Lab 1   Time Domain Reflectometry

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1   Introduction

How do you connect a receiver or transmitter to an antenna? Simple - a transmission line. You are no doubt familiar with transmission lines (sometimes abbreviated as tx lines). If you plug any electric device into a wall outlet, the wires that connect the wall outlet to the device is a transmission line.

However, transmission lines behave very oddly at high frequencies. In traditional (low-frequency) circuit theory, wires connect devices, but have zero resistance. There is no phase delay across wires; and a short-circuited line always yields zero resistance.

For high-frequency transmission lines, things behave quite differently. For instance, short-circuits can actually have an infinite impedance; open-circuits can behave like short-circuited wires. The impedance of some load (ZL=XL+jYL) can be transformed at the terminals of the transmission line to an impedance much different than ZL. The goal of this Lab report is to understand transmission lines and the reasons for their odd effects.

Also for instance reflected signals in a network that has an open circuit will create excess traffic, bandwidth goes down and the network collapses.

In our experiment, the transmission line were tested through nine different conditions, simulated using pSpice and Matlab. Each of these conditions is determined by finding the reflection coefficient which is calculated by using the equation:

$$\Gamma = \frac{Vref}{Vinc} \tag{1}$$

which is written as:

$$\Gamma = \frac{ZL - ZO}{ZL + ZO} \tag{2}$$

Where: ZL is the impedance of the load. Z0 is the impedance of the line. Γ is the reflection

coefficient.

2 objective

- To determine the behaviour of a transmission line under the nine different conditions listed above,

- Obtain waveforms from pSpice simulations then validate each of our results using Matlab©,

- mathematical analysis, to verify results.

3 Required tests:

using Pspice the following 10 conditions were built and simulated determining what waveform's were created by each condition, using ZO=50 Ω

1. Unstable system Rs = short circuit and RL= circuit.

2. Stable system, using a pulse waveform where will RS be short circuit and RL will be open circuit. With a max step size of $0.1nS$

3. RS = 50Ω and RL will be open circuit.

4. matched condition where RS = 50Ω and RL = 50Ω.

5. A 1nF capacitor connected in series to a matched RS.

6. A 1nF capacitor connected in parallel to a matched RS.

7. A 10H inductor connected in parallel to a matched RS of 50Ω.

8. A 10H inductor connected in series to a matched RS of 50Ω.

9. RLC circuit

We were asked to set up a pulse wave using the following settings in Pspice:

- TD = 19.6n

- V1 = 0

- V2 = 1

- TD = 0

- TR = 10n

- TF = 20n

- PW = 10

- PER = 20

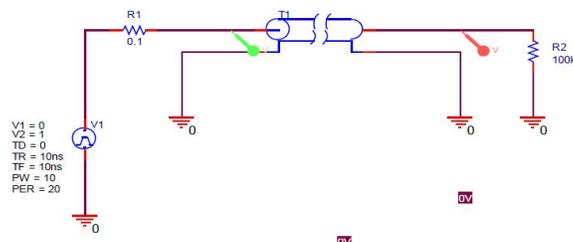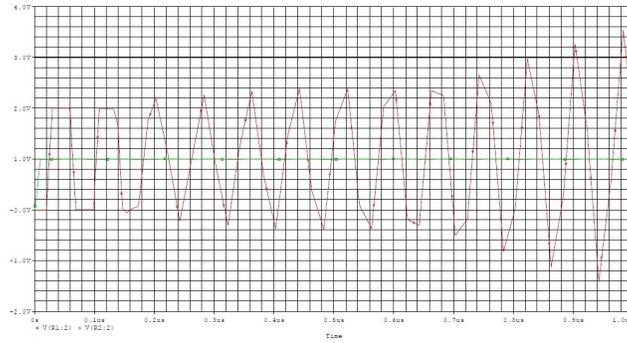## 3.1 Unstable system, Rs is a short circuit and RL an open circuit.

Figure 1: Circuit diagram

As in figure 2 we can see that the output looks somewhat like a chirp signal. however It is inherently unstable. Later this will be rectified by using alternating sampling steps in pSpice.

