İhsan Doğramacı Bilkent University

Department of Electrical and Electronics Engineering

EEE202 Lab 2

Atalay Üstündağ

22203554

EE202-03

Software LAB:

Introduction:

Lab 2 aims to create a passive linear circuit capable of producing high voltage spikes from a 10V peak-to-peak square wave source, with a source resistance of 50Ω and a frequency below 5MHz. The report will detail the circuit design steps, outcomes, and requisite computations. Initially, the design will undergo testing via Lt Spice simulation, followed by result analysis. The voltage spike's desired peak value, denoted as Vp, should fall within the range of 20V to 25V, as indicated in Figure 1.

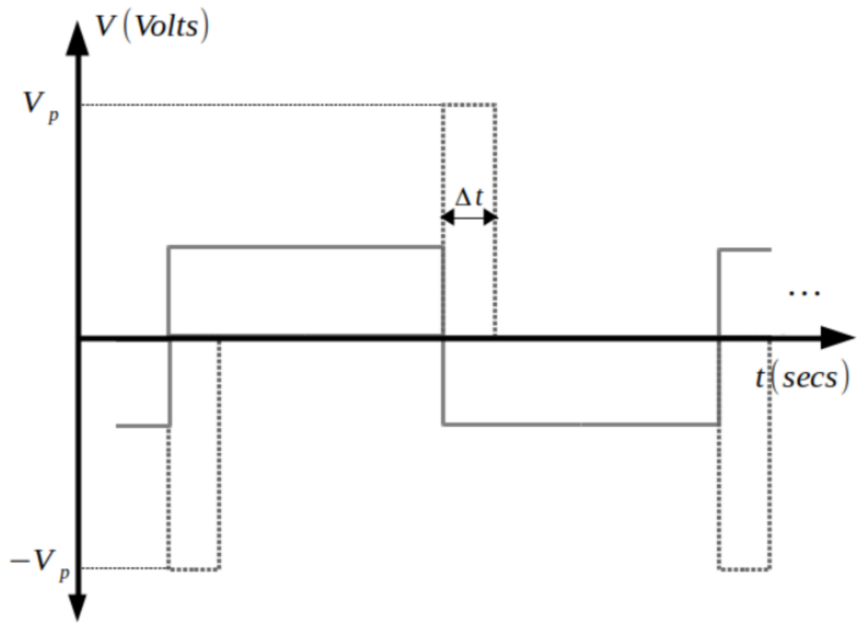

Figure 1: The Voltage-Time Graph on the Lab 2 Document

Moreover, it's crucial that the full width at half maximum (FWHM) remains under 100ns per the requirements in the Lab02 documents. And it is shown as Δt. At first, it is thought that the use of OPAMPs could make easier to achieve the purpose. However another significant consideration is that the circuit must exclusively employ passive circuit elements. Consequently, the use of OPAMPs is prohibited, limiting the components to resistors, capacitors, inductors, and independent voltage sources for circuit design.

To meet the specified criteria, I'll incorporate two resistors and two inductors. The inductors will facilitate the creation of a transformer to achieve the desired voltage spike magnitude. To offset potential losses, the voltage will be elevated from a 10V peak-to-peak value to a range of 40-50V peak-to-peak. To reduce the width, which must remain under 100ns, the value of the second resistor will be determined through calculations.

Analysis:

In order to design a transformer, it is essential to learn how an ideal transformer functions. A basic transformer is in the Figure 2.

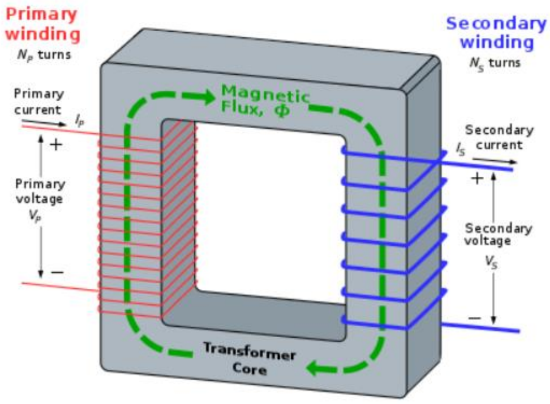

Figure 2: A Basic Transformer

And since it is crucial to use only passive components, this transformer implementation will be done by using two inductors. An example implementation is shown in Figure 3.

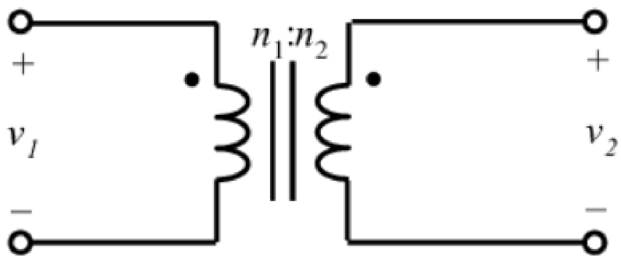

Figure 3: A Transformer Example by Using 2 Inductors

Transformers are devices utilized in electrical energy transfer, functioning through electromagnetic induction. In a practical transformer model, two inductors with different winding values are connected in parallel. The primary inductor links to the power source, while the secondary inductor connects to the load. The voltage ratio or gain is directly related to the ratio of windings between the primary and secondary inductors, a principle derived from Faraday's Law of Induction. There is the corresponding ratios in Equation 1. And what Equation 1 means is that the ratio between primary over secondary voltage is equal to the ratio between secondary over primary currents and it is also equal to the ratio between the primary number of windings over secondary number of windings.

