EEE 202 CIRCUIT THEORY
LAB 2

Voltage Spike Generator

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Section 3

SW Implementation

Introduction:

The purpose of this lab is 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. the peak value of the voltage spikes (V_P) has to be within the allocated limit, which is $20\text{ V} \leq V_P \leq 25\text{ V}$. Full Width at Half-Maximum (FWHM) must be less than 100 ns. Figure.1 is provided in the lab assignment and shows the required input-output plot.

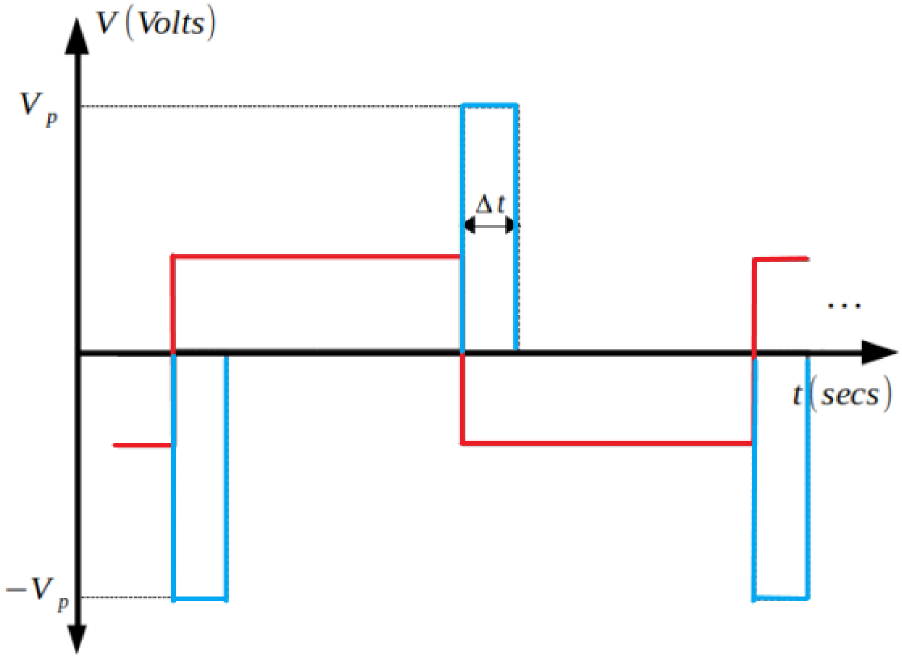

Figure.1 Input (red line) & Output (blue line) plot

Analysis:

Since we are not allowed to use active components in this lab, the safest and the easiest way to generate a voltage spike is by using an inductor. Moreover, by using an inductor, the duration of the expected voltage spike can be reduced significantly. The voltage of an inductor can be found by the following formula:

$$V_L = L\frac{di}{dt} \tag{1}$$

where L is the inductance and i is the current passing through the inductor.

The current i can be expressed as:

$$i(t) = i_t(0) + \frac{1}{L}\int_0^t V(x)\,dx \tag{2}$$

If you implement a simple circuit consisting of only an inductor and a voltage source of amplitude $\mathrm{V_x}$, the voltage of the inductor becomes equal to $\mathrm{V_x}$ rapidly. If $\mathrm{V_x}$ is constant, the formula (2) becomes as following:

$$\mathrm{i(t)} = \frac{\mathrm{V_x}}{\mathrm{L}}\mathrm{t} \tag{3}$$

If you cut the connection of the said simple circuit, the current i decreases over time until it reaches to zero. Using formula (1), we obtain that the voltage should go to infinity. However, since i(t) is a continuous function, the change in current cannot occur instantaneously. This is how we obtain voltage spikes in out circuits.

To limit the voltage spikes' voltages, we can use transformers. Since a transformer is basically two inductors winded on the same -generally toroidal- core, we can also make use of the properties of the inductors. Figure.2 is a transformer.

