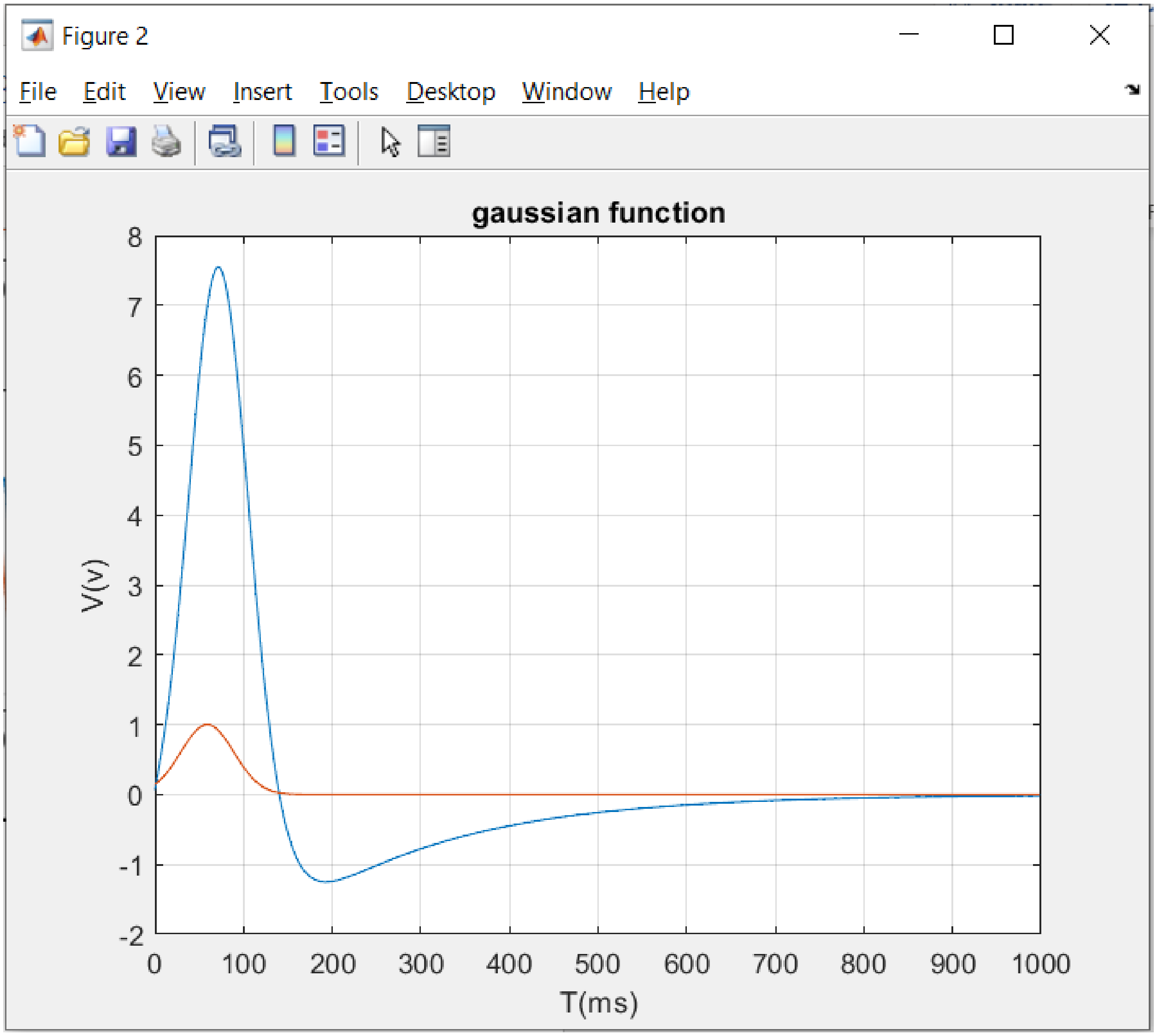


Figure 2
File Edit View Insert Tools Desktop Window Help
gaussian function
V(v)
T(ms)
8
7
6
5
4
3
2
1
0
-1
-2
0
100
200
300
400
500
600
700
800
900
1000

