SW Implementation

Introduction

The goal of the second lab is to visually observe the voltage spikes in a designed passive linear circuit. This circuit is supposed to be sent a square wave of 10 Vpp, there should be a 50 Ω input resistance, the value of full width at half maximum (FWHM) has to be less than 100 ns, frequency should be below 5 MHz and the observed peak output voltage should be between 20 and 25 Volts. In this lab I implemented a design that involves a transformer to obtain the desired voltage gain and spike behavior.

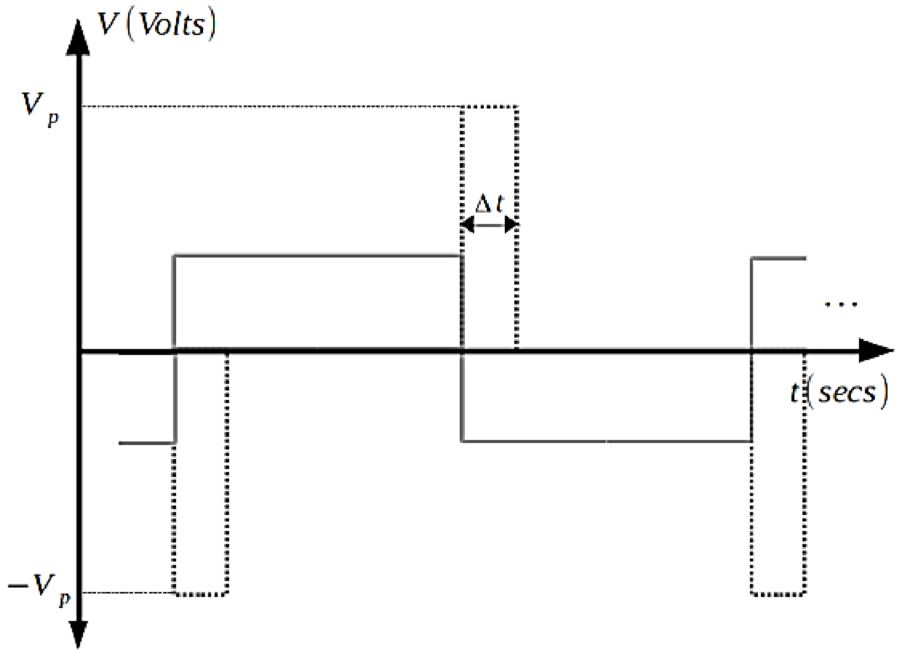

Figure 1: The unbroken line is the input, and the dashed line is the output

Analysis

The nature of inductors in electronics lets them to be used in voltage spike generating circuits, as they resist instant changes of current and create instant voltage spikes when they meet instant changes of input voltage. Since the voltage of an inductor is equal to its inductance (L) times the derivative of the current that flows through it, that current i_L can be displayed with the following formula:

$$i_L(t) = i(0) + \frac{1}{L} \cdot \int_0^t V(x)dx \tag{1}$$

When an inductor goes through a square shaped wave ranging from 0 to +V, as the input voltage increases to V from 0 at the beginning, its voltage also becomes +V, and as the input voltage decreases to 0, the voltage on the inductor also decreases to 0. As the voltage on an inductor goes through such changes, its current does not instantly change since (1) is a continuous function and the inductor causes voltage spikes in order to resist instant changes.

When the such change happens to the current, a spike of voltage gets created since (1) is a continuous function and its value cannot possible become its negative value instantly. In order to make use of this principle, and in addition adjust the circuit to obtain the desired voltage gain, a transformer that controls voltage spikes with two inductors is necessary. The voltage gain can be displayed with the formula:

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} \tag{2}$$

Here, N displays the number of turns, and since inductance equals N^2 times inductance per turn, the ratio of voltages between two sides of a transformer can be expressed as:

$$\frac{L_1}{L_2} = \left(\frac{V_1}{V_2}\right)^2 \tag{3}$$

Since the pulse wave we sent in this lab is 10 Vpp (-5V to +5V) and the desired range of output voltage is 20 to 25 Volts, the ratio of voltages should be between 5/20 and 5/25, implying that the ratio of inductance of the inductors that make up the transformer should be between 1/16 and 1/25. I picked 560 nH and 6.8 µH for L1 and L2, chose the input frequency as 1 MHz, and had an output resistor of 1 MΩ including the given input resistance of 50Ω. Calculating the necessary number of turns to obtain this transformer, including the fact that the inductance per turn (r) is 20nH per turn square in the T38-8 toroid:

$$N_1 = \sqrt{\frac{L_1}{r}} = \sqrt{\frac{560}{20}} \approx 5$$

$$N_2 = \sqrt{\frac{L_2}{r}} = \sqrt{\frac{6800}{20}} \approx 18$$

Simulations

On LTSpice I implemented the following circuit involving a transformer. V1, the input voltage, is a 10 Vpp square wave of 1 MHz frequency, and there is a 50Ω input resistance.

