Bilkent University

Electrical and Electronics Department

EE202-03 Lab 2 Report:

“The Design of a Passive Linear Circuit to Generate High Voltage Spikes from Square Wave Signals”

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1- Software Implementation

1.1- Introduction:

In the experiment we were asked to design a passive linear circuit to generate high voltage spikes from 10V peak-to-peak square wave with a source resistance of 50Ω and frequency less than 5MHz. Here you can see the specific type of desired circuit behaviour we were given in the lab manual **(Figure 1)**. The peak voltage in the spikes were desired to be between 20 and 25 Volts. Also, the rise and fall times of the square wave input were assumed to be 10 nanoseconds in the simulations.

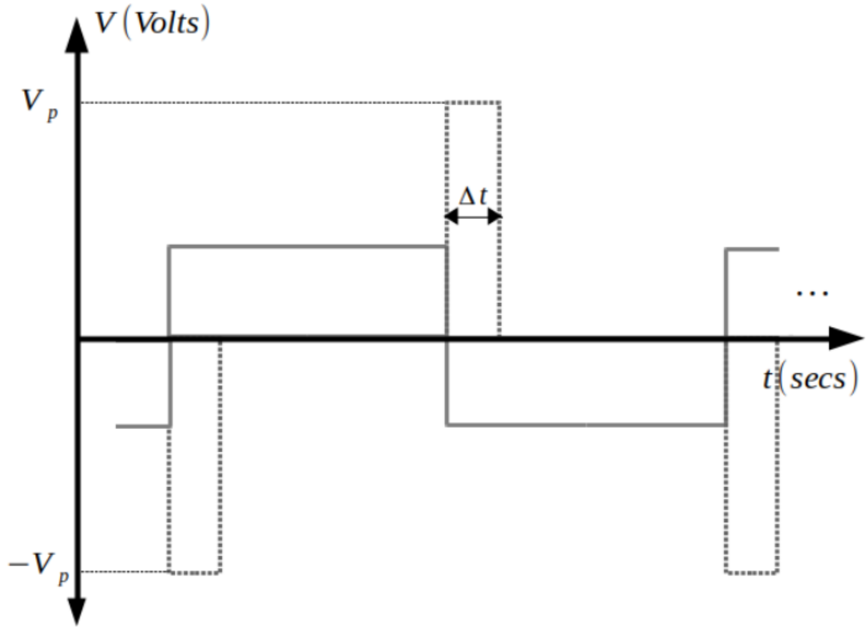

Figure 1: Desired Circuit Behaviour

My initial thought was to split the problem into two. The first task I committed myself, was to create a circuit with such voltage spikes. Amplifying the voltage spikes was the second order of business.

Using a series inductor was my solution to the first problem. This did indeed turn out to be a correct approach because I could also use the inductor as a transformer to amplify the high-voltage spikes. Therefore by using a series inductor, I handled the two problems at once.

1.2- Analysis:

Here is the equation for the inductance of a coil where N is the number of turns:

$$L = A_L \cdot N^2 \quad \textbf{(Equation 1)}$$

In the hardware lab, there was a toroidal core with an A_L value of 20nH/turns^2. So, I picked the inductance values of two inductors in the transformer to be 320nF (4 turns) and 5780nF (17 turns) because I didn't want to end up with an N value which is not close to an integer.

Here is the equation for the relation between the voltages and the number of turns for the two sides of a transformer, where n is the number of turns per coil and k is the coupling coefficient between two inductors.

$$\frac{V_2}{V_1} = \frac{n_2}{n_1} \cdot k \qquad \textbf{(Equation 2)}$$

I used k as 1.0 in my simulations, this means the output will be multiplied with 1.0 in the secondary circuit. If it was lower than 1.0, I would get a lower voltage output. k = 1.0 is the condition for ideal transformers.

1.3- Simulation:

Here you can see the circuit **(Figure 2.1)** I designed for the initial problem –creating voltage spikes without the amplification part- and the output I got **(Figure 2.2)**.

