Report: Circuit Theory Lab 2

Bilkent University Electrical and Electronics Department
EE202-03 Lab 2

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Purpose:

In this lab work, a passive linear circuit is designed to generate high voltage spikes from a 10V peak-to-peak square wave with a source resistance of 50Ω and frequency less than 5MHz using the LTSpice tool and time-domain analysis.

Software Implementation:

Introduction:

This lab contains performing time-domain analyses in LTSpice in a proposed circuit. The lab requires these parts as following:

- The peak value (V_p) of the voltage spikes must be between 15V-25V.
- The full width at half maximum (FWHM) must be less than 80ns.
- The spikes are not required to be square-shaped.
- The fall and rise times of the square wave are assumed to be 10ns.
- The spike duration must be much shorter than the input period.

In the analysis part, a circuit that satisfies all of these conditions will be suggested.

Analysis:

For the analysis section, since the proposed solution consists of two parts, these ideas will be investigated separately.

RL Circuit Idea

Due to the input signal being a square wave, an RL circuit will be able to create spikes in the form of $e^{\tau^{-1}t}$ by choosing the proper values for the inductor and resistor, one will be able to create spikes with FWHM less than 80ns. Assuming that after 5τ spike will vanish. Here is the following calculation for inductor value when $R = 50\Omega$,

$$5\tau < 80ns \Rightarrow \tau < 16ns \Rightarrow \tau = \frac{L}{R} < 16ns \Rightarrow \frac{L}{50\Omega} < 16ns \Rightarrow L < 800nH$$

So from here, one can see that as long as the inductor value is less than 800nH, the spike's FWHM will be less than 80ns. So for convenience, the inductor value has been chosen 320nH. The reason is that by using the T38-8/90 toroid, the minimum number of turns is required to create the inductor, and 320nH gives an integer number of turns for this toroid. The following equation is the calculation of turns for the inductor.

$$n^2 = \frac{320nH}{20nH/N^2} \Rightarrow n = 4$$

Thus it will require only 4 turns to create the inductor with 320nH inductance and spike with FWHM less than 80ns.

Transformer Idea

After creating the spike one needs to increase its amplitude since the lab work requires the voltage of the spike to be between 15V and 25V thus one needs to increase the voltage on the inductor from the previous RL circuit to achieve this goal. To satisfy this condition, one might implement a transformer with the already existing inductor. So following calculations will be to determine the other inductor's value so that the spike voltage is between 15V and 25V. Leakage will be taken into consideration since, in reality, it is about $L_{leakage} = 0.55$ [1].

$$V_s = \frac{n_2}{n_1} V_p(1 - L_{leakage}) \Rightarrow V_s = 5\frac{n_2}{4}(1 - 0.55) \Rightarrow n_2 = 42; for, V_s = 23.625V$$

Thus one can calculate the inductance of the secondary inductor as following,

$$L_2 = {n_2}^2 A_L, A_L = 20nH/N^2 \Rightarrow L_2 = 35.28\mu H$$

From the equation, it can be seen that the other inductor value needs to be $35.28\mu H$. To get this value, one needs to do 42 turns in the T38-8/90 toroid.

Even though the value will show satisfactory results in the simulation since, in practice, there exists leakage in the toroid so it is advised that one does extra turns. Luckily there exists an option to take into account this leakage in LTSpice by changing the value K to 0.45, one may achieve a realistic transformer.

By implementing this proposed circuit, one satisfies previously mentioned criterias for this lab work.

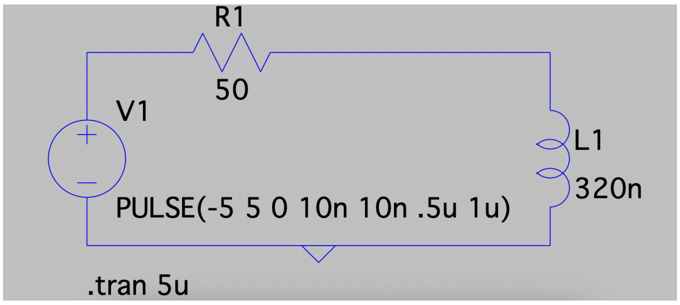
Simulation:

As done in the analysis section in the simulation part, a similar approach will be followed to investigate and discuss each part. The following figures include the implementation of the LTSpice tool from the previously explained analysis part.

