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EE202 SECTION 1

CIRCUIT THEORY LAB 2

Software Implementation

In this lab experiment, we are expected find a way (passive linear circuit) to create voltage spikes while the given input is a $10V_{pp}$ square wave. In addition to that there were some other restrictions which are the given square wave input frequency must be less than 5MHZ, and the voltage spike obtained must be in the range of 15V to 20V, also the half width of the spikes must be less than 90ns.

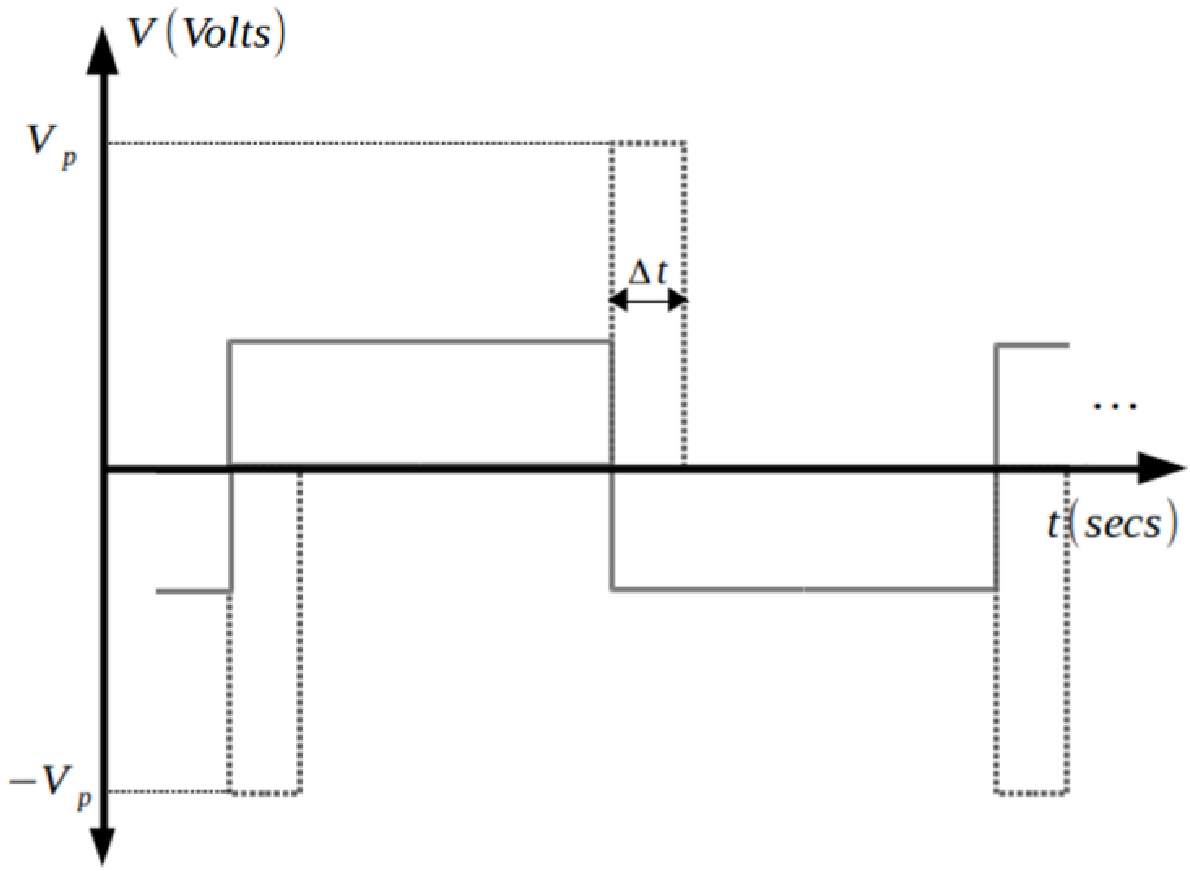

Figure-1: Dashed Lines Represent Voltage Spikes (Output), Input is a Square Wave

Discussion

To create voltage spikes with small half width there are 2 possible ways. Since the circuit must be passive and linear, we only can create spikes using inductor or capacitor. However, using these elements it is not possible to create 15V spike with small half width. That's why we need to use an amplifier; however, we can not use OP-AMP since it is active element.

Method

As mentioned in discussion part, I have decided to use an inductor to create voltage spikes. First of all, I tried to create a voltage spike without caring its amplitude. To realize that I used 3μH inductor, and 100KHZ 10V_{pp} square wave input. The circuit is shown below (Figure-2).