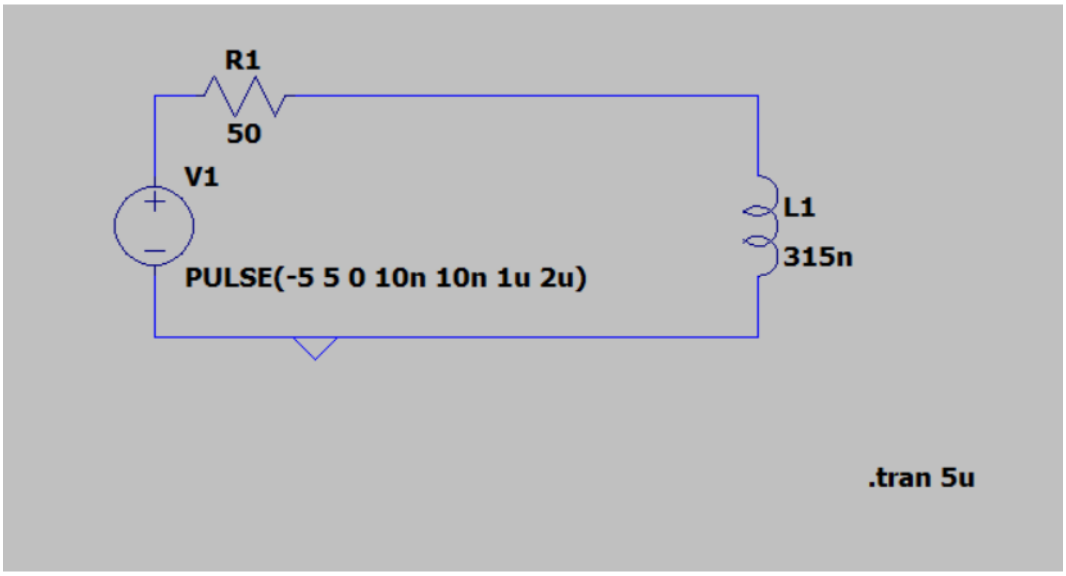

Figure 2.1: The Circuit for the Initial Problem

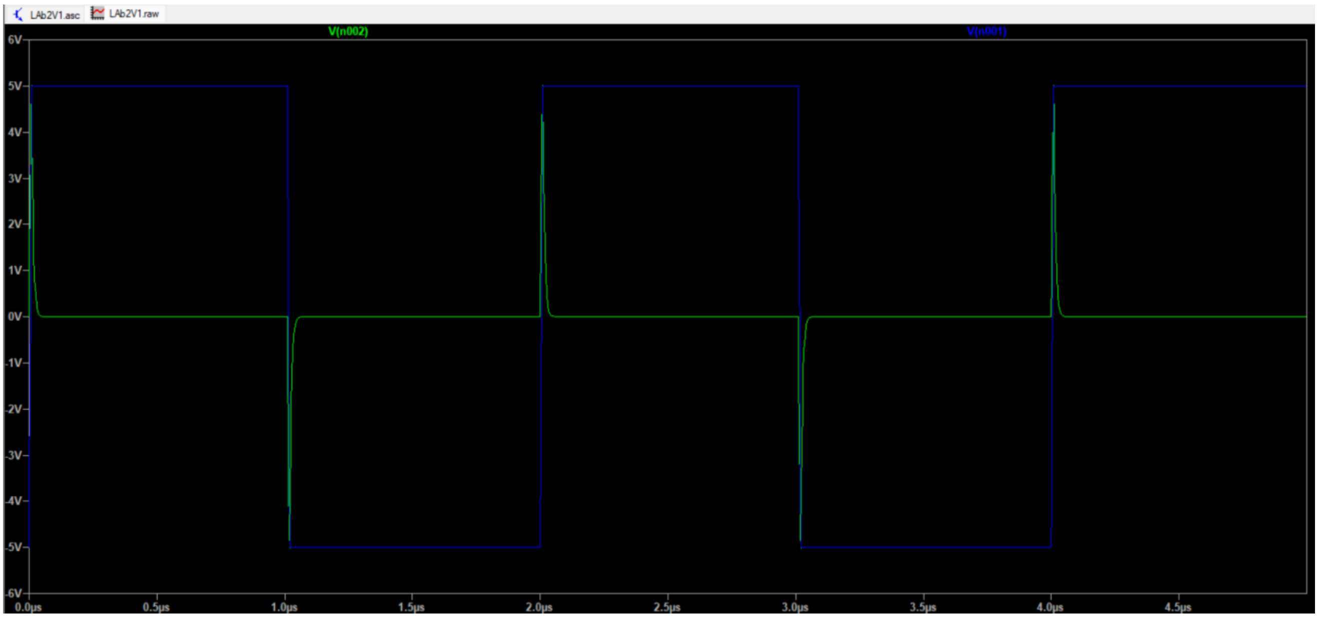

Figure 2.2: The Output of the initial circuit

It was time to solve problem number two: the amplification of the voltage spikes. I did this through adding a transformer to the circuit. Also, I've taken the coupling coefficient between two inductors as 1 mainly because I wanted to see the results on an ideal inductor. The coupling coefficient not being 1 was mostly a matter of the hardware part of the experiment. Here is the new circuit **(Figure 3.1)** and the output **(Figure 3.2)** on the secondary inductor.

