ELEC 4700 Modelling of Integrated Devices

Assignment 4: Finite Difference Method

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Professor: Tom Smy

Student Name: Rudi Hidvary

Student Number: 101037815

Introduction

This assignment focuses on circuit modelling and how a computer can automate circuit simulation using a few engineering principles. This is shown using a specific example done in a previous PA and an explanation is given as to how a computer can use kirchoff's current law and node voltages to come up with a reasonable accurate circuit simulator that works in discrete chunks of time.

Part 1: Current-Voltage Characteristics

For the first section of this report the previous report is used to get V-I characteristics of the bottleneck. This will then be used to determine a resistance value in later sections. Since this was not completed in the previous lab, the linear fit section can not be completed, the value of R3 =10

Part 3: Explanation of Circuit Simulation PA

The way to create the circuit simulation for this circuit is to find the currents flowing into each node. By using Kirckoff's current law all current flowing into a node are equal to the current flowing out of the node. Using this equation the nodal voltage difference is found which can be used along with the component value and frequency variable to find the current flowing in and out of the nodes.

First the nodal equations need to be determined using the information from the circuit. There are five nodes so there will be at least five equations. one more equation will be used to solve for the inductor current and for the current through R3 which is used to solve for the unknown voltage at N4. In the equations V1 = N1, V5 = V0, and so on.

(i) Nodal Equations

$$C\frac{d(V1-V2)}{dt}+\frac{(V1-V2)}{R1}=I_L+\frac{V2}{R2} \qquad (1)$$

$$\frac{V3}{R3}=I_L=I_3 \qquad (2)$$

$$(V2-V3)=L\frac{d(I_L)}{dt} \qquad (3)$$

$$\frac{V4-V5}{R4}=\frac{V5}{R0} \qquad (4)$$

Using Conductance values instead which makes solving the equation easier.

$$C\frac{d(V1-V2)}{dt}+G1(V1-V2)=I_L+V2G2 \qquad (1)$$

$$V3G3 = I_L = I_3 \tag{2}$$

$$(V2 - V3) = L\frac{d(I_L)}{dt} \tag{3}$$

$$G4(V4 - V5) = G0(V5) \tag{4}$$

(ii) Frequency Domain

Using the laplace variable (s) the equations can be written as follows

$$sC(V1 - V2) + G1(V1 - V2) = I_L + V2G2 \tag{1}$$

$$V3G3 = I_L = I_3 \tag{2}$$

$$(V2 - V3) = sL(I_L) \tag{3}$$

$$G4(V4 - V5) = G0(V5) \tag{4}$$

The equations then needed to solve this in matlab needed two more to be added to solve. One for the input voltage at V1 = N1, and an equation to find the voltage at V4 = N4 based on the current going through R3 which is the same as the current going through the inductor.

$$sC(V1 - V2) + G1(V1 - V2) = I_L + V2G2 \tag{1}$$

$$V3G3 = I_L = I_3 \tag{2}$$

$$(V2 - V3) = sL(I_L) \tag{3}$$

$$G4(V4 - V5) = G0(V5) \tag{4}$$

$$V1 = Vin \tag{5}$$

$$V4 = aI_3 \tag{6}$$

(iii) Matrix Equations

Using these six equations, matrices can be used to hold the component values and using an input function F, then the voltages at each node can be found as well as the current through the inductor. The equations have been rearranged to be solved for zero

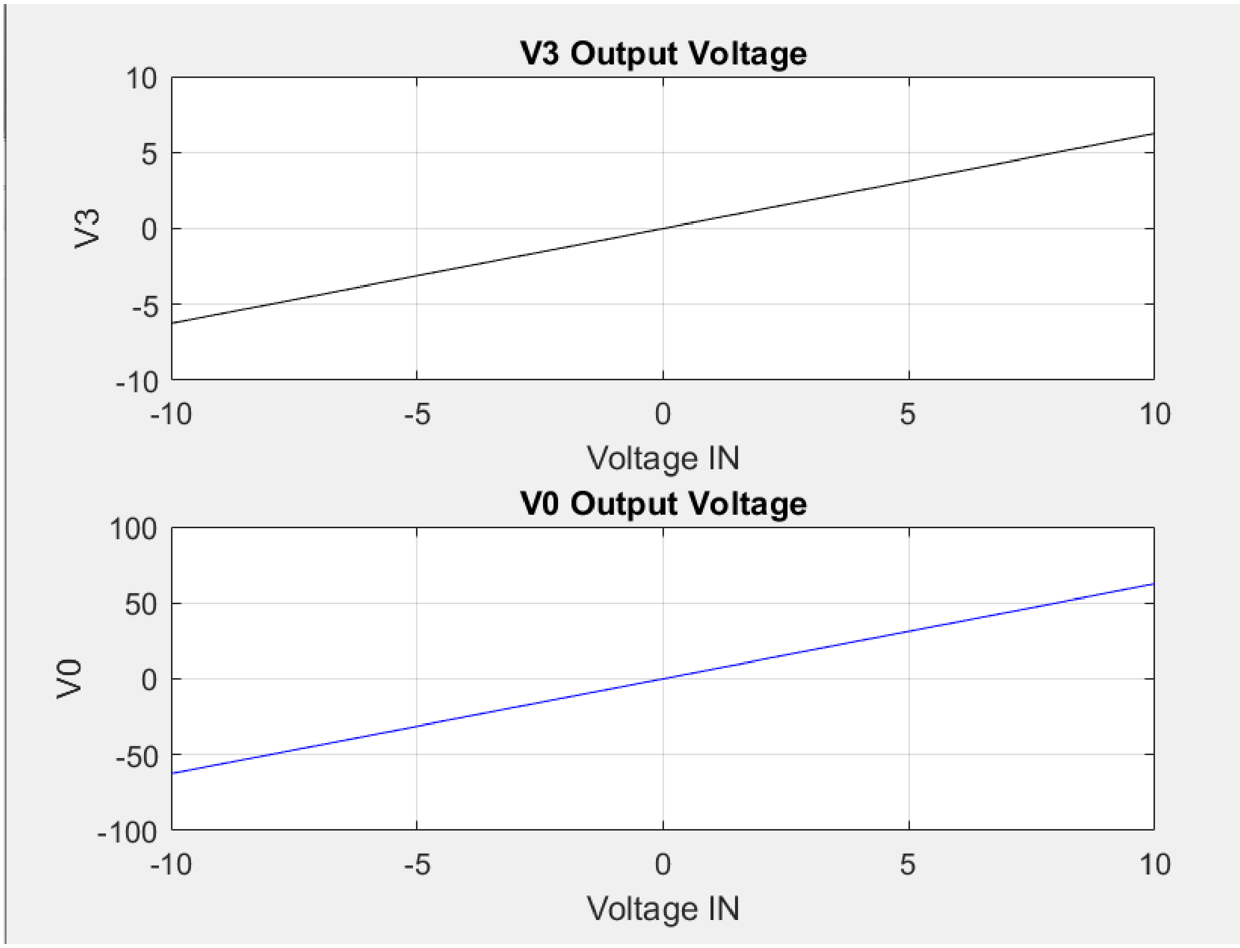
C Matrix	V1	V2	V3	V4	V5 = V0	I_L	I_3
(1)	C	-C	0	0	0	0	0
(2)	0	0	0	0	0	0	0