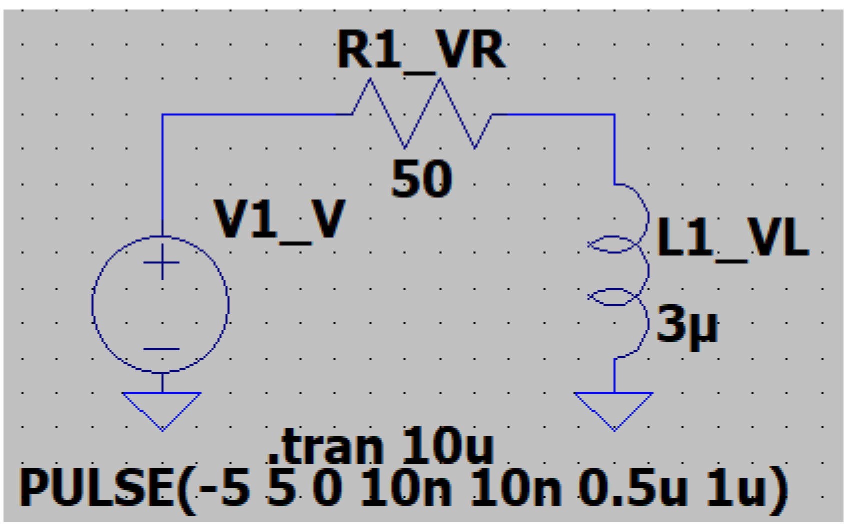

Figure-2: The Designed Circuit to Create Voltage Spikes

In this circuit I need to calculate the voltage on the inductor. To calculate the voltage KVL is used.

$$-V_1 + V_R + V_L = 0$$

V_1= Voltage supplied by power source

V_R= Voltage on the resistor

V_L= Voltage on the inductor

By using $V_R = I(t) * R_1$ and $V_L = L * \frac{d}{dt} I(t)$

$I(t)$= The current passing through the circuit according to time.

L= Inductance of the inductor.

$$\frac{V_1}{L} = I(t) * \frac{R_1}{L} + \frac{d}{dt} I(t)$$

A first order linear differential equation is obtained in terms of I(t).

Using the basic formula of first order linear differential equation I(t) is calculated.

$$I(t) = e^{-\int_0^t \frac{R_1}{L} dx} \left(\int_0^t \frac{V_1}{L} * e^{\int_0^t \frac{R_1}{L} dx} * dt + I(0) \right)$$

If the calculated, I(t) phrase is used in $V_L = L * \frac{d}{dt} I(t)$, $V_L(t)$ is easily found as below.

$$V_L(t) = R_1 * \left(\frac{V_1}{R_1} + I(0) \right) * e^{-\frac{R_1 * t}{2L}}$$

Known that $I(0) = \frac{V_1(0)}{R_1} = \frac{5V}{50\Omega} = 0.1A$ and the peak value of the spike is reached at 10ns since square wave is changed in 10ns. Using this information $V_{spike-1}(peak) = V(10ns)$ is calculated as below.

$$V(10ns) = 50\Omega * \left(\frac{5V}{50\Omega} + 0.1A \right) * e^{-\frac{50\Omega * 10ns}{2 * 3\mu H}} = 9.2V$$

The simulation result of Figure-2 that gives 9.2V for the voltage on the inductor is given below, which is the confirmation of the result we calculated.