Figure 2: Waveform

3.2 Stable system, using a pulse waveform where will RS be short circuit and RL will be open circuit. With a max step size of 0.1nS
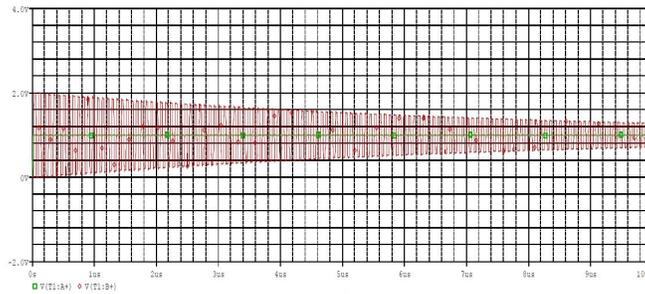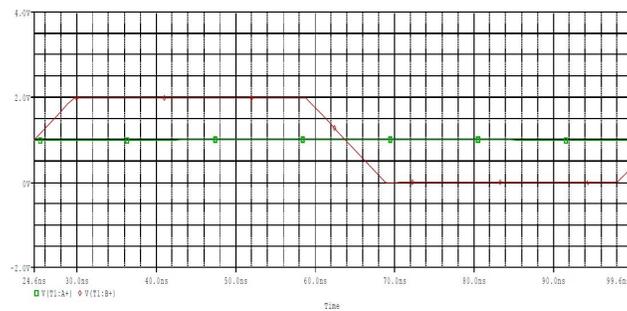

Figure 3: Waveform 1

Figure 4: Waveform 2

In Fig 3 we can see the classic chirp signal. After we changed the sampling step size in pSpice to 1nS. So that the waveform is now stablised compared to figure 2.

4

To calculate the reflection coefficient:

$$\Gamma = \frac{Vref}{Vinc} \tag{3}$$

which is written as:

$$\Gamma = \frac{ZL - ZO}{ZL + ZO} \tag{4}$$

$$\Gamma = \frac{\infty - 50}{\infty + 50} = 1\angle 0° \tag{5}$$

In Fig 4 one can see that the output voltage is 2 volts, even though our input voltage was 1V. Which is explained as follows:

$$Vref = \Gamma Vinc \tag{6}$$

$$Vref = Vinc \tag{7}$$

$$Vout = Vinc + Vinc \tag{8}$$

$$1 + 1 = 2V \tag{9}$$

We get 2v output as our reflection coefficient is equal to 1V, where our supply voltage 1v. The reason for this phenomena is because our supply voltage is reflected through the line as our signal is tranmitted at different impedances, causing the voltage to appear double.
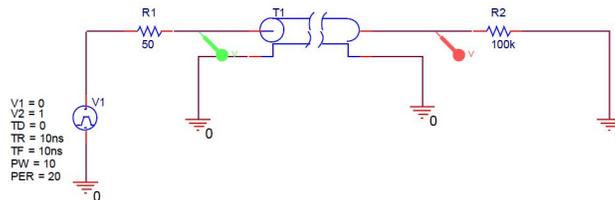
3.3 RS = 50Ω and RL will be open circuit.

Figure 5: Circuit

The reflection coefficient is:

$$\Gamma = \frac{Vref}{Vinc} \tag{10}$$
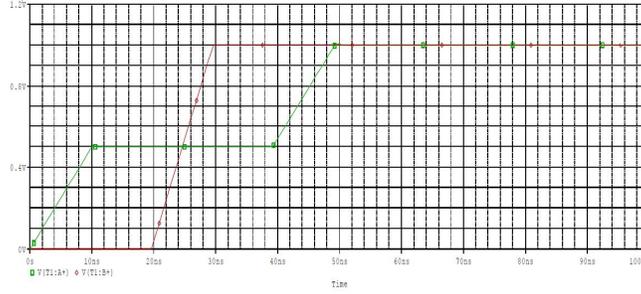
$$\Gamma = \frac{ZL - Z0}{ZL + Z0} \tag{11}$$

