Carleton University

Department of Electronics

ELEC 4700

Assignment 4

Circuit Modelling

Student Name: Saifuddin Mohammed

Student Number: 101092039

1. ***Introduction***

The fourth and the final assignment of the semester involves the application of principles and concepts associated with Modified Nodal Analysis to perform DC and AC Analysis of a linear circuit. The circuit utilized for this assignment is given in Figure 1 below.

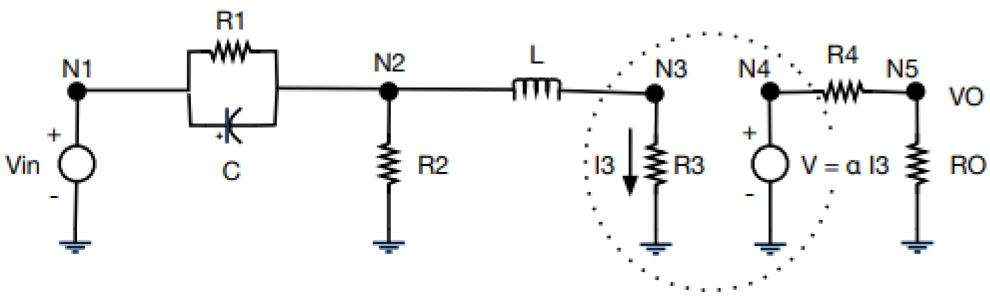

Figure 1: Schematic of the Linear Circuit Utilized

The schematic has been adapted from the Assignment instructions manual. The assignment comprises of 3 modules each requiring the application of the MNA techniques for the analysis of the linear circuit and exploration of non-linearities.

The calculations, code and atomistic simulations required for this assignment were completed with the aid of MATLAB. The report discusses the techniques applied and results obtained after the completion of the assignment.

2. ***Results and Discussion***

The assignment consisted of 3 sections requiring MATLAB programming for each. The sections covered in the assignment are:

- Utilization of PA 9 material for circuit analysis using MNA techniques.
- Modelling of the noise to the circuit.
- Non- Linearity of the Circuit

The results obtained for each part have been discussed in this report.

1. Report on the Work Done in PA9

a) Formulation

The first module of the assignment involved formulation of the KCL associated with the circuit and determination of the G and C matrices. Prior to the formulation, the assignment 3 was for the bottle neck was swept from 0.1 V to 10V in order to determine the value of R3 for the circuit shown in Figure 1. The resultant value of R3 obtained was 25 Ohms which was not consistent with the expectations. Therefore, the value of 10 Ohms, which was provided in the PA9 was utilized instead. The linear fit performed with the assignment 3 code has also been included.

The G and C matrices for the system were determined to be as follow: -

```
G =

    1.0000         0         0         0         0         0         0
   -1.0000    1.5000         0         0         0    1.0000         0
         0         0    0.0400         0         0   -1.0000         0
         0         0   -4.0000    1.0000         0         0   -1.0000
         0         0         0  -10.0000   10.0010         0         0
         0   -1.0000    1.0000         0         0         0         0
         0         0         0    1.0000         0         0 -100.0000
```

```
C =

         0         0         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    0.2000         0
         0         0         0         0         0         0         0
```

The G and C matrices have dimensions of 7x7 as there are 7 equations.

The break down of both G and C matrices is given as:

- The G matrix:

```
G(1,:)=[1 0 0 0 0 0 0];
G(2,:)=[(-1/R_1) (1/R_2+1/R_1) 0 0 0 1 0];
G(3,:)=[0 0 1/R_3 0 0 -1 0];
G(4,:)=[0 0 -1*aL/R_3 1 0 0 -1];
G(5,:)=[0 0 0 -1/R_4 (1/R_4+1/R_0) 0 0];
G(6,:)=[0 -1 1 0 0 0 0];
G(7,:)=[0 0 0 1 0 0 -aL];
```

- The C matrix

```
C(1,:)=[0 0 0 0 0 0 0];
C(2,:)=[-C_1 C_1 0 0 0 0 0];
C(3,:)=[0 0 0 0 0 0 0];
C(4,:)=[0 0 0 0 0 0 0 ];
C(5,:)=[0 0 0 0 0 0 0];
C(6,:)=[0 0 0 0 0 L_1 0 ];
C(7,:)=[0 0 0 0 0 0 0];
```

The next part required programming to determine the AC and DC response of the circuit.

b) Programming

i. The first requirement for this section was to perform the DC analysis of the circuit. This was done by sweeping the voltage V1 from -10V to 10V. The output voltage V0 and the voltage V3 were plotted as well, and the DC analysis was performed.