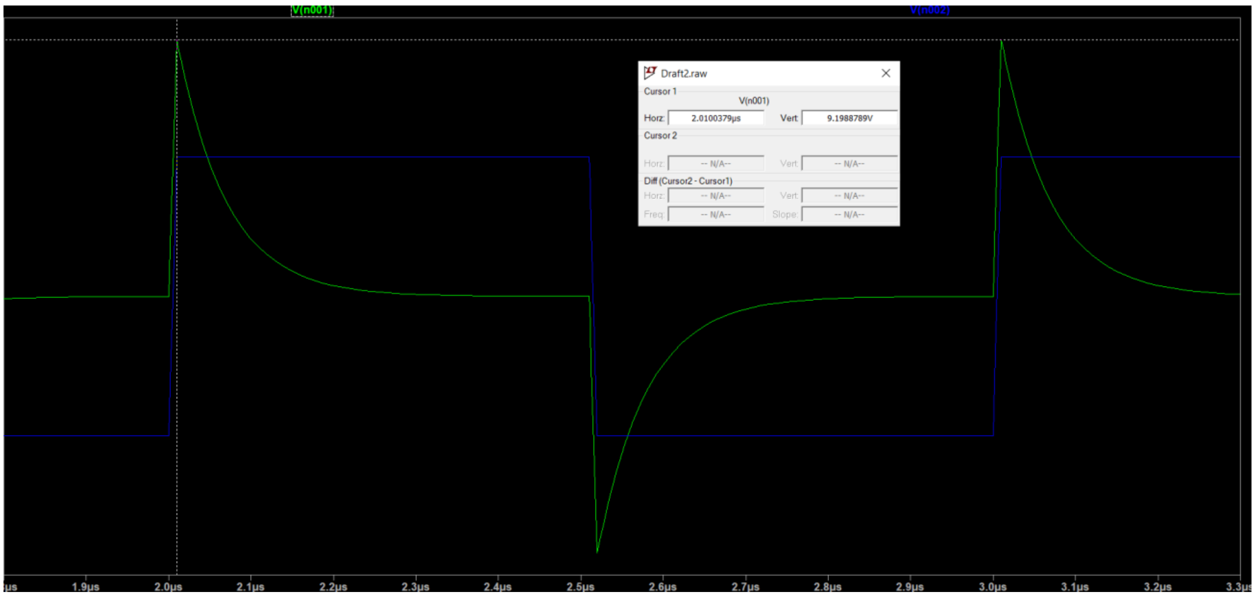

Figure-3: Simulation Result of the Circuit in Figure-2, which shows 9.2V Voltage Spikes

The simulation result that shows spike's creating time and rising time of square wave, which both are 10ns, are shown below.

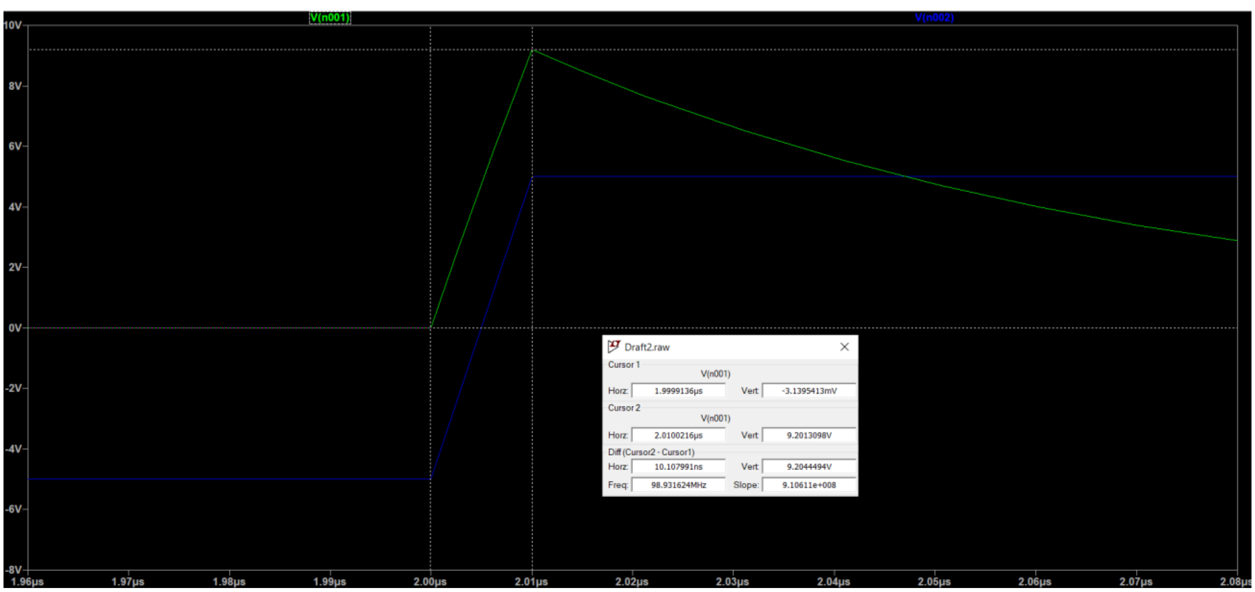

Figure-4: Created Spikes Reach the Max Voltage in 10ns

Now spikes are created however their voltage amplitudes are not enough since we need a voltage between 15V-20V.

To amplify the voltage output I used a transformer.