Figure 6: waveform

$$\Gamma L = \frac{100k - 50}{100k + 50} = 1 \tag{12}$$

$$\Gamma s = \frac{50 - 50}{50 + 50} = 0 \tag{13}$$

In the above waveform fig6, the voltage from source to load is 0.5v. This $\frac{1}{2}V$ doubles in as the value of ΓL is equal to $1v$.
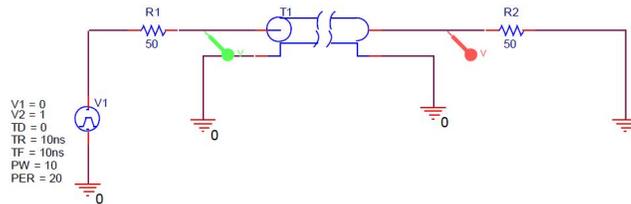
3.4 matched condition where RS = 50Ω and RL = 50Ω.

Figure 7: circuit

This is called a matched condition as RS and RL and both equal to 50Ω

There is no reflection back through the line as both impedance's are equal This reflection coefficient can be proven below:

$$\Gamma = \frac{ZL - Z0}{ZL + Z0} \tag{14}$$

$$\Gamma = \frac{5050}{50 + 50} = 0 \tag{15}$$

6

As seen in figure 8, the signal from the source is being completely absorbed by the load, therefore, there is no reflection through the line.

$$\Gamma = \frac{ZL - Z0}{ZL + Z0} \tag{16}$$
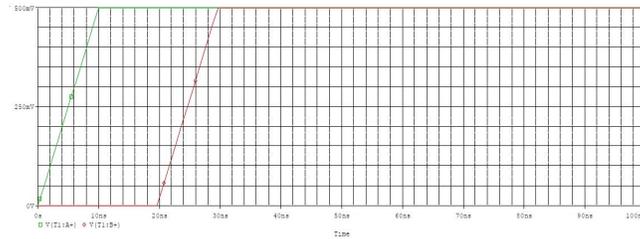
$$\Gamma = \frac{50 - 50}{50 + 50} = 0 \tag{17}$$

Figure 8: waveform

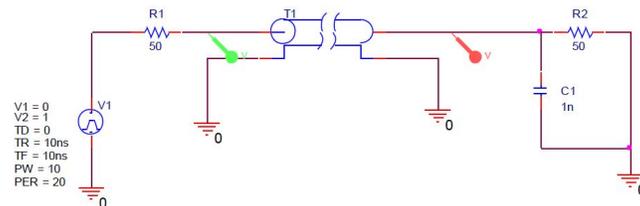## 3.5 A 1nF capacitor connected in parallel to a matched RS.

Figure 9: circuit

for conditon 5 we derived a set of calculations to determine the step reponse before put the values into Matlab©using the step function to get the step response of the system.

here below is how the step response of the system was derived: since this circuit has a matched condition,

$$Rs = RL. \tag{18}$$

we can assume that:

$$Rs = RL = R. \tag{19}$$

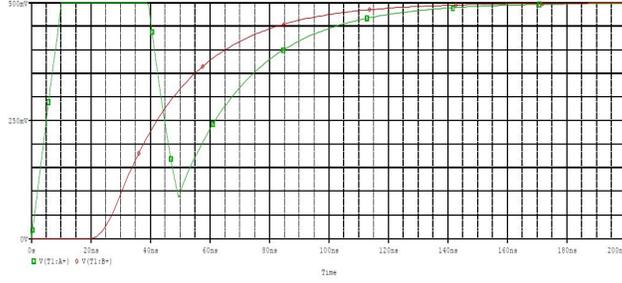Figure 11: Circuit diagram of the sixth condition

Figure 10: waveform

this is a parallel capacitor and we are looking step response so we use the laplace transfrom.

$$Zc = \frac{1}{sc} = \frac{1}{jwc} \tag{20}$$

$$Vo = \frac{ZRC}{ZRC + 50} \quad where \ Zrc = \frac{\frac{1}{sc}}{\frac{1}{sc} + R} \tag{21}$$