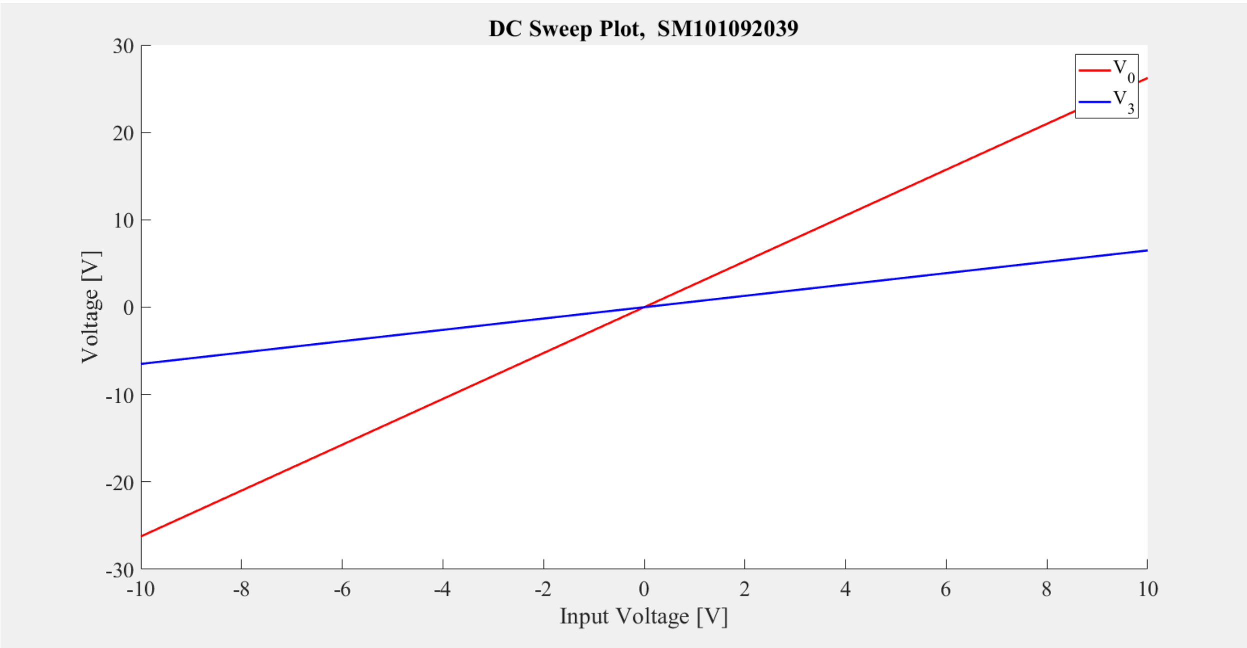

Figure 2: DC Response of the Circuit.

The plot in figure 2 depicts V0 and V3 after the voltage at node 1 V1 was swept from the -10V to 10V.

ii. The second step involved the analysis of the parameters associated with the AC components of the circuit. The output Voltage V_0 of the circuit was plotted as a function of the angular frequency, **ω.**

The plot shown in figure 3 below depicts the variation of the V_0 with respect to **ω.**

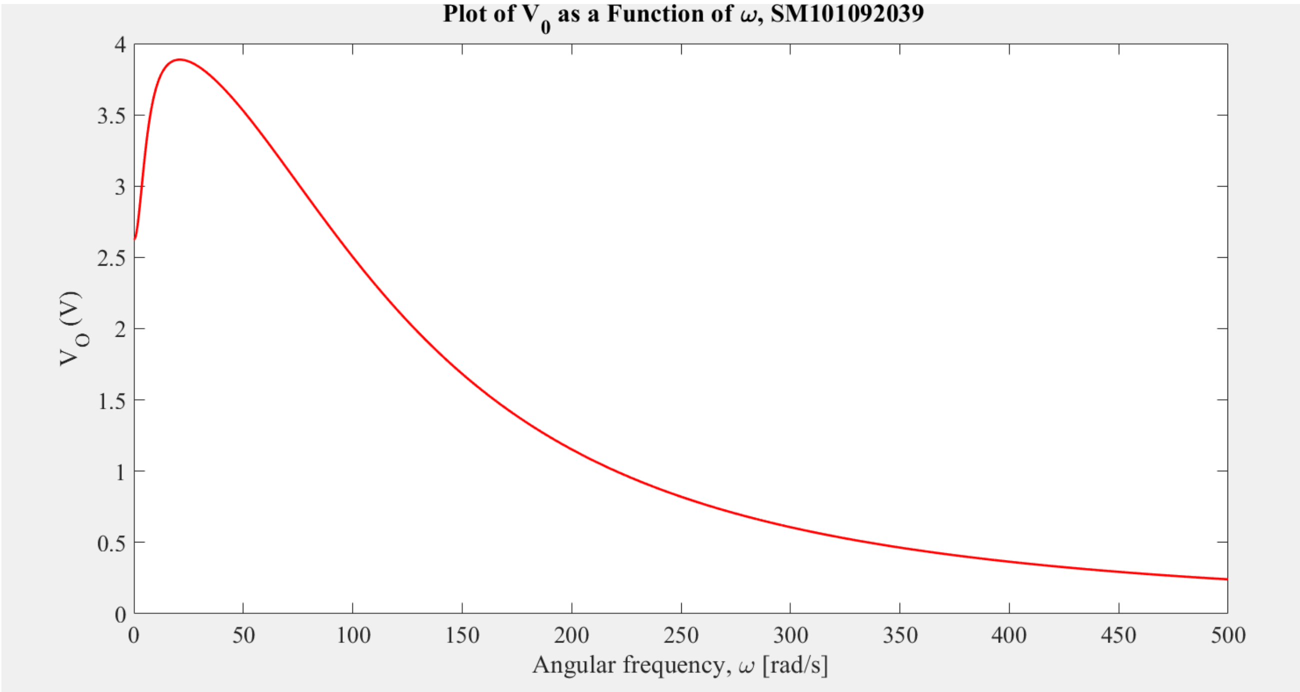

Figure 3: Plot of Output Voltage versus Angular Frequency

The variation of the gain with respect to **ω** was plotted as well.