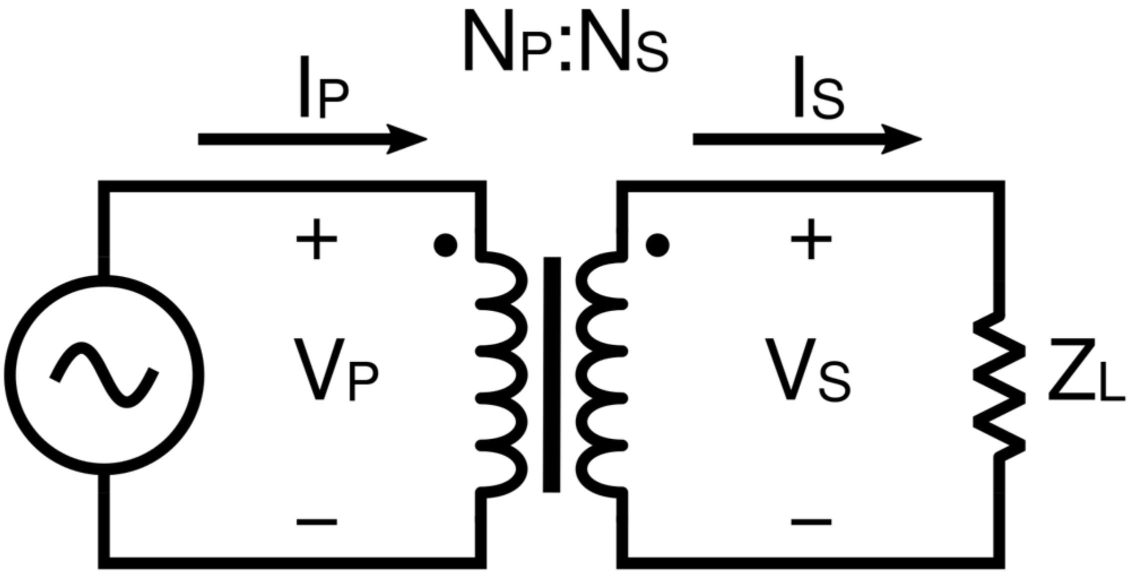

Figure-5: A Simple Ideal Transformer Figure

V_P= Voltage of Primary Inductance

V_L= Voltage of Secondary Inductance

N_P= Turn Numbers of Primary Inductance

N_S= Turn Numbers of Secondary Inductance

By Faraday's Law:

$$V_P = -N_P * \frac{d}{dt}\Phi \qquad and \qquad V_S = -N_s * \frac{d}{dt}\Phi$$

Φ= Magnetic flux

Using these equations, the rate below is obtained.

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

By the inductance formula $L = A_L * N^2$

A_L= Inductor constant

N= Number of turns

Using the rate and inductance formula, the equation below is obtained.

$$\frac{V_P}{V_S} = \sqrt{\frac{L_P}{L_S}}$$

Since the rate of voltages is proportional to square of inductances' rate, I choose 10µH inductor to amplify the output voltage. Since 9.2V*$\sqrt{\frac{10}{3}}$ =16.8V. Which is in the range 15V to 20V.

Now we need last one step. Which is arranging the half width.

Known from formula by time for voltage

$$\mathrm{V(t)} = V_{max} * e^{\frac{-t}{L/R}}$$

$e^{\frac{-t}{L/R}}$ must be equal to 0.5 since we need to calculate width at half voltage.

$$e^{\frac{-t}{L/R}} = 0.5$$

By using logarithmic function

$$\frac{-t}{L/R} = -0.69$$

If R is chosen as 12KΩ, t (half width) is found as 57.5ns; however, 10ns is rising time so the real half width is found as 47.5ns. This result is shown on simulation in Figure-8

According to all the findings the last version of the circuit with transformer (3µH to 10µH) and 12KΩ resistor is found below.