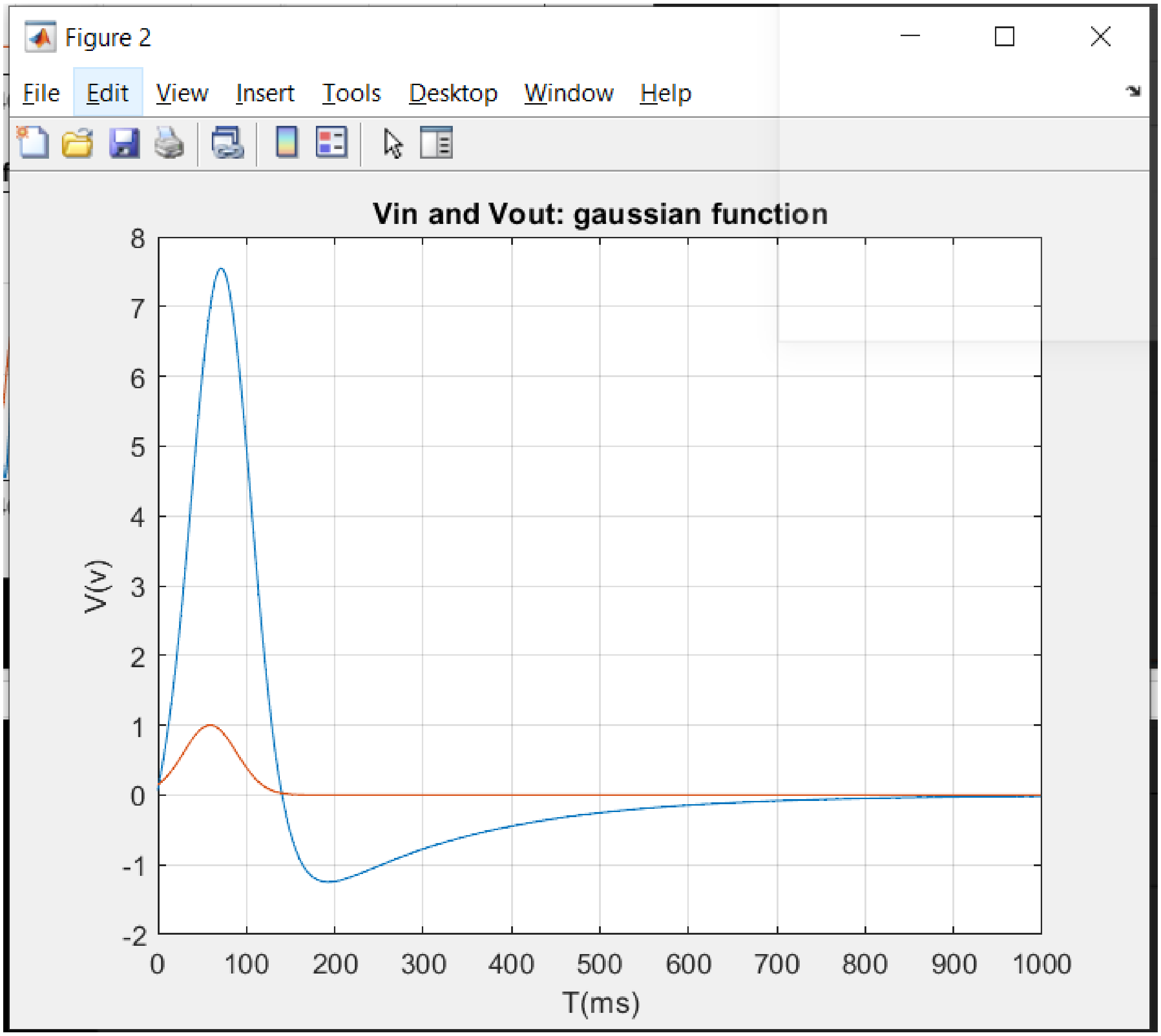


Figure 2
File
Edit
View
Insert
Tools
Desktop
Window
Help
Vin and Vout: gaussian function
V(v)
T(ms)
8
7
6
5
4
3
2
1
0
-1
-2
0
100
200
300
400
500
600
700
800
900
1000

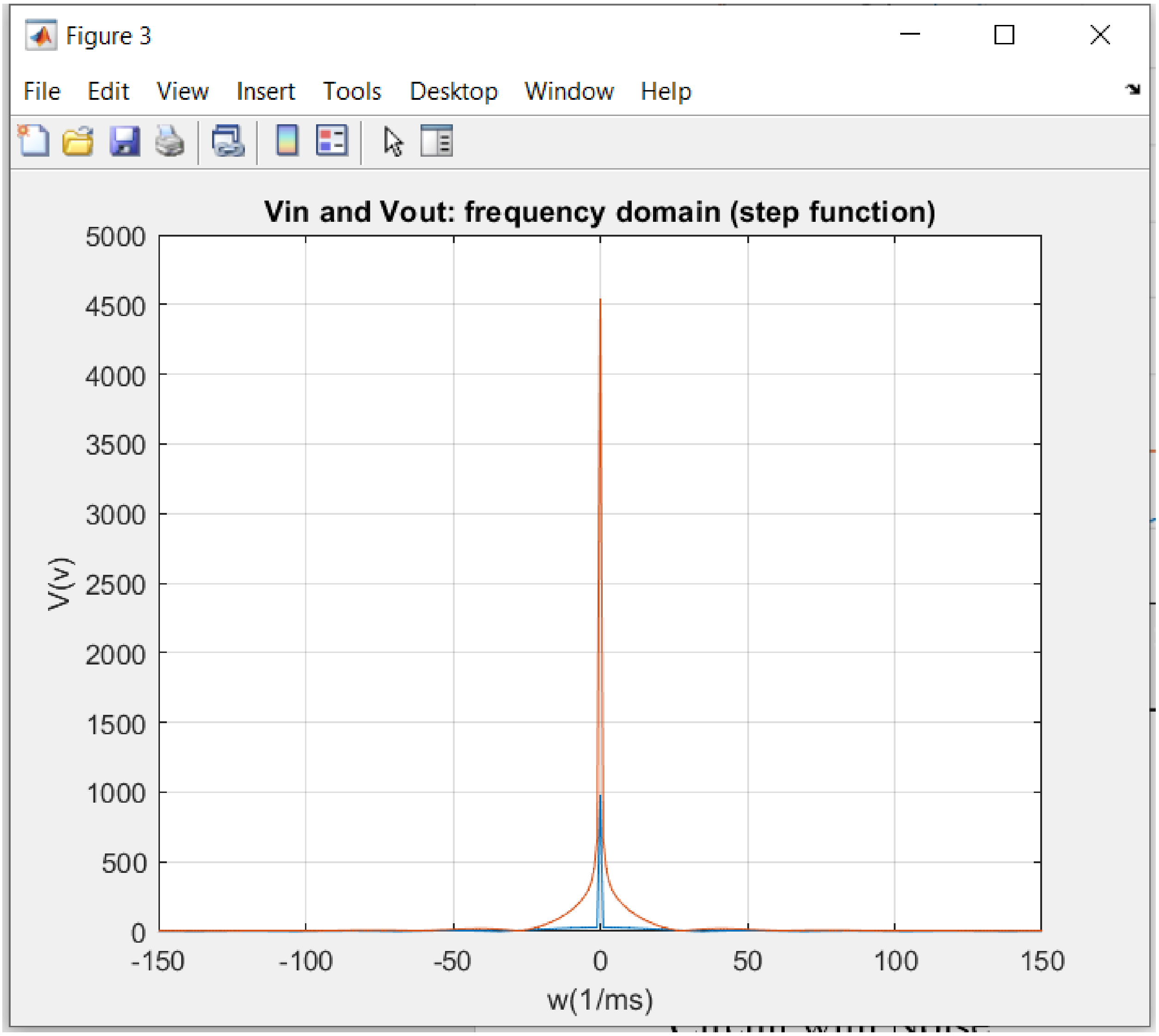


Figure 3
File Edit View Insert Tools Desktop Window Help
Vin and Vout: frequency domain (step function)
V(v)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
-150
-100
-50
0
50
100
150
w(1/ms)