Thus Zrc can be further simplified as :

$$\frac{R}{scr + 1} \tag{22}$$

So :

$$Vo = \left(\frac{R}{R + (scr + 1)50} \right) * Vin \tag{23}$$

$$Vo = \left(\frac{50}{s(1 * 10^{-8})50^2 + 100} \right) * Vin \tag{24}$$

$$Vo = \left(\frac{1}{sRC + 2} \right) * Vin \tag{25}$$

So our equation to calculate the step response is:

$$H = \left(\frac{1}{sRC + 2} \right) * Vin \tag{26}$$

$$H = \left(\frac{1}{(50)(1 * 10^{-8})s + 2} \right) * Vin \tag{27}$$

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$$H = \left(\frac{1}{(50 * 10^{-8})s + 2} \right) * Vin \tag{28}$$

We inputted this equation was into Matlab© using the step function and gained the plot shown below:

```
num = [1];
den = [50e-8,2];
H=tf(num,den)
step(H)
grid on

H =
1
-----------
5e-08 s + 2
Continuous-time transfer function.
```
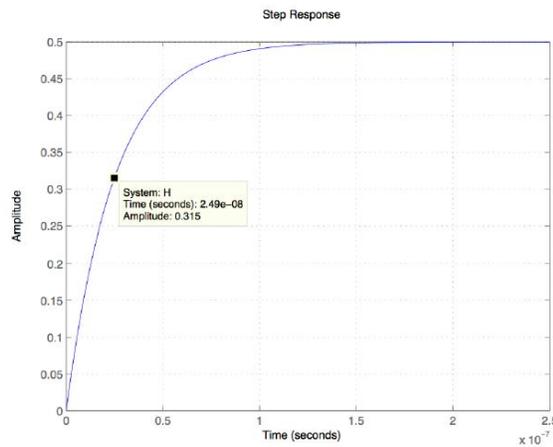

Figure 11: matlab step response

to calculate the reflection coefficient of this system we use:

$$\Gamma = \frac{ZL - Z0}{ZL + Z0} \tag{29}$$

$$\Gamma = \frac{50 - 50}{50 + 50} = 0 \tag{30}$$

There is no reflection back throught the transmission line so to calculate the transmission in the load we use:

$$\Gamma L = \frac{0 - 50}{0 + 50} = -1 \tag{31}$$

9

3.6 A 1nF capacitor connected in series to a matched RS.

In figure 13. We can see that at the start of the simulation there is no reflection until 24ns. At 0.5volts though The capacitor acts like an open circuit, so current is not passed through the capacitor. At this point the output voltage will equal the input voltage as seen in Matlab© output.
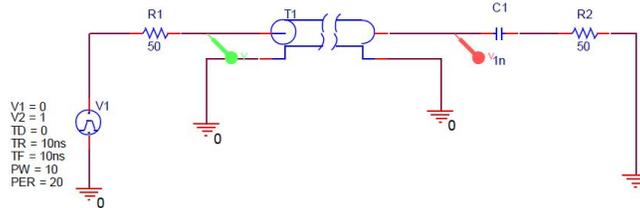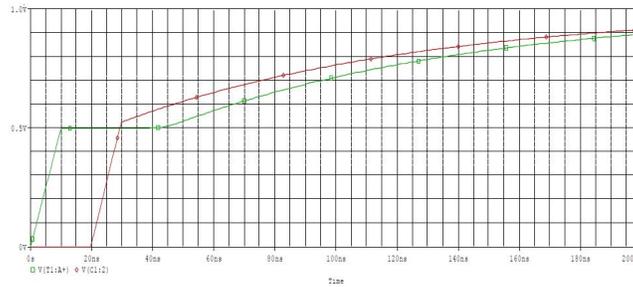