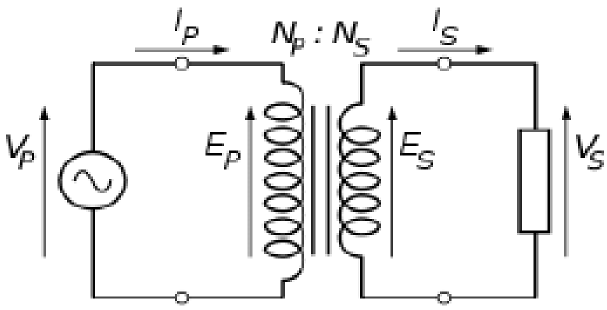

Figure.2 Transformer

The relationship between the voltages, currents and the number of turns is expressed as:

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p} \tag{4}$$

The relationship between the inductance L and the number of turns is expressed as:

$$\mathrm{L} = \mathrm{A} \cdot \mathrm{N}^2 \tag{5}$$

where A is the inductance per turn of the toroidal core. By using formulae (4) and (5), we find:

$$\frac{\mathrm{L_p}}{\mathrm{L_s}} = \left(\frac{V_\mathrm{p}}{\mathrm{V_s}}\right)^2 \tag{6}$$

Now we are ready to calculate the specifications for our circuit. Since the peak value of the square input is 5 V peak-to-peak and the output's peak value should be between 20 V and 25 V, the voltage ratio $\frac{V_\mathrm{p}}{\mathrm{V_s}}$ should be between $\frac{5}{20}$ and $\frac{5}{25}$. By using formula (6), the inductance ratio $\frac{\mathrm{L_p}}{\mathrm{L_s}}$ should be between $\frac{1}{16}$ and $\frac{1}{25}$. The chosen values are: $\mathrm{L_p} = 0.5\ \mu H$ and $\mathrm{L_s} = 9\ \mu H$. The chosen toroidal core is T38-8/90 and this core's A value is $20\ \mathrm{nH/N^2}$. For the load resistor, 4.7 KΩ is selected. The input voltage frequency is 2 MHz. The number of turns to make the corresponding transformer is calculated as:

$$N_p = \sqrt{\frac{\mathrm{L_p}}{A}} = \sqrt{\frac{0.5\ \mu H}{20\ nH\ /\ N^2}} \approx 5$$

$$N_s = \sqrt{\frac{\mathrm{L_s}}{A}} = \sqrt{\frac{9\ \mu H}{20\ nH\ /\ N^2}} \approx 21$$

For percentile error calculations, the following formula is used:

$$\%\ Error = \left|\frac{Experimental\ Value - Theoritical\ Value}{Theoritical\ Value}\right| * 100$$

Simulations:

The designed circuit is shown in Figure.3. The input is a square wave with 10 V peak-to-peak amplitude and 2 MHz frequency. The signal generator's internal resistance, 50 Ω, is also included.

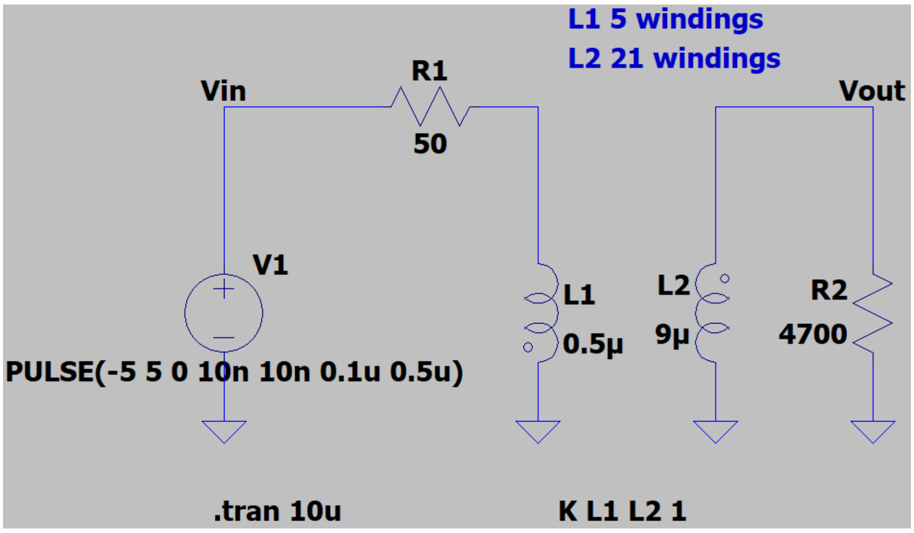

Figure.3 Voltage spike generator circuit

All of the related simulations are found in the following Figures 4-6. The output voltage and Full Width at Half-Maximum (FWHM) values are shown in Table.1. As expected, we were able to generate a spike. V_p and FWHM values are within the desired values. The spike duration is much shorter than the input voltage period (0.5 μs).