$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S} = K$$

Equation 1: Ratio in Transformers

In Equation 2, it can be understood how to calculate the inductance value by using the inductance constant and the number of windings.

$$L = A_L \, x \, n^2$$

Equation 2: The Equation of Inductance by Using Number of Windings

Ratio between the primary and the secondary inductances can be derived by using the 1st and 2nd Equations.

$$\frac{L_P}{L_S} = \left(\frac{N_P}{N_S}\right)^2 = K^2$$

Equation 3: Derived Equation by Using Equation 1 and Equation 2

By using Equation 3 and Equation 1, 4th Equation can be found:

$$\frac{L_P}{L_S} = \left(\frac{V_P}{V_S}\right)^2 = K^2$$

Equation 4: Inductance ratios and voltage ratios of primer and seconder inductors

We are now equipped with the necessary equations to commence computations for constructing the desired transformer. Before selecting the inductance values of the inductors, the input and output voltage values in the Lab 2 instruction document are again wieved. The desired theoretical output voltage is chosen as 25V. And this sets the $\frac{V_p}{V_S}$ ratio to $\frac{1}{5}$, thereby determining that $\frac{L_P}{L_S}$ should be $\frac{1}{25}$. Since the cores of the inductors remain consistent, the A_L value has no effect on the turn ratios. Consequently, after analysis, it has been determined that the secondary inductor should be 10µH and the primary inductor should be 0.4µH to adhere to the required ratio. A schematic of the transformer, integrated with a voltage source and a primary resistor of 50 Ohm, is illustrated in the Figure 4.

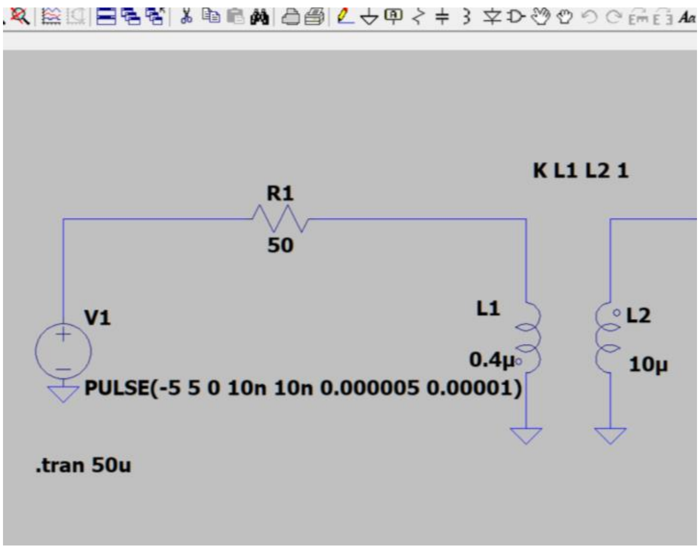

Figure 4: The Transformer Circuit with an Internal Resistor and a Voltage Source

In addition, in the instruction document for Lab 2, it is said that the frequency should be lower than 5 MHz, so in order to satisfy that 500Khz frequency is chosen for the source.

In the second step, the second resistor value should be chosen in order to minimize the full width at maximum voltage and guarantee that the output voltage remains within the range of 20V to 25V. Equation 5 has the necessary information to calculate the second resistance value.

$$\left(\frac{L_S}{L_P}\right)^2 = \frac{R_L}{R_S}$$

Equation 5: Relation Between Inductance Values and Resistor Values

By using Equation 4, Ls and Lp ratio is found as $\frac{L_p}{L_S} = \frac{1}{25}$ therefore $\frac{L_S}{L_p} = \frac{25}{1}$. And it is known that the internal resistor Rs is 50 ohms. Therefore the left side of the Equation 5 is $(\frac{25}{1})^2$ and the right side of the equation is $\frac{R_L}{R_S} = 31250$ ohm which is approximately 30Kohms. However after the simulation is run with this R_S value, the results were not satisfactory as the output voltage was higher than it should be. Therefore after the discussions with TAs, it was decided to use a 3Kohm resistor for only simulation purposes.

Simulation:

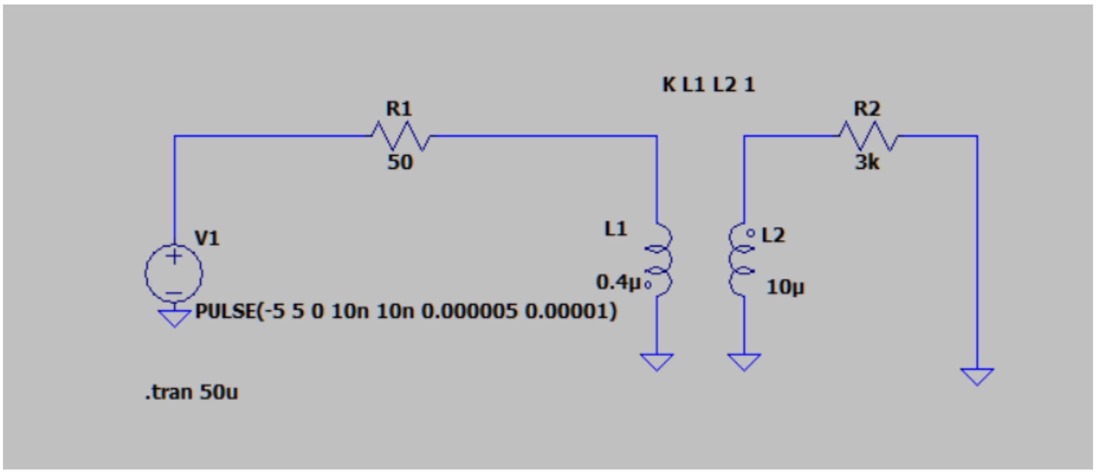

Figure 4: Whole Circuit Design in LTSpice

To simulate the transformer, we employ the "K1 L1 L2 1" direction. Here, L1 and L2 represent the names of the inductors, with 1 denoting the mutually coupling coefficient it is assumed that the transformer is ideal and there is no loss. The input voltage is specified as a 10V peak-to-peak square wave with a 1µs delay and a frequency of 500 kHz. In Figure 5, the input voltage can be viewed.

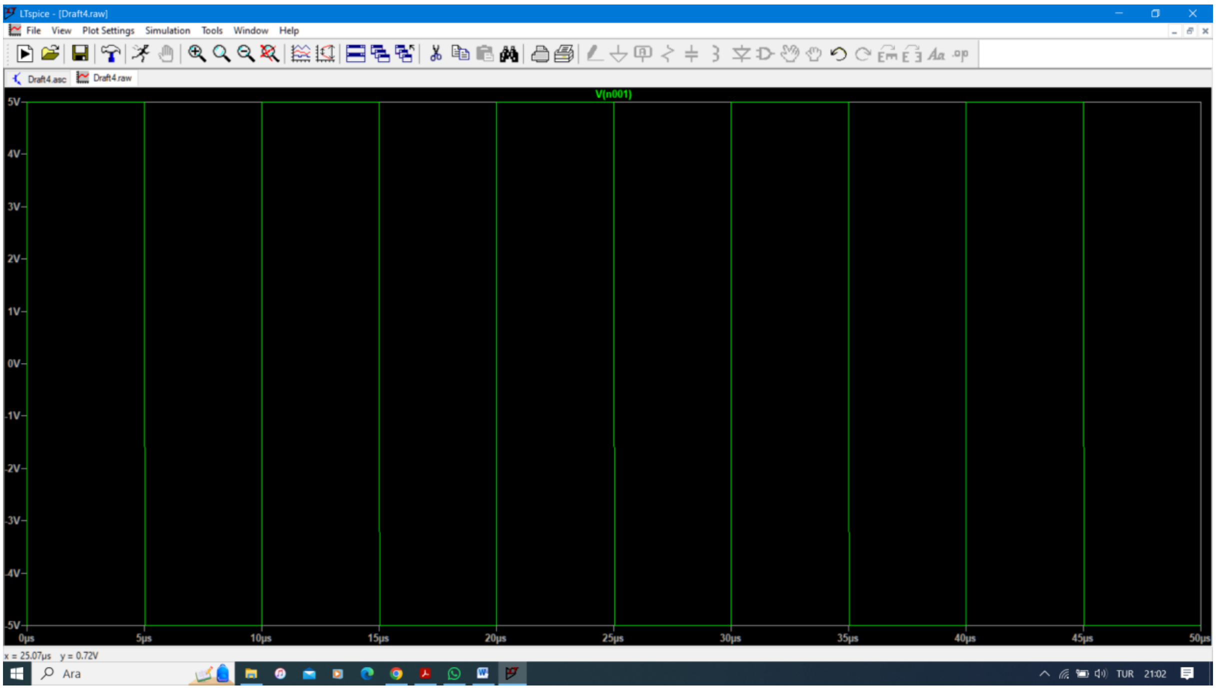

Figure 5: Simulation Result for Input Voltage

As it is seen in Figure 5, the input voltage is correct, it is a 10 V peak-to-peak square wave input.

In Figure 6, input and output voltage can be viewed.