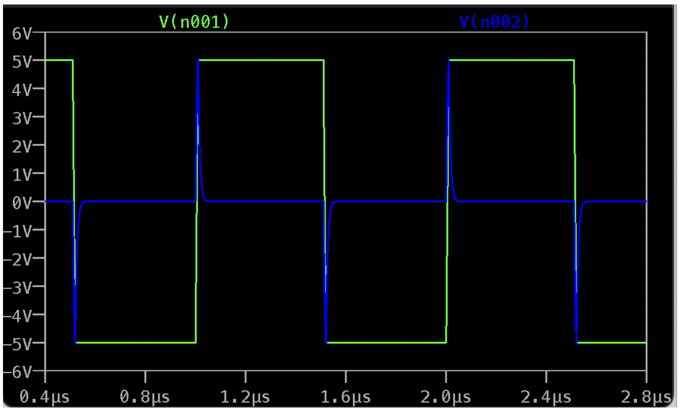
Note that the figures below may seem little, but since they are high quality, the reader may zoom in as much as they wish. The size of the figures is as they are just because of aesthetic concerns. If plots are not as visible as required, please kindly zoom in.

RL Circuit Idea

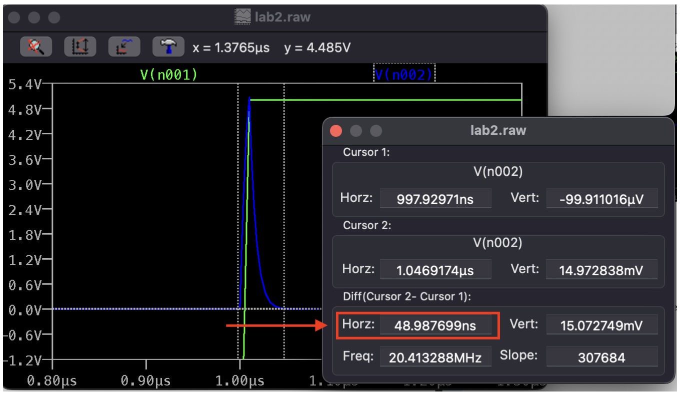
The below figures include the simulations on the LTSpice,



(a) The RL circuit's voltage response to the input signal.



(b) Circuit itself.



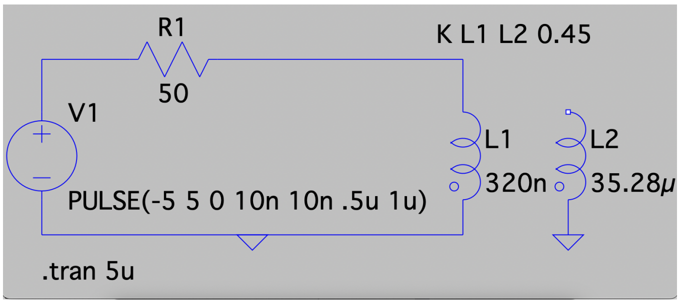
(c) Circuit itself.

Figure 1: RL circuit idea in LTSpice.

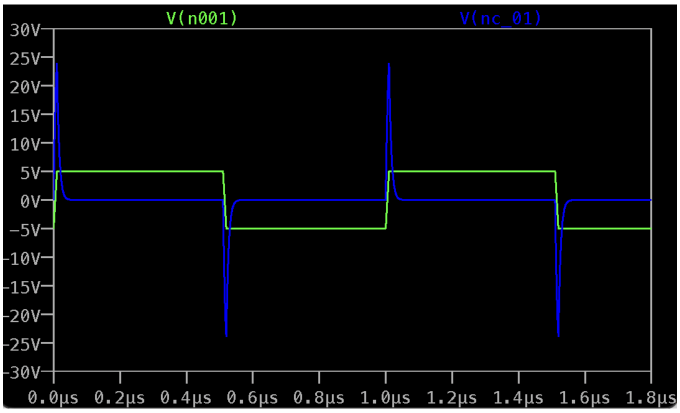
The figures confirm that, the required condition is satisfied for $\Delta t < 80ns$

Transformer Idea

The below figures include the simulations for the transformer idea on the LTSpice tool.



(a) The transformer circuit's voltage response to the input signal.



(b) Circuit itself.

Figure 2: The proposed circuit in LTSpice.

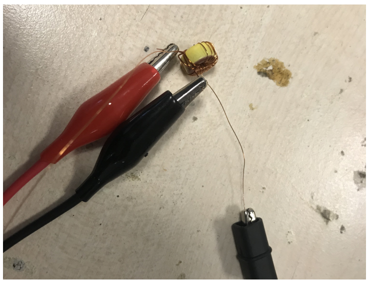
As one can see from the graphs, the required conditions are satisfied with the proposed design solution.