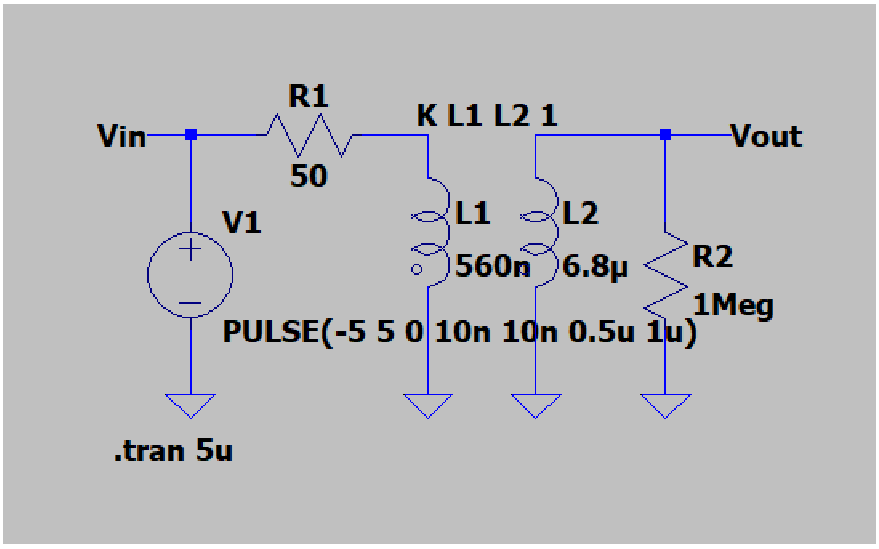

Figure 2: Design on LTSpice

After running a simulation I observed the output and input voltage waves as in Figure 3. The output voltage Vout carries the desires spike pattern, and has a peak voltage of 23.05 V. The value of FWHM is 14.21 ns, and the total spike duration is 82.01 ns, against the input pulse wave's 1µs period. Simulation results are tabled in Table 1 and they are as in Figures 3-5.