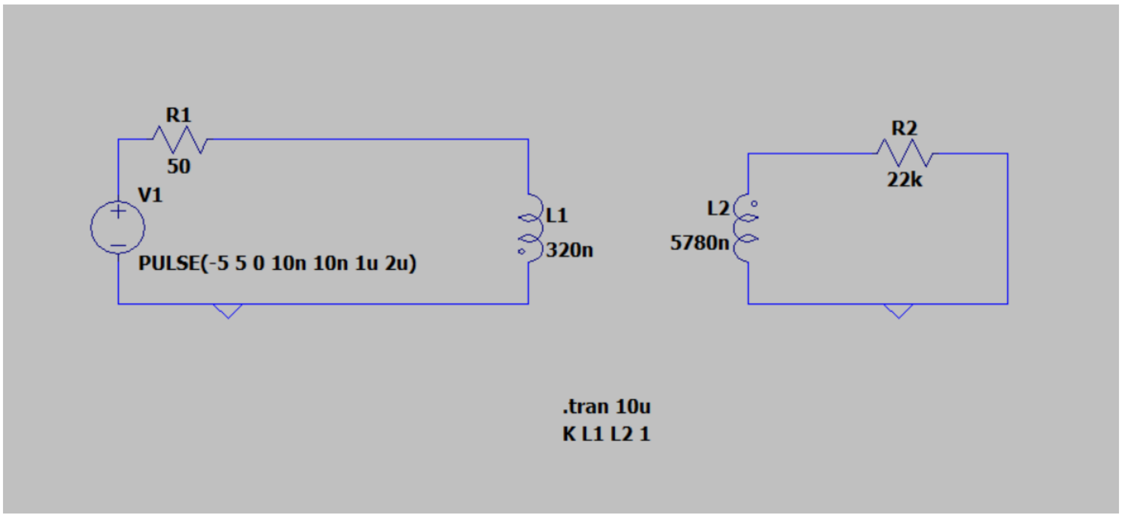

Figure 3.1: The Circuit for the Second Problem

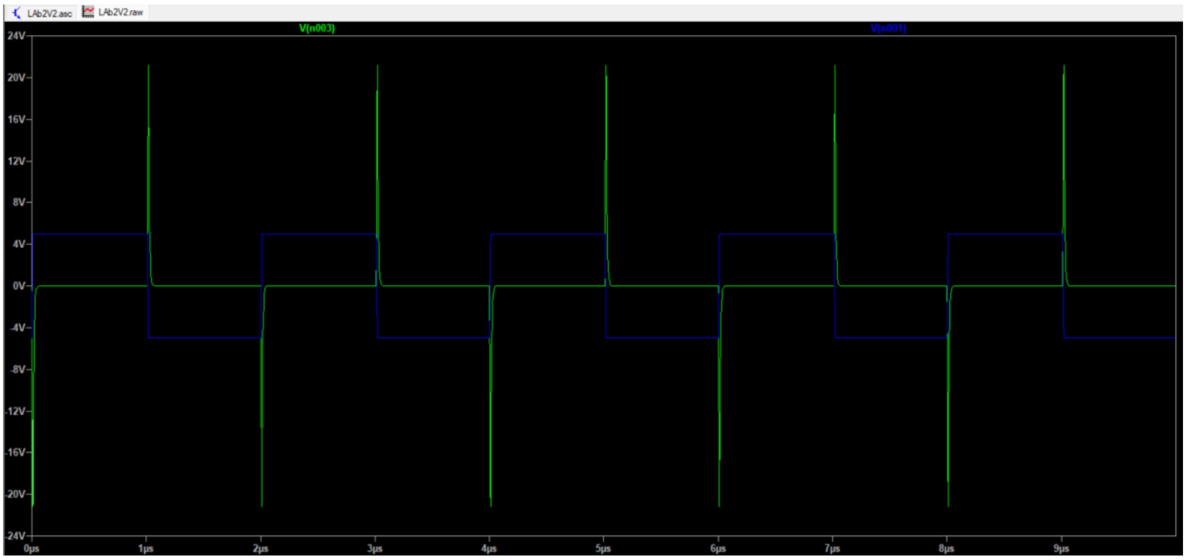

Figure 3.2: The Output of the second circuit

The proposed design was successful in both creating and amplifying voltage spikes from square wave signals. The peak voltage was 20.9 volts. Here you can see the FWHM of the output of the same circuit **(Figures 3.3&3.4)**. The FWHM depends on the resistance value of the series resistor in the secondary circuit. If the resistance value was higher, the FWHM got smaller.

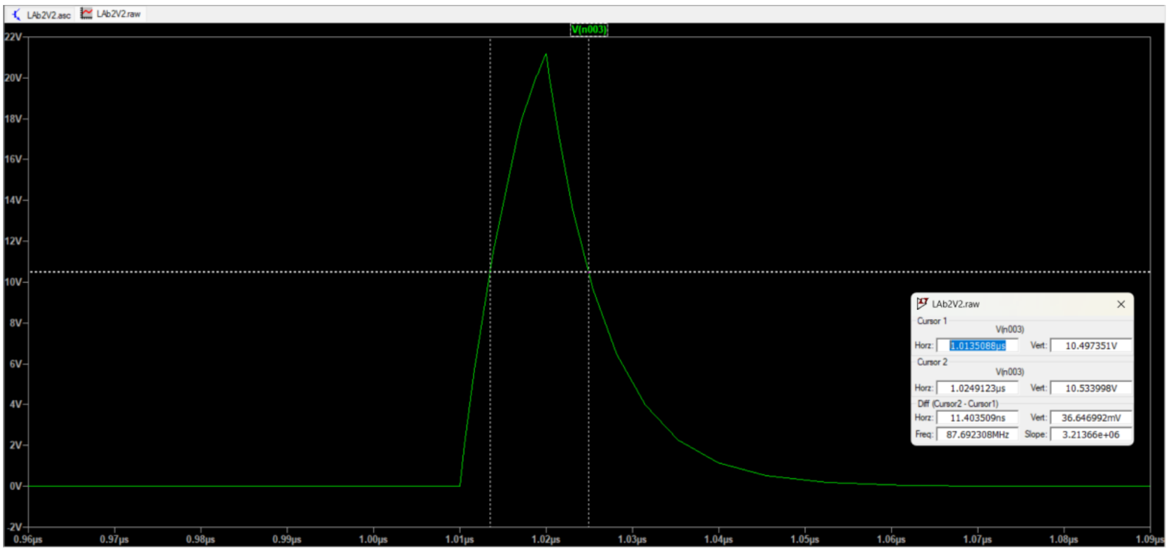

Figure 3.3: The FWHM of the output

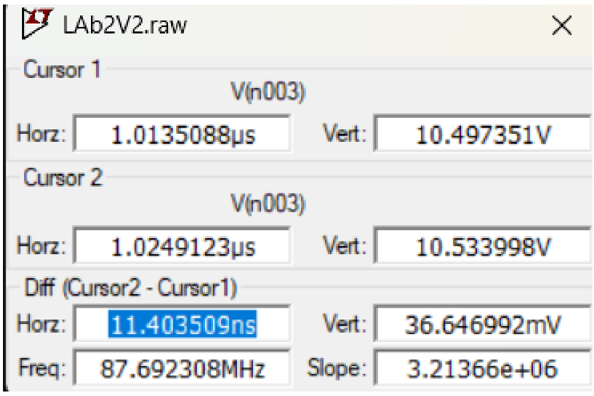

Figure 3.4: The FWHM of the output

The measured FWHM was 11.4 nanoseconds, which is well under the 100 nanoseconds limit we were given in the manual.

Up until this point, everything seemed normal for the software part. But I had to increase the number of turns to 32 in the hardware part. Now, I'd like to demonstrate the circuit I built in the hardware part and the theoretical and practical results I should get **(Figures 3.5 to 3.10)**.