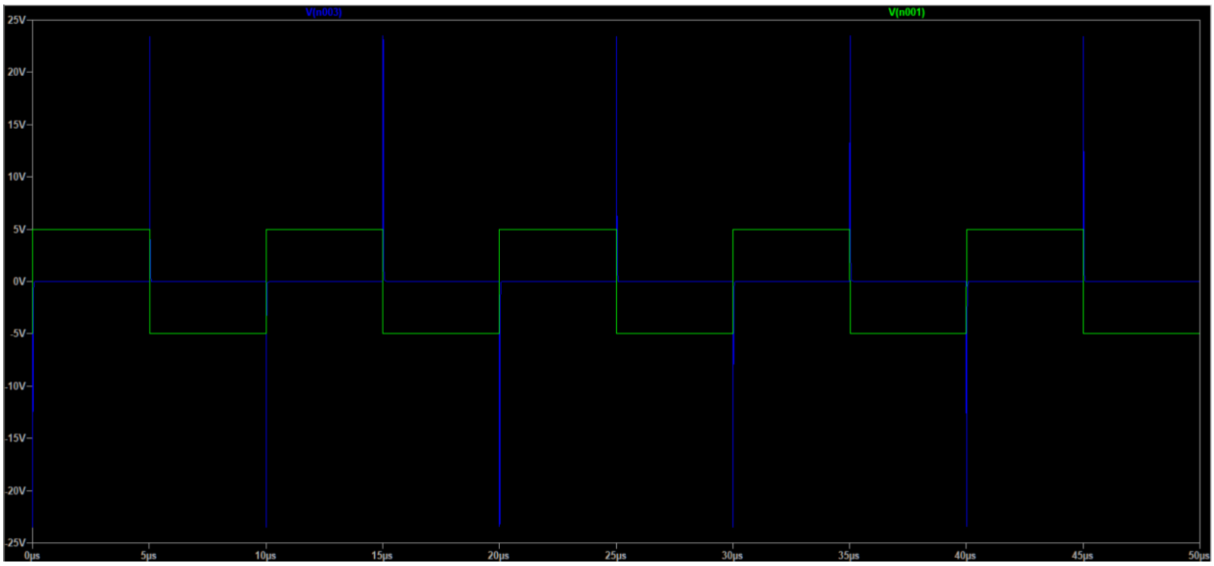

Figure 6: Simulation Result for Input and Output Voltage

In Figure 6, the output voltage (blue lines) satisfies the expected values since the maximum value is between 20V and 25V. And the spike duration lasts much shorter than the input period.

In figure 7, the maximum value of the output voltage is shown. And as it is approximately 23.4 V, it is satisfactory. Again, it can be seen that the spike duration is much shorter than the input period.

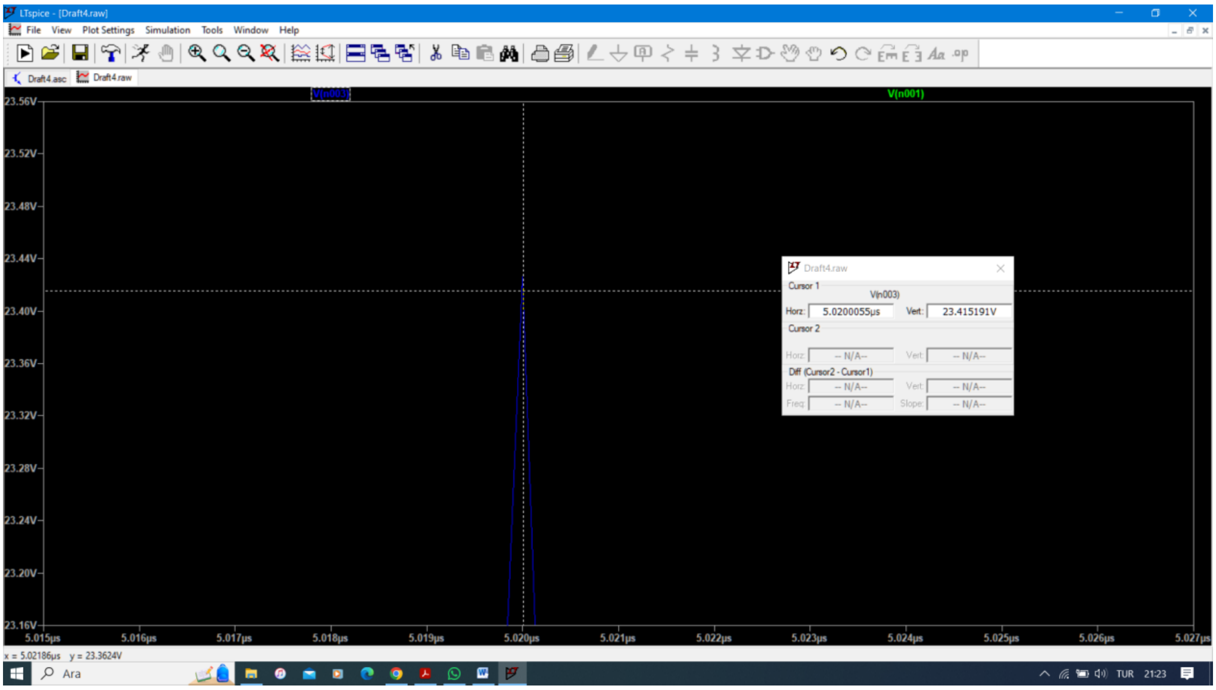

Figure 7: The Peak Voltage Value of Input Voltage in LTSpice Simulation

In Figure 8, value of full width at half maximum (FWHM) can be seen.