Hardware Implementation:

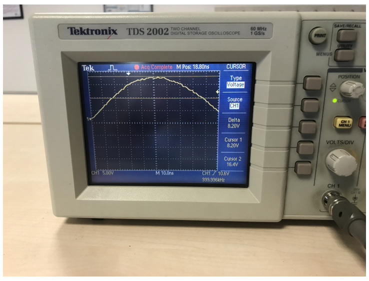
The hardware implementation consists of the above-described software results' application. Additionally, the lab required an extra step to analyze the waveform that the signal generator generates.

The Proposed Circuit

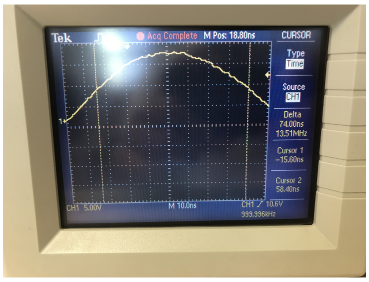
This part is the implementation of the proposed circuit for the lab work.



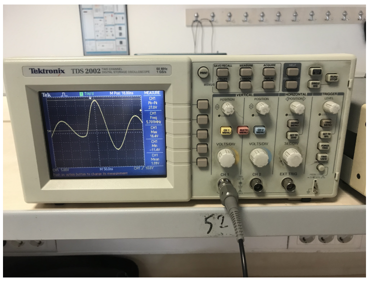
(a) Circuit itself



(b) FWHM value for the input signal.



(c) Δt value for the input signal.



(d) Voltage response if the circuit.

Figure 3: Proposed circuit implementation.

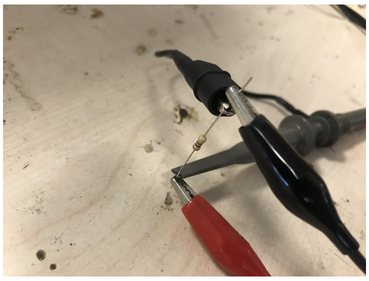
Comparison between theoretical and practical values will be shown in the following table,

	Experimental Value	Theoretical Value
FHWM time	74ns	48.98ns
V_{max}	16.4V	23.625V

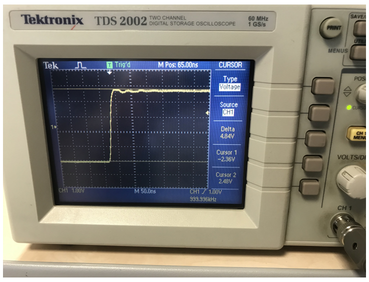
Table 1: Table of the expected and measured data.

The Input Signal Analysis

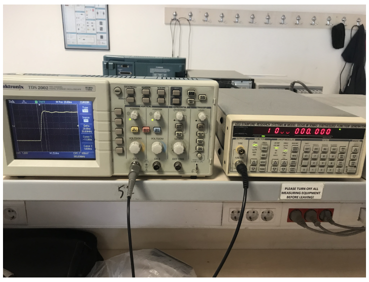
As asked in the lab work in this part, the analysis of the input signal generated by the signal generator will be done.



(a) Circuit itself for analyzing the signal.



(b) Voltage output.



(c) The rise time of the signal.

Figure 4: Analysis of the signal.

	Experimental Value	Theoretical Value
Voltage	4.84V	5V
Rise time	20ns	10ns

Table 2: Table of the analyzed signal.

Conclusion:

In conclusion, the aim of the lab experiment was to generate a spike with a voltage range between 15V and 25V using a pulse input voltage (square wave) between 5V and -5V. It was required that the FHWM time of the spike should not exceed 80ns. To achieve this, an RL circuit has been used combined with a transformer to increase the voltage output.
However, errors have been encountered in the course of the lab work due to certain reasons such as the oscilloscope was not in an ideal condition, and the transformer windings were not as expected which resulted in more leakage than estimated in the simulation. As a result, the measured values were not as expected, such as V_max and FHWM time of the spike. To reduce these

errors, one could also use less stressed components and wind the inductor windings more closely.
To summarize, the experiment demonstrated how RL circuits can generate spikes with pulse input voltage and how transformers can amplify the voltage across the inductor to fit into the desired voltage range.

References:

- [1] A. Atalar, "Conversation during lab hours", 24 April 2023.
- Analog Electronics, A. Atalar, Accessed from Moodle.