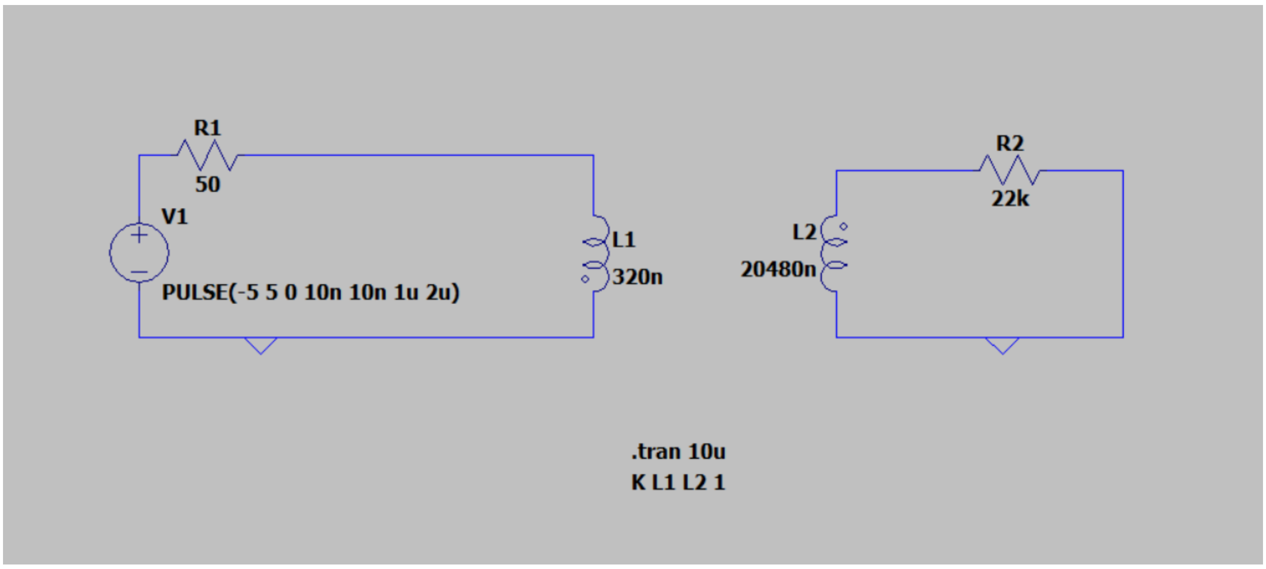

Figure 3.5: The Circuit I Actually Built in the Hardware Part (k=1)

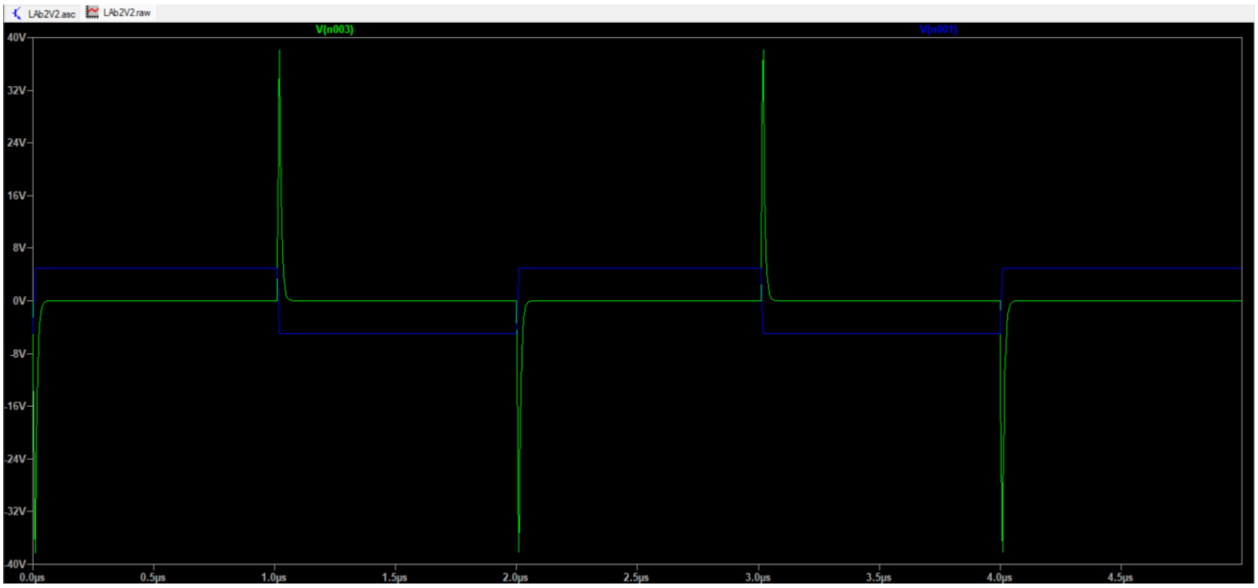

Figure 3.6: The Ideal Output I Should Have Gotten in the Hardware Part, peak voltage is 38 Volts

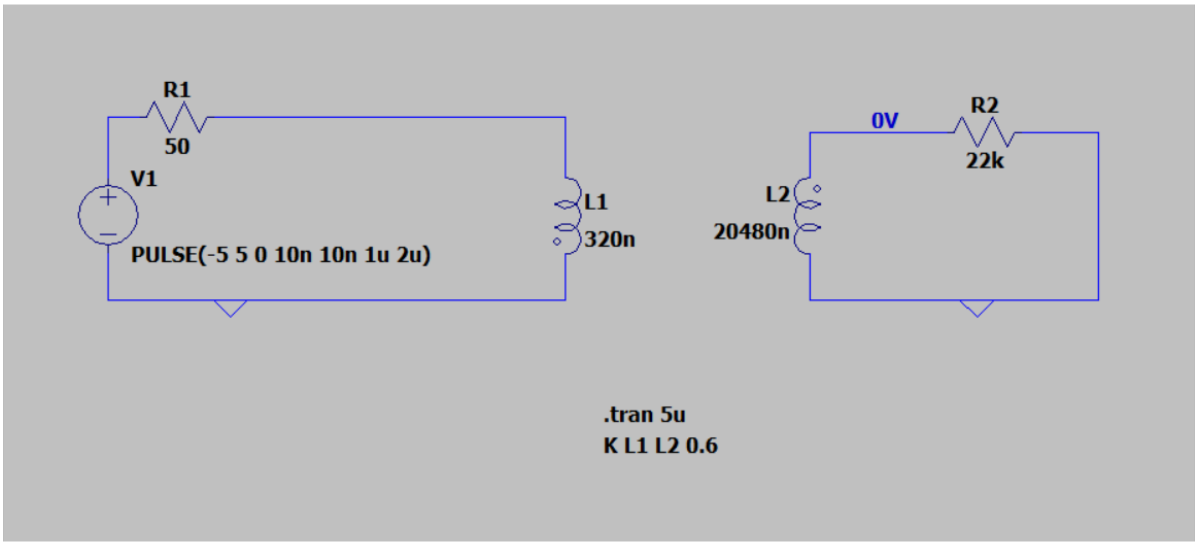

Figure 3.7: The Circuit I Actually Built in the Hardware Part (k=0.6)