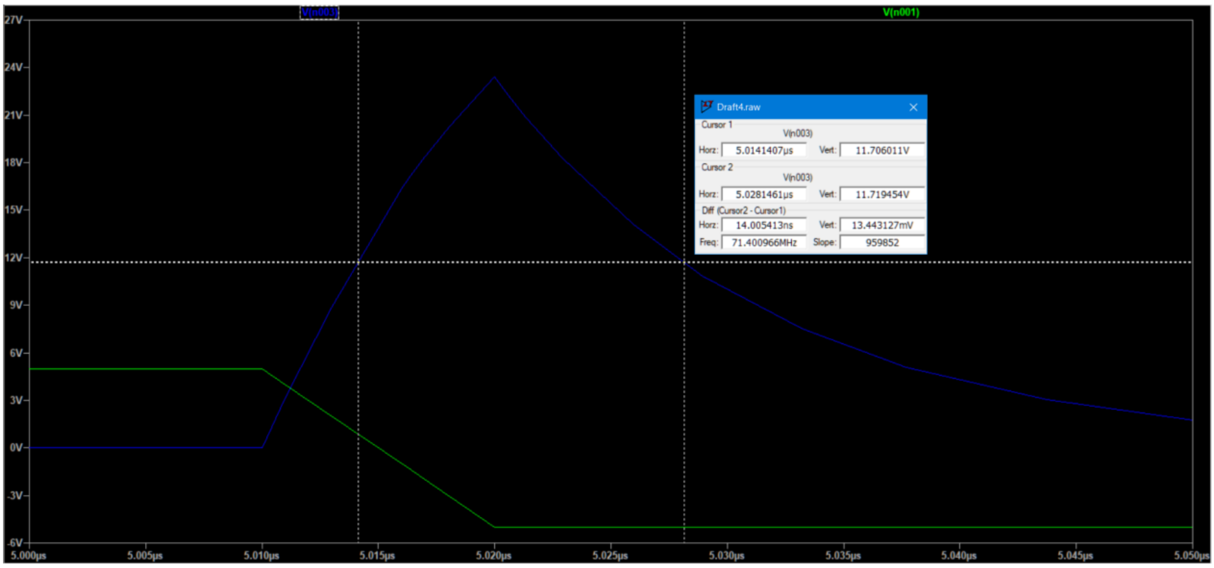

Figure 8: Graph of FWHM in LTSpice Simulation

The value of full width at half maximum (FWHM) is calculated by using Cursor 1 and Cursor 2. And the value is approximately 14ns as it satisfies the condition which it should be shorter that 100 ns. Therefore all of the expected results are satisfactory.

Hardware Lab:

Signal generator with 5 volts peak-to-peak and 2MHz frequency is connected with a 47 Kohm resistor as it is wanted in Figure 9.

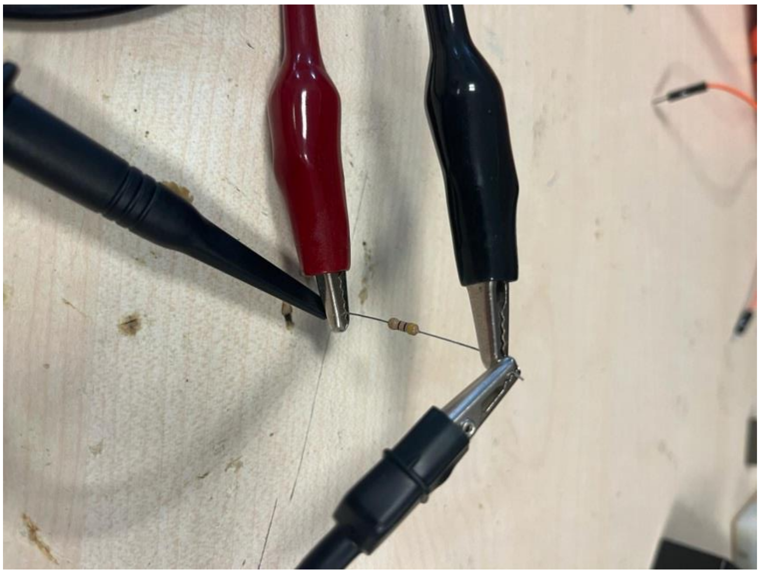

Figure 9: Signal Generator Connected Resistor

In Figure 10, the oscilloscope results can be seen. And the results are correct since it is a 5 V peak-to-peak square form graph.