Figure 12: circuit

Figure 13: waveform

Calculations for step response as entered into Matlab©

$$H = \frac{Vo}{Vin} \tag{32}$$

$$H = \frac{\frac{1}{sC} + R + R}{\frac{1}{sC} + 2R} \tag{33}$$

Which can be simplified as:

$$H = \frac{sRC + 1}{2sRC + 1} \tag{34}$$

$$H = \frac{(50)(1 * 10^{-9})s + 1}{2(50)(1 * 10^{-9})s + 1} \tag{35}$$

simplified as:

$$H = \frac{(5 * 10^{-8})s + 1}{100 * 10^{-9})s + 1} \tag{36}$$

Step response graph from Matlab©:

```
num = [1];
den = [50e-8,2];
H=tf(num,den)
step(H)
grid on

H =
1
-----------
5e-08 s + 2
Continuous-time transfer function.
```


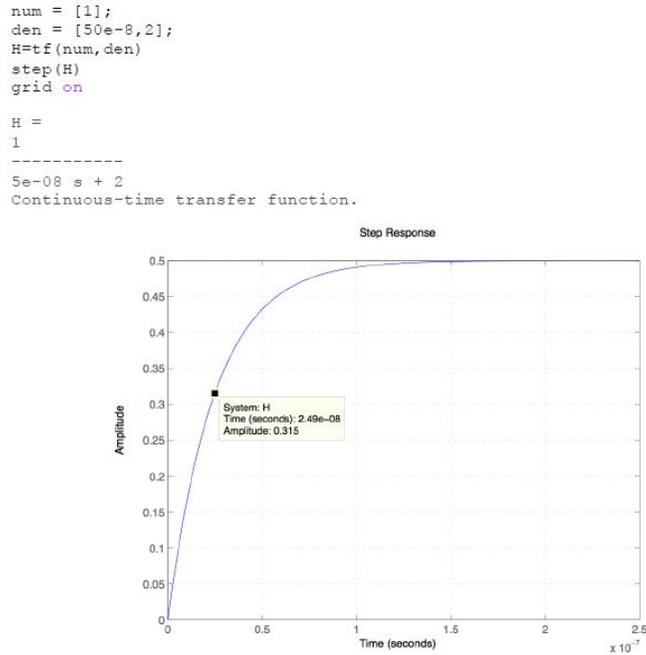Figure 14: matlab step response

3.7   A 10H inductor connected in parallel to a matched RS of 50Ω.

for this circuit we have an inductor in series, so for this circuit there will be a different step response even though the calculations for matlab©will be similar to those of having a capacitor connected in parallel this matched where RS and RL are equal :

$$Rs = RL = R \tag{37}$$

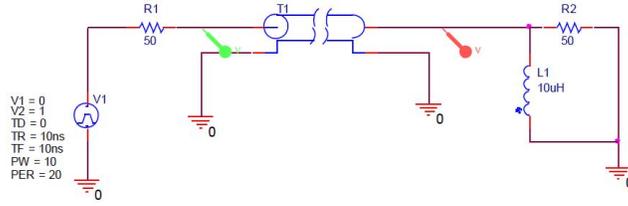Calculations required for MAtlab©:

$$H = \frac{Vo}{Vin} \tag{38}$$

Figure 15: circuit

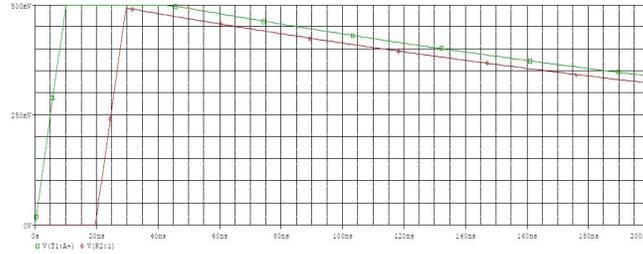Figure 16: waveform

$$\frac{ZRL \,||\, L}{ZRL \,||\, L + R} \tag{39}$$

$$\frac{Vo}{Vin} = \frac{\frac{sLR}{sL+R}}{\frac{sLR}{sL+R} + R} \tag{40}$$

Which is simplified to:

$$\frac{sLR}{sLR + sLR + R^2} \tag{41}$$

So our step response can be calculated as:

$$H = \frac{sL}{2sL + R} \tag{42}$$

$$H = \frac{(1 * 10^{-5})s}{2(1 * 10^{-5})s + 50} \tag{43}$$

simplified as:

$$H = \frac{(1 * 10^{-5})s + 1}{(2 * 10^{-5})s + 50} \tag{44}$$

Below is the graph produced by matlab©

```
num = [1e-5,0];
den = [2e-5,50];
H=tf(num,den)
step(H)
grid on

H =
1e-05 s
-----------
2e-05 s + 50
Continuous-time transfer function.
```


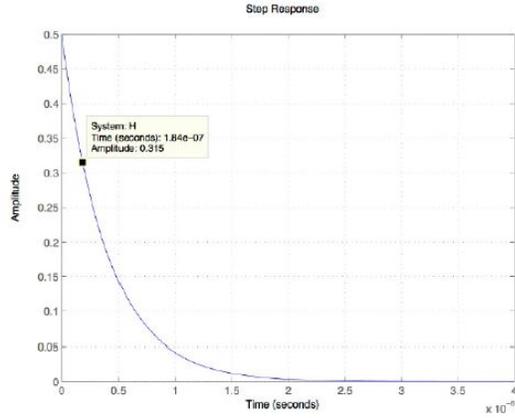Figure 17: matlab step response

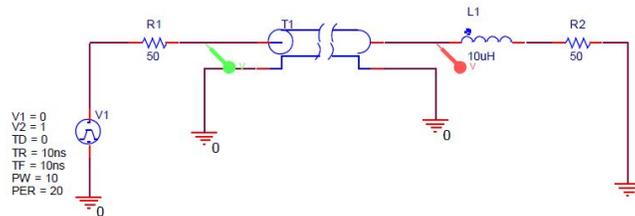## 3.8 A 10H inductor connected in series to a matched RS of 50Ω.

Figure 18: circuit

At lower frequencies, the inductor acts as an open circuit as can be seen in figure 19, the voltage starts to drop. At 0.5v it acts like a short. The step response of the system is calculated as below:

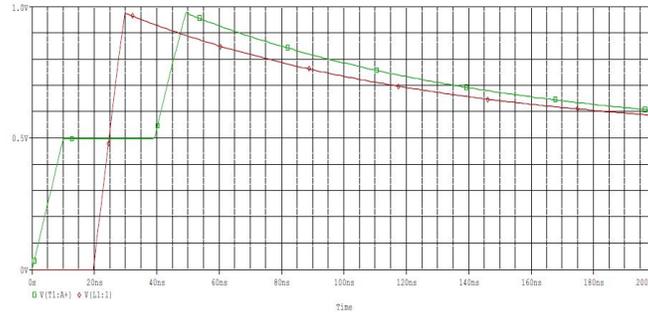$$H = \frac{Vo}{Vin} = \frac{sL + R}{sL + R + R} \tag{45}$$

So our step response is:

Figure 19: waveform

$$H = \frac{sL + R}{sL + 2R} = \frac{(10 * 10^{-6})s + 50}{(10 * 10^{-6})s + 2(50)} = \frac{(10 * 10^{-6}s + 50)}{(10 * 10^{-6})s + 100} \quad (46)$$