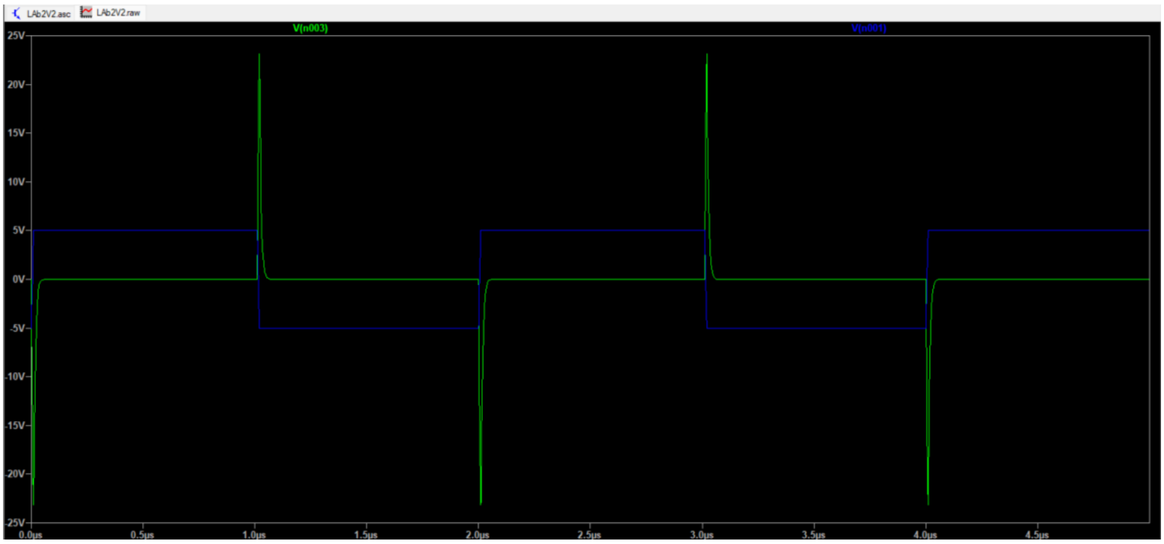

Figure 3.8: The Actual Output I Got in the Hardware Part, peak voltage is 23.2 Volts

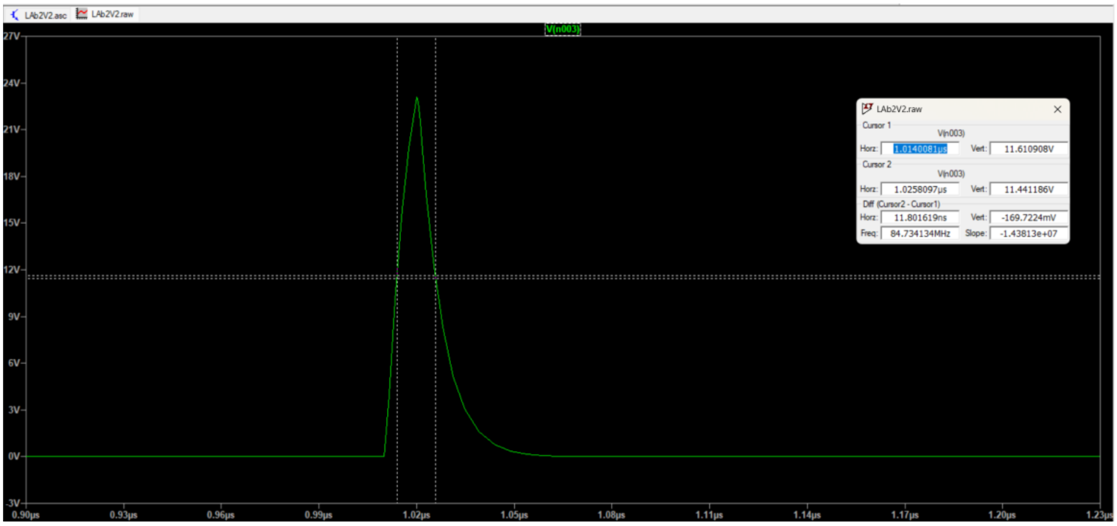

Figure 3.9: The FWHM of the circuit I built in hardware part with k = 0.6

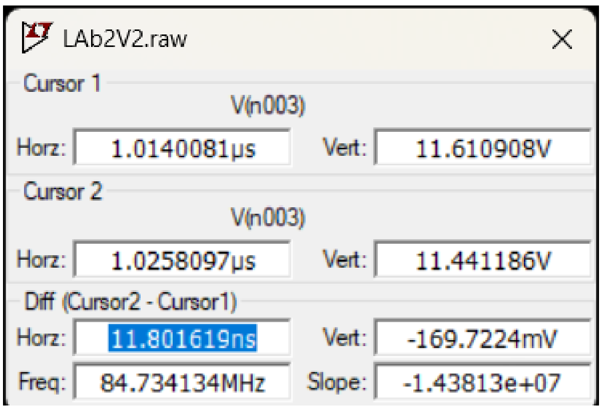

Figure 3.10: The FWHM of the circuit I built in hardware part with k = 0.6, FWHM is 11.8 nanoseconds

Circuit In:	L1	L2	k	FWHM	Peak Voltage Spike
Figure 3.1	320nF	5780nF	1	11.4ns	21.0
Figure 3.5	320nF	20480nF	1	11.8ns	38.7
Figure 3.7	320nF	20480nF	0.6	11.8ns	23.2

Figure 3.11: Table of Results in Simulation Part

2- Hardware Implementation

2.1- Introduction

In the laboratory, we were provided with toroidal cores with different A_L values. I used the T38-8 toroidal core with an A_L value of 20nH/turns^2. Equation 1 is used to calculate the number of turns required for the desired inductance value of an inductor.

$$L = A_L \cdot N^2 \quad \textbf{(Equation 1)}$$

Initially by taking k as 1; I calculated the number of turns for primary and secondary windings to be 4 and 17 accordingly –with inductance values of 320nF and 5780nF which are taken from the software part. Nevertheless, these numbers failed to achieve the desired output in terms of voltage in real life and then I had to increase the number of turns drastically to 32 for the secondary winding.