(3)	0	0	0	0	0	-L	0
(4)	0	0	0	0	0	0	0
(5)	0	0	0	0	0	0	0
(6)	0	0	0	0	0	0	0
(7)	0	0	0	0	0	0	0

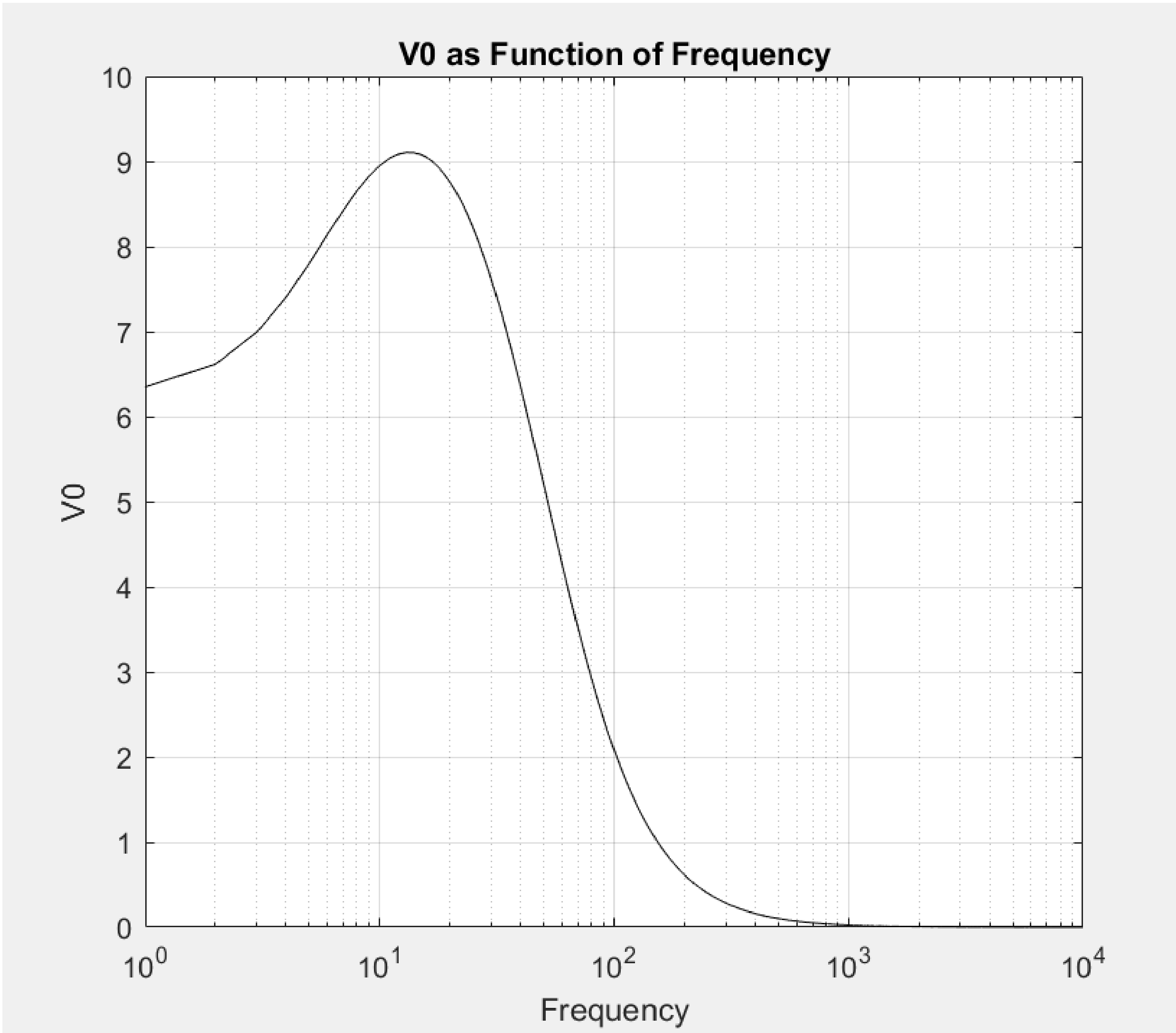
G Matrix	V1	V2	V3	V4	V5 = V0	I_L	I_L
(1)	G1	-(G1+G2)	0	0	0	-1	0
(2)	0	0	G3	0	0	-1	0
(3)	0	1	-1	0	0	0	0
(4)	0	0	0	G4	-(G4+G5)	0	0
(5)	1	0	0	0	0	0	0
(6)	0	0	0	1	0	0	-a
(7)	0	0	G3	0	0	0	-1

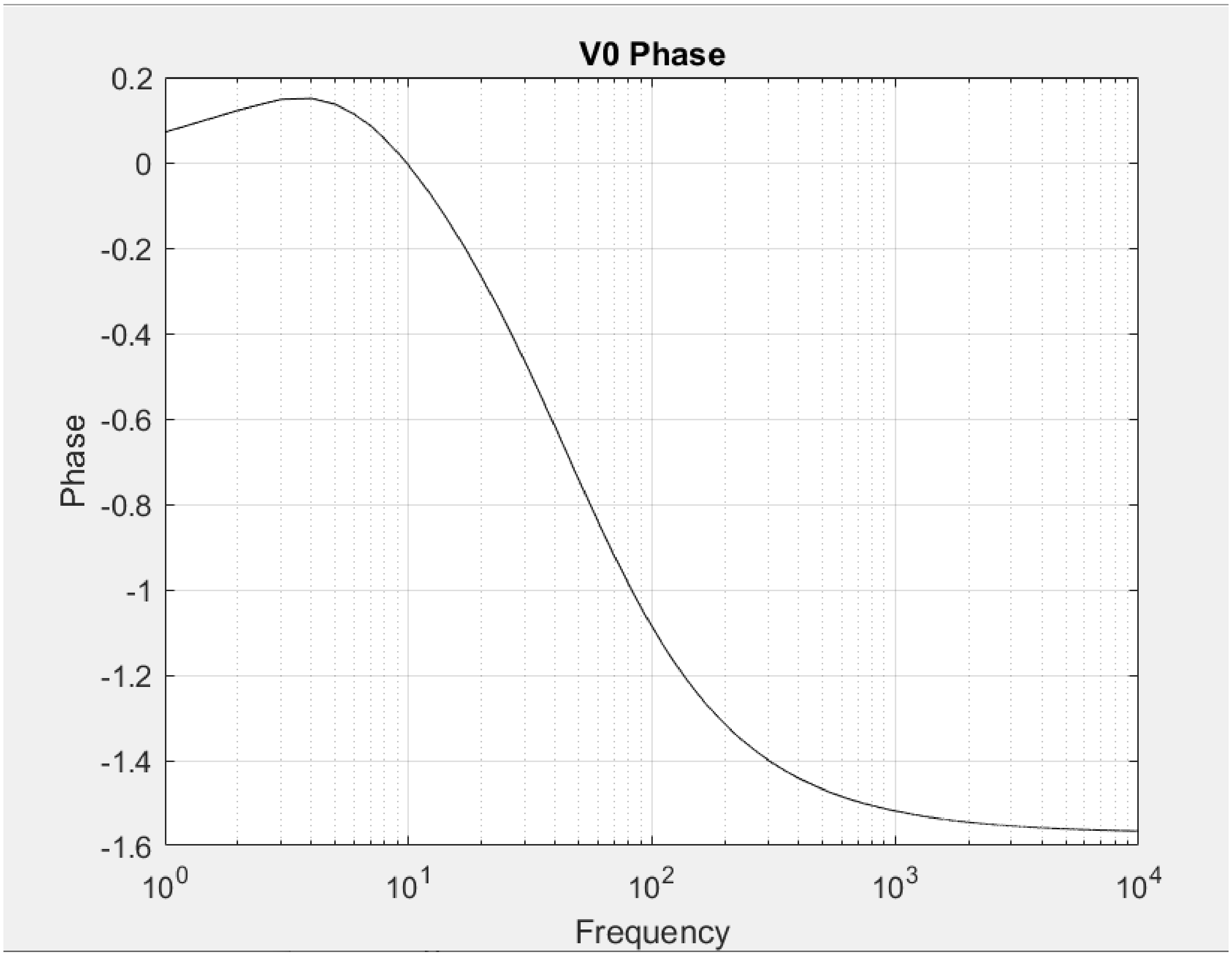
F Vector	Value
(1)	Vin
(2)	0
(3)	0
(4)	0
(5)	0
(6)	0
(7)	0