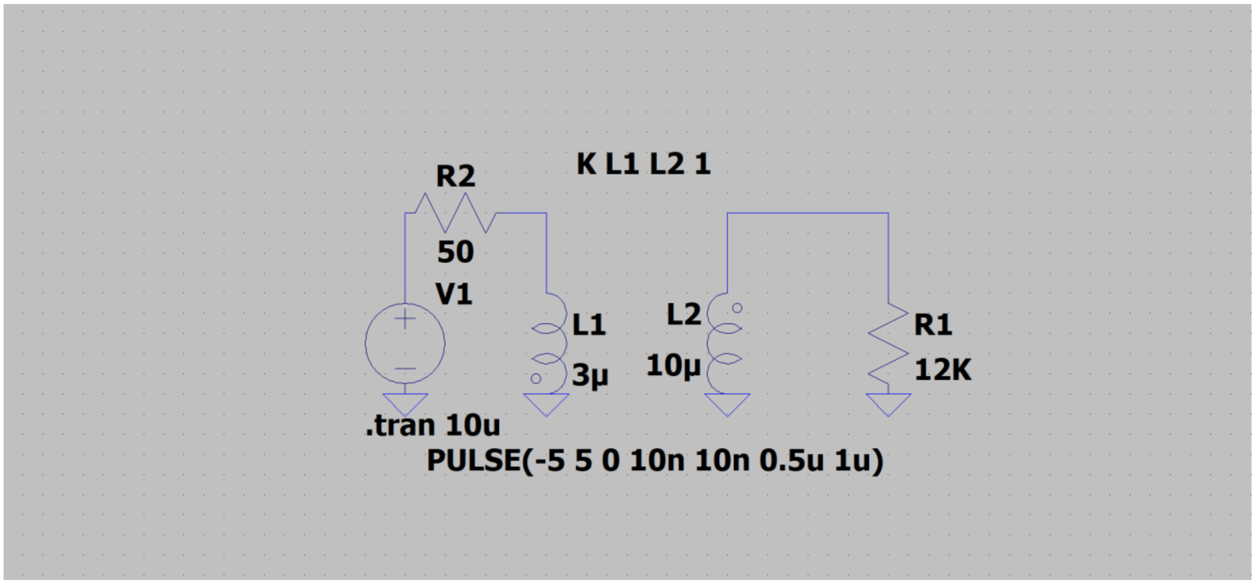

Figure-6: Created Circuit with Transformer to Have Higher Voltage Spikes

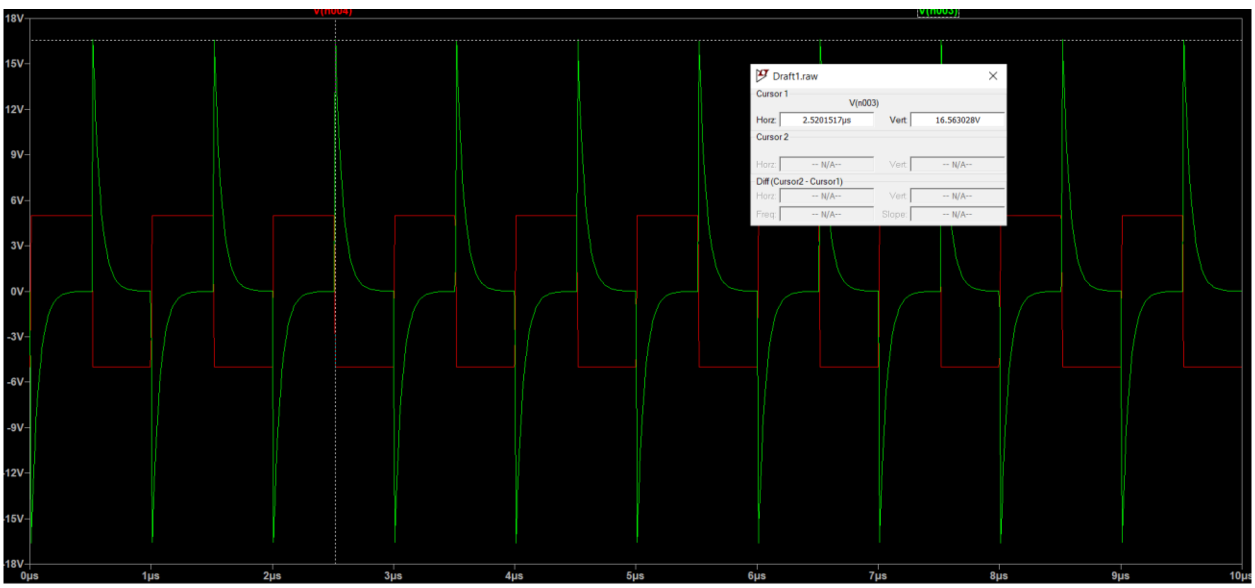

Figure-7: Simulation Result of the Circuit in the Figure-6, which shows wanted Spikes