2.2- Results

The input signal was set to $5V_{pp}$ from the signal generator and the frequency was set to 1MHz. Here are the oscilloscope observations for this part **(Figures 4.1 to 4.5)**.

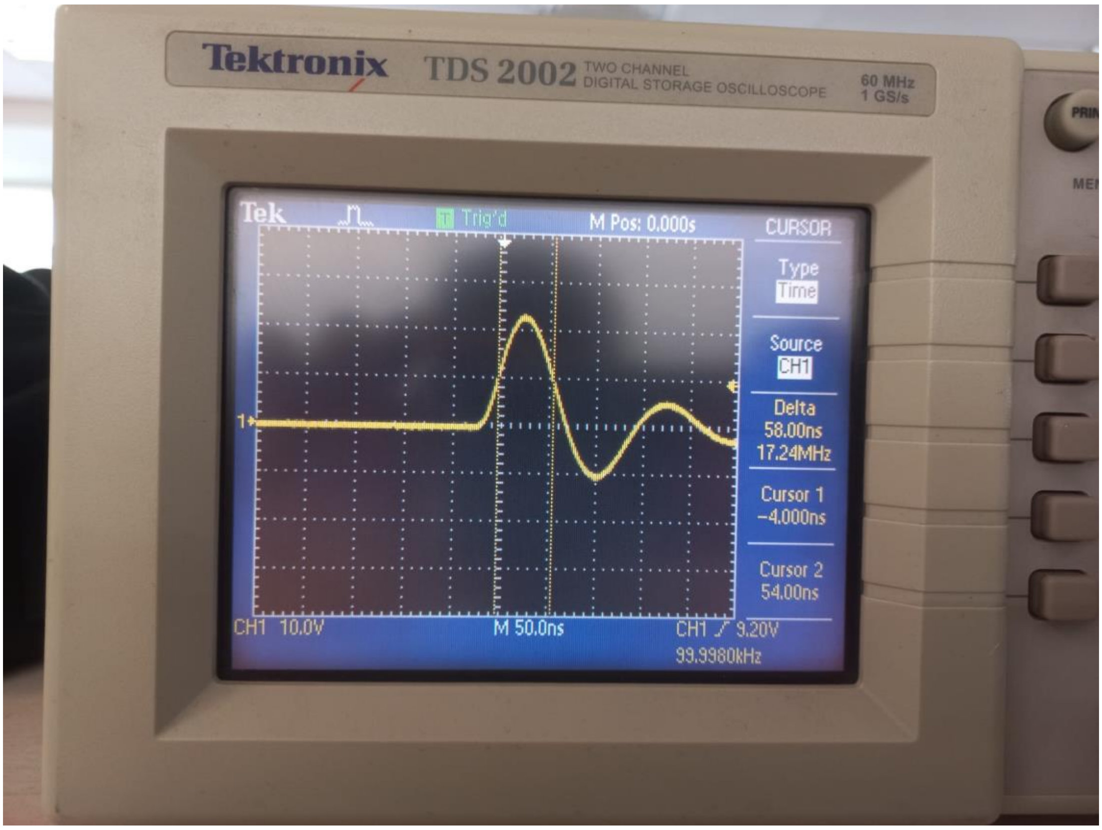

Figure 4.1: The Full Width at Half Maximum (FWHM) of the Circuit –measured as 58ns