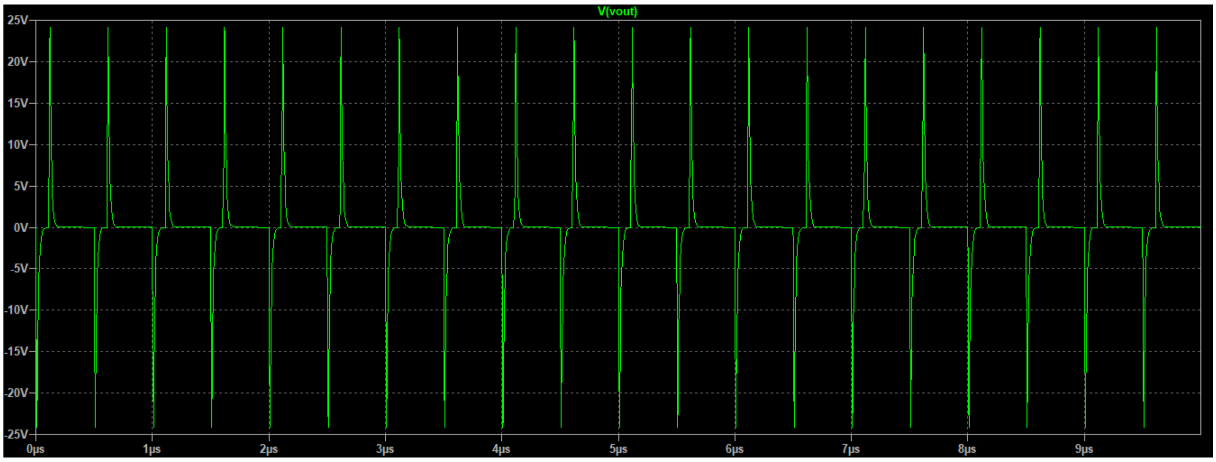

Figure.4 Output voltage spikes

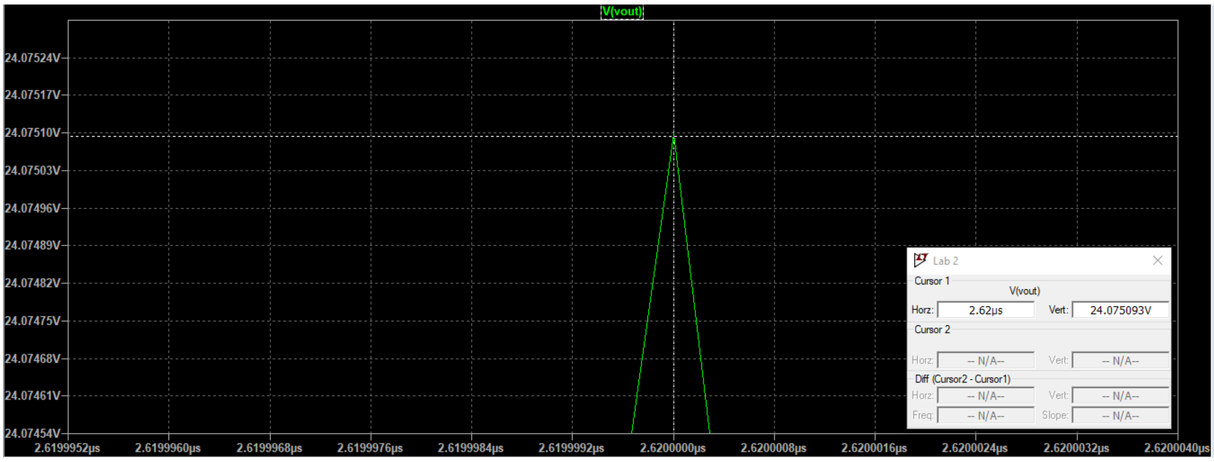

Figure.5 The peak value (V_p) of the voltage spikes

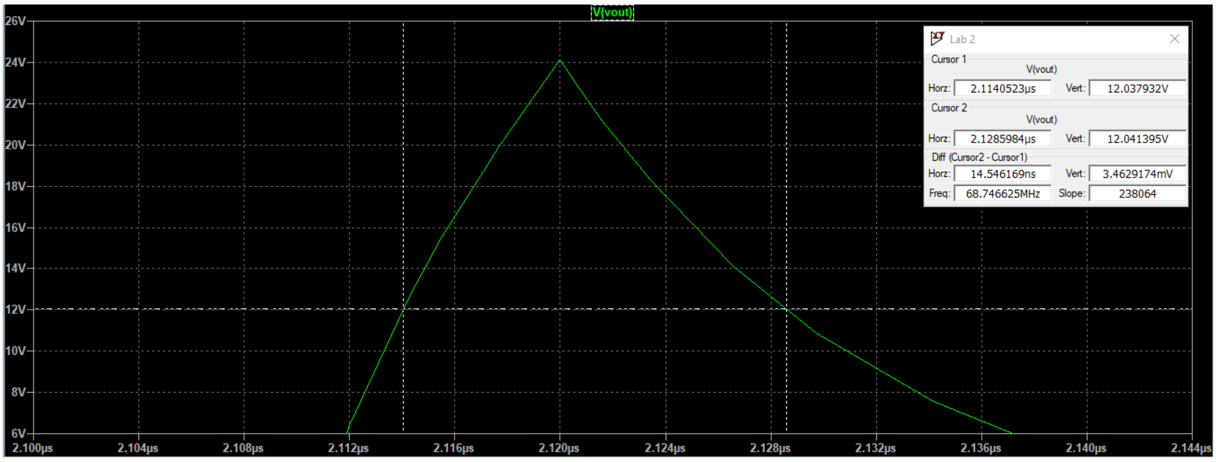

Figure.6 FWHM

Input Voltage	**Input Frequency**	$\boldsymbol{V_p}$	**FWHM**
10 V	2 MHz	24.08 V	14.55 ns

Table.1 Simulation results

HW Implementation:

The rise time, fall time and the peak value of the input voltage (10 V, 2 MHz square wave) are measured by connecting a 47 Ω resistor across the terminals of the signal generator. The setup is shown in Figure.7. The results are shown in Table.2.