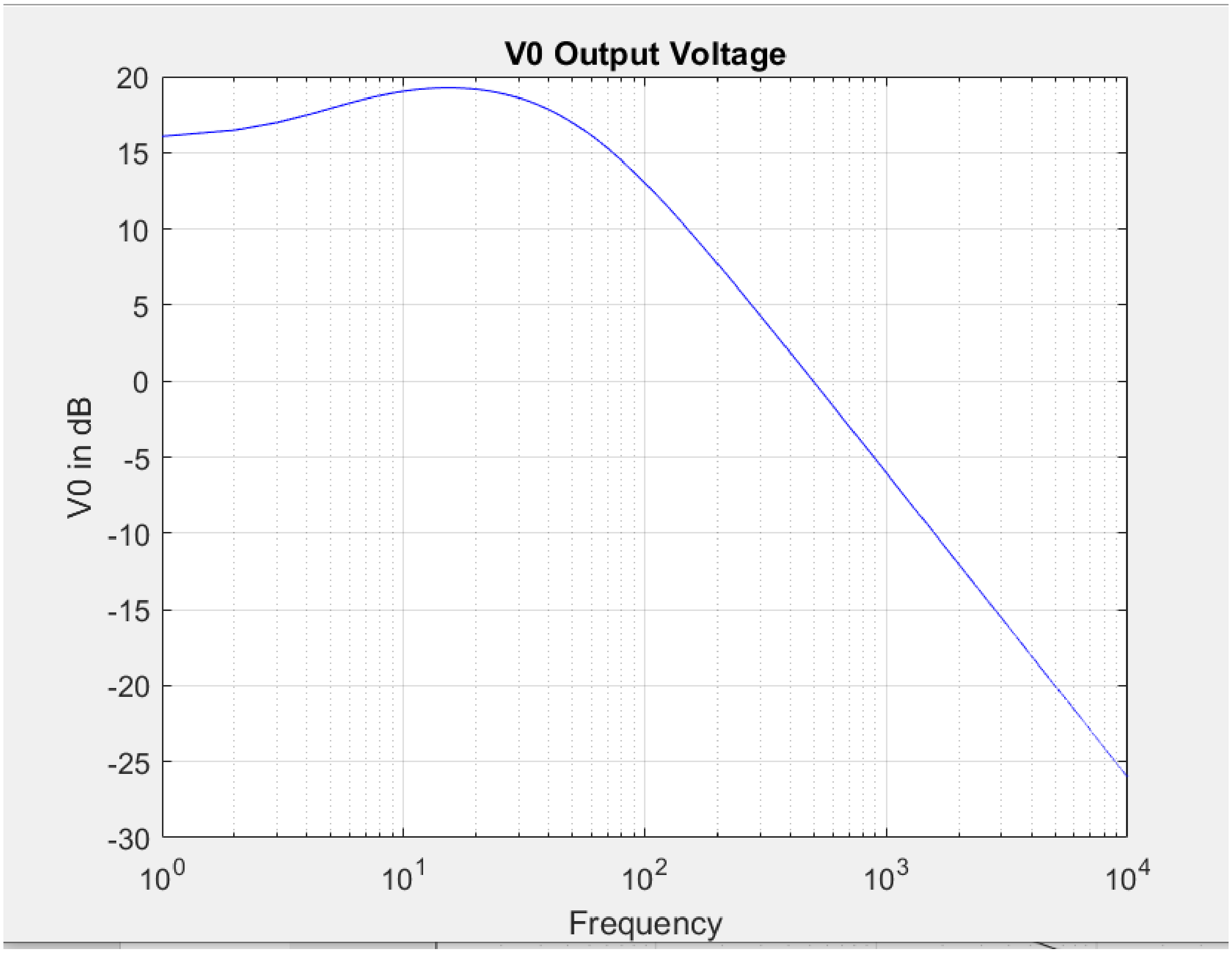
Using these matrices MATLAB can calculate a few things about the circuit. First a DC sweep was done to get the following result for the output voltage and the V3 voltage.



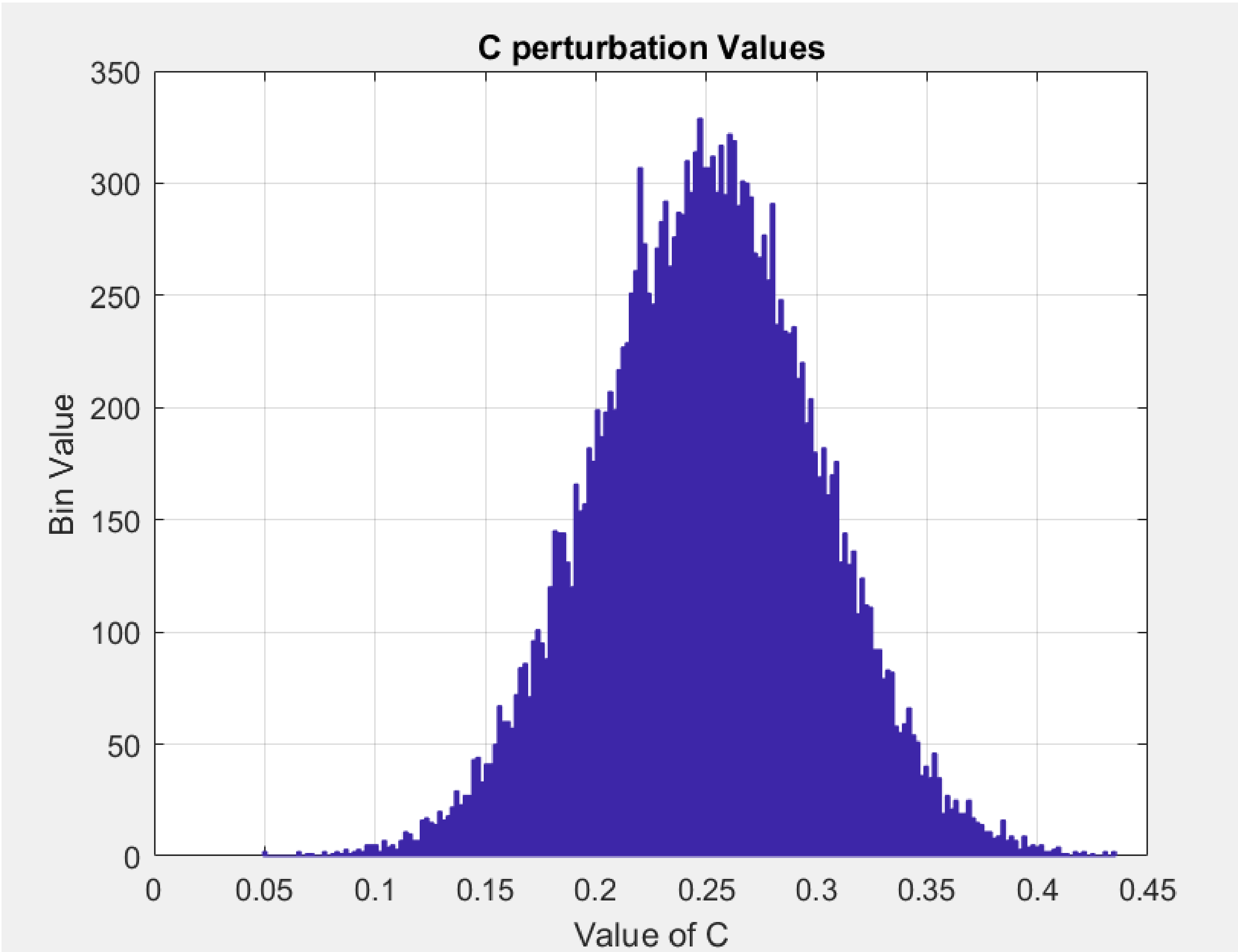
Next the frequency was swept to see the phase and magnitude response in V/V and in dB