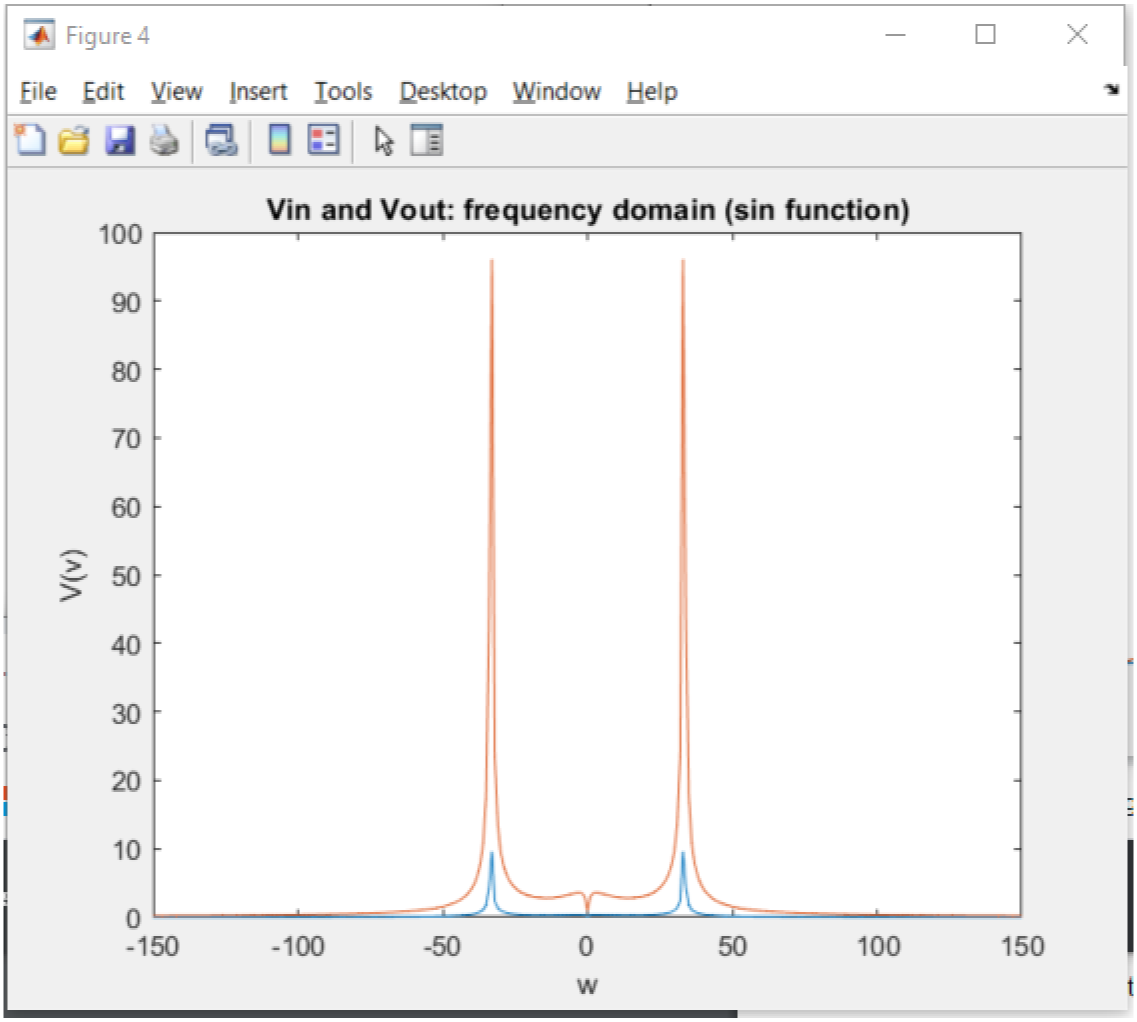
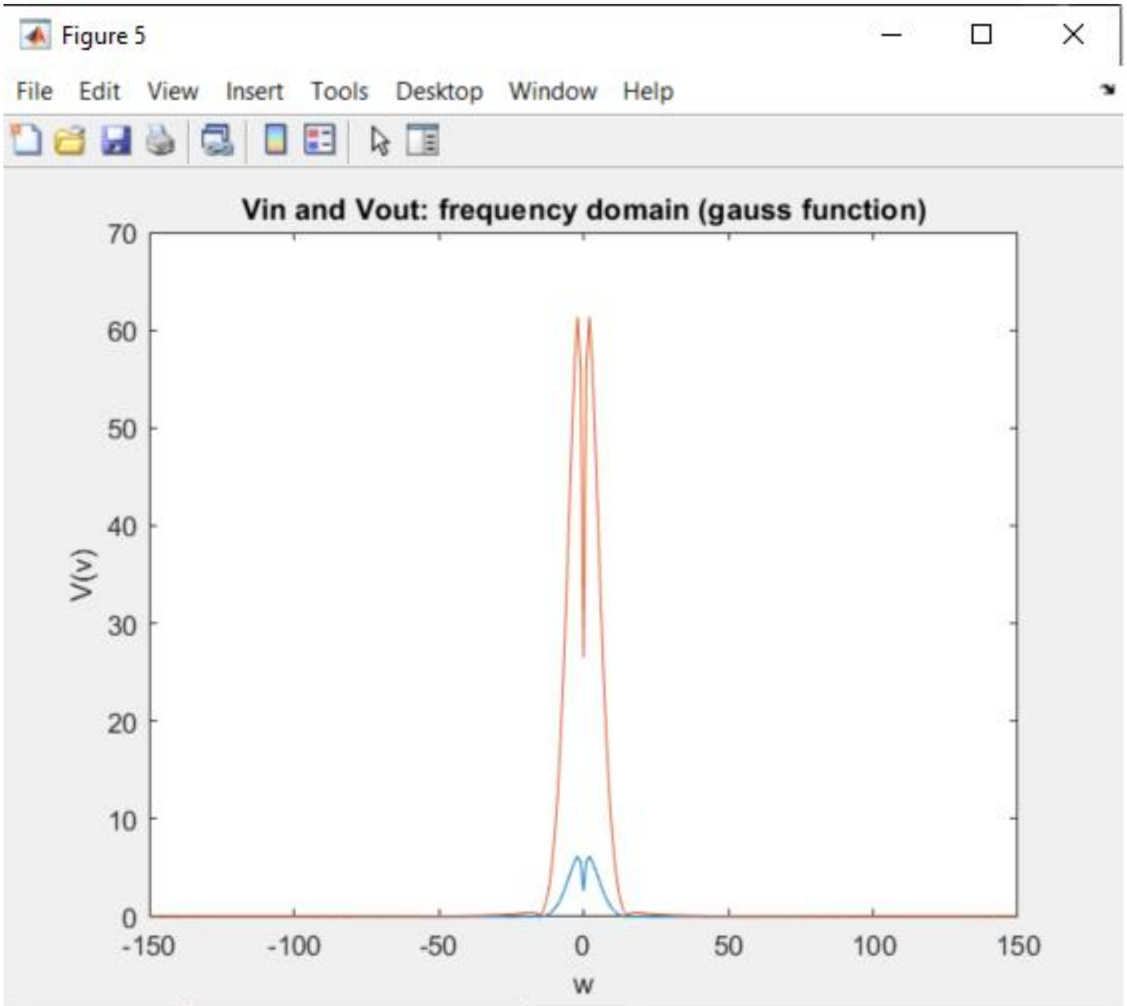