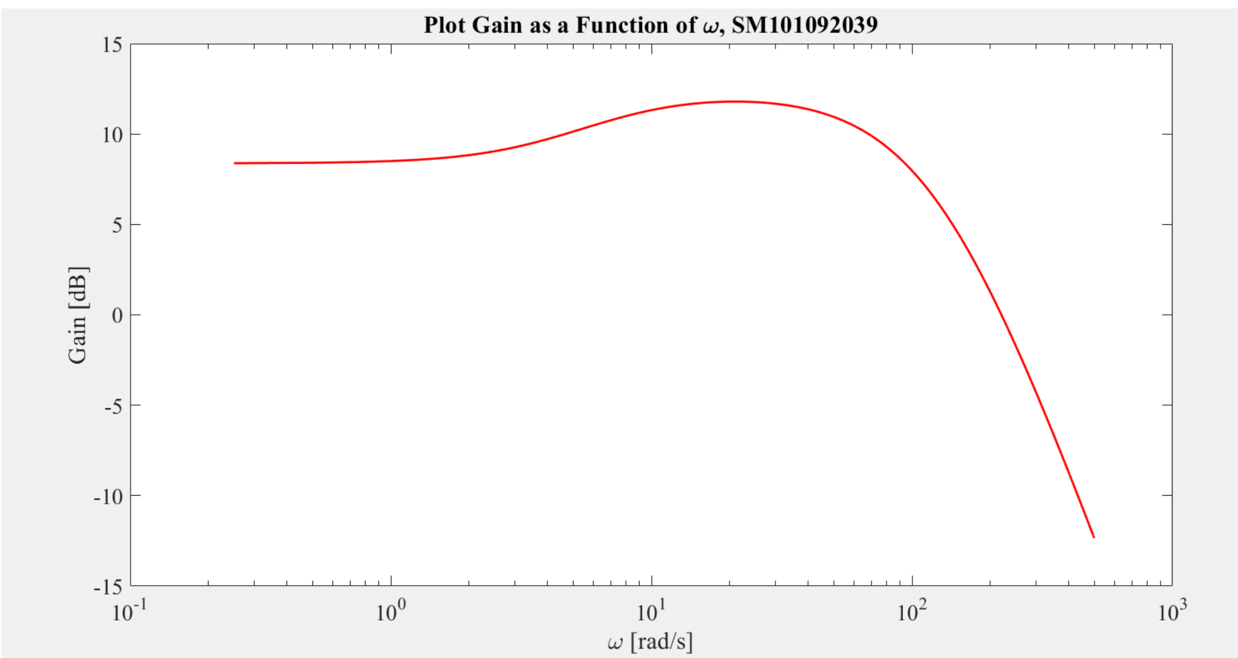

Figure 4: Plot of Gain versus ω.

The plot shown in figure 4 depicts the gain as a function of the angular frequency.

iii) The third step required generation of a histogram of the gain as a function of random perturbations on C.

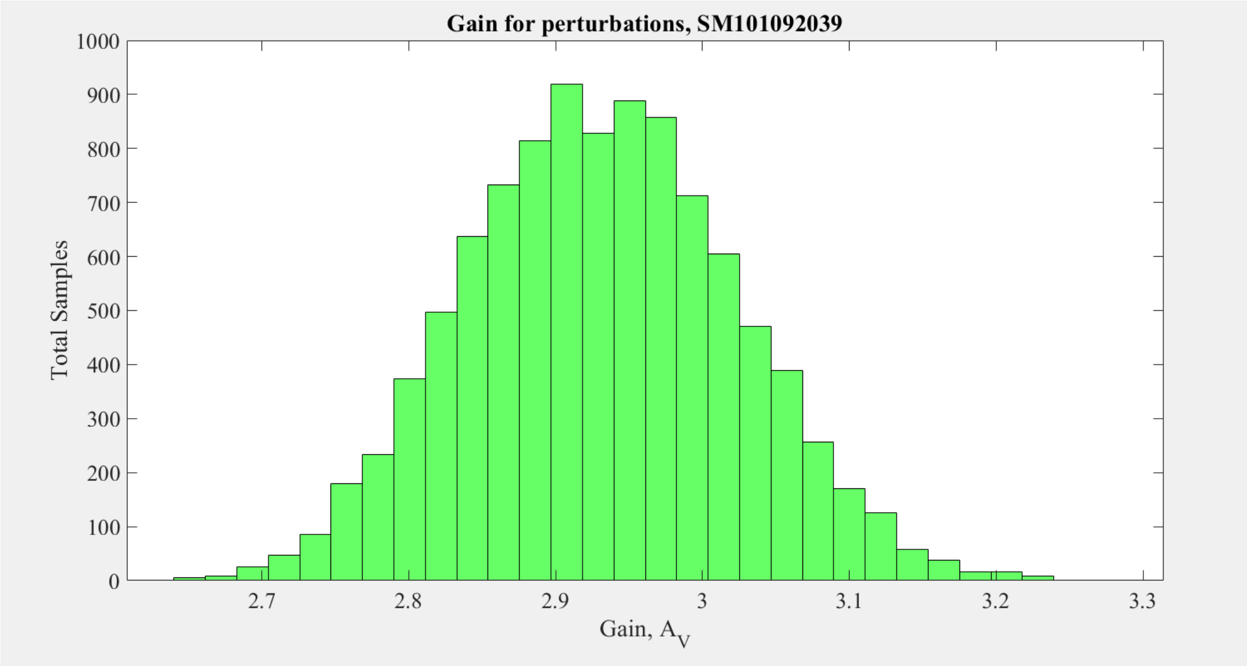

Figure 5: Histogram of the Gain.

The Figure 5 depicts the histogram of the gain as a function of random perturbations on the capacitors. The normal distribution process with a standard deviation of 0.05 was implemented in order to generate the histogram.

<u>Transient Analysis</u>

The next segment of the laboratory involved the transient analysis of the circuit. The circuit can be modelled in time using the equation given below:

$$\mathbf{C}\frac{d\mathbf{V}}{dt} + \mathbf{G}\mathbf{V} = \mathbf{F}$$

a) From the analysis of the response, it can be observed that the circuit's response is consistent with the operation of a high pass filter. Therefore, it can be concluded that the circuit operates as a high pass filter.

b) The frequency response would entail the rejection of any frequencies below the cutoff frequencies. Hence, high frequencies will pass through system and a high gain will also be observed at those frequencies.

c) The finite difference method can be utilized for determining the time domain representation of the equation above. The equation boils down to:

$$\mathbf{[C/dt + G]V(j)] = CV(j-1)/dt + F(t(j))}$$

The next part involved programming with MATLAB to analyze the transient response of the circuit.