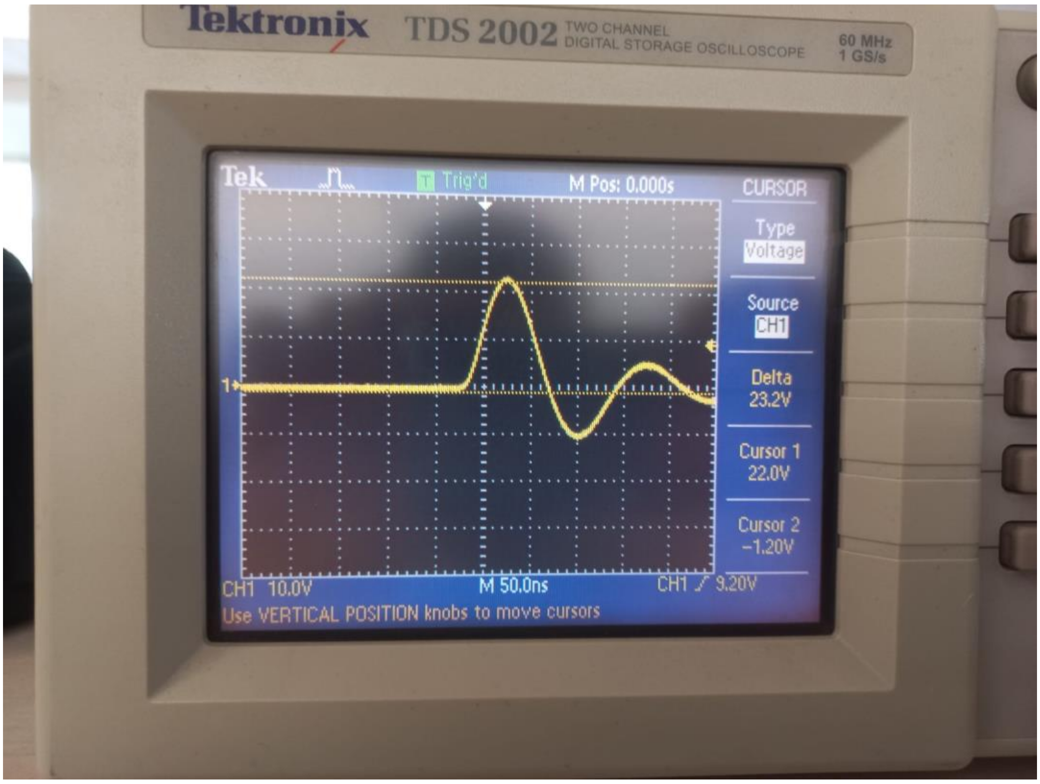

Figure 4.2: The Peak Voltage of a Single Spike –measured as 23.2 Volts

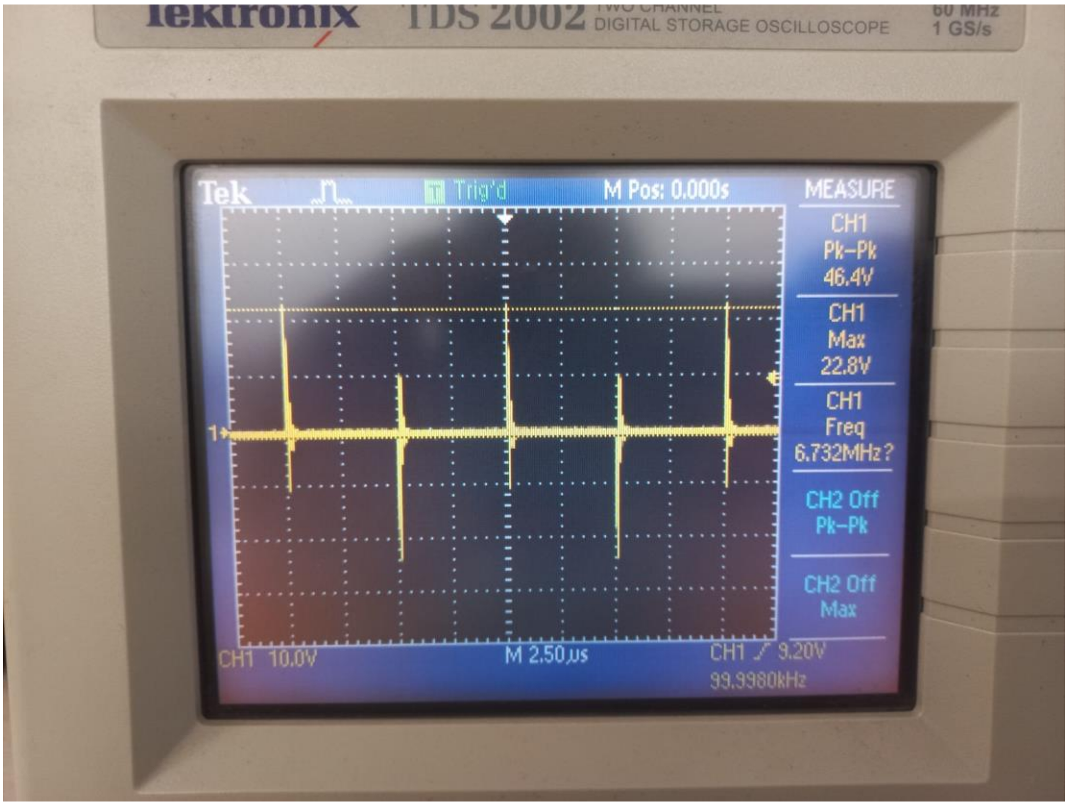

Figure 4.3: Voltage Spikes that the Circuit Generates

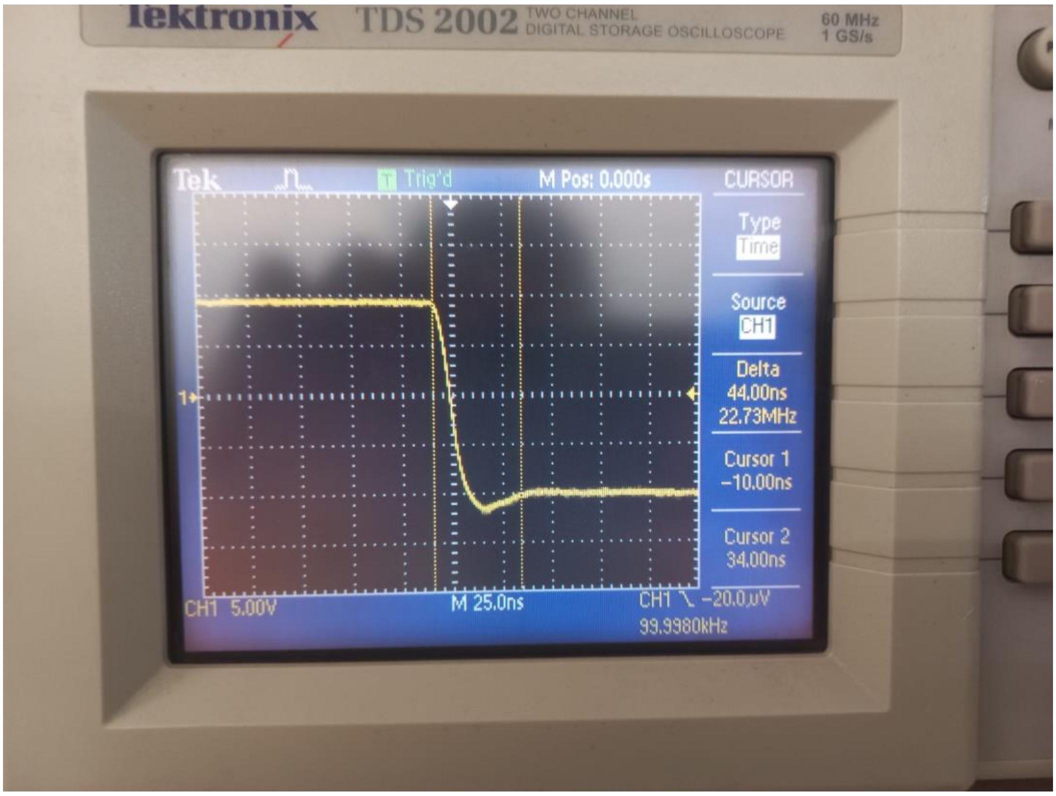

Figure 4.4: Fall Time of the Input from the Signal Generator –measured as 44ns

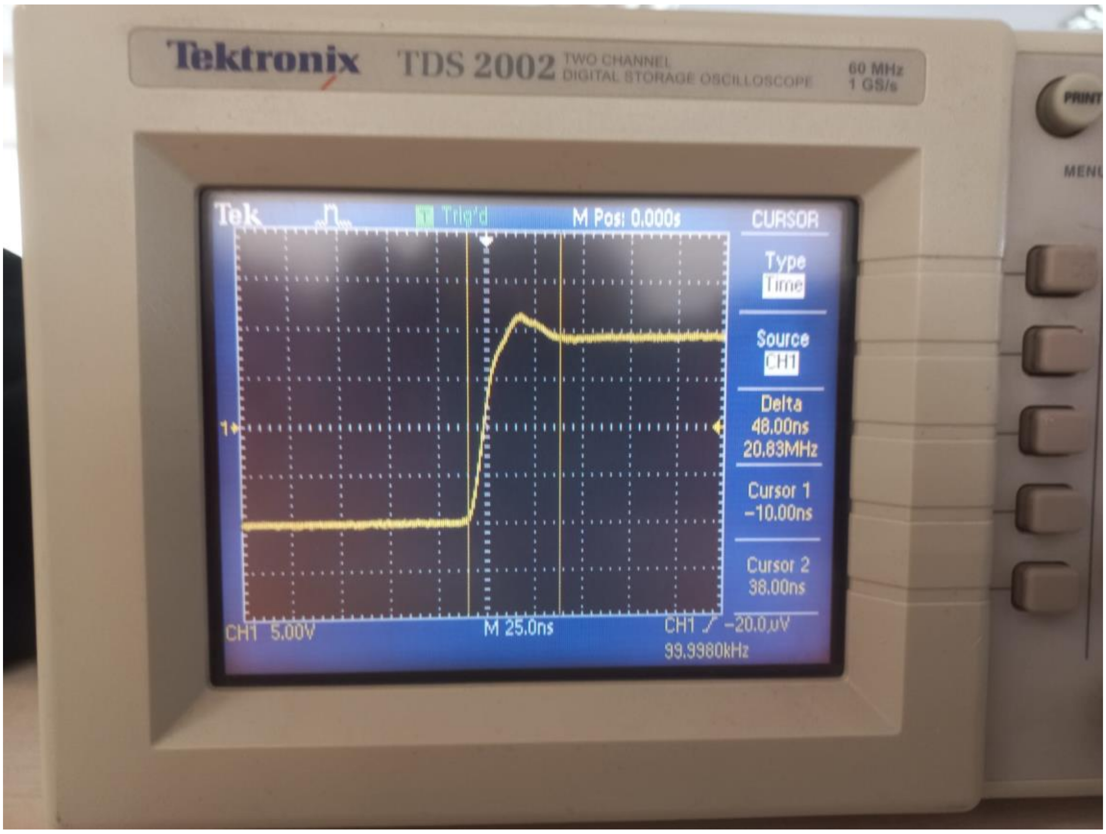

Figure 4.5: Rise Time of the Input from the Signal Generator –measured as 48ns

2.3- Comments

The voltage of a single voltage spike was measured as 23.2 volts, which falls in the middle of the desired limit of 20 to 25 volts. Also, the FWHM was measured as 58 ns, which was simulated as 11.8ns. Also, the rise time of the input from the signal generator on a 47Ω resistor, was measured as 48ns whereas the fall time was measured as 44ns.

3- Conclusion

3.1- Analysis on the Experiment Results

With the coupling coefficient being 0.6, I have successfully designed and implemented on hardware the circuit with the desired behaviour in the lab manual. The coupling coefficient being 0.6 means that there was a 40% drop in the output in terms of voltage. This huge drop might be due to the analog characteristics of the equipments I have used. Wiring a toroid might cause huge, unexpected errors because of the chaotic nature it has. The wires might overcome each other, or maybe you may have run out of space –I've experienced both these issues.

Also, I measured the FWHM as 58 nanoseconds, whereas in the simulation it was 11.8 nanoseconds. Again, this might be due to the characteristics of the lab equipment we use.

3.1- Comments on the Experiment