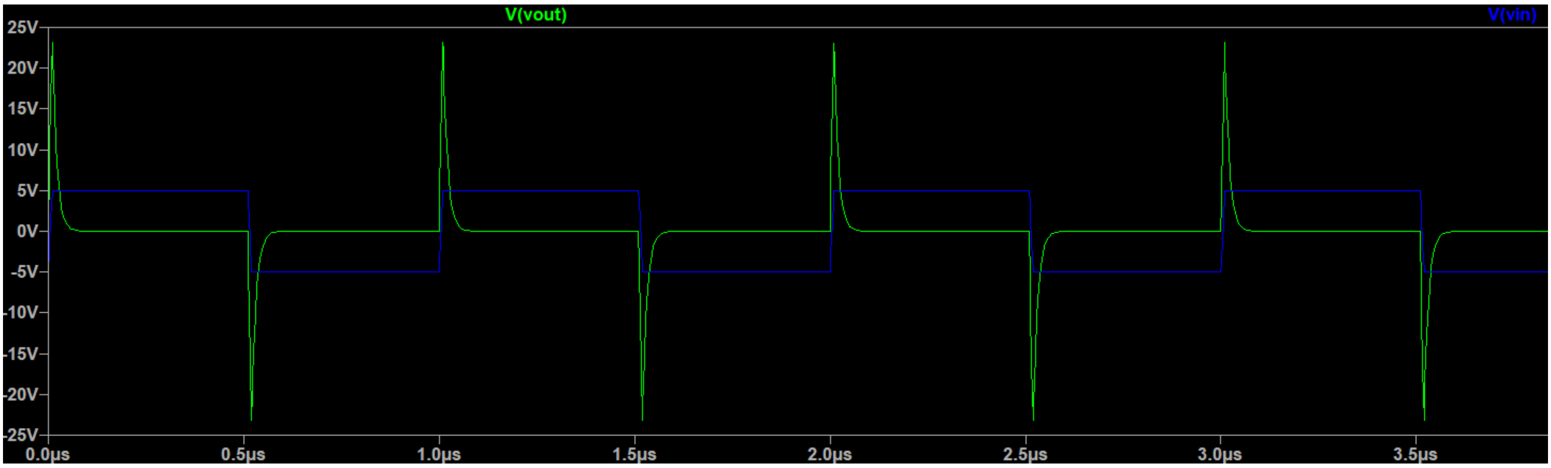

Figure 3: Input and Output Voltages

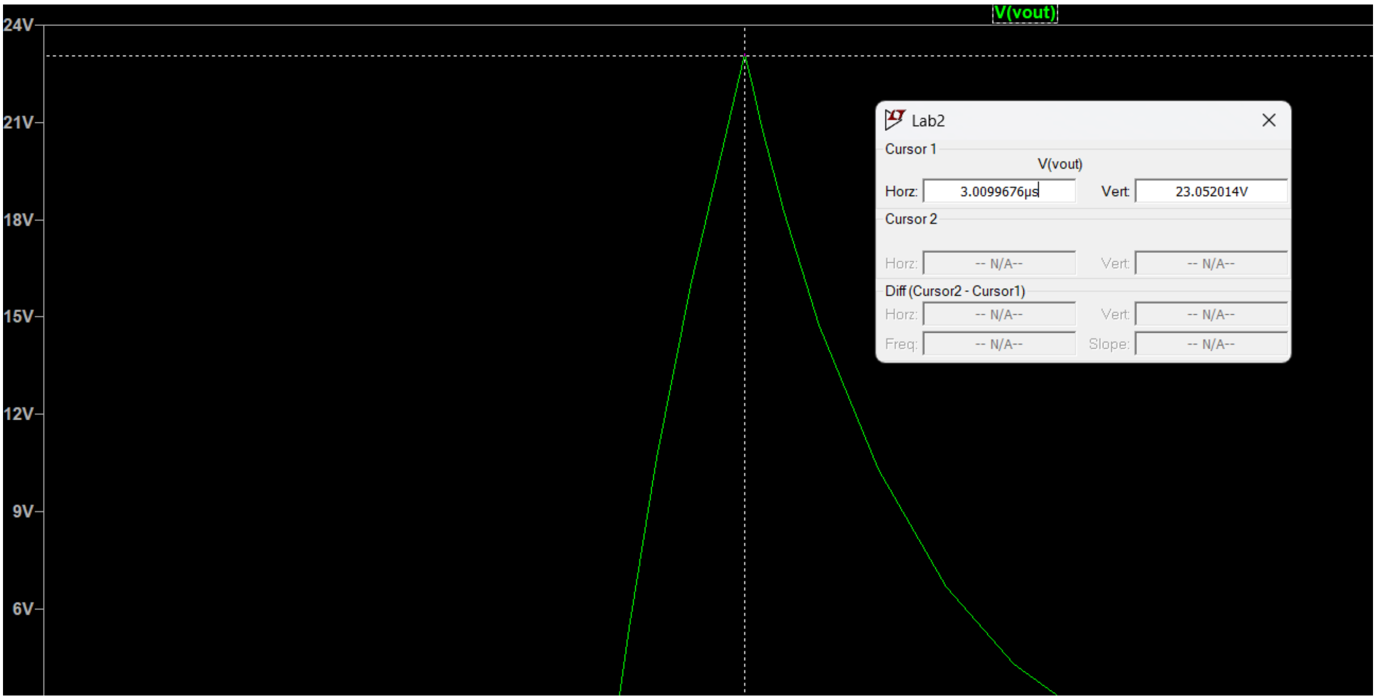

Figure 4: Peak Voltage Value

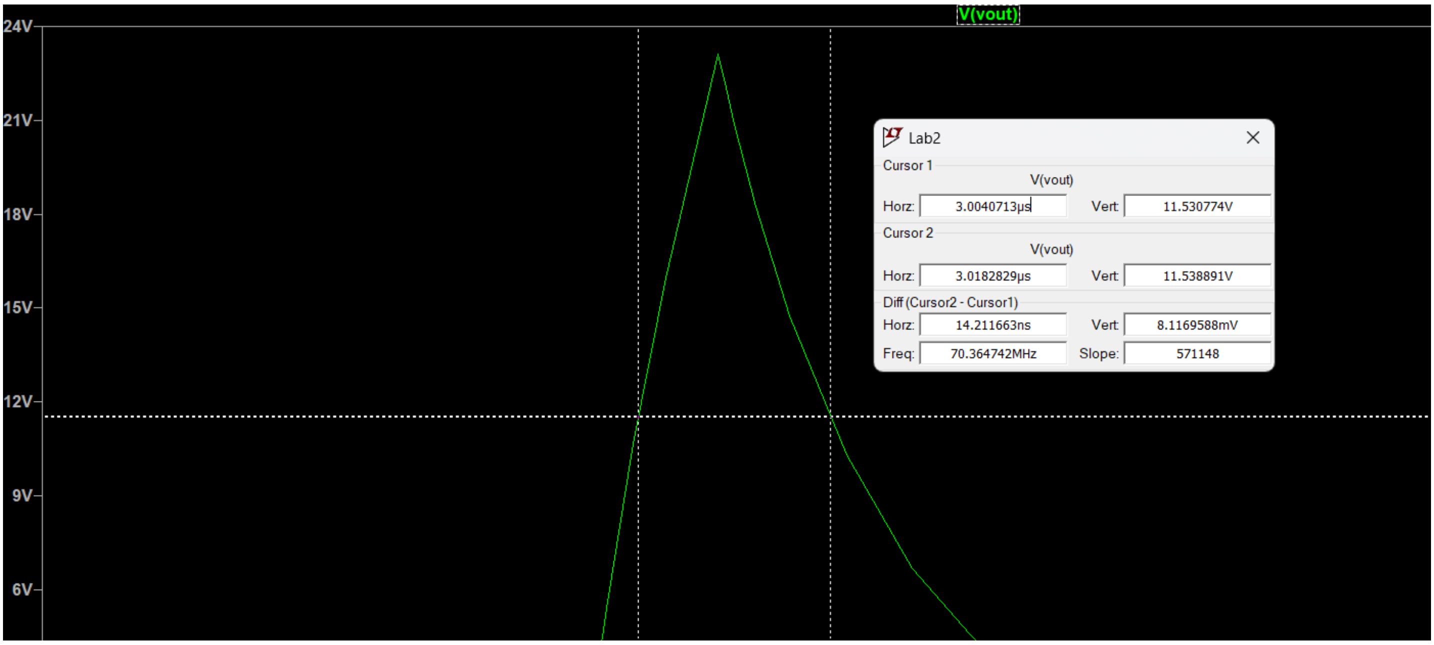

Figure 5: Full Width at Half Maximum (FWHM) Value

Vpp of Input Voltage Wave	Vpp of Output Voltage Wave	FWHM Value	Spike Duration
10 V	23.05 V	14.21 ns	82.01 ns

Table 1: Results of the Simulation

HW Implementation

For the first part of the experiment a 47Ω resistor's two ends are connected to the terminals of the signal generator, and the inputted voltage is observed on the oscilloscope. On the image, the rise and fall time, as well as the input voltage's peak value is observed. I found out that the rise time is 24 ns, the fall time is also 24 ns, and the maximum value of the input voltage is 4.72 V. Measurements for the first part are as in Figures 6-9, and the design is in Figure 10.