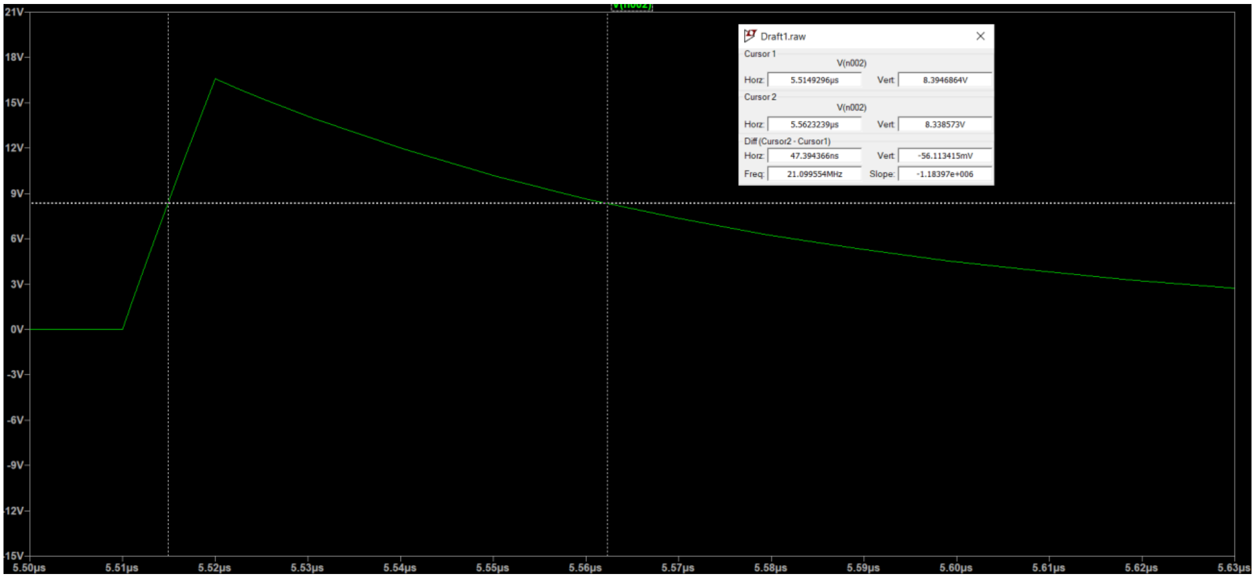

Figure-8: Simulation Result of the Circuit in the Figure-6, which shows half-width of the Spikes

Hardware Implementation

In the hardware part of this lab, I used the same circuit with my software part, which is shown below (Figure-9). The given input voltage is $10V_{pp}$ and 100KHZ, which is same with software part.

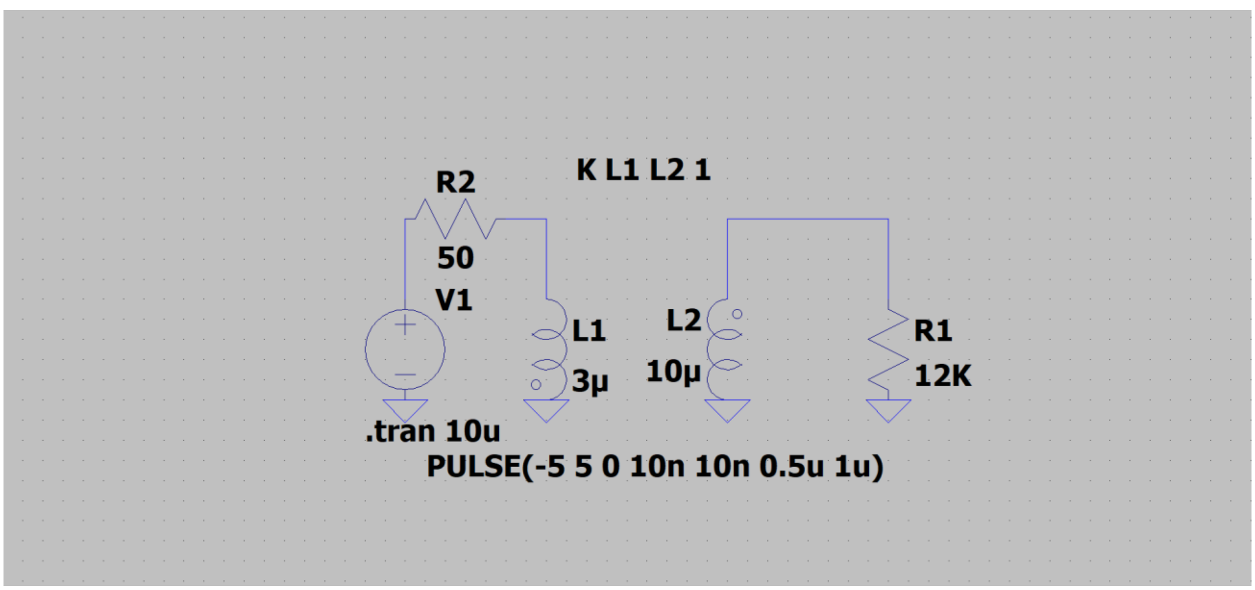

Figure-9: Used Circuit to Create in Real Life

For this circuit I needed to have 3μH and 10μH inductors. To have these inductors I used T38-8, it A_L is 20nH.