Figure 4
File Edit View Insert Tools Desktop Window Help
Vin and Vout: frequency domain (sin function)
V(v)
w
100
90
80
70
60
50
40
30
20
10
0
-150
-100
-50
0
50
100
150



v. Comments on Increasing the time step: Increasing or decreasing the time step, either increases or decreases the definition of the plot, respectively. Reducing the time step too low will break the simulation.

Code used for this section is as below:

```
%Kwabena Gyasi Bawuah
%101048814

close all
clear

global G
global C
global F
```

```
global Foff
global V2

%G = zeros(6, 6);
%C = zeros(6, 6);
F = zeros(7, 1);
Foff = zeros(7, 1);
Fsin = zeros(7,1);
Fg = zeros(7,1);


vo2 = zeros(1000, 1);
W = zeros(1000, 1);
%part d
CC = zeros(1000,1);
GG = zeros(1000,1);


%Circuit Parameters
%resistances and conductances
R1 = 1;
R2 = 2;
R3 = 10;
R4 = 0.1;
R0 = 1000;
G1 = 1/R1;
G2 = 1/R2;
G3 = 1/R3;
G4 = 1/R4;
G0 = 1/R0;
L = 0.2;
a = 100;
Cap = 0.25;
ts = 1000;

vi = zeros(100, 1);
vo = zeros(100, 1);
v3 = zeros(100, 1);


V2 = zeros(7, ts);
V3 = zeros(7, ts);

% G(1, 1) = 1;
```