Figure.7 47 Ω connected between the terminals

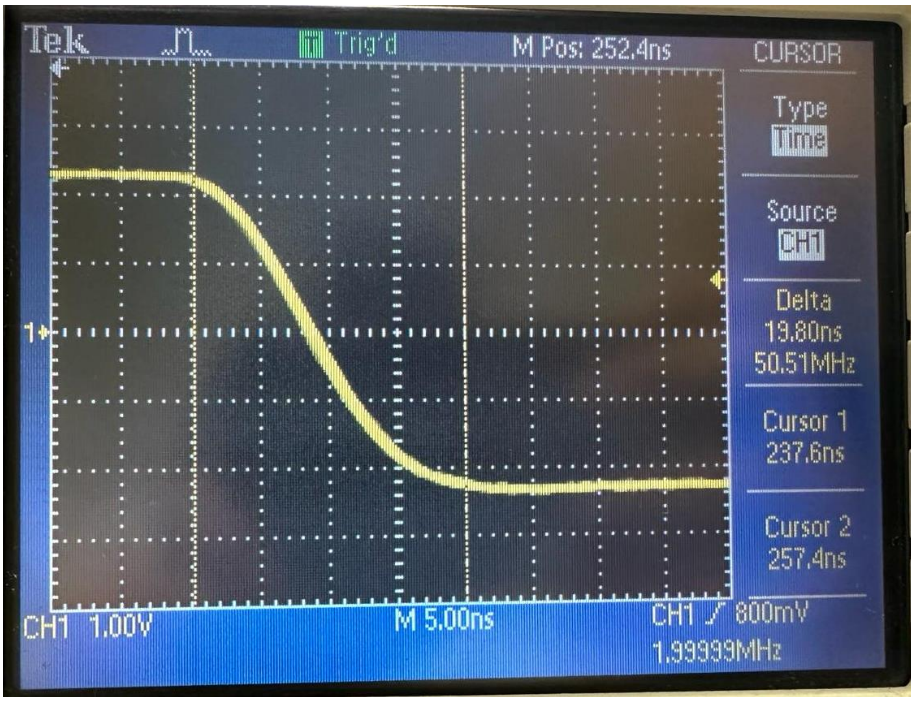

Figure.8 Fall time

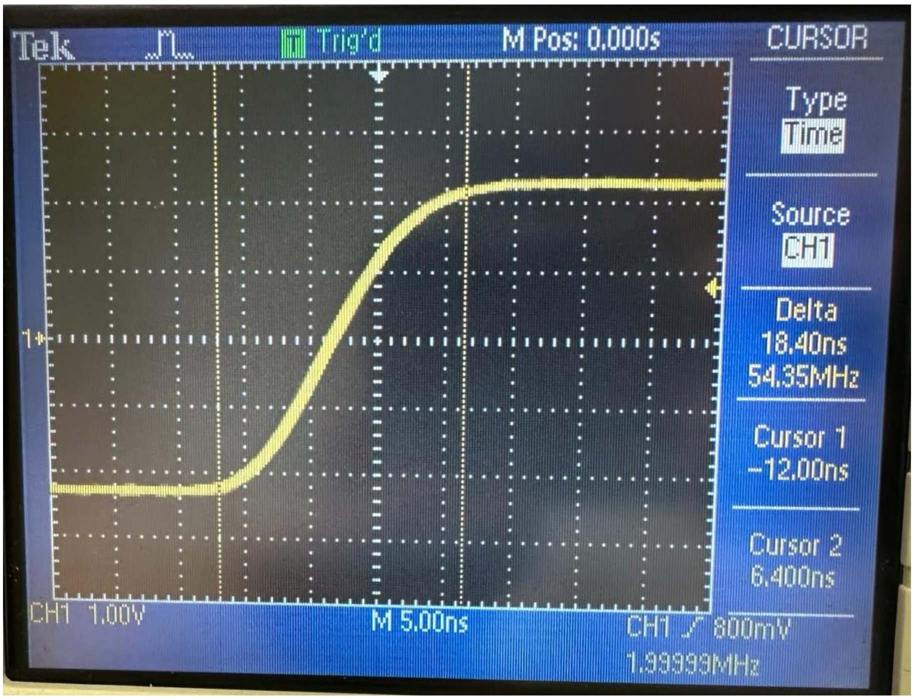

Figure.9 Rise time

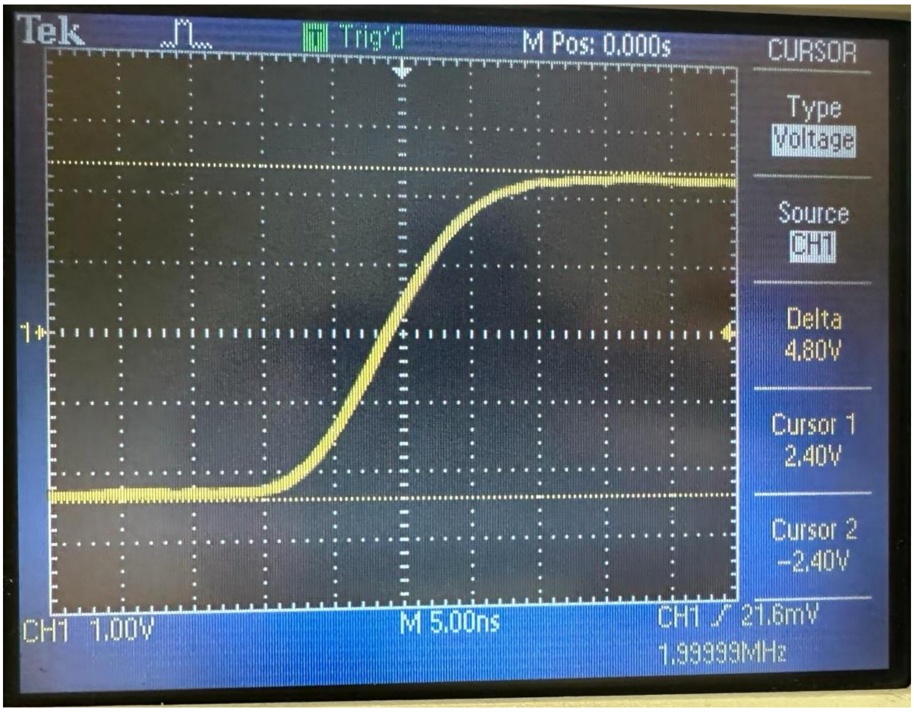

Figure.10 Peak voltage

Fall Time (ns)	Rise Time (ns)	Peak Voltage (V)