The circuit was subjected to a supply of 3 different input signals. The results from the implementation have been discussed below.

- **Step Input**
  The circuit was supplied step input signal that would transition from 0 to 1 at 0.03.

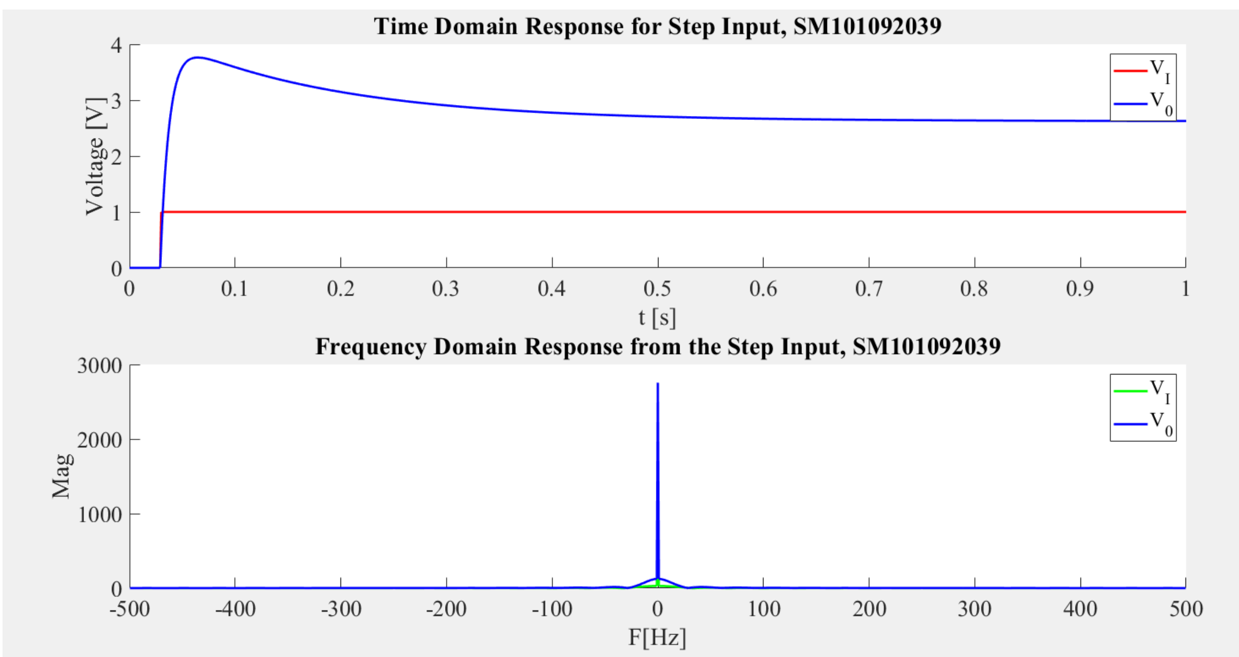

Figure 6: Time and Frequency Response with step Input.

The Figure 6 depicts the time and frequency domain response of the circuit when the step input signal was supplied. The Fast Fourier transformation was utilized to perform the conversion between time and frequency domain.

- **Sine Function Input**

The circuit was supplied a sine input signal with a frequency of 33.3 Hz.

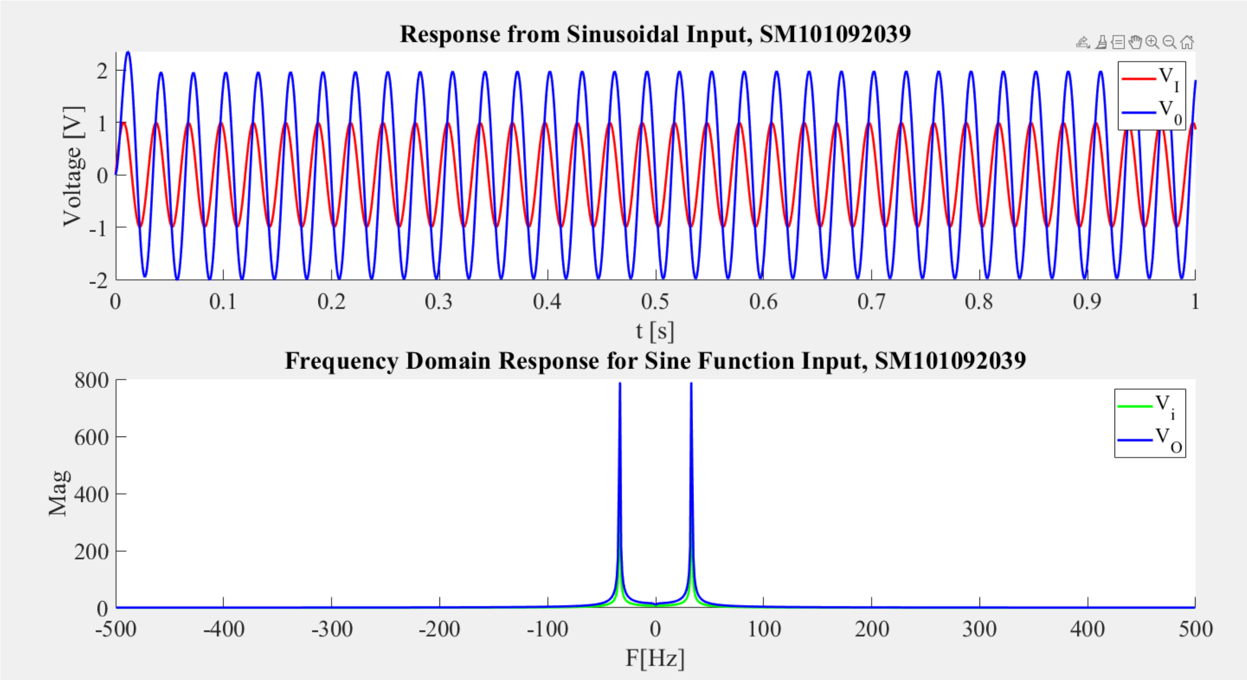

Figure 7: Time and Frequency Response with Sinusoidal Input.