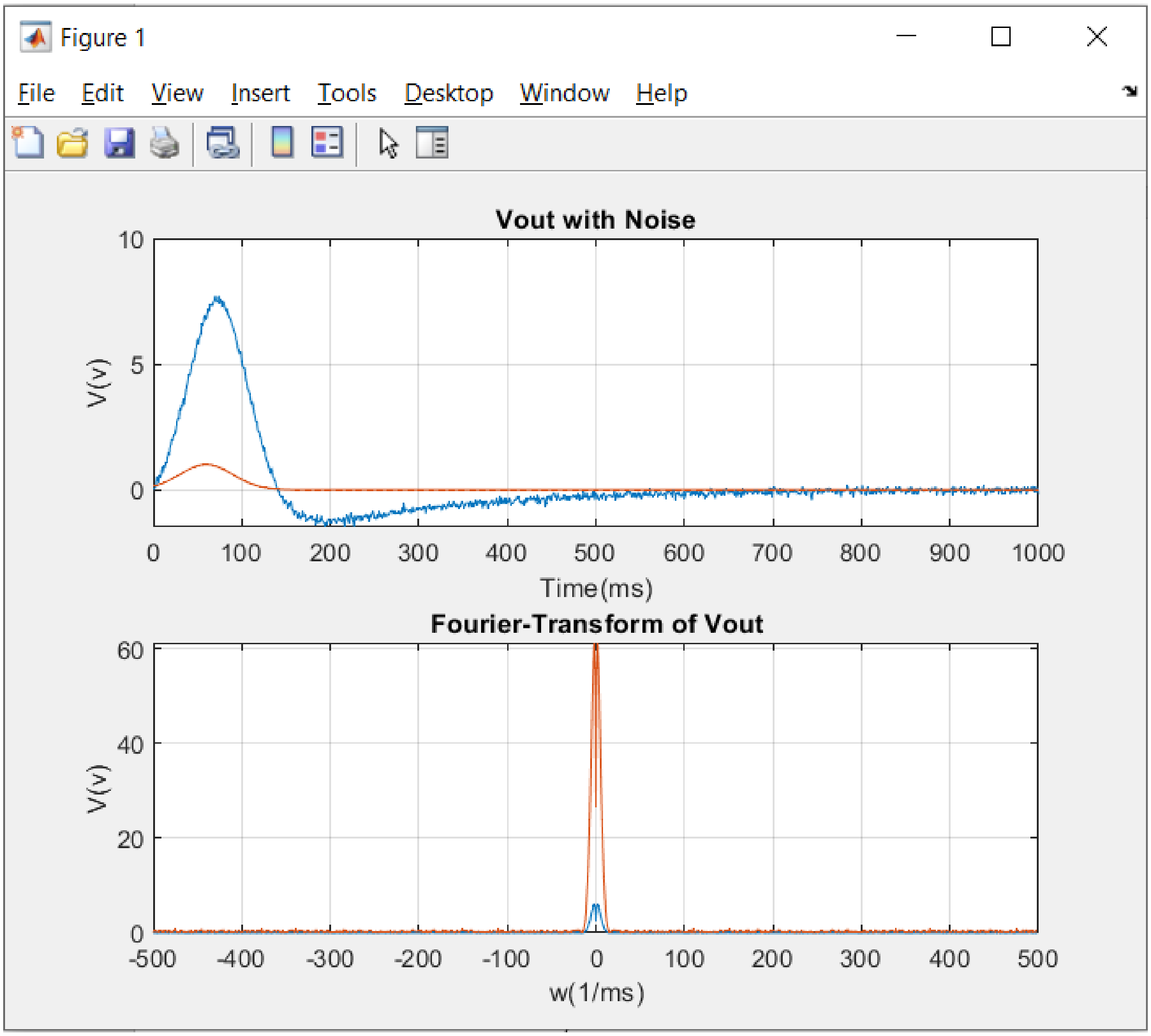
```
% G(2, 1) = G1; G(2, 2) = -(G1 + G2); G(2, 6) = -1;
% G(3 ,3) = -G3; G(3, 6) = 1;
% G(4, 3) = -a*G3; G(4, 4) = 1;
% G(5, 5) = -(G4+G0); G(5, 4) = G4;
% G(6, 2) = -1; G(6, 3) = 1;

G = [1 0 0 0 0 0 0;
           -G2 G1+G2 -1 0 0 0 0;
            0 1 0 -1 0 0 0;
            0 0 -1 G3 0 0 0;
            0 0 0 0 -a 1 0;
            0 0 0 G3 -1 0 0;
            0 0 0 0 0 -G4 G4+G0];


% C(2, 1) = Cap; C(2, 2) = -Cap;
% C(6, 6) = L;

C = [0 0 0 0 0 0 0;
           -Cap Cap 0 0 0 0 0;
            0 0 -L 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;];


v = 0;
% [V1 Iin V2 I3 V4 Icc Vo]

%DC Case
%capacitive/inductive effect
s = 0;

Vin = 1;

F(1,1) = Vin;

Foff(1,1) = Vin-Vin;


%2D:ii:A 0.03s time step
V1 = zeros(7, ts);
Vstart = zeros(7, 1);
```

```
dt=1e-3;

for i = 1:ts
    if i < 30
        V1(:,i) = (C./dt+G)\(Foff+C*Vstart/dt);
    elseif i == 30
        V1(:,i) = (C./dt+G)\(F+C*Vstart/dt);
    else
        V1(:,i) = (C./dt+G)\(F+C*Vpast/dt);
    end
    Vpast = V1(:, i);
end

figure(1)
subplot(2,1,1)
plot(1:ts, V1(7,:))
hold on
plot(1:ts, V1(1,:))
title('step that transitions 0-1 at 0.03s')
xlabel('Time(ms)')
ylabel('V(v)')
grid on

for i = 1:ts

    Vsin = sin(2*3.14*(1/0.03)*i/ts);
    Fsin(1,1) = Vsin;
    if i == 1
        V2(:,i) = (C./dt+G)\(Fsin+C*Vstart/dt);
    else
        V2(:,i) = (C./dt+G)\(Fsin+C*Vpast/dt);
    end
    Vpast = V2(:, i);
end

figure(1)
subplot(2,1,2)
plot(1:ts, V2(7,:))
hold on
plot(1:ts, V2(1,:))
title('sin function Vin and Vo')
xlabel('Time(ms)')
ylabel('V(v)')
grid on
```

```matlab
for k = 1:ts

    Vgauss = exp(-1/2*((k/ts-0.06)/(0.03))^2);
    Fg(1,1) = Vgauss;
    if k == 1
        V3(:,k) = (C./dt+G)\(Fg+C*Vstart/dt);
    else
        V3(:,k) = (C./dt+G)\(Fg+C*Vpast/dt);
    end
    Vpast = V3(:, k);

end

figure(2)
plot(0:ts-1, V3(7,:))
hold on
plot(0:ts-1, V3(1,:))
title('Vin and Vout: gaussian function')
xlabel('T(ms)')
ylabel('V(v)')
grid on

%Plot of Vin, Vo withinput signal in f-domain
f = (-ts/2:ts/2-1);
fV1in = fft(V1(1, :));
fV1out = fft(V1(7, :));
fsV1in = fftshift(fV1in);
fsV1out = fftshift(fV1out);

figure(3)
plot(f, abs(fsV1in))
hold on
plot(f, abs(fsV1out))
xlim([-150,150]);
title('Vin and Vout: frequency domain (step function)')
xlabel('w(1/ms)')
ylabel('V(v)')
grid on

%sine function
fV2 = fft(V2.');
fsV2 = fftshift(fV2);
```

```
figure(4)
plot(f, abs(fsV2(:, 1)))
hold on
plot(f, abs(fsV2(:, 7)))
xlim([-150,150]);
title('Vin and Vout: frequency domain (sin function)')
xlabel('w')
ylabel('V(v)')

%guass function
fV3 = fft(V3.');
fsV3 = fftshift(fV3);
figure(5)
plot(f, abs(fsV3(:, 1)))
hold on
plot(f, abs(fsV3(:, 7)))
xlim([-150,150]);
title('Vin and Vout: frequency domain (gauss function)')
xlabel('w')
ylabel('V(v)')
```

Circuit with Noise:



c) Vi) Cout variation

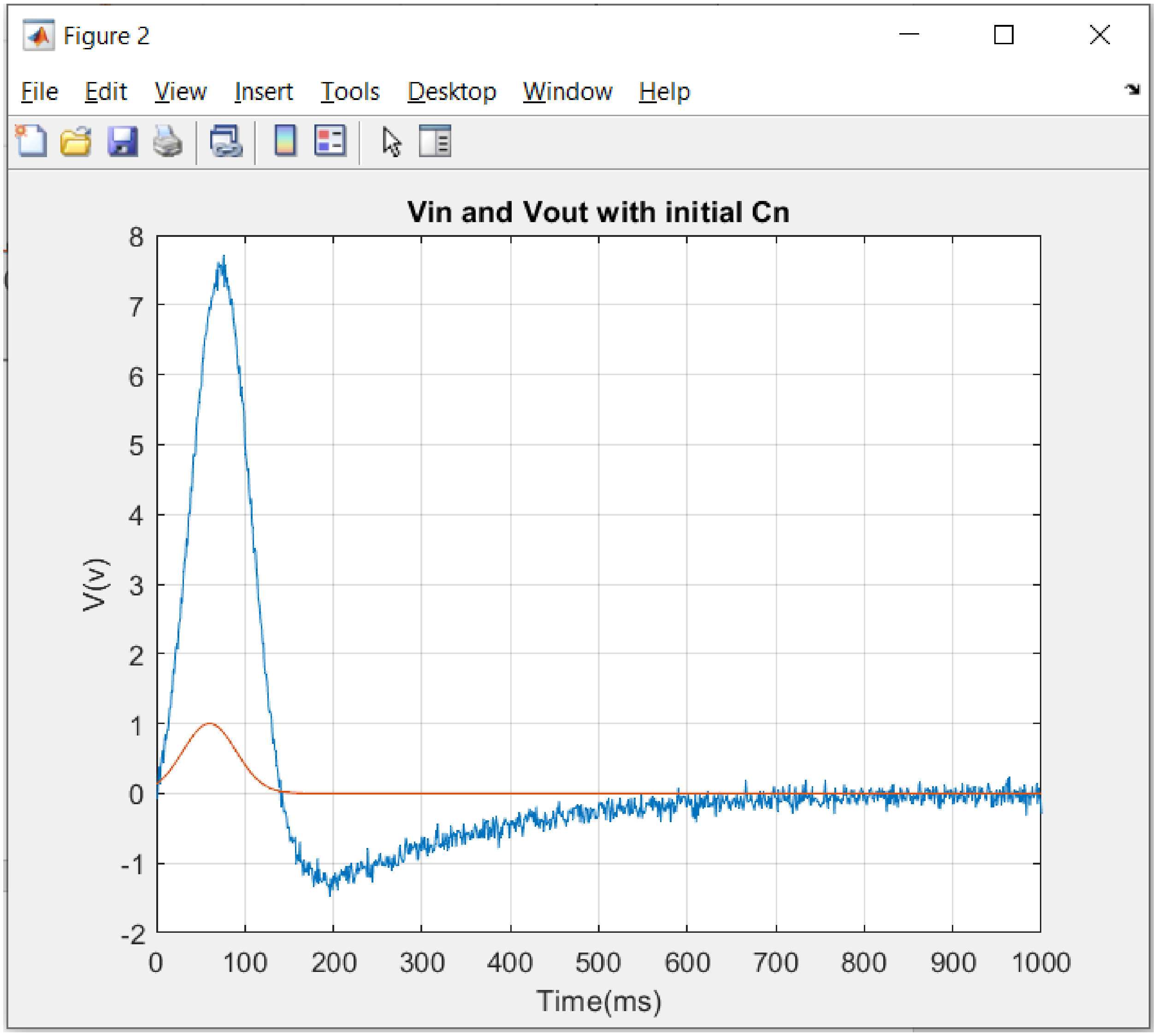