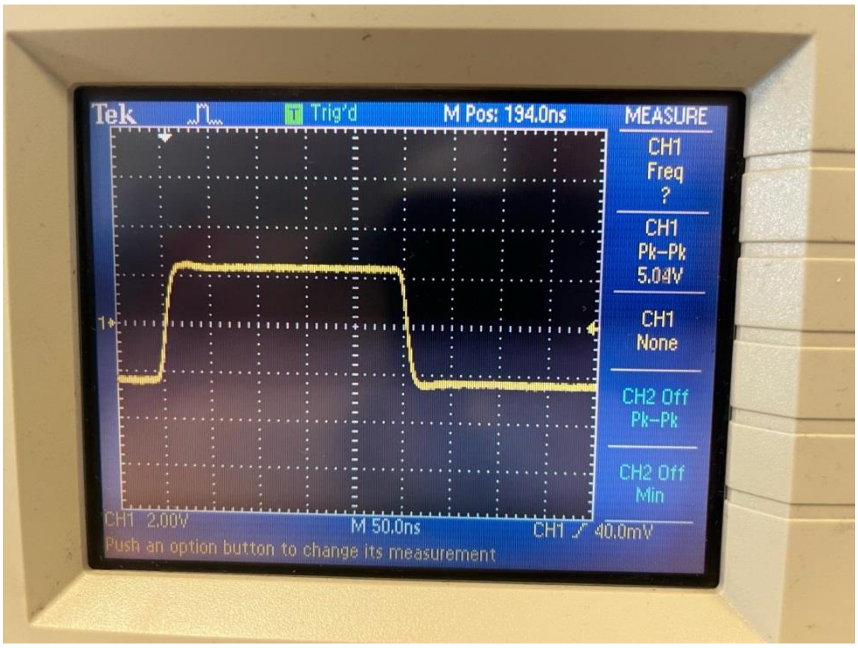

Figure 10: Graph of Input Voltage

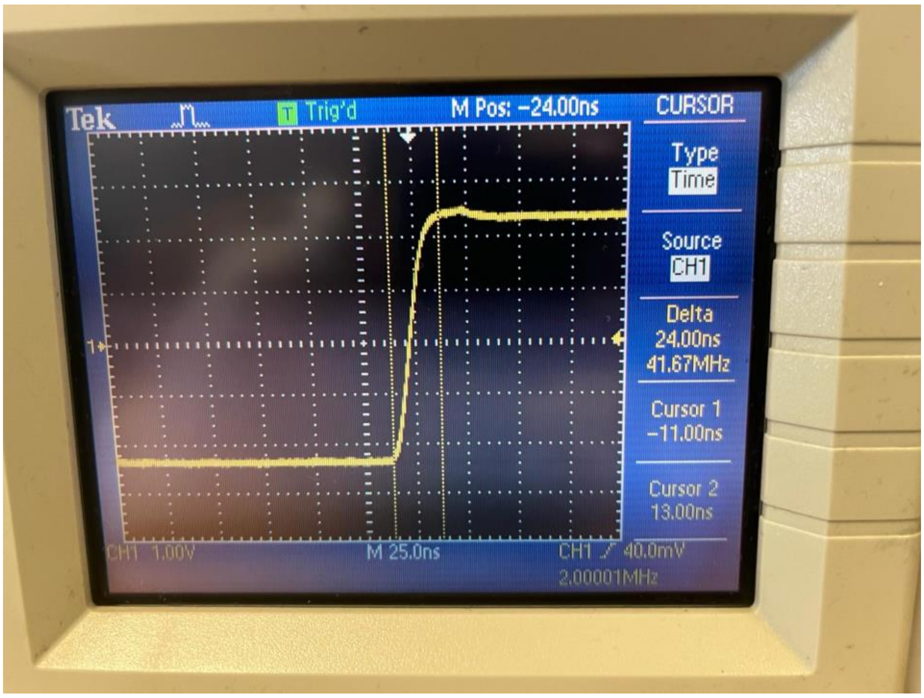

Figure 11: Rise Time of the Input Voltage Signal

The rise time of the input voltage signal is seen in Figure 11. The calculation is done with using 2 vertical cursors and by subtracting their values. The rise time is found 24ns.

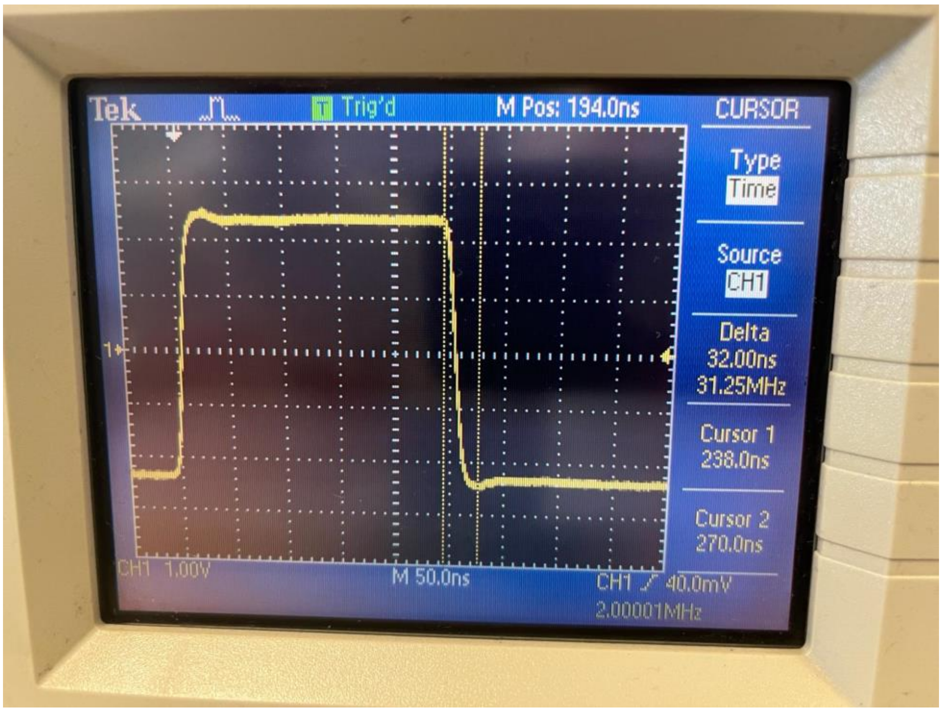

Figure 12: Fall Time of the Input Voltage Signal

The fall time of the input voltage signal is seen in Figure 12. The calculation is done with using 2 vertical cursors and by subtracting their values. The fall time is found 32.0 ns.

In software lab, by using Equation 2, the winding value for primary inductor was found 4.47 which is approximately 4 turns and the winding value for secondary inductor was found 22.36 which is approximately 22 turns with using T38-8 toroid which has the constant value $\frac{20nH}{n^2}$. The mathematical operation is below:

$$0.4 * \ 10^{-6} = 20 * 10^{-9} * n_p^2$$

$$n_p = 4.47$$

$$10 * \ 10^{-6} = 20 * 10^{-9} * n_s^2$$

$$n_s = 22.36$$

Equation 6: Calculating the Winding Values

Even though the ratio between primary winding and secondary winding is $\frac{1}{5}$ and correct theoretically, it is not satisfactory for real life implementation since the value of the output voltage is much less than the desired value. After discussing with TAs, I was told to increase the number of turns without changing the ratio $\frac{n_p}{n_s} = \frac{1}{5}$ and should not add a resistor, therefore the windings are chosen as 8 turns for primary and 40 turns for secondary. And finally the hardware results were satisfactory.