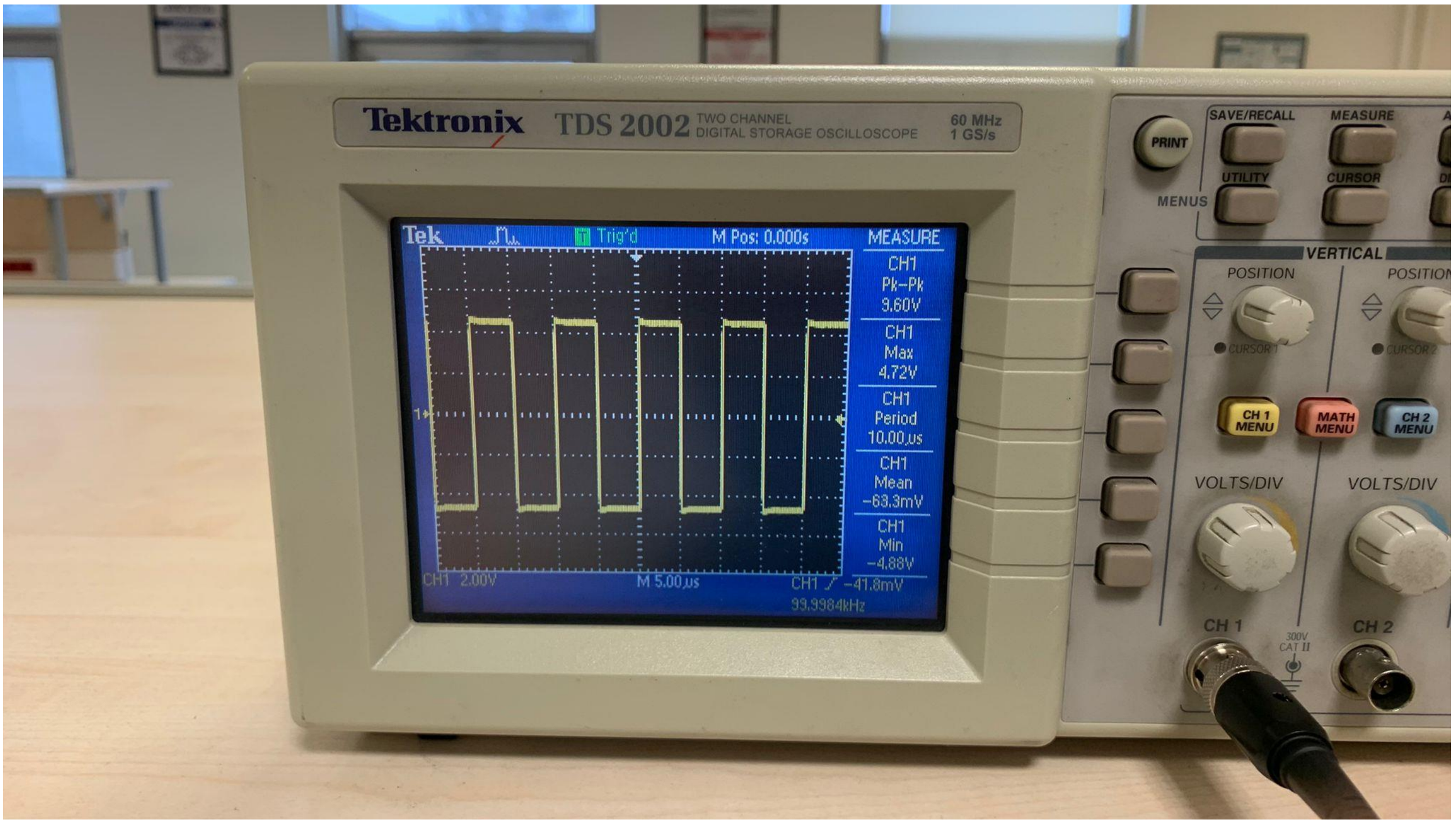

Figure 6: Input Square Wave

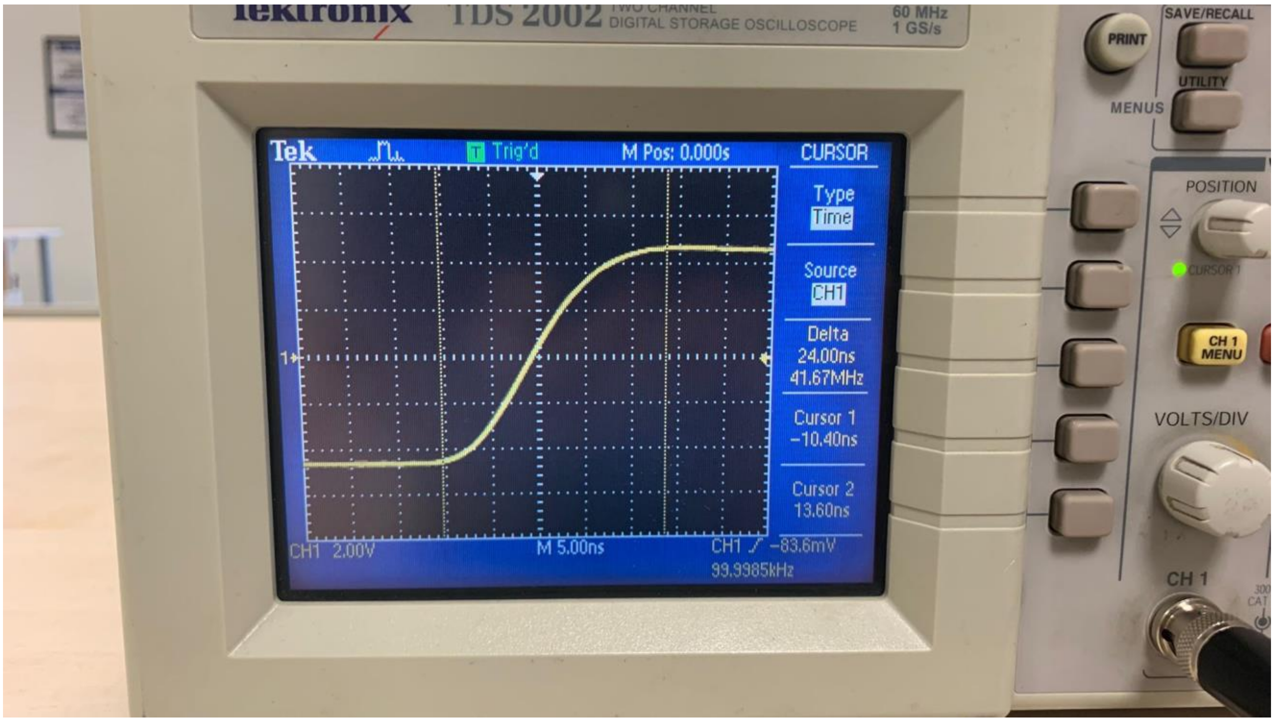

Figure 7: Rise Time

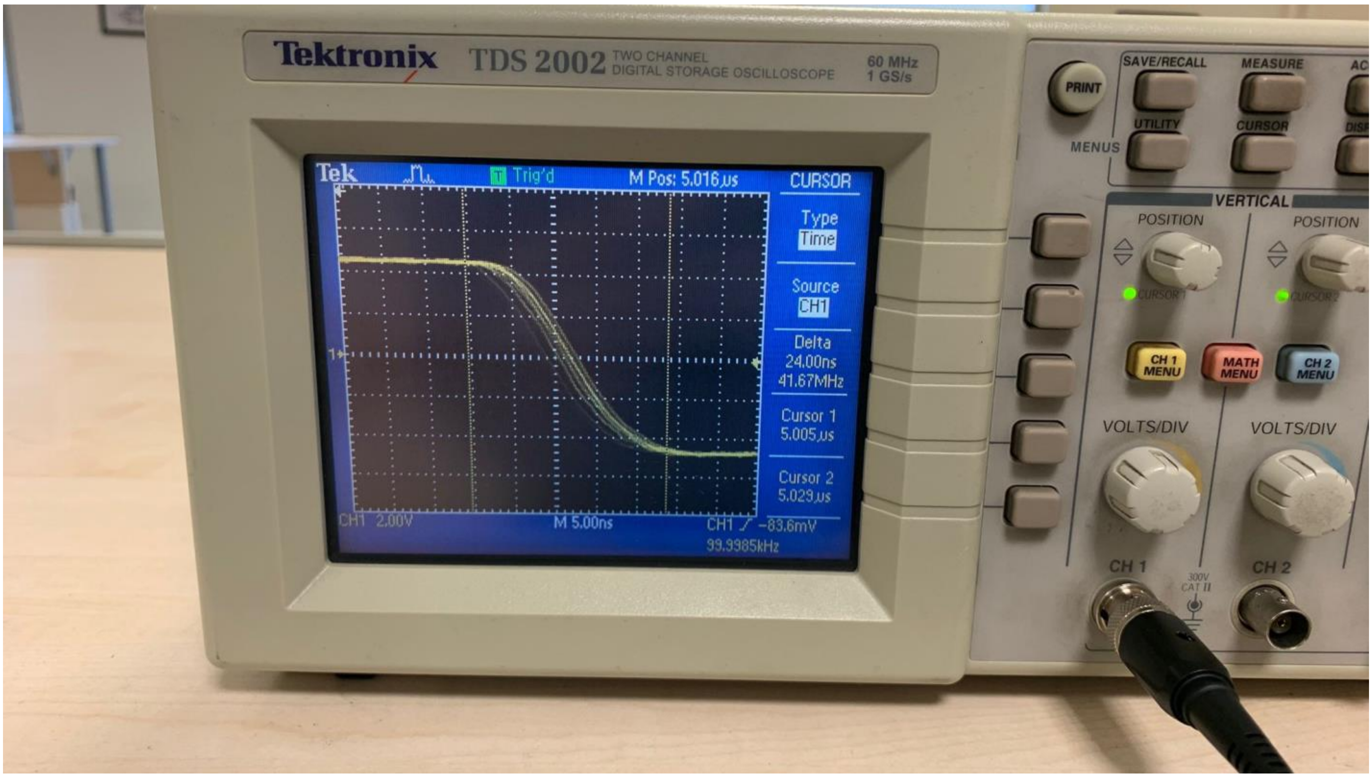

Figure 8: Fall Time

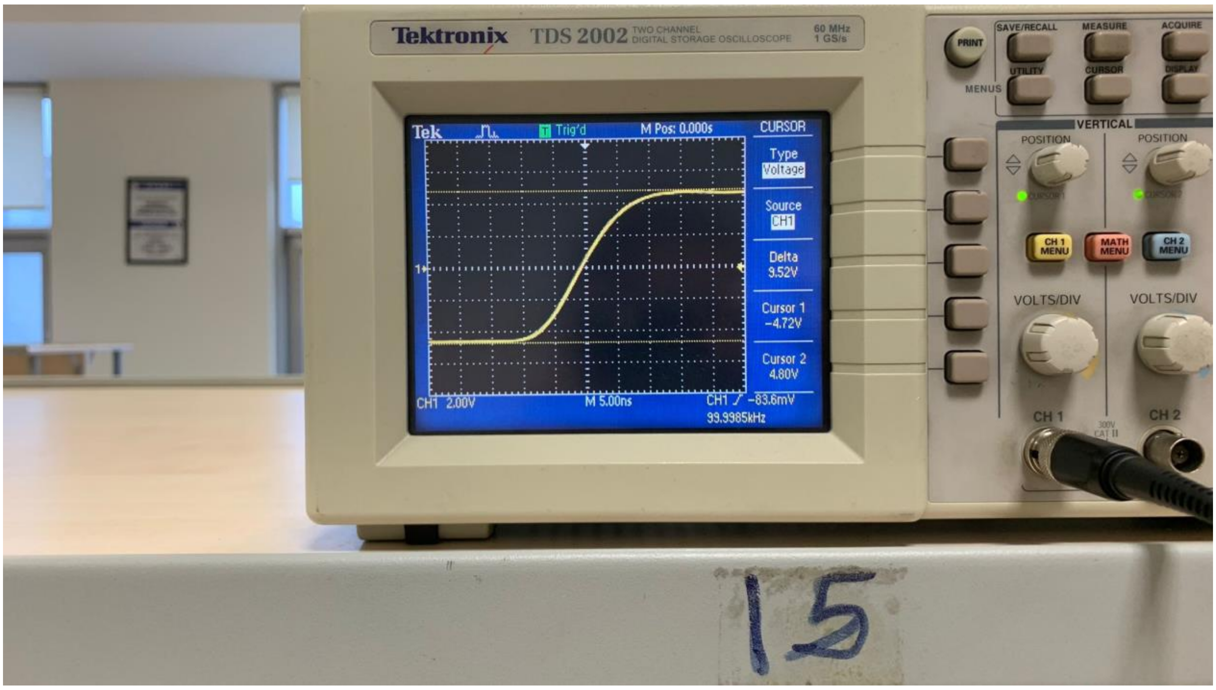

Figure 9: Peak Input Voltage Value

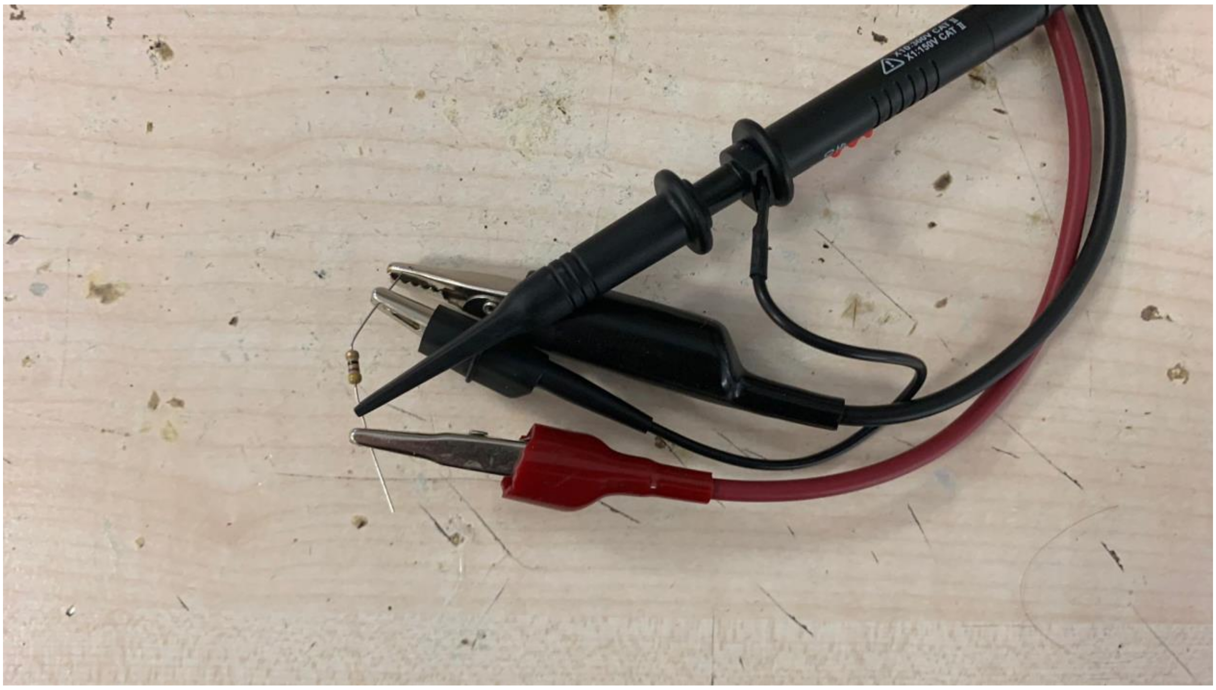

Figure 10: Connected a Resistor through Signal Generator Terminals

Later, I connected the toroid between the signal generator and oscilloscope probe's ends and observed the same input wave's changing behavior and spike generation due to the existence of a transformer. I winded around the T-38-8 core and intended to obtain the simulation results I found earlier. Using the 5 to 18 turn ratio I obtained the images in Figures 11-13, and the connections were as in Figure 14. The peak voltage was 22.8 V, and the FWHM value was 48 ns. Table 2 includes the results for the measurements and error perctentages.