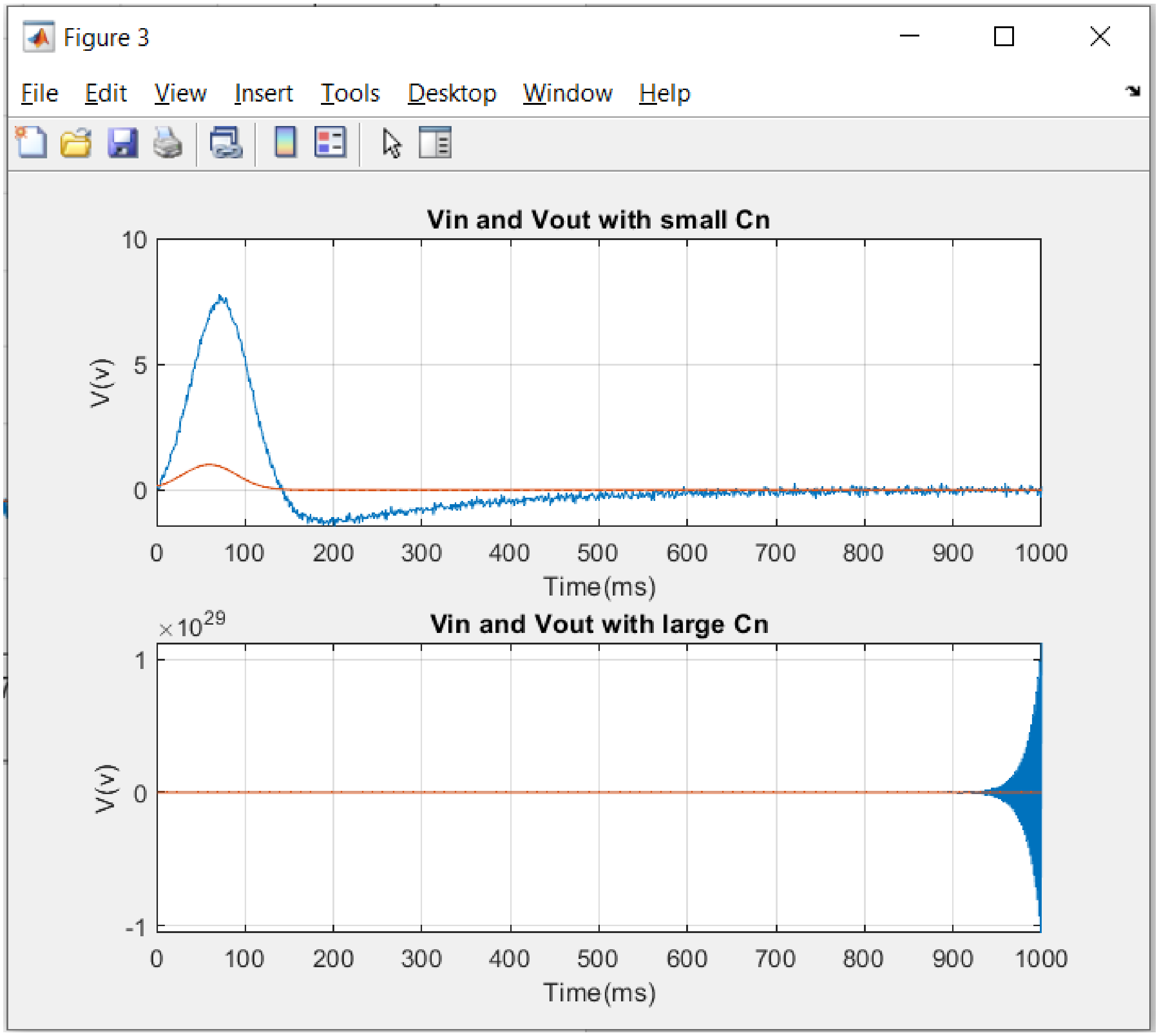
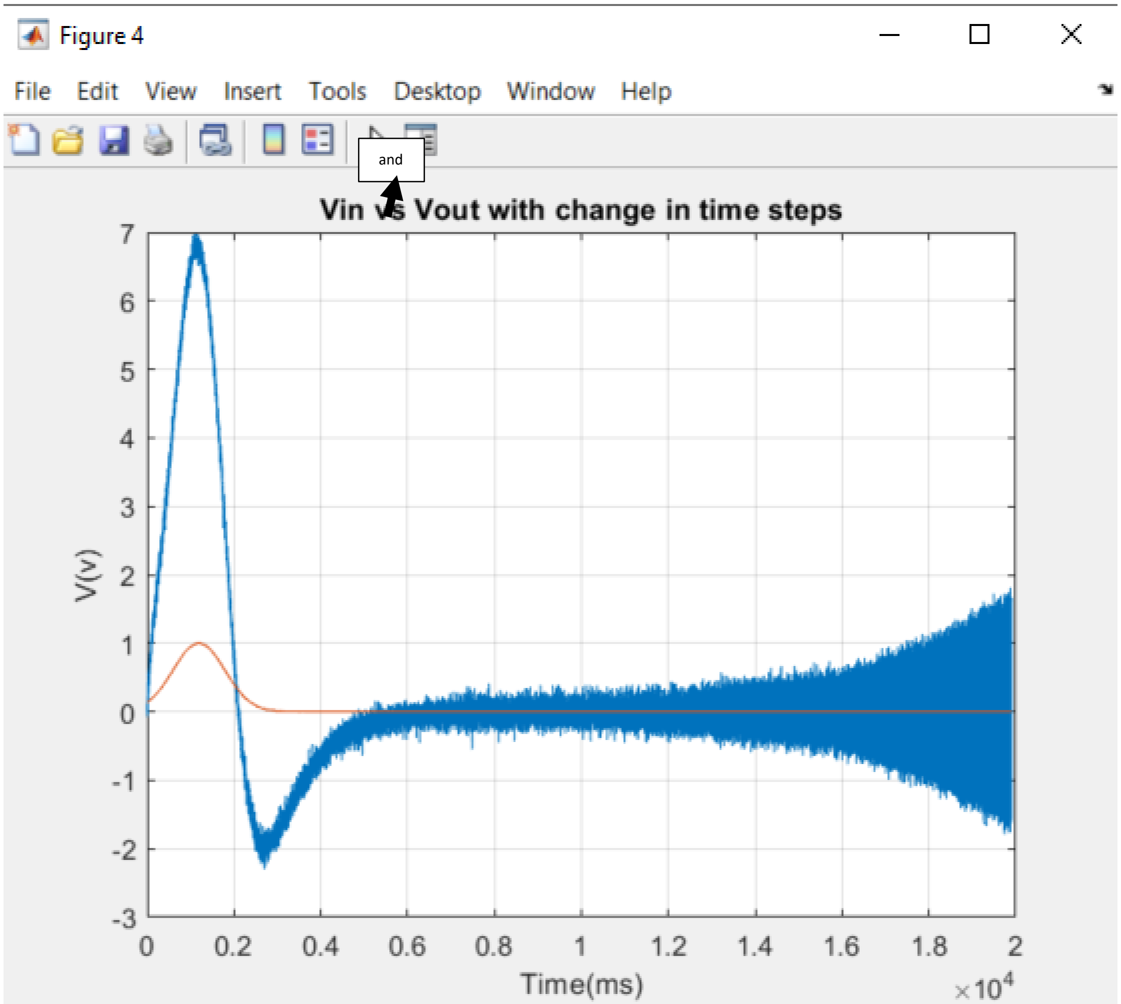