$$L_p = 20 * 10^{-9} * n_p^2$$

$$n_p = 8$$

$$L_s = 1.28 \, uH$$

$$L_s = 20 * 10^{-9} * n_s^2$$

$$n_s = 40$$

$$L_s = 32.00 \, uH$$

Equation 7: Calculating the Real Life Winding Values

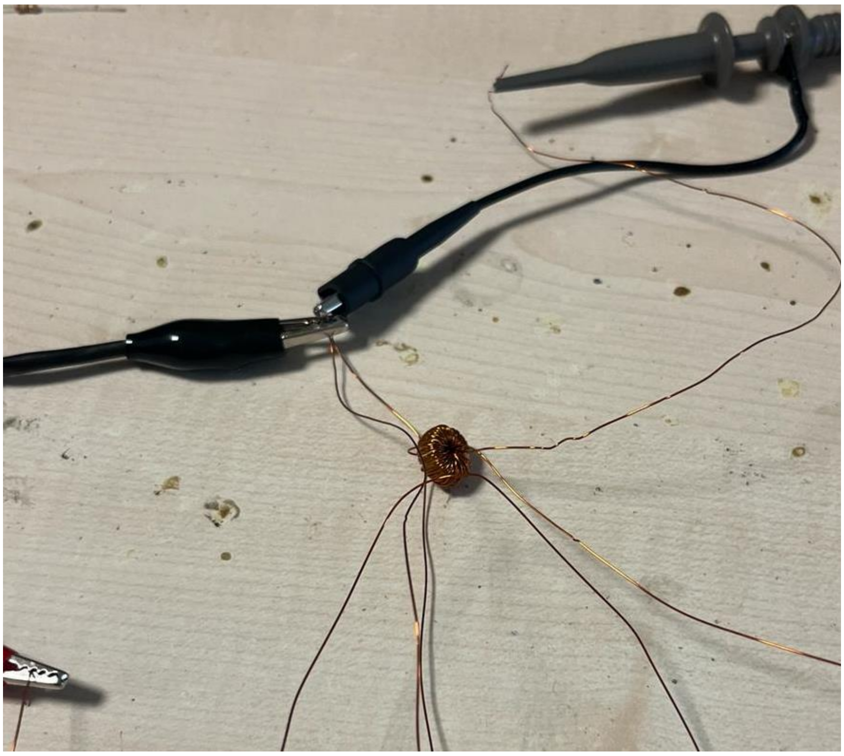

Figure 13: The Final Hardware Circuit

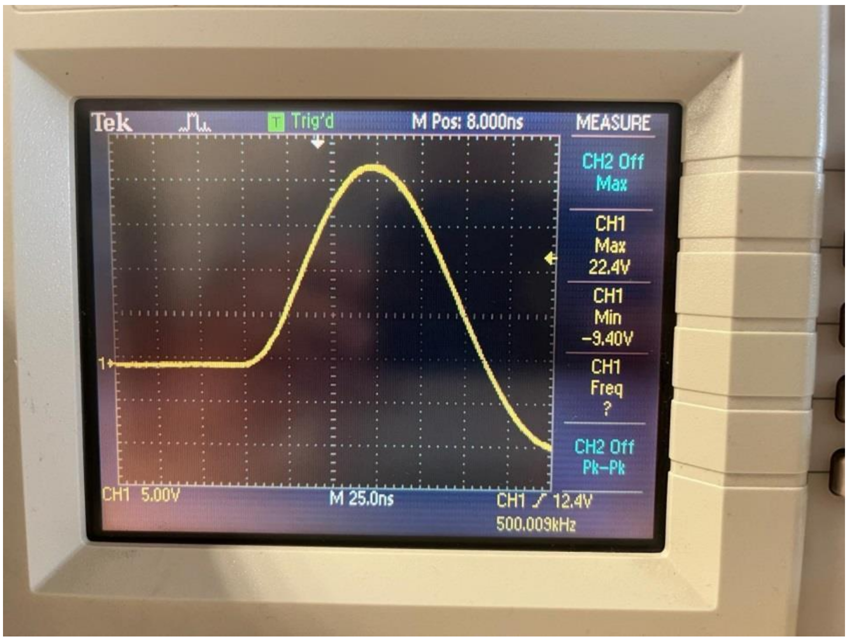

Figure 14: The Maximum (Peak) Value of Output Voltage

As it can be seen in the Figure 14, the maximum value of output voltage is 22.4 V which is 44.8 peak-to-peak value. And it is satisfactory, since the desired peak-to-peak value should be between 40V to 50V.

In order to find the full width at half maximum (FWHM), the half maximum point is determined by using a horizontal cursor as it is seen in figure 15.