Figure 11: Output Voltage Wave

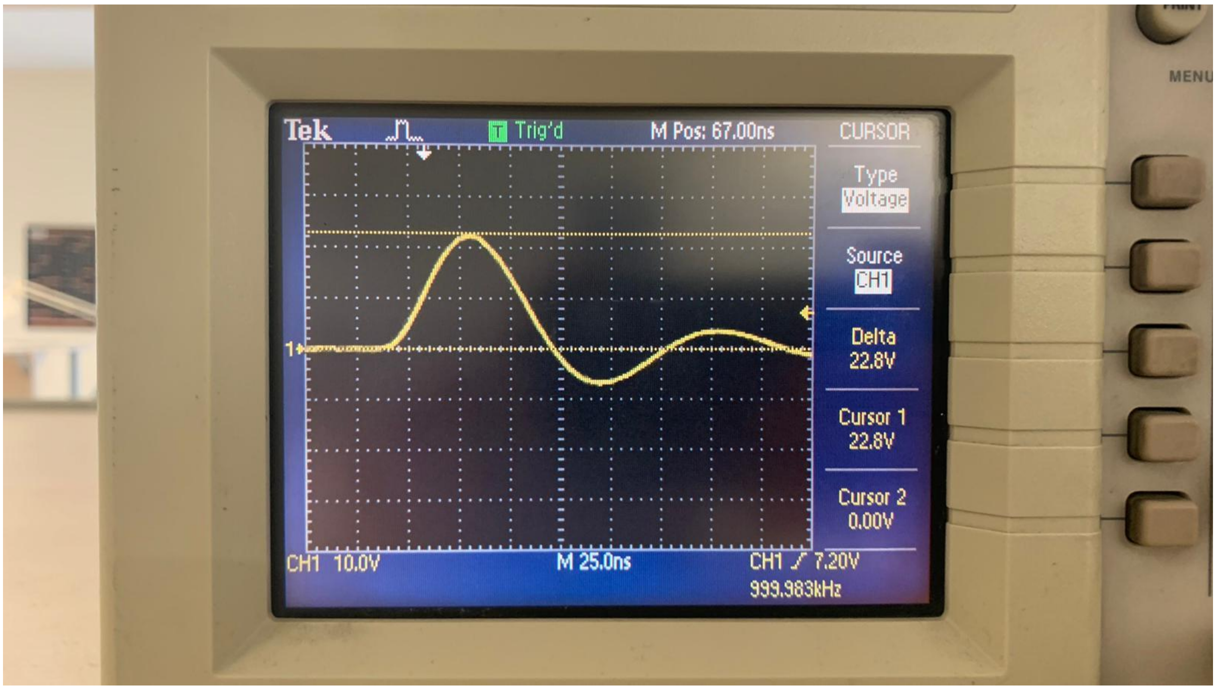

Figure 12: Peak Voltage Measurement

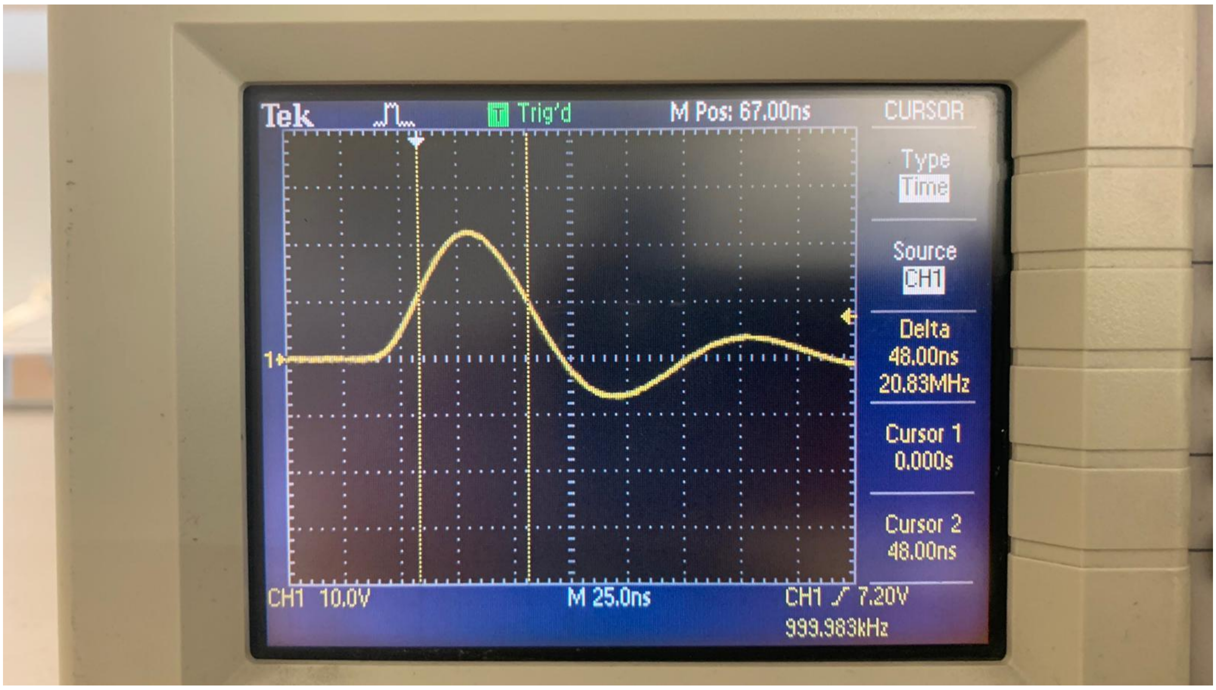

Figure 13: FWHM Measurement

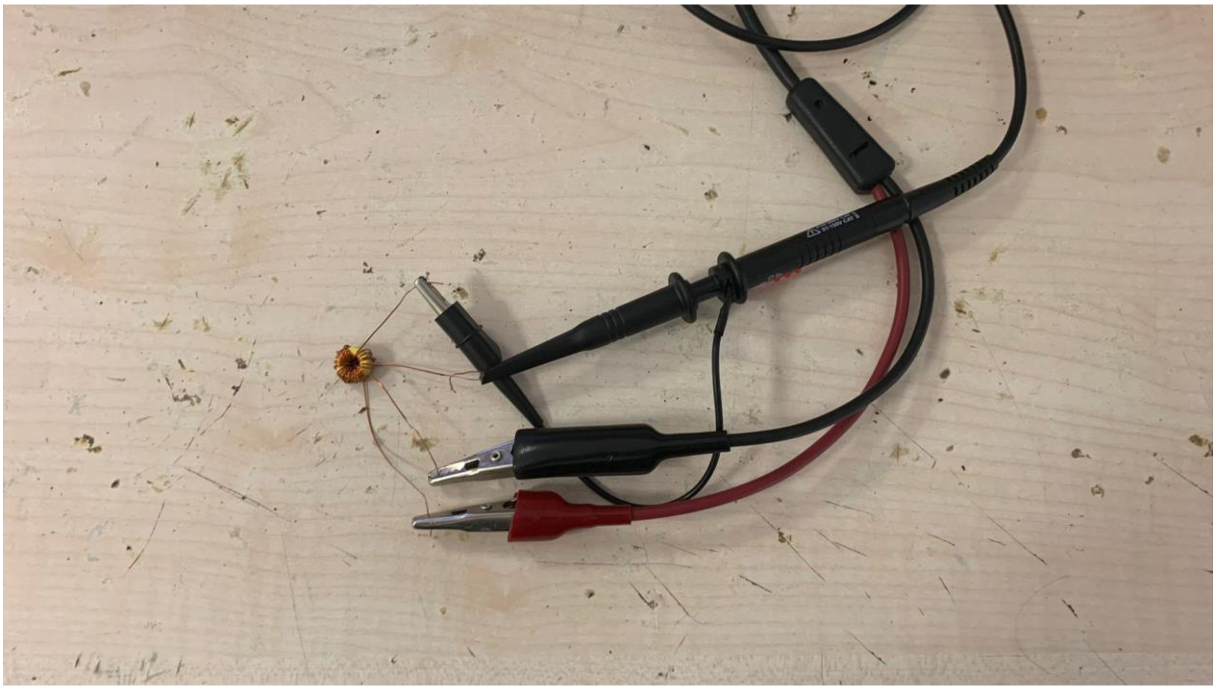

Figure 14: Implementation of Transformer Circuit

Rise and Fall Times for First Part	Peak Input Voltage of First Part	Peak Voltage of Second Part	FWHM of Second Part	Error Percentage for Peak Voltage	Error Percentage for FWHM
242 ns, 24 ns	4.72 V	22.8 V	48 ns	0.1 %	237%

Table 2: Measurements for The Hardware Implementation

Conclusion

The error percentages between the software and hardware implementations were consecutively 0.1% and 237%. The reason for this magnitude of difference between voltage and time calculations could be due to leakage inductances, extra resistances due to the winded cable's structure, and human measurement errors. In addition, since the calculations for the voltage are calculated within 0.1V intervals, but as the calculations for the FWHM was measured in nanoseconds, error percentages for the FWHM are highly likely to be greatly higher than voltage errors. Despite the error percentages, the hardware implementation values were in the desired ranges in the lab sheet, just like the software implementation.

The reason for obtaining voltage spikes was the nature of inductors, as they resist instant current changes, they create great voltage spikes in order to maintain the continuity of their current using the magnetic energy they carry. We implemented transformer circuits in this lab, that have two inductors with different number of windings to adjust these voltage spikes to obtain desires voltage gain between inputs and outputs.

In this lab, we gained knowledge of inductors, especially transformers and fall and rise times. We got along LTSpice by implementing a transformer including circuit, and learned about how transformers create voltage spikes and can be adjusted to give desired voltage gains.