The Figure 7 depicts the time and frequency domain response of the circuit when the sinusoidal input signal was supplied. The Fast Fourier transformation was utilized to perform the conversion between time and frequency domain.

- **Gaussian Pulse Input**

The circuit was supplied a gaussian input signal with a magnitude of 1, having a standard deviation of 0.03 s and a delay of 0.06s.

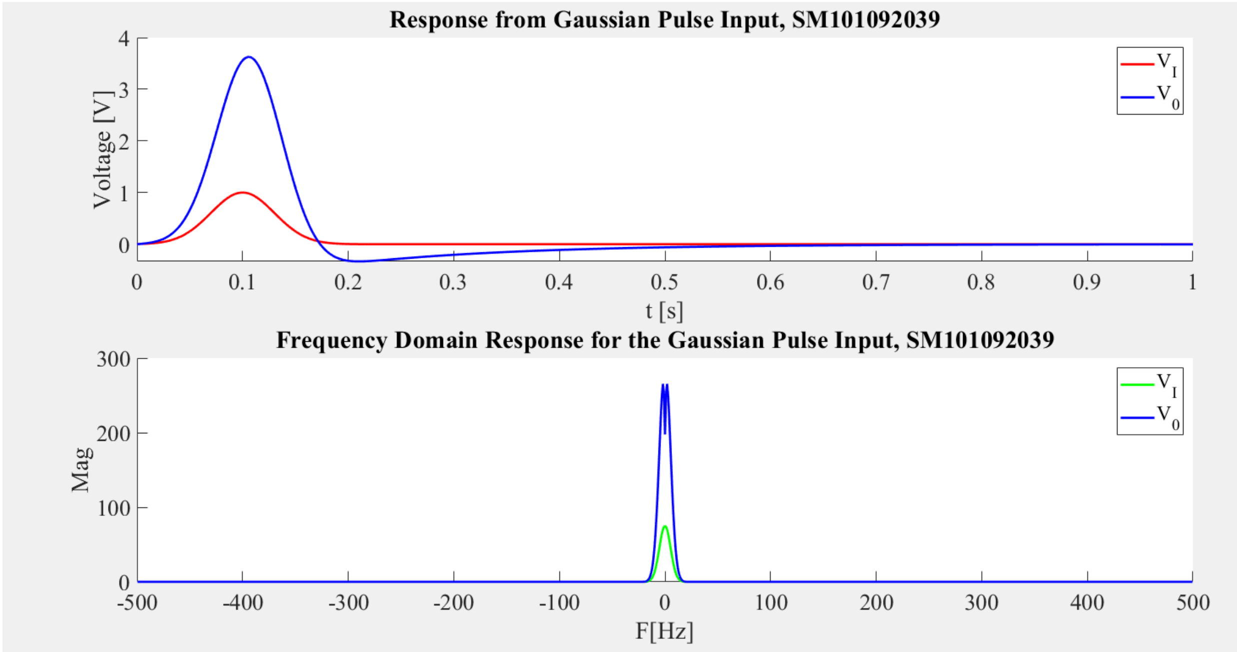

Figure 8: Time and Frequency Response with Gaussian Pulse Input.

The Figure 8 depicts the time and frequency domain response of the circuit when the gaussian input signal was supplied. The Fast Fourier transformation was utilized to perform the conversion between time and frequency domain.

The associated time step was also increased from 1000 to 10000. The generated results showed that response for the gaussian input was much smoother with a greater time step. Beyond 10000 steps, the simulation is not feasible due to limited bandwidth.

2. Circuit With Noise

The second module of the laboratory required modelling of the noise to the circuit. A current source was added in parallel with the resistor R3. A capacitor was also connected in parallel with the resistor. This was done in order limit the noise bandwidth.

The C matrix was updated as a result of the addition o the new capacitor. The updated C matrix is:

```
C = [0 0 0 0 0 0 0;
     -C_1 C_1 0 0 0 0 0;
     0 0 C_n 0 0 0 0;
     0 0 0 0 0 0 0;
     0 0 0 0 0 0 0;
     0 0 0 0 0 L_1 0;
     0 0 0 0 0 0 0];
```

The noise was added to the circuit and the response of the circuit was analyzed. The current source, In was set to 0.001 and the Cn capacitor was set to 0.00001.

The circuit was utilized to the model the output signal with noise utilizing the gaussian exication.