Using the inductance formula $A_L * N^2 = L$

For the 3μH inductor 11 turns winded, according to formula it is a 2.42μH inductor but by squeezing this value increased.

For the 10μH inductor 21 turns winded, according to formula it is an 8.82μH inductor but by squeezing this value increased.

The real-life results are shown below. (Figure-10 and Figure-11)

Figure-10: Secondary Inductance of the Transformer

Figure-11: Primary Inductance of the Transformer

When transformer is ready to integrate in circuit, the circuit in the figure-9 is built.

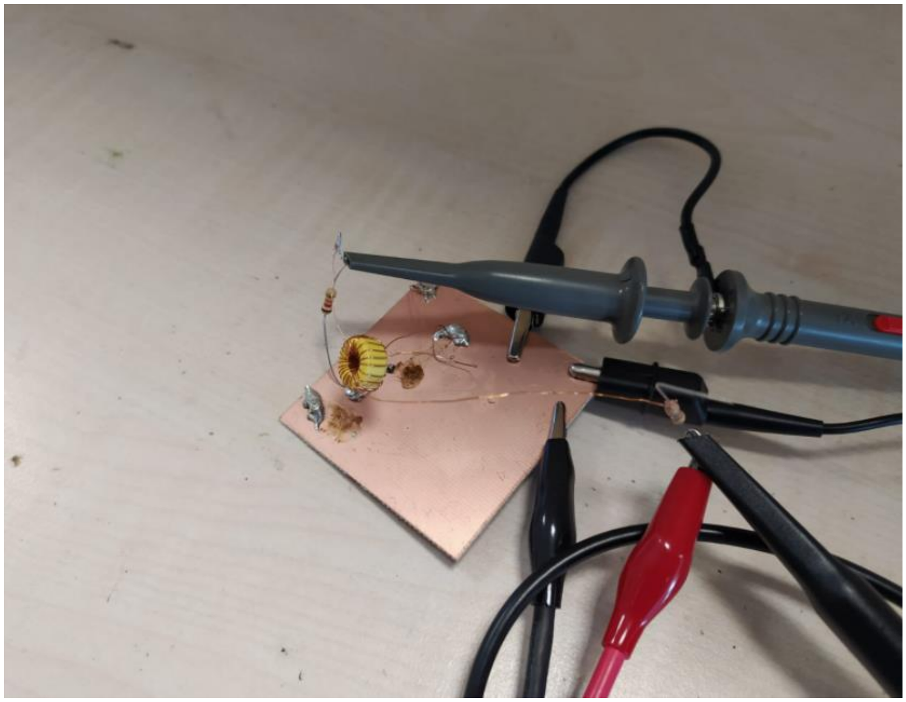

Figure-12: Implemented Circuit in Real Life to Create Voltage Spikes

The results of this circuit are given below.

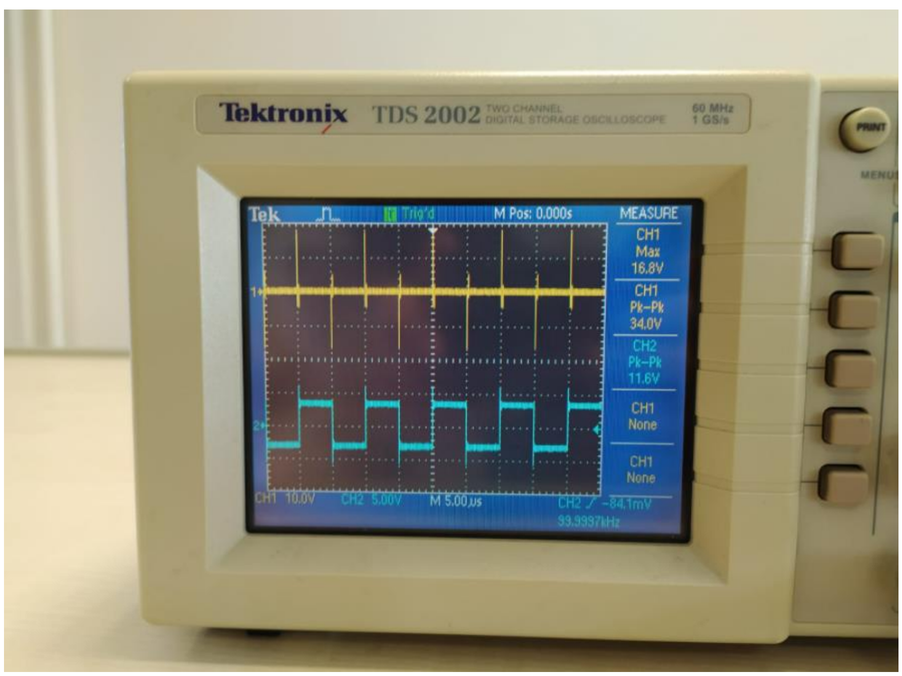

Figure-13: The Results of the Circuit in Figure-12, which shows input (square wave) and output(Voltage Spikes)