19.80	18.40	2.40

Table.2 The results from Figure.8.

Then, the voltage spike generator is implemented on the breadboard. The transformer is winded around the T38-8/90 toroidal core. The primary inductor has 5 windings and the secondary inductor has 21 windings. The transformer is shown in Figure.11. Figure.12 shows the voltage spike generator circuit.

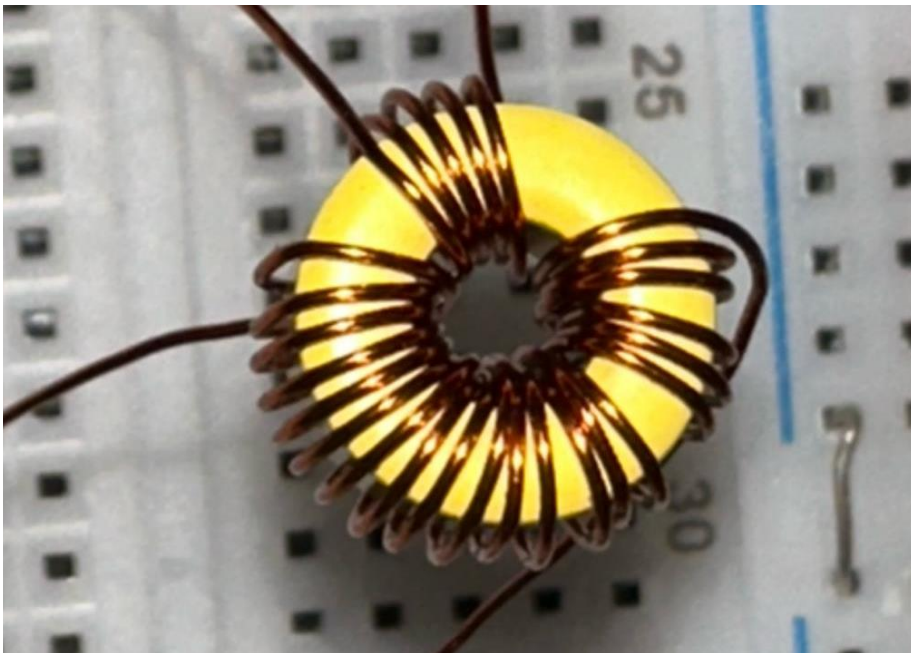

Figure.11 Transformer

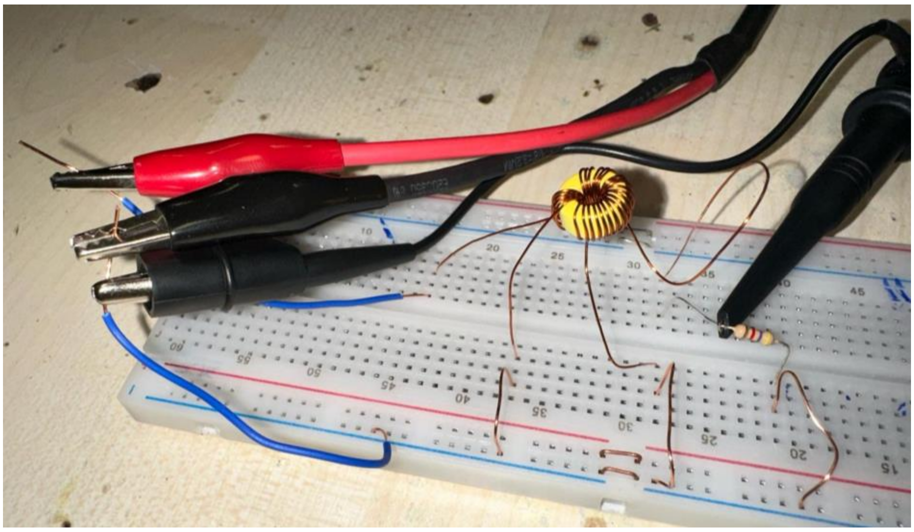

Figure.12 Voltage spike generator circuit

The inductor values are shown in Figure.13 and Figure.14.