I believe this experiment was really hard. Wiring a toroid is very time-consuming. But I understand we should do these in order to get a better understanding of electrical circuits in general. But I can’t comprehend one thing. It is the structure of the experiment. I did the software part without knowing the coupling coefficient, I took it as 1. Then I wired the toroid according to the initial number of turns I calculated (4 and 17). I got an output voltage close to 12 Volts. TA's told us that they wouldn't give checks to anything with spikes lower than 20 Volts in the hardware part. Most of my friends including me had to rewire our toroids again and again to get the check. I increased the number of turns (to 4 and 32). Aren't we supposed to implement the simulation we did on the software part and comment on the errors. Why are we trying to get the ideal simulation results in the hardware part? Here you can see the hardware part instructions in the lab manual we were given **(Figure 5.1)**.

> **Hardware lab**
>
> Implement your design. Measure fall, rise times and peak value of the square wave by connecting a 47Ω resistor across the terminals of the signal generator. Measure the peak voltage and half-amplitude width of the output. Compare expected and observed values.

Figure 5.1: The Instructions in the Lab Manual for the Hardware Part

The manual instructs us to compare expected and observed values, not achieve the expected value. I believe we are mistreated in this lab as students. Most of the students spent extra hours to get an output over 20 volts. Was this really necessary, or was it an unnecessary push, it is arguable. Nevertheless, I think it is important to specify openly in the lab manual this type of structural details. Because this would give us the opportunity to know better about the lab details and make our preparations accordingly.