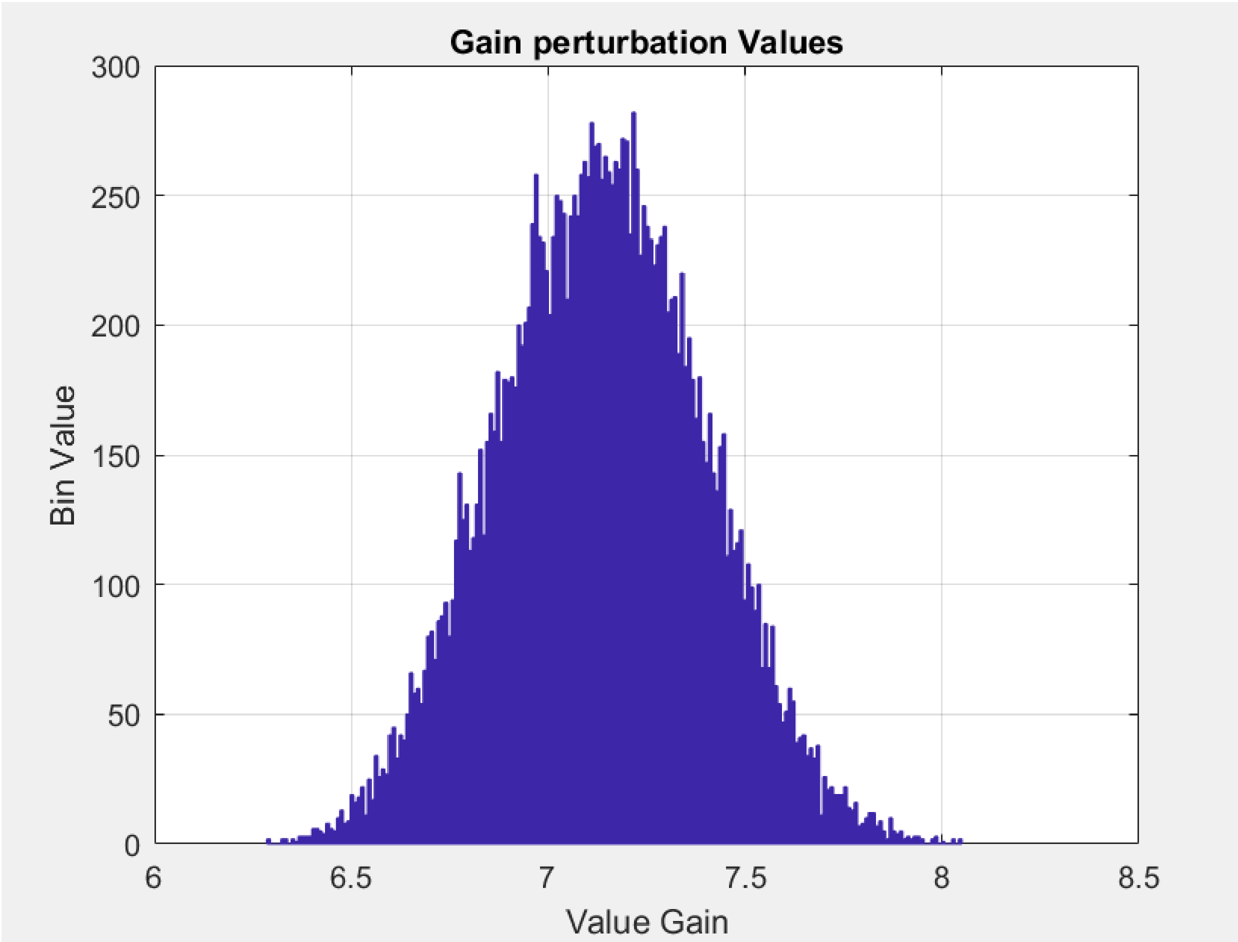

V0 as Function of Frequency
V0
Frequency
10
9
8
7
6
5
4
3
2
1
0
10^0
10^1
10^2
10^3
10^4


V0 Phase
Phase
Frequency
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
10^0
10^1
10^2
10^3
10^4



By using perturbations in the C value, a histogram of the perturbations and how they effect the circuit's gain are shown below.


C perturbation Values
Bin Value
Value of C
0
50
100
150
200
250
300
350
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45



Part 4: Transient Circuit Analysis

(a)

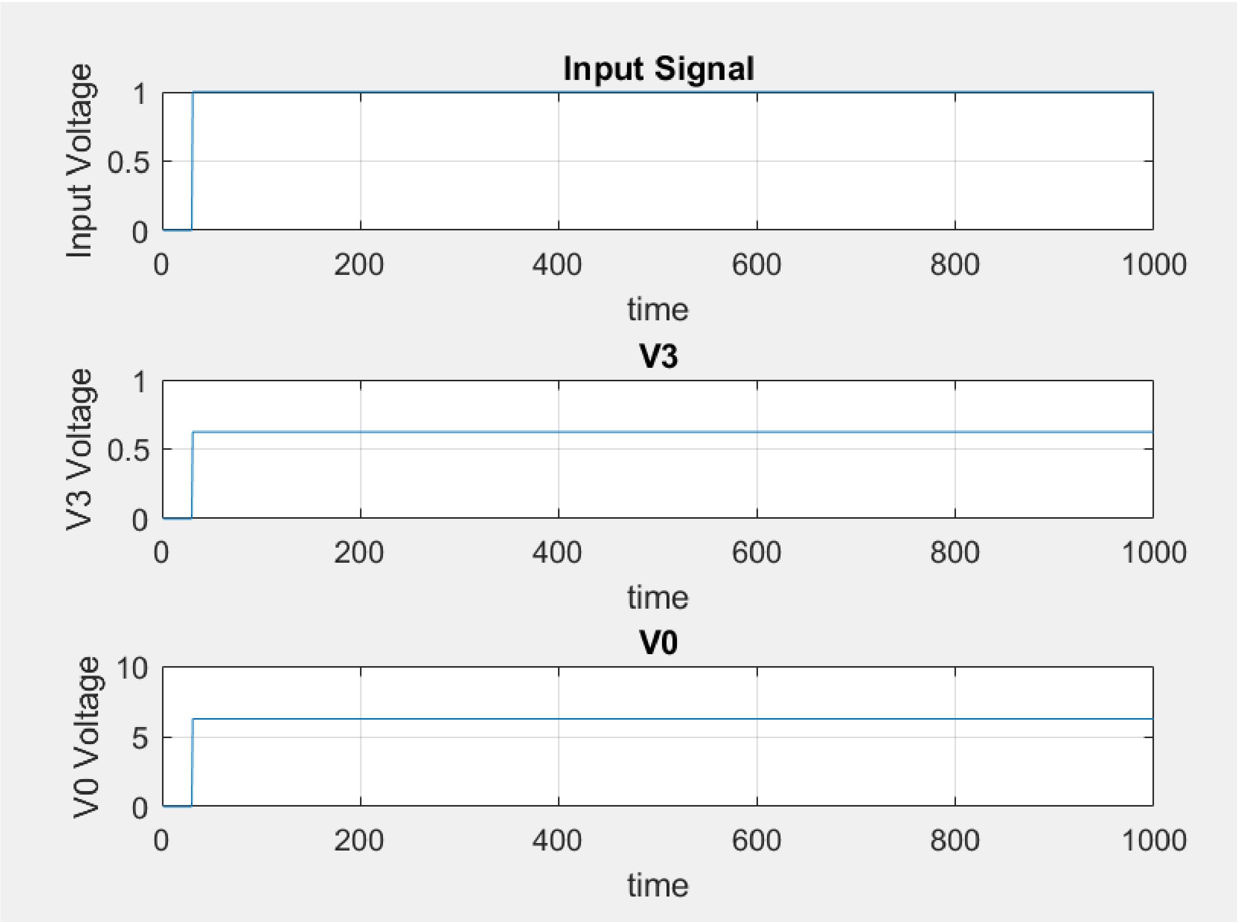
By inspection this looks like some type of small signal model which is essentially a current controlled voltage source with a few equivalent internal components.