Figure.13 The inductance value of the primary inductor is 0.497 μH

Figure.14 The inductance value of the secondary inductor is 8.97 μH

Then, the output waveform is observed on the oscilloscope. The following figures show the peak voltage and the FWHM values. Table.3 holds the measured values and the calculated error percentages according to the LTSpice simulations.

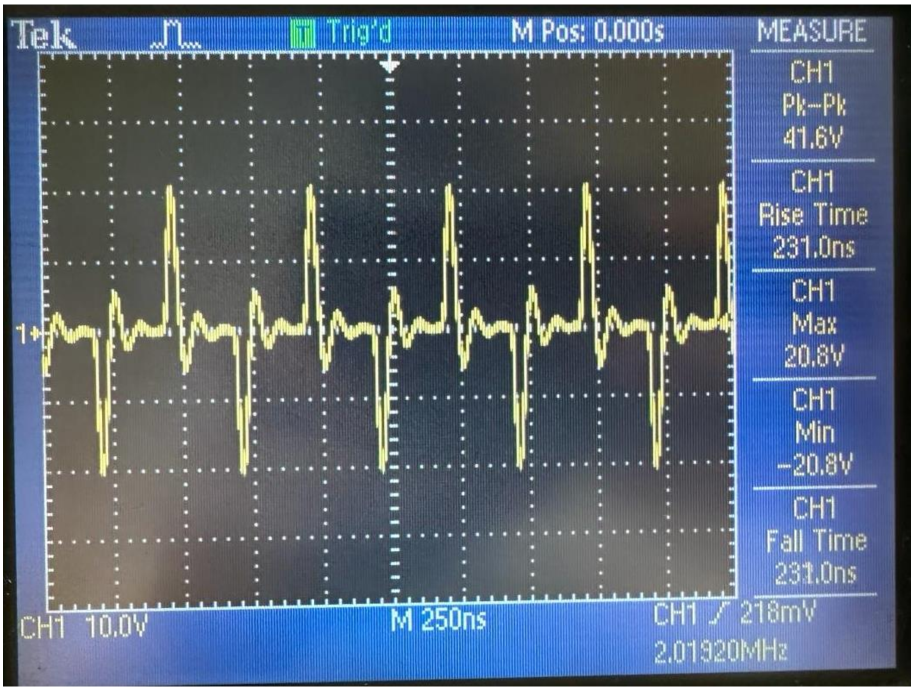

Figure.15 The output waveform on the oscilloscope screen

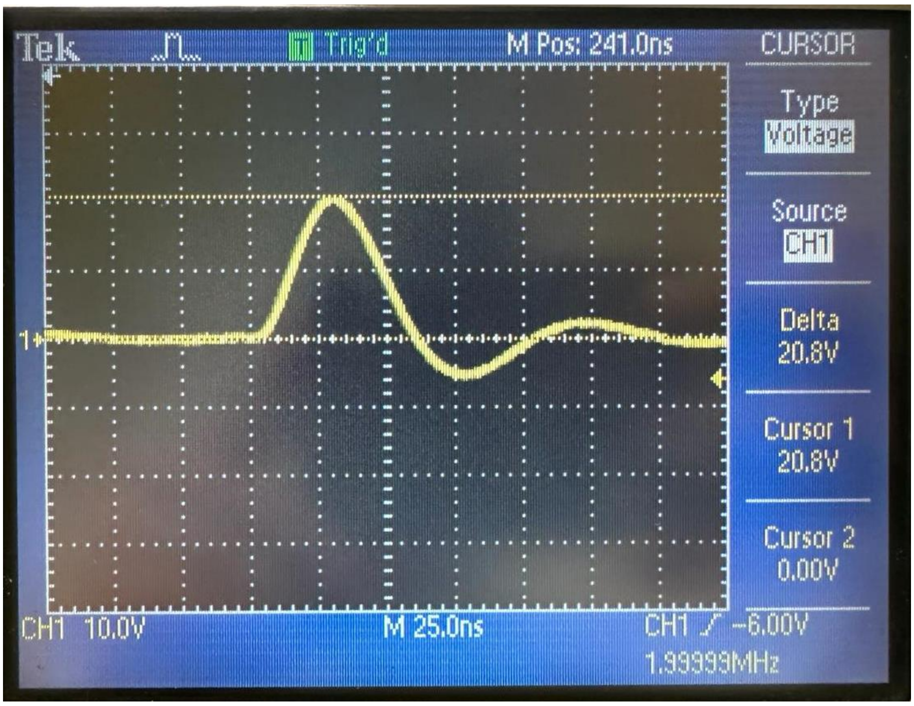

Figure.16 The peak voltage

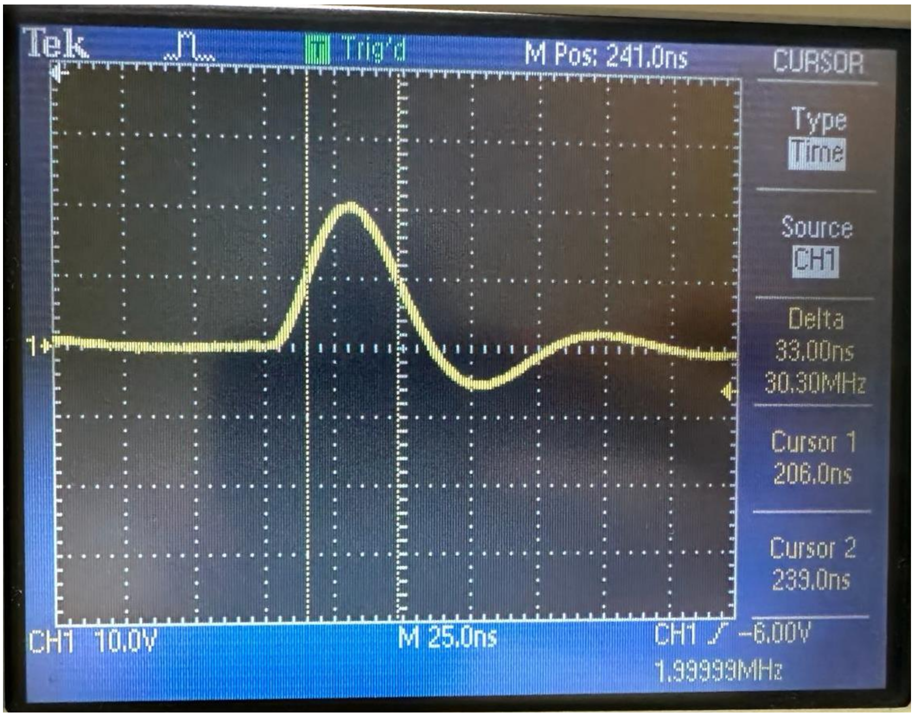

Figure.17 FWHM

Output Voltage (V)	**Error**	**FWHM (ns)**	**Error**
20.8	%16.61	33	%126.80

Table.3 HW implementation results

Conclusion:

Since the inductor current i cannot change instantaneously, it causes voltage spikes to occur. To control the spike's peak voltage, a transformer circuit is designed and implemented, which involves winding two different inductors.

In the HW implementation, the peak voltage of a spike is measured as 20.8 V, which is between the wanted values 20 V and 25 V. FWHM is 33 ns, which is also smaller than 100 ns and in the allowed limit. The HW implementation showed the expected values. The software and hardware results for peak voltage and the FWHM matched with %16.61 and %126.80 percentile errors respectively. The reason of these errors can be the inner resistances of the wires, leakage inductances of the transformer or simply human error. Also, measurements for FWHM involve nanoseconds, so measuring it wrong even slightly causes high measurement errors.

This lab helped us to examine the behavior of inductors and transformers. It also taught how to implement a transformer both on LTSpice and on hardware using toroidal cores.