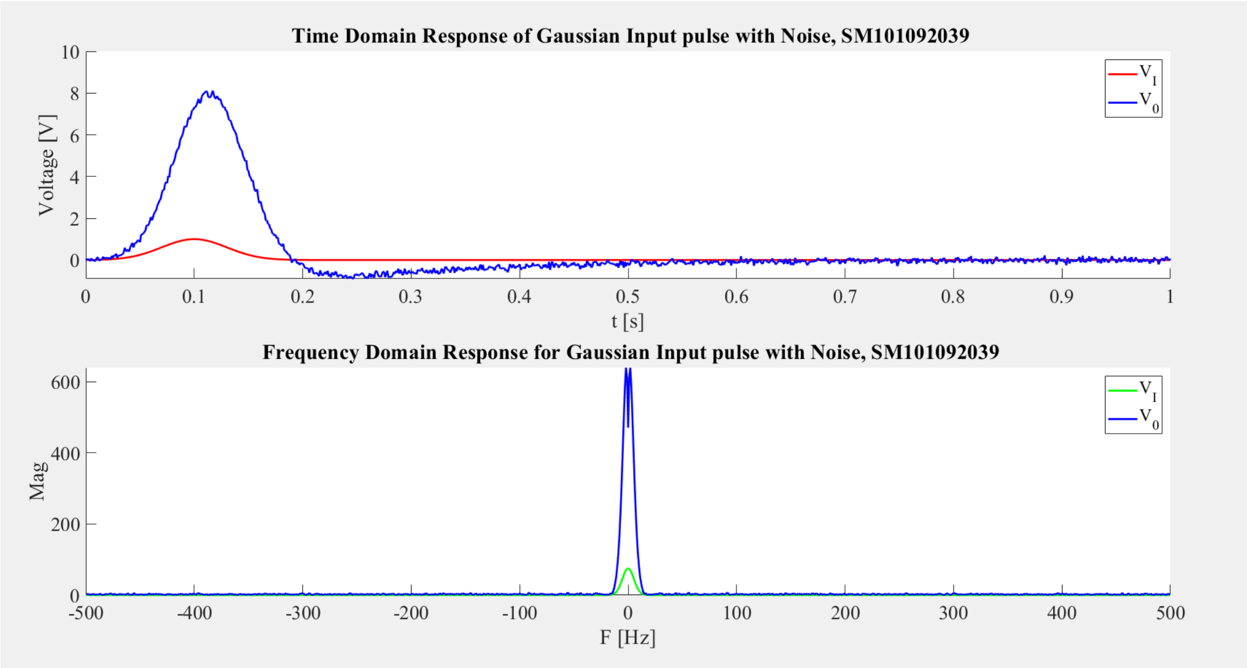

Figure 9: Response of the circuit with noise

The Figure 9 depicts the time and frequency domain response of the circuit with noise associated with a gaussian pulse. The fast Fourier transformations were utilized to move between time and frequency domains.

The circuit was also simulated with different values of the capacitors to analyze the response. The results obtained from simulating different values of the capacitors have been given below.

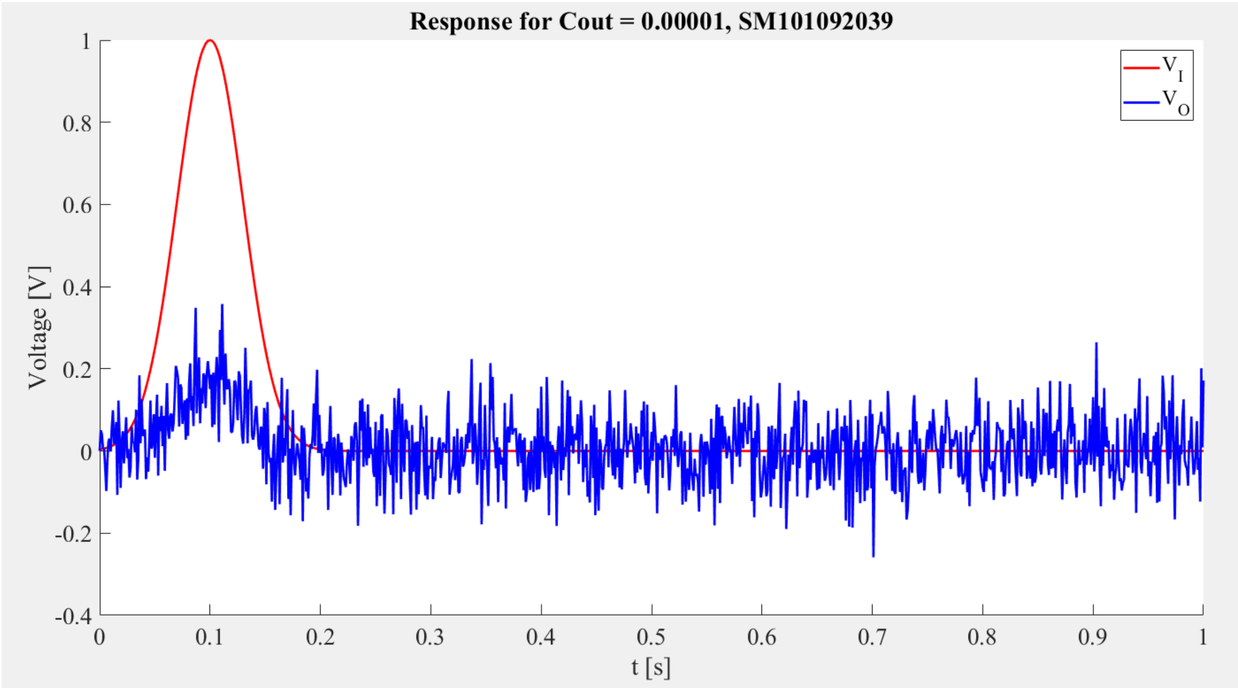

Figure 10: Response with Cn = 0.0001.