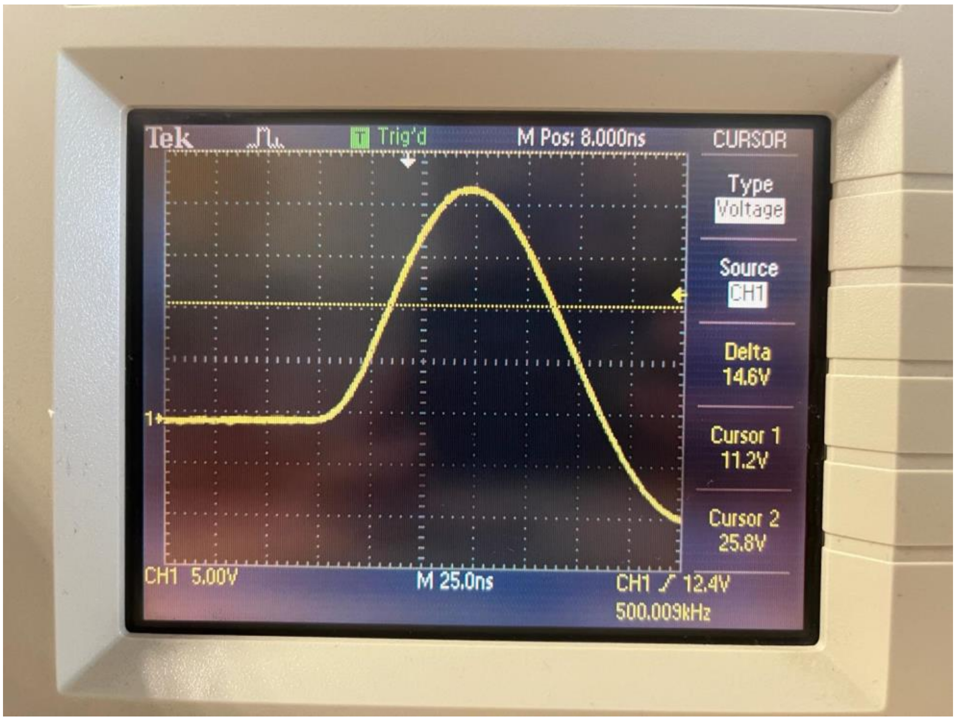

Figure 15: The Middle of the Output Voltage

Then 2 vertical cursors are added to the beginning and the ending points of the horizontal cursor in Figure 15. And the full width at half maximum (FWHM) value which is 76.0 ns is seen in the Figure 16.

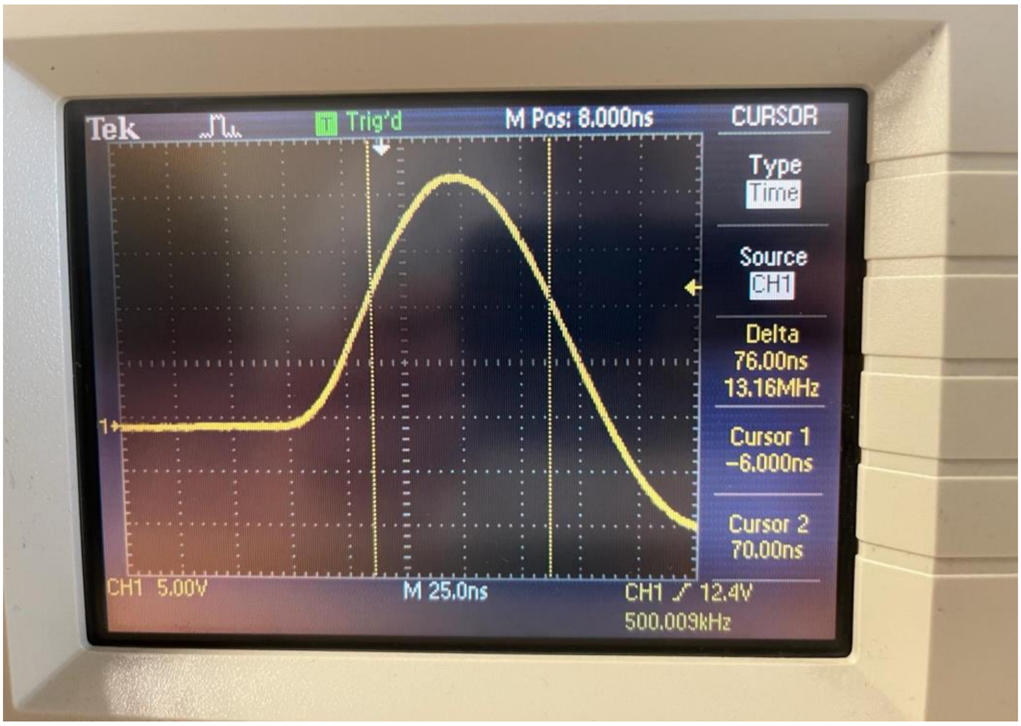

Figure 17: Full Width at Half Maximum (FWHM) Graph

The Full Width at Half Maximum (FWHM) value is different than the software result, however it is still satisfactory since it is less than 100ns.

Peak Value in the Simulation	Peak Value Measured at the Implemented Circuit (V)	Error Percentage of the Peak Value
23.4	22.4	%4.27

FWHM Value in the Simulation (ns)	FWHM Value Measured at the Implemented Circuit (ns)	Error Percentage of the FWHM Value
14	76	%442

Conclusion:

In summary, Lab 2 proved to be successful overall, encompassing both software and hardware components. The desired voltage spikes were achieved within the specified criteria in both labs, and the theoretical understanding of the circuits proved adequate. The designed circuit, employing toroidal cores and standard components such as resistors, and inductors demonstrates an effective means of generating the required high voltage spikes. By ensuring the spike duration is significantly shorter than the input period, the circuit enables rapid and precise response to the input square wave. While some errors were encountered in the hardware lab regarding output voltages, successful results were obtained through significant changes to the design and circuit element values. Additionally, potential errors stemming from friction and tightness in the windings may have occurred. Moreover, the lab proved beneficial in enhancing knowledge of LtSpice for transformer creation and contributed to the development of circuit design skills involving transformers.