Using the step function in Matlab©we gained the following graph:

```
num = [1e-5,50];
den = [1e-5,100];
H=tf(num,den)
step(H)
grid on

H =
1e-05 s + 50
-------------
1e-05 s + 100
```
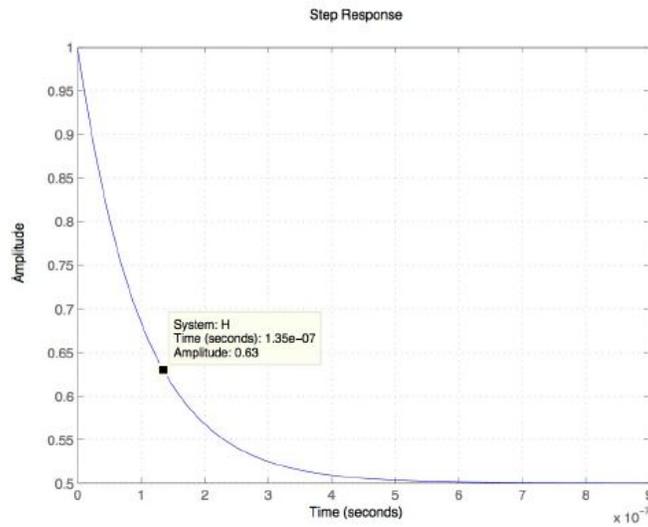

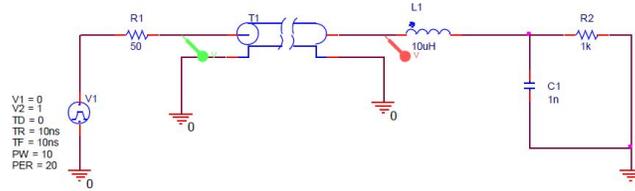Figure 20: matlab step response

14

3.9   RLC circuit

Figure 21: Applying 6.0v to the the regulator

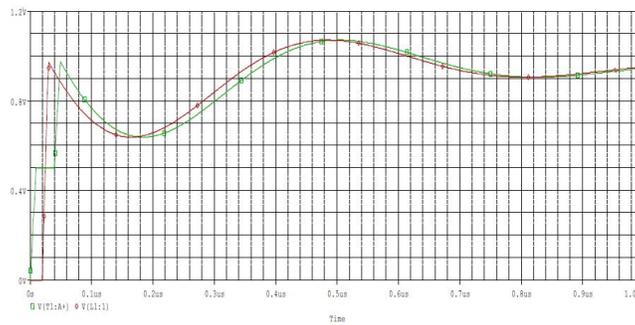Figure 22: waveform

To calculate the step response of the RLC circuit we use the equations below:

$$ZRLC = sL + \frac{R}{sRC + 1} \tag{47}$$

$Where:$

$$H = \frac{ZRLC}{ZRLC + R} \tag{48}$$

$So:$

$$\frac{sL + \frac{R}{sRC+1}}{sL + \frac{R}{sRC+1} + R} \tag{49}$$

$Simplfied\ to:$

$$\frac{sL(sRc + 1) + R}{sL(sRC + 1) + R + R(sRC + 1)} \tag{50}$$

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$$\frac{s^2 + \frac{s}{RC} + \frac{1}{LC}}{s^2 + s\left(\frac{1}{RC} + \frac{R}{LC}\right) + \frac{2}{LC}} \tag{51}$$
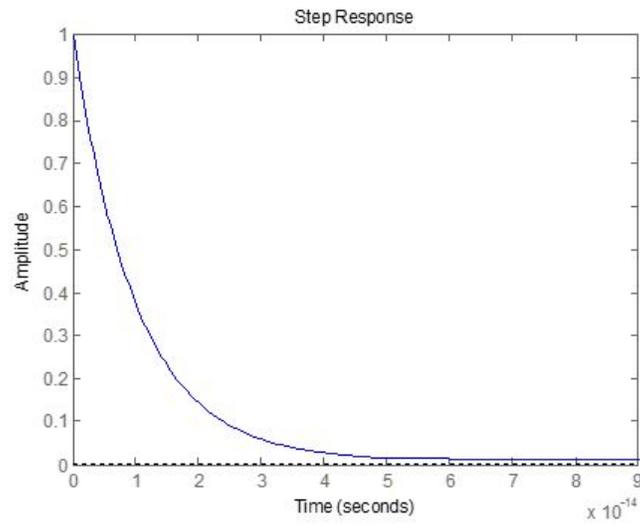
$$H = \frac{s^2 + s(20 * 10^6) + 10^{14}}{s^2 + s(10^{14}) + (2 * 10^{14})} \tag{52}$$

Figure 23: matlab step response