(b)

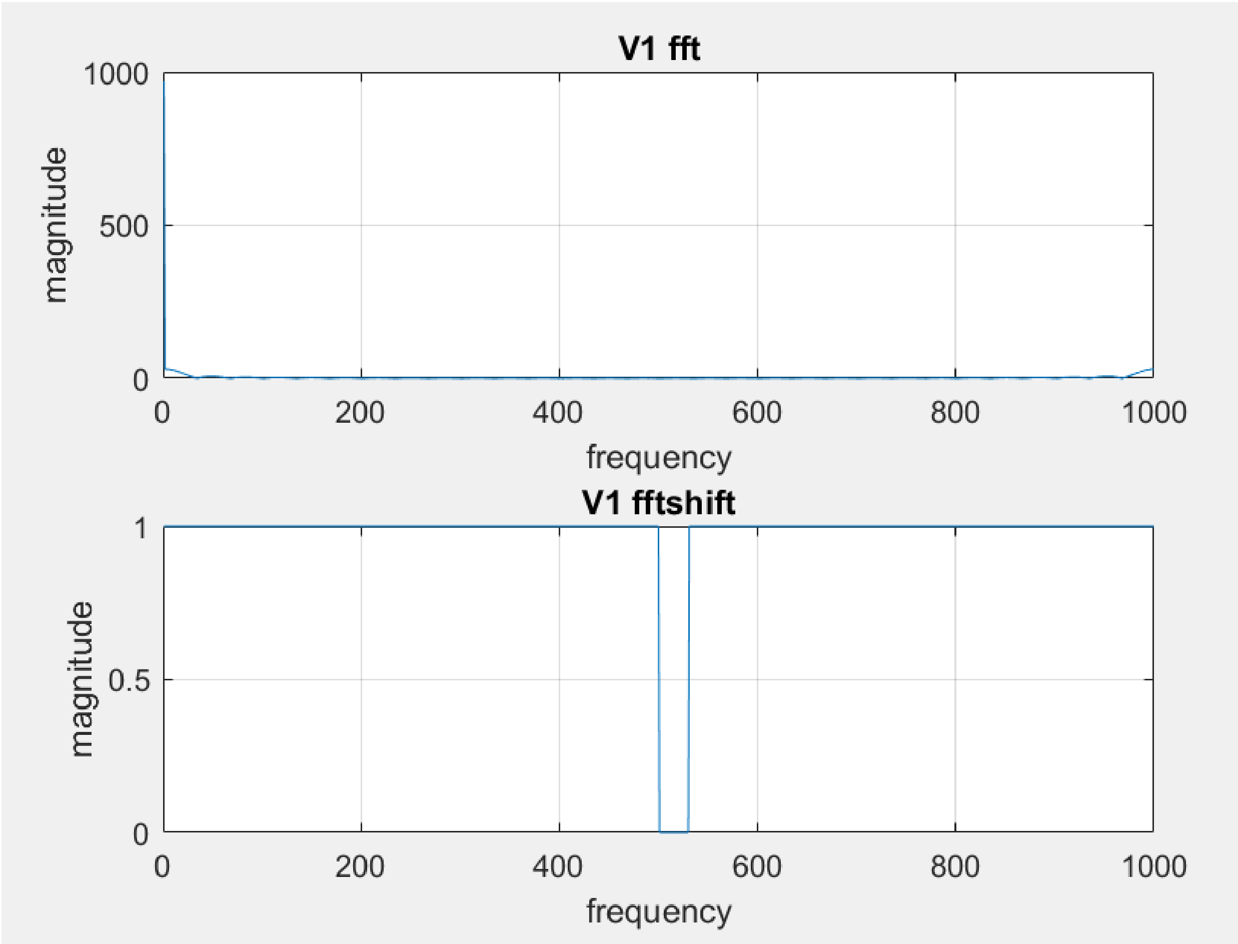
The frequency response from this circuit is a low pass filter so it is expected that high frequencies are attenuated and lower frequencies are amplified. The reason the circuit has different gain values over the frequency spectrum is due to the inductor and capacitor added in the circuit which are energy storing elements. These elements and the resistance values can be used to determine the corner frequencies which may overlap or be complex.

(c)

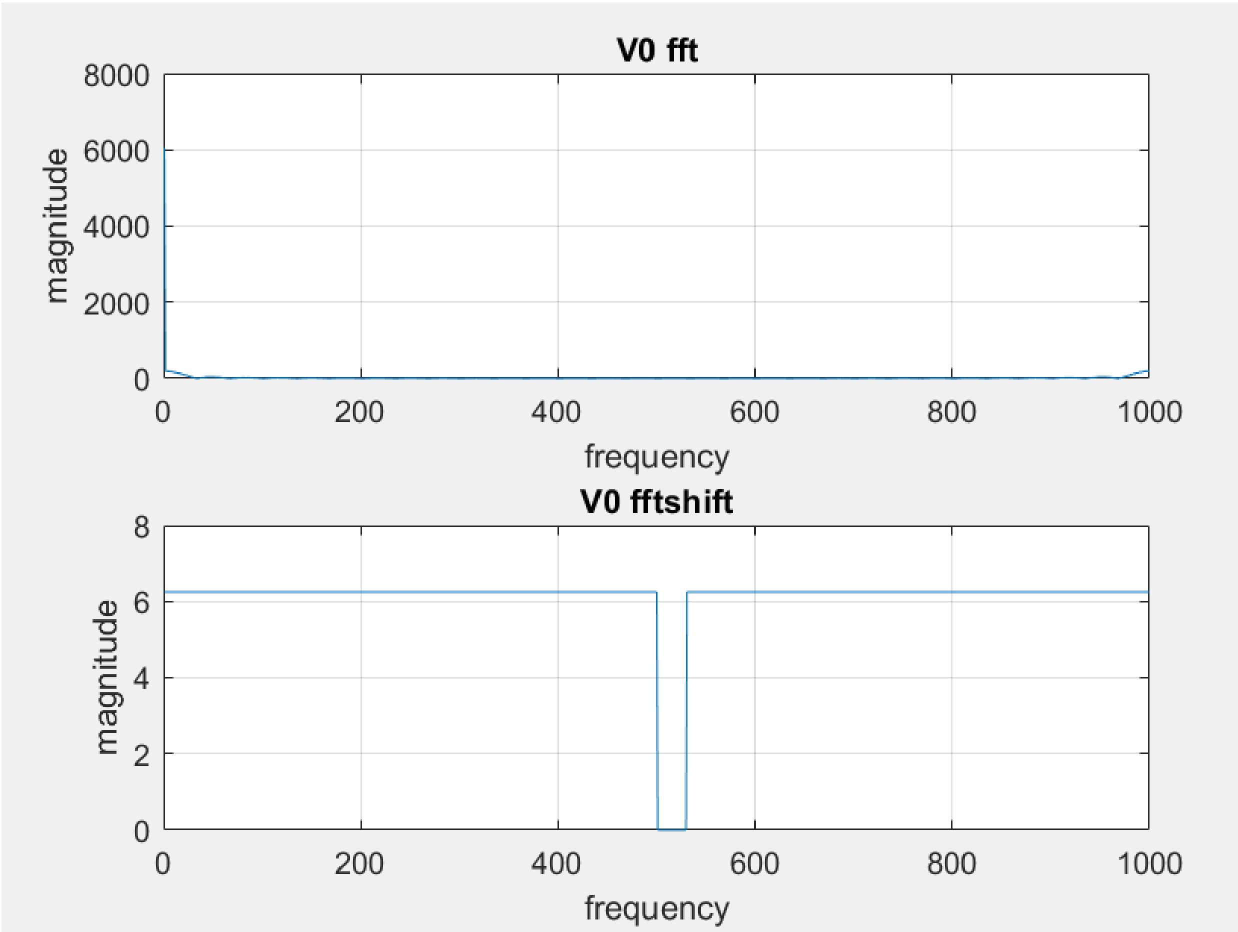
Step function at 0.03 seconds with all time being in milliseconds.