Figure 2
File Edit View Insert Tools Desktop Window Help
Vin and Vout with initial Cn
V(v)
8
7
6
5
4
3
2
1
0
-1
-2
0 100 200 300 400 500 600 700 800 900 1000
Time(ms)



It is observable that a reduction in the value of Cout (Cn) does not cause much of a difference. Increasing the Cout (Cn) value cause the circuit to enter a feed back loop hence the simulation breaks down.

c) vii) time step variation



Observation:

Reducing the time step crashes the system due it is getting stuck in a feedback loop.

Code used in this section is as below:

```
%Kwabena Gyasi Bawuah
%101048814

close all
clear

global G
global C
global F
global Foff
global V2
```

```
%G = zeros(6, 6);
%C = zeros(6, 6);
F = zeros(7, 1);
Foff = zeros(7, 1);
Fsin = zeros(7,1);
Fg = zeros(7,1);


vo2 = zeros(1000, 1);
W = zeros(1000, 1);
%part d
CC = zeros(1000,1);
GG = zeros(1000,1);


%Circuit Parameters
%resistances and conductances
R1 = 1;
R2 = 2;
R3 = 10;
R4 = 0.1;
R0 = 1000;
G1 = 1/R1;
G2 = 1/R2;
G3 = 1/R3;
G4 = 1/R4;
G0 = 1/R0;
L = 0.2;
a = 100;
Cap = 0.25;
ts = 1000;
ts2 = 1.9898e4;
Vin = 1;
% Capacitance
Cn = 0.00001;


vi = zeros(100, 1);
vo = zeros(100, 1);
v3 = zeros(100, 1);


V2 = zeros(7, ts);
V3 = zeros(7, ts);
```

```
V4 = zeros(7, ts2);

% G(1, 1) = 1;
% G(2, 1) = G1; G(2, 2) = -(G1 + G2); G(2, 6) = -1;
% G(3 ,3) = -G3; G(3, 6) = 1;
% G(4, 3) = -a*G3; G(4, 4) = 1;
% G(5, 5) = -(G4+G0); G(5, 4) = G4;
% G(6, 2) = -1; G(6, 3) = 1;

G = [1 0 0 0 0 0 0;
          -G2 G1+G2 -1 0 0 0 0;
           0 1 0 -1 0 0 0;
           0 0 -1 G3 0 0 0;
           0 0 0 0 -a 1 0;
           0 0 0 G3 -1 0 0;
           0 0 0 0 0 -G4 G4+G0];


% C(2, 1) = Cap; C(2, 2) = -Cap;
% C(6, 6) = L;

C = [0 0 0 0 0 0 0;
          -Cap Cap 0 0 0 0 0;
           0 0 -L 0 0 0 0;
           0 0 0 -Cn 0 0 0;
           0 0 0 0 0 0 0;
           0 0 0 -Cn 0 0 0;
           0 0 0 0 0 0 0;];



v = 0;
% [V1 Iin V2 I3 V4 Icc Vo]

%DC Case
%capacitive/inductive effect
s = 0;


F(1,1) = Vin;

Foff(1,1) = Vin-Vin;


%2D:ii:A 0.03s time step
```

```matlab
V1 = zeros(7, ts);
Vstart = zeros(7, 1);
dt=1e-3;
dt2 = 1.9898e-4;


for i = 1:ts

    F(1,1) = exp(-1/2*((i/ts-0.06)/(0.03))^2);
    F(4,1) = 0.001*randn();
    F(7,1) = 0.001*randn();

    if i == 1
        V1(:,i) = (C./dt+G)\(F+C*Vstart/dt);
    else
        V1(:,i) = (C./dt+G)\(F+C*Vpast/dt);
    end
    Vpast = V1(:, i);
end

figure(1)
subplot(2,1,1)
plot(1:ts, V1(7,:))
hold on
plot(1:ts, V1(1,:))
title('Vout with Noise')
xlabel('Time(ms)')
ylabel('V(v)')
grid on

% Frequency domain
f = (-ts/2:ts/2-1);

fV1 = fft(V1.');
fsV1 = fftshift(fV1);
%simulation
figure(1)
subplot(2,1,2)
plot(f, abs(fsV1(:, 1)))
hold on
plot(f, abs(fsV1(:, 7)))
title('Fourier-Transform of Vout')
xlabel('w(1/ms)')
ylabel('V(v)')
```

```
grid on

for i = 1:ts

    F(1,1) = exp(-1/2*((i/ts-0.06)/(0.03))^2);
    F(4,1) = 0.001*randn();
    F(7,1) = 0.001*randn();
    if i == 1
        V3(:,i) = (C./dt+G)\(F+C*Vstart/dt);
    else
        V3(:,i) = (C./dt+G)\(F+C*Vpast/dt);
    end
    Vpast = V3(:, i);

end
figure(2)
plot(1:ts, V3(7,:))
hold on
plot(1:ts, V3(1,:))
title('Vin and Vout with initial Cn')
xlabel('Time(ms)')
ylabel('V(v)')
grid on

C(4,4) = -1e-13;
C(6,4) = -1e-13;

for i = 1:ts

    F(1,1) = exp(-1/2*((i/ts-0.06)/(0.03))^2);
    F(4,1) = 0.001*randn();
    F(7,1) = 0.001*randn();
    if i == 1
        V2(:,i) = (C./dt+G)\(F+C*Vstart/dt);
    else
        V2(:,i) = (C./dt+G)\(F+C*Vpast/dt);
    end
    Vpast = V2(:, i);

end
figure(3)
subplot(2,1,1)
plot(1:ts, V2(7,:))
hold on
```

```
plot(1:ts, V2(1,:))
title('Vin and Vout with small Cn')
xlabel('Time(ms)')
ylabel('V(v)')
grid on

C(4,4) = -5.3e-5;
C(6,4) = -5.3e-12;

for i = 1:ts

    F(1,1) = exp(-1/2*((i/ts-0.06)/(0.03))^2);
    F(4,1) = 0.001*randn();
    F(7,1) = 0.001*randn();
    if i == 1
        V3(:,i) = (C./dt+G)\(F+C*Vstart/dt);
    else
        V3(:,i) = (C./dt+G)\(F+C*Vpast/dt);
    end
    Vpast = V3(:, i);

end
figure(3)
subplot(2,1,2)
plot(1:ts, V3(7,:))
hold on
plot(1:ts, V3(1,:))
title('Vin and Vout with large Cn')
xlabel('Time(ms)')
ylabel('V(v)')
grid on

%%%%%%%%%%%%%%

C(4,4) = -Cn;
C(6,4) = -Cn;

for i = 1:ts2

    Fg(1,1) = exp(-1/2*((i/ts2-0.06)/(0.03))^2);
    Fg(4,1) = 0.001*randn();
    Fg(7,1) = 0.001*randn();
    if i == 1
        V4(:,i) = (C./dt2+G)\(Fg+C*Vstart/dt2);
```

```
    else
        V4(:,i) = (C./dt2+G)\(Fg+C*Vpast/dt2);
    end
    Vpast = V4(:, i);

end
figure(4)
plot(1:ts2, V4(7,:))
hold on
plot(1:ts2, V4(1,:))
title('Vin vs Vout with change in time steps')
xlabel('Time(ms)')
ylabel('V(v)')
grid on
```

Non-Linearity:

a) The problem will become nonlinear. Iterative solution such as Jacobian method will have to be used instead of exact numerical method as we have been using. New vector ‘B’ will therefore need to be introduced and added to the term.

b) The new equation will also need to be fitted. Matrix sizes will increase hence the iterations required to go through will increase as well. The values of alpha and better will need to be reconsidered with I3 in mind or i3 will not be able to have a noticeable effect on the circuit.