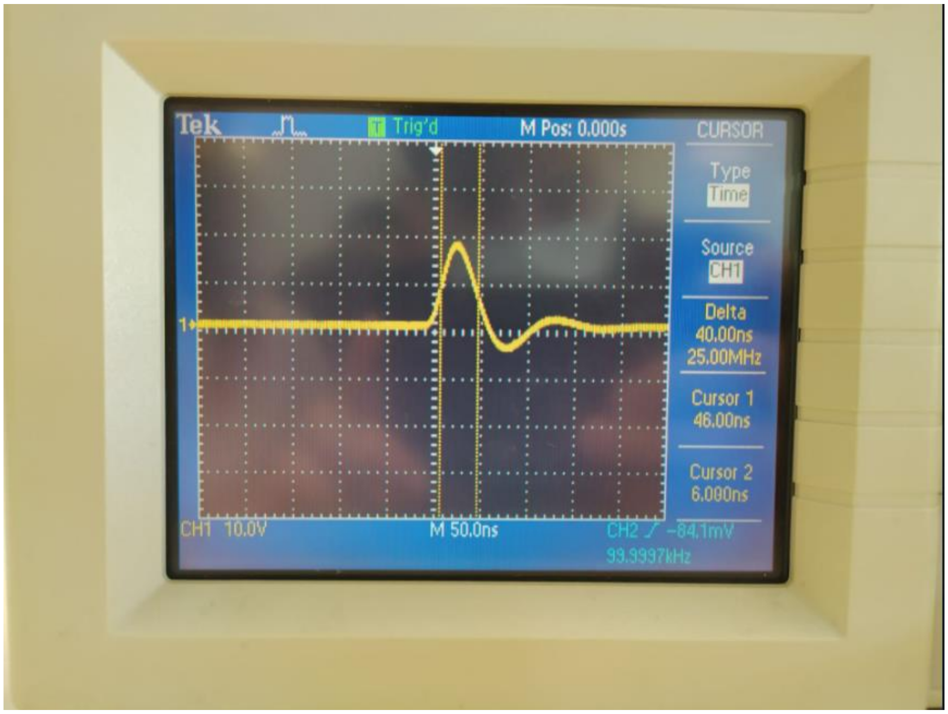

Figure-14: The Results of the Circuit in Figure-12, which shows the half-with of the Spikes

In this part expected value for the max of spike was around 16.56V, but in the lab I got 16.8V, which is still in range. In addition to that expected half width was 47.5ns but in the lab I got 40ns, which is still in range. On top of those, given input from signal generator is not measured properly since when tried to measure it is kind of integrated with small spikes as seen in the figure-13 and its peak-to-peak voltage is seen as 11.6V; however, the real V_{pp}value is 10V.

Conclusion

In this lab experiment it is learnt how to create voltage spikes and its concepts. In this way, we tried to create specific voltage spikes. That's why we had to learn how to control it. First of all, we have to create a small amplitude voltage spike and then amplify these spikes. To realize both of these parts, I decided to use inductors. Indeed, to create a voltage spike either inductor or capacitor could be used. However, once the voltage is created it may need to be amplified. That's why using inductor was more efficient. Since this inductor is used to create a transformer to amplify. I couldn't use OP-AMP to amplify the voltage since it is an active circuit element, but we are expected to use only passive linear circuit elements. After deciding the secondary inductor, to have a half width in the wanted range resistor value for the second circuit is decided. All in all for the software part, everything is done step by step. For the hardware part I used the same circuit from software part. However, there were some errors. First one is I couldn't measure the input voltage directly in real life unlike LtSpice. It was because the input is kind of integrated with small spikes. In addition to that I didn't have perfect exact Inductor values they are same with software parts. It is because the inductor values were easily changed, and I decided to use the closer ones. That's why half width value was a little bit different from simulation, and the max value of spike was a little bit more than simulation results. Fortunately, all the result were in the expected ranges. To sum up, in this lab ramp function and voltage spikes concepts are learnt and applied to real life.