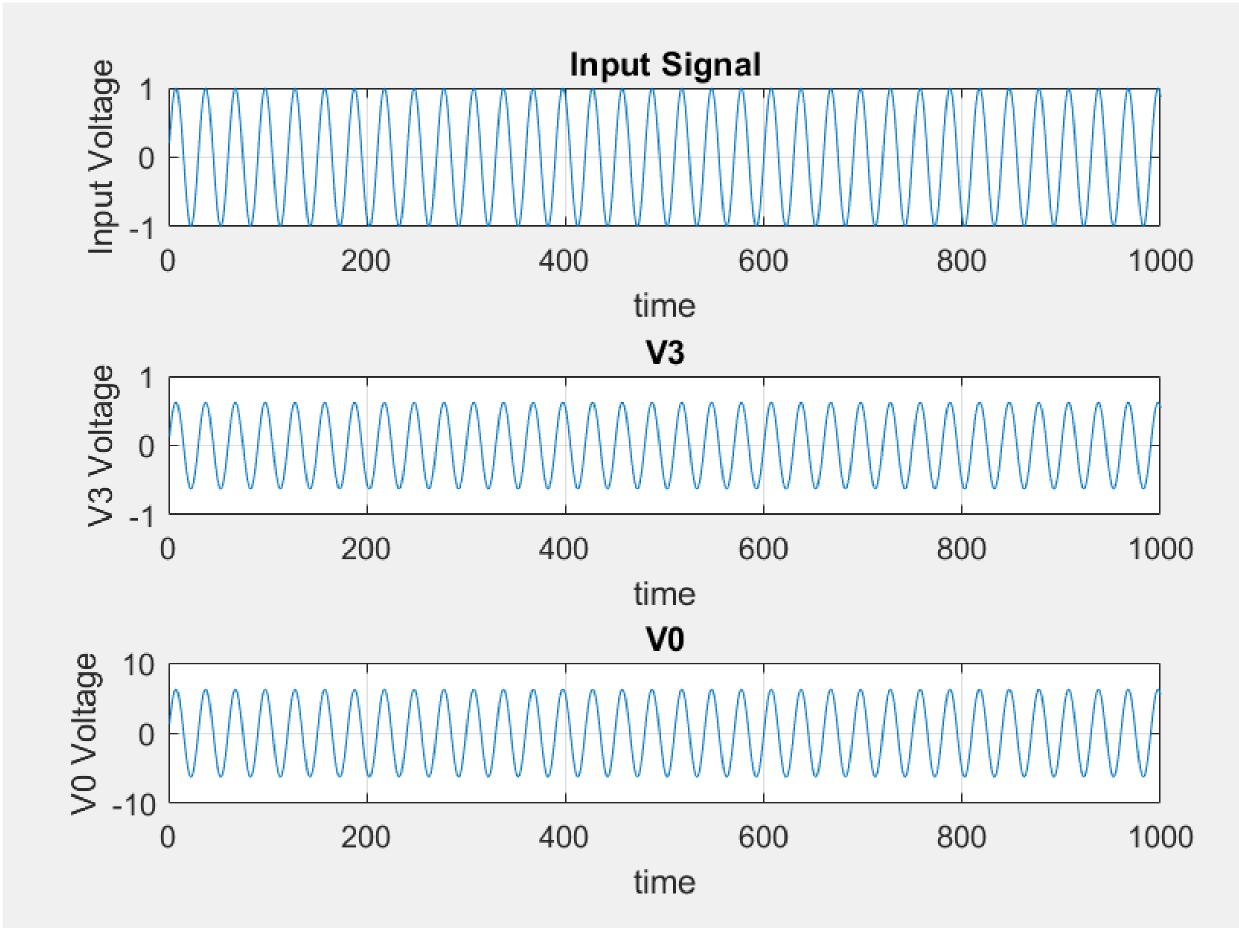
The fast fourier transform and the fftshift() function can be used to get the following result which is the signals in the frequency domain.



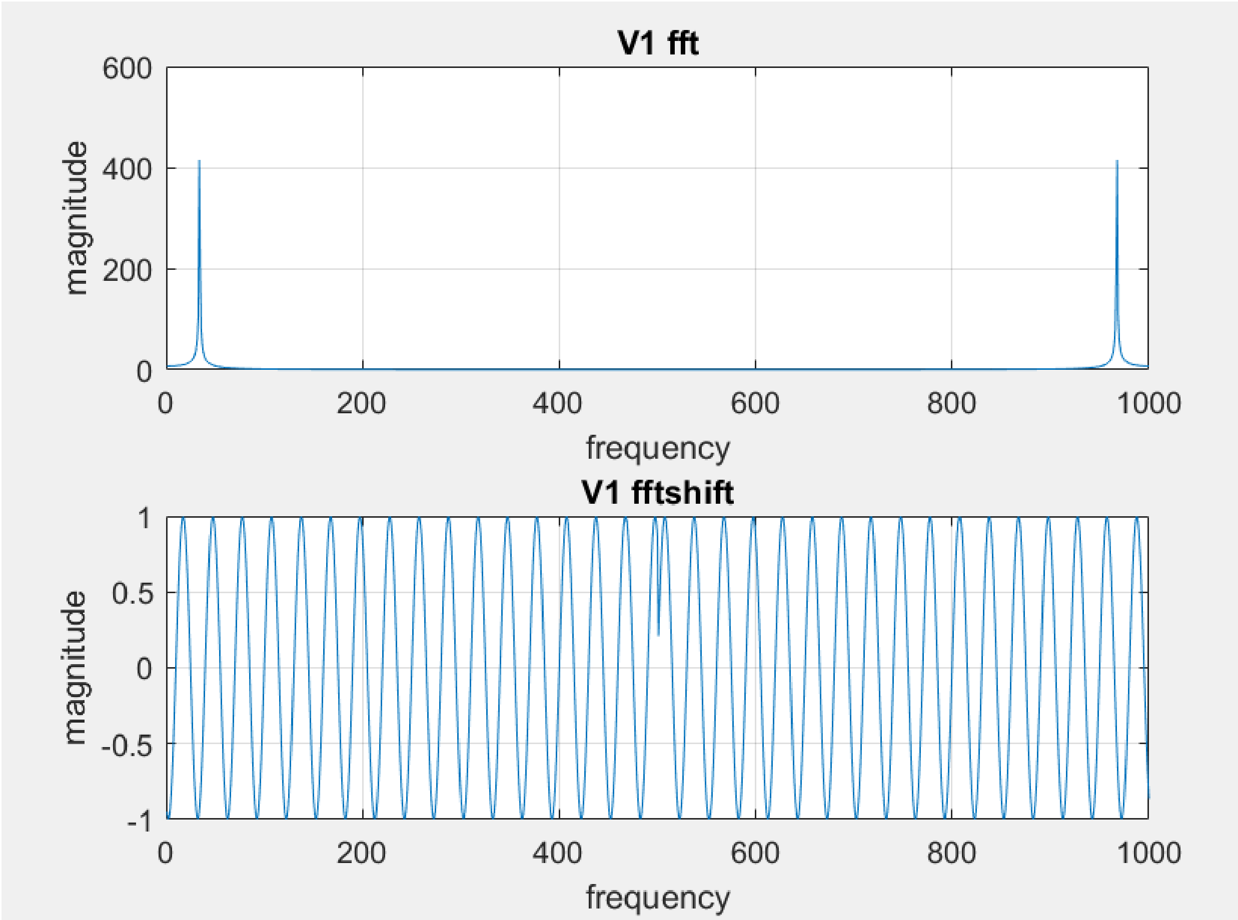
V1 fft
magnitude
1000
500
0
0
200
400
600
800
1000
frequency
V1 fftshift
magnitude
1
0.5
0
0
200
400
600
800
1000
frequency