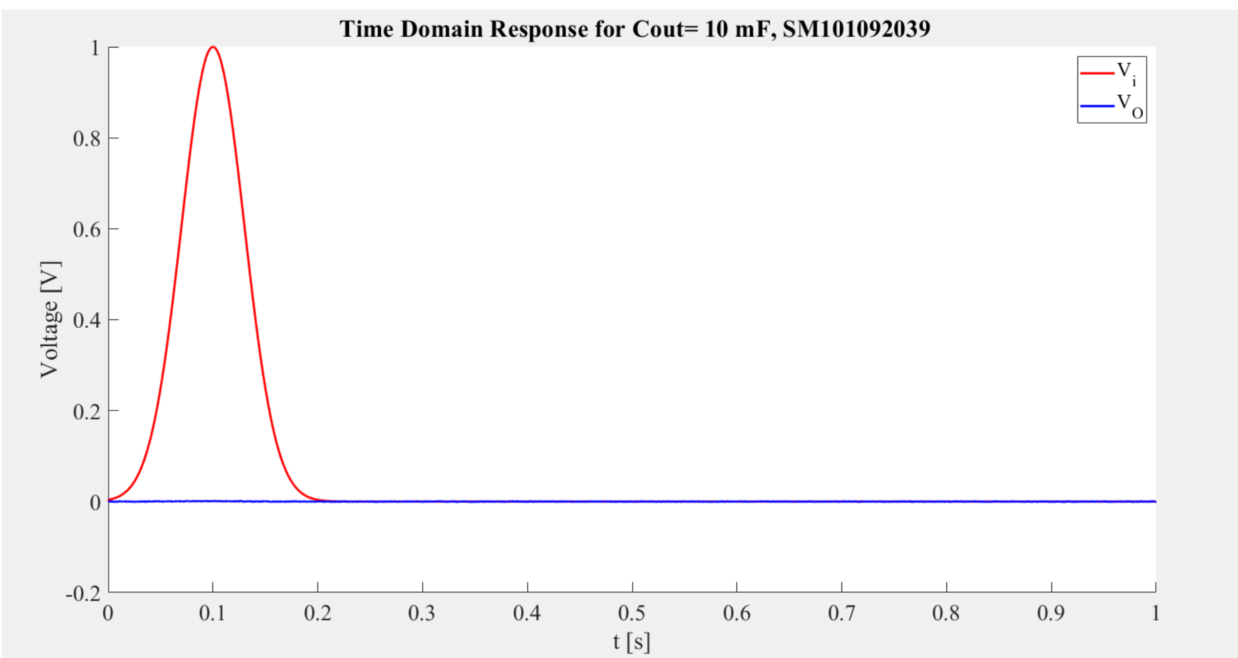

Figure 11: Response with Cn = 10mF.

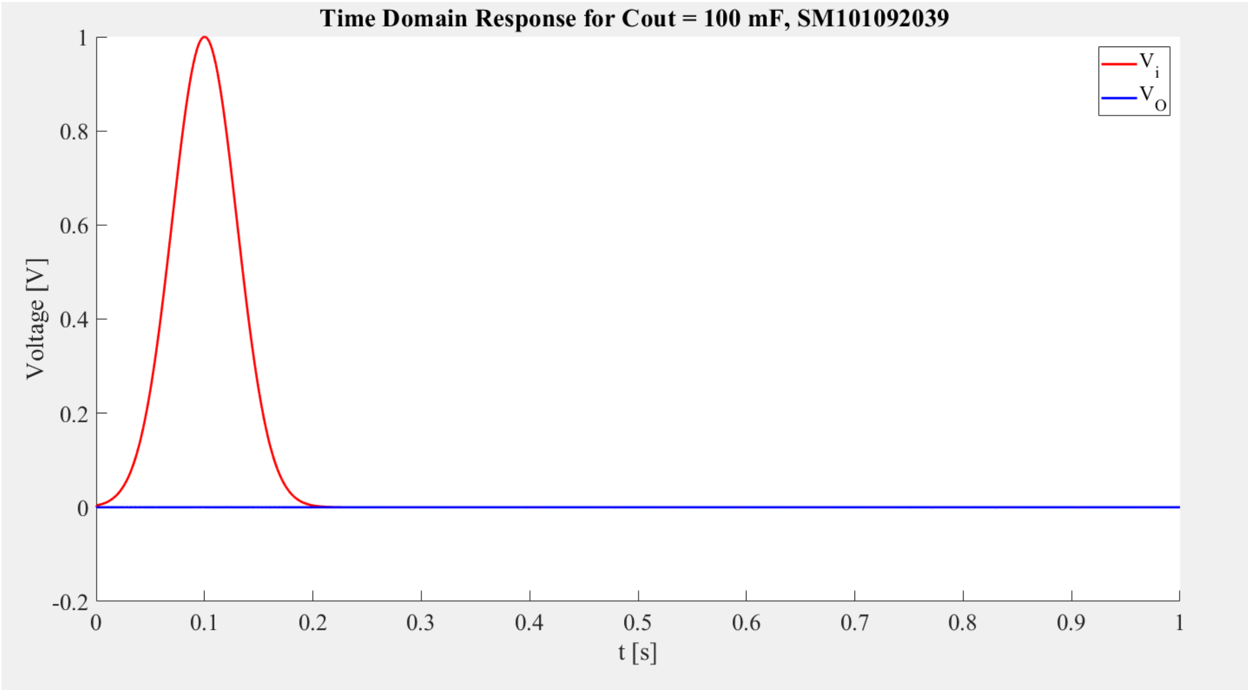

Figure 12: Response with Cn = 100mF.

The Figures 10, 11 and 12 depict the response of the circuit with noise for different capacitances. The response for Cn = 0.0001 indicates that a significant amount of noise was being picked up. The responses for the Cn = 10mF and Cn = 100mF were expected to exhibit oscillations.

The circuit was also simulated with varying time steps to analyze the response. The results obtained from simulating different time steps have been given below.