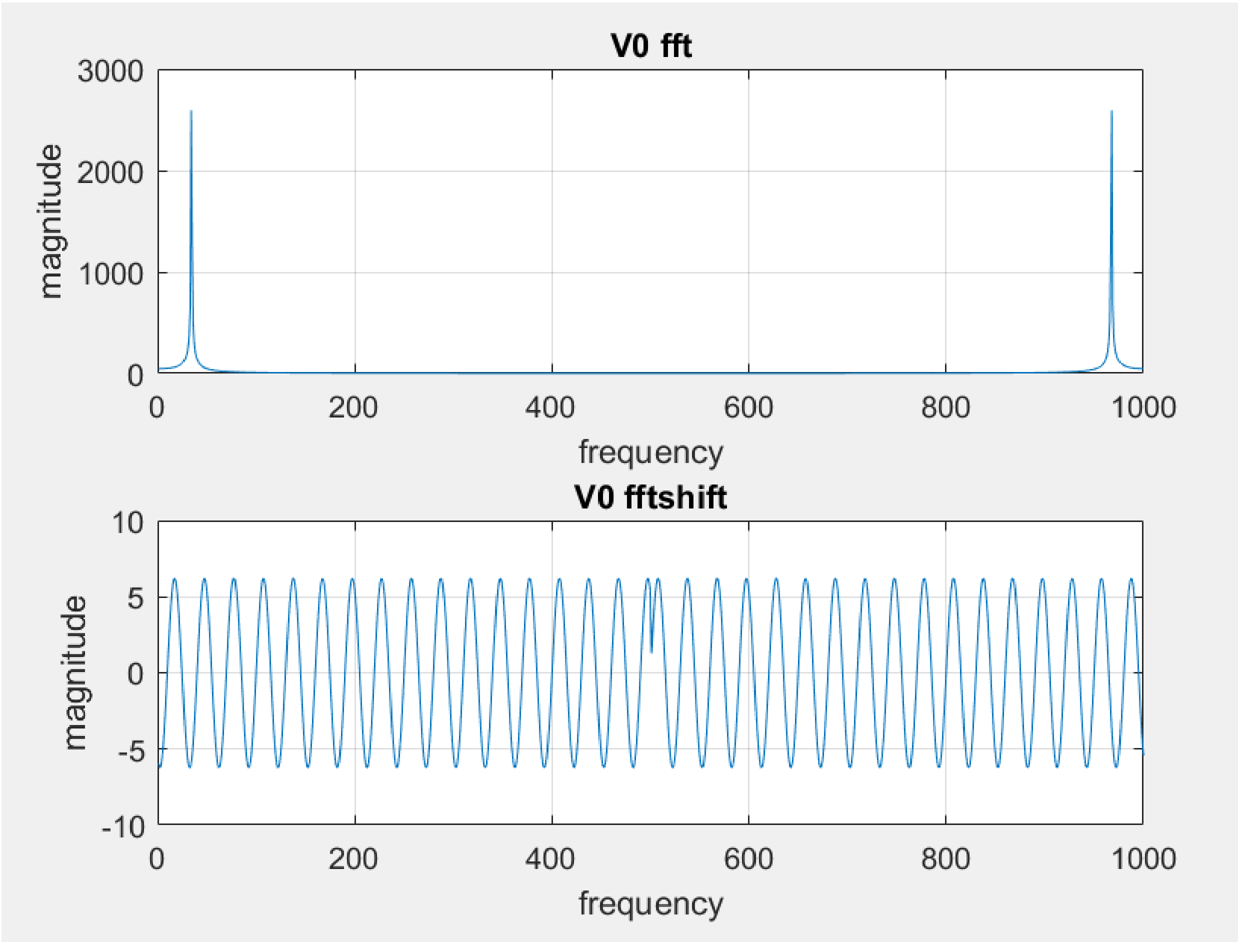


Using a Sine function with f = 1/0.03 seconds as the input the

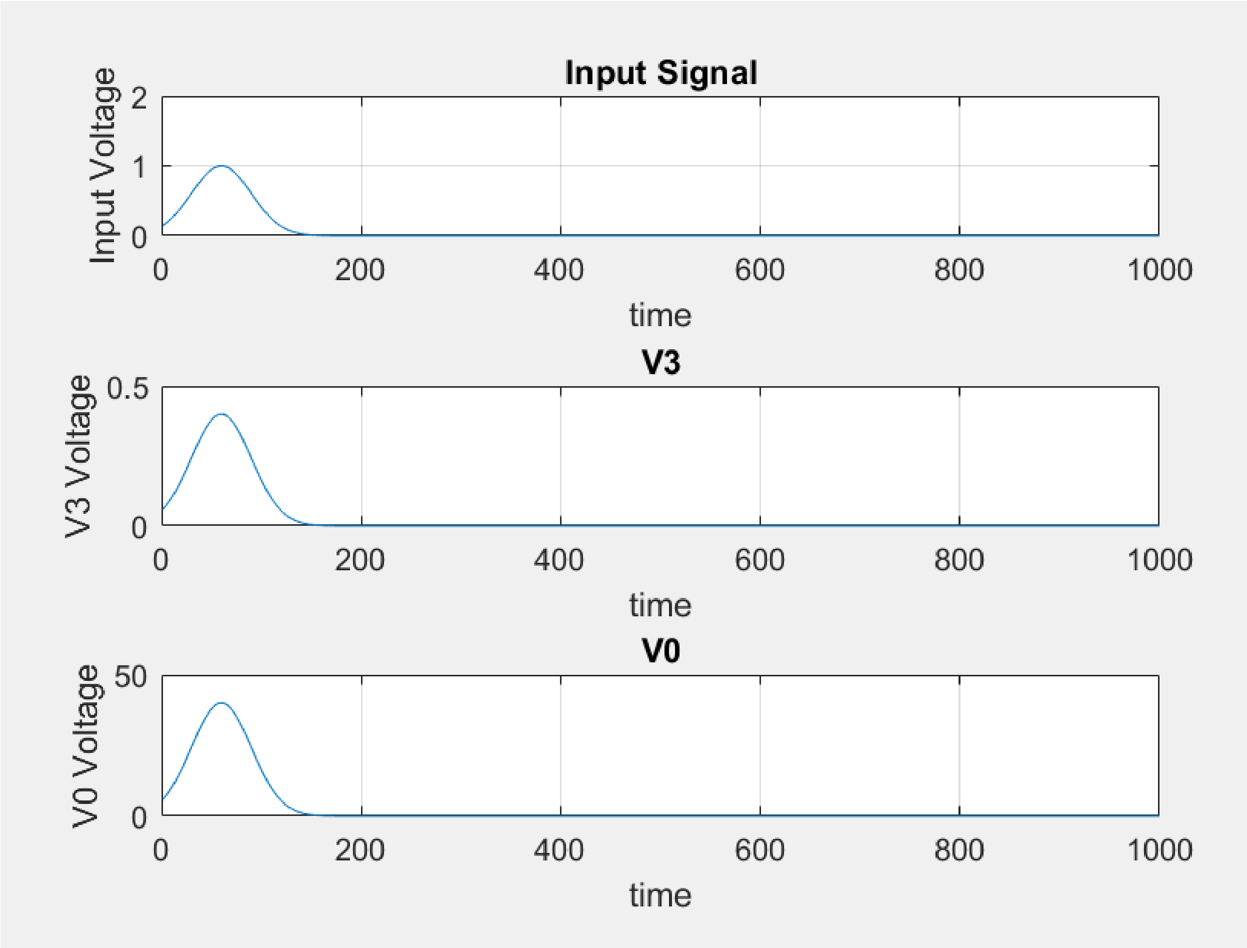


The fft and fftshift are shown here

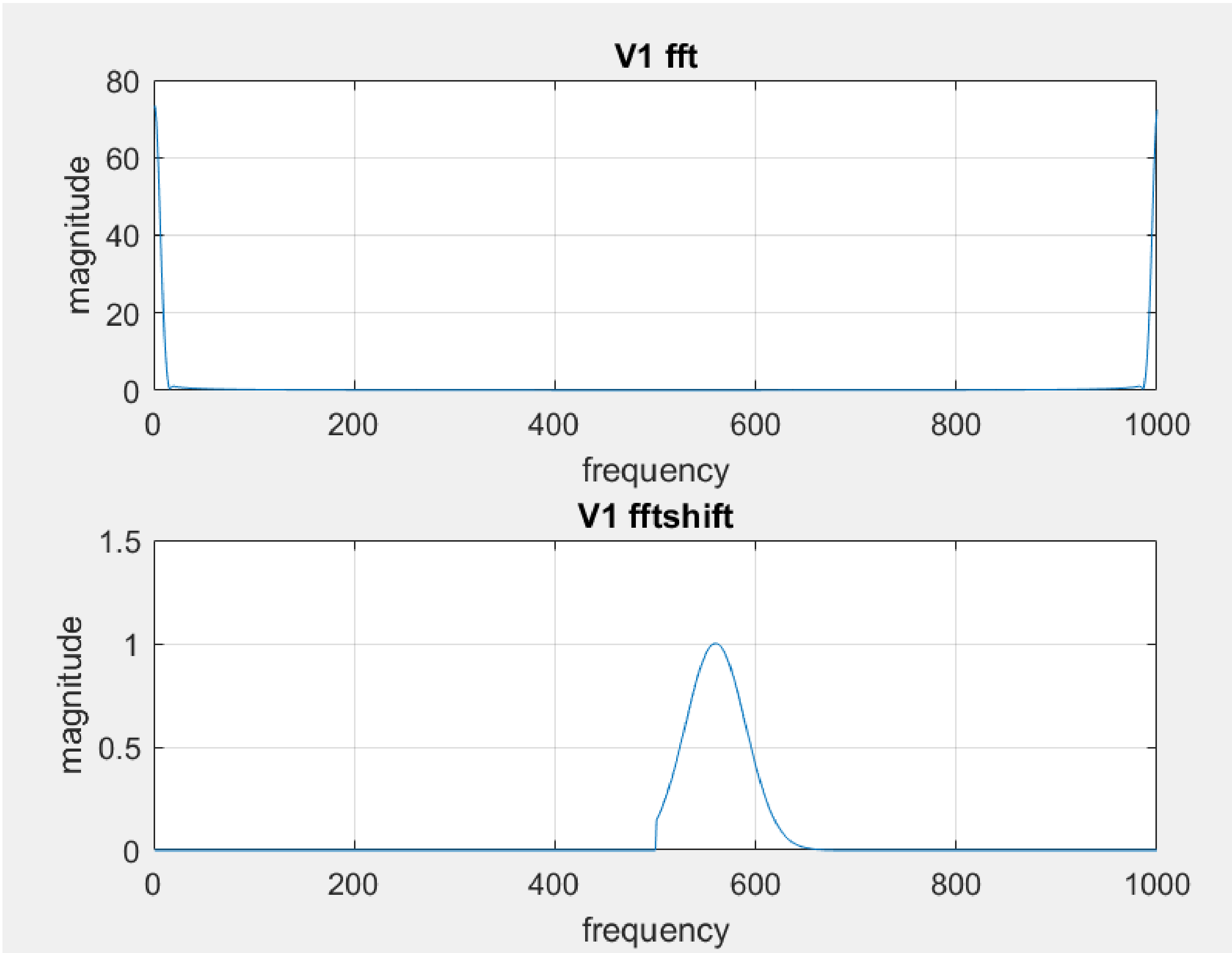

V1 fft
600
400
200
0
magnitude
0
200
400
600
800
1000
frequency
V1 fftshift
1
0.5
0
-0.5
-1
magnitude
0
200
400
600
800
1000
frequency

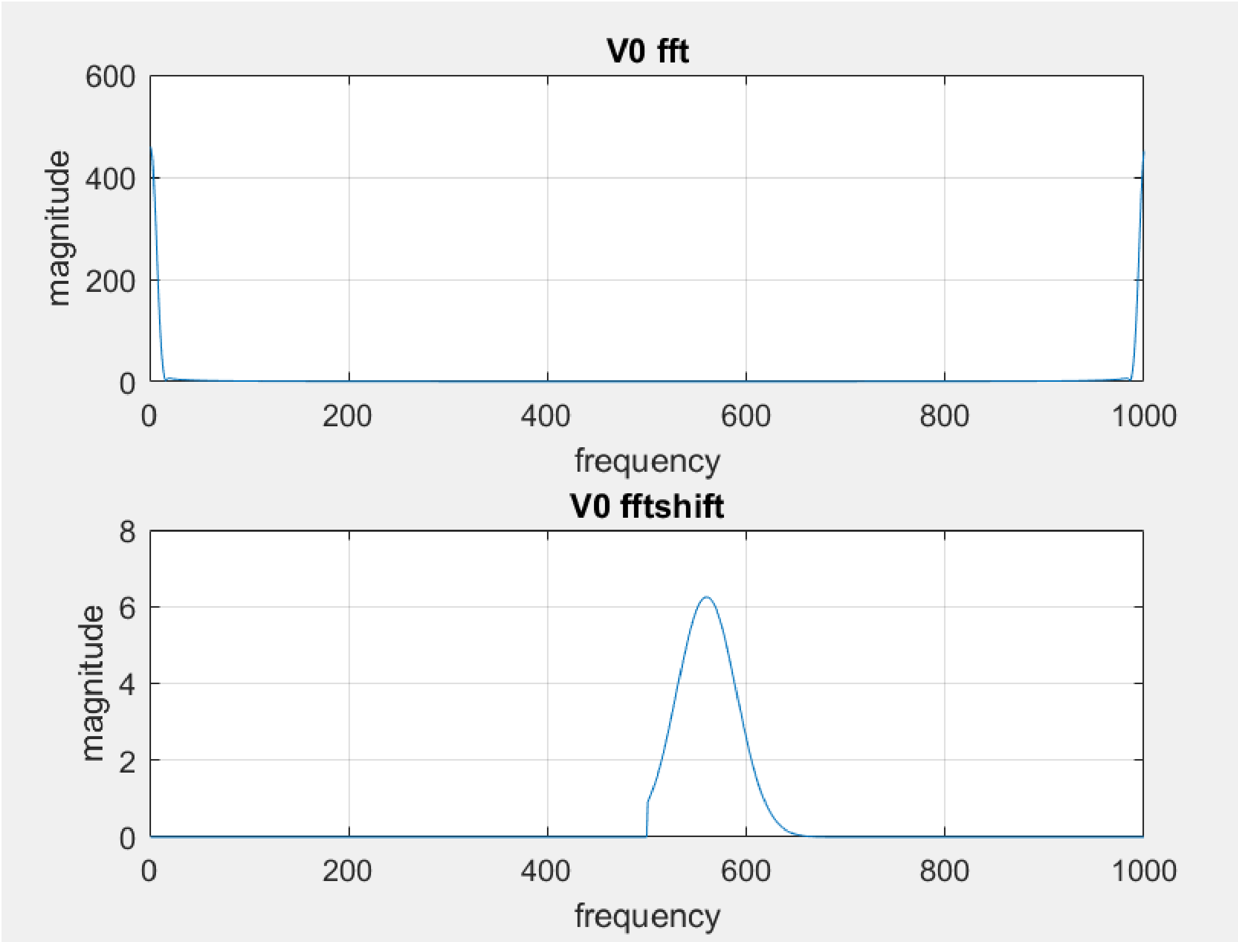


When the input is gaussian pulse,



The frequency domain signals for the input and output are shown here


V1 fft
magnitude
0
20
40
60
80
0
200
400
600
800
1000
frequency
V1 fftshift
magnitude
0
0.5
1
1.5
0
200
400
600
800
1000
frequency



From these plots it seems like the frequency filtering response effects the signal in the time domain if the frequency component of the signal is attenuated by the circuit.

Part 5: Circuits with Noise

Part 6: Non-Linear Circuit Elements