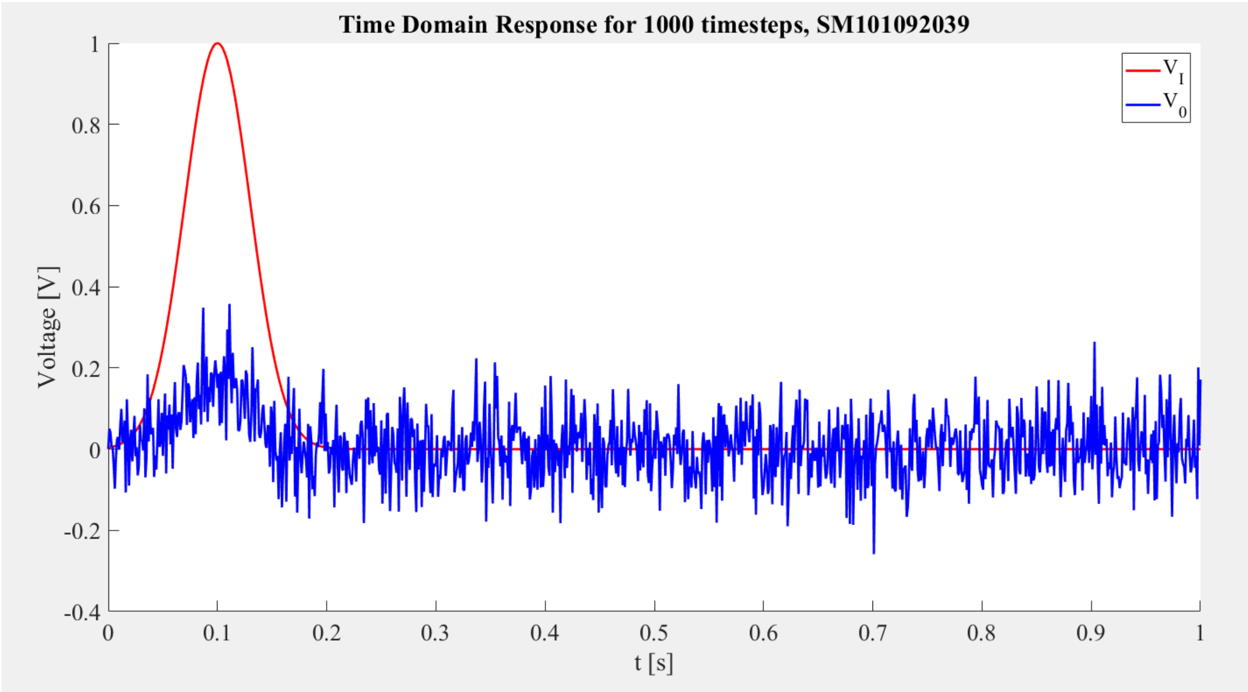

Figure 13: Response for 1000 timesteps.

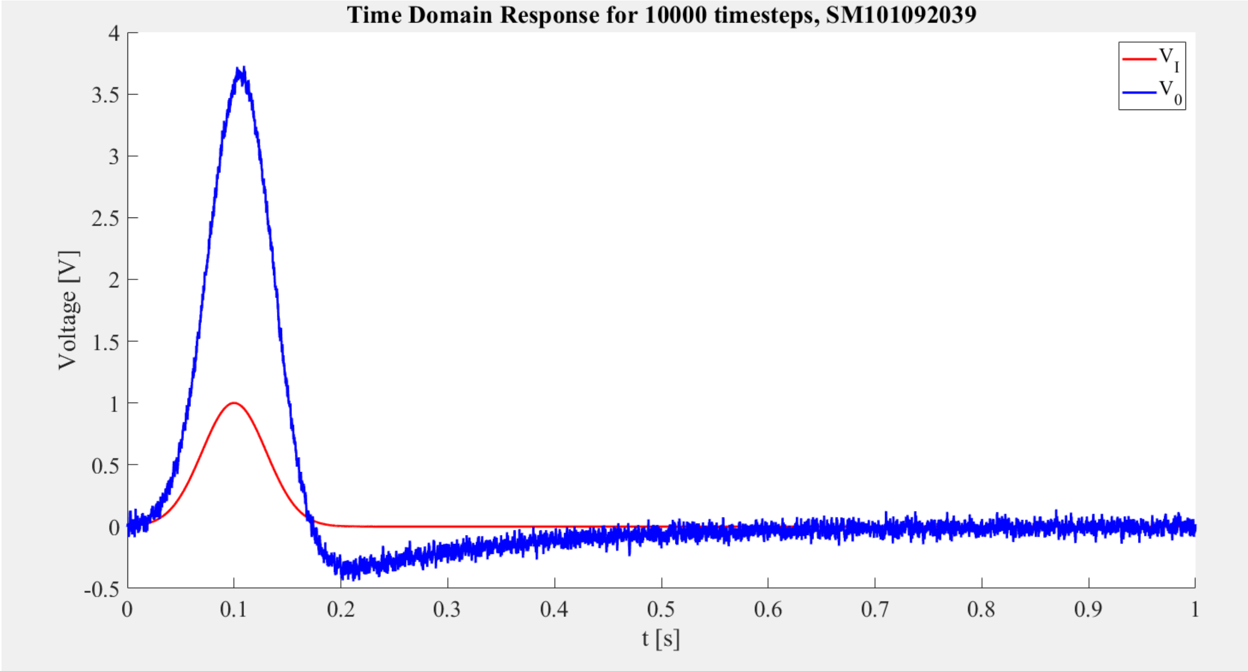

Figure 14: Response for 10000 timesteps.

The analysis of the obtain data reveals that the circuit tends to pass a lot of noise at a lower time step. However, it can be seen that at 10000-time steps, the response become much smoother and apparent.

3. Non-Linearity

The final segment of the assignment involved the exploration of the non-linearity of the circuit. If the circuit was modelled with the transconductance equation $V = \alpha I_3 + \beta I_3^2 + \gamma I_3^3$, non-linearity would come into play. The system could be solved and implemented by setting up a matrix that could aid in the formation of the Jacobian. The approach would be similar to the approach for solving the Newton Raphson equation as shown in the class. The implementation would involve setting up a non -linear vector B which would serve as the Jacobian matrix for the system. The process of implementation would be similar to the process utilized for the linear model. The variation with respect to non-linear elements can be evaluated with the presence of a Jacobian matrix.

3. Conclusion

The primary objective of the assignment was to utilize the Modified Nodal Analysis to solve and analyze the linear circuit. The assignment provided a great opportunity to experiment and understand the concepts associated MNA techniques and how the concepts from the previous assignments can be utilized for modelling and analysis of circuits. The code was assembled, and a separate file has been prepared which will be attached with the report and submitted on GitHub as well as CuLearn.