Bilkent University Department Of Electrical and Electronics Engineering

EEE212 Circuit Theory

Lab 2

Voltage Spike Generator

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Purpose:

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.

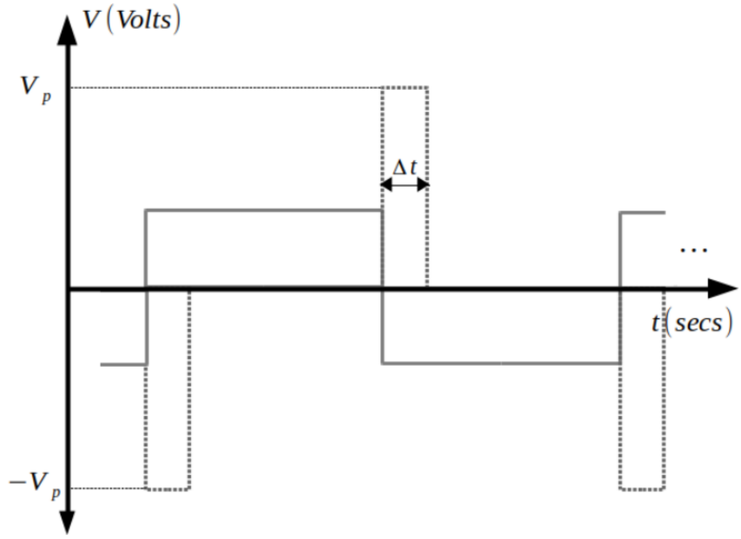

Figure 1 The Lab Task

The max value of the spike must be between 15V and 20V. The full width at half maximum must be less than 90ns.

Methodology:

There are many different ways to generate a voltage spike. However, one of the most common reasons for this phenomenon is "inductor kickback." We can demonstrate this with a simple RL circuit with a switch. At time 0, the switch opens, and the current is zero.

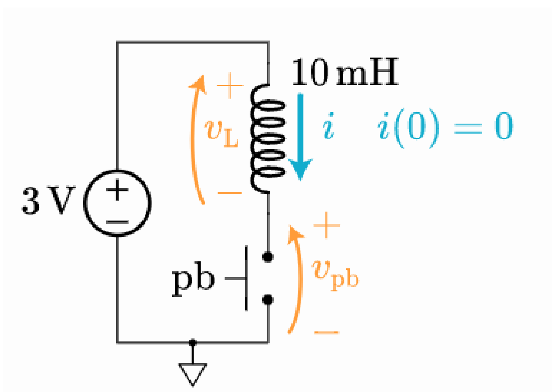

Figure 2 Basic RL circuit at time = 0

The current-voltage relationship of an inductor can be expressed as:

$$V = \frac{di}{dt}\mathrm{L} \quad (1)$$

When the switch closes, the inductor's voltage abruptly changes from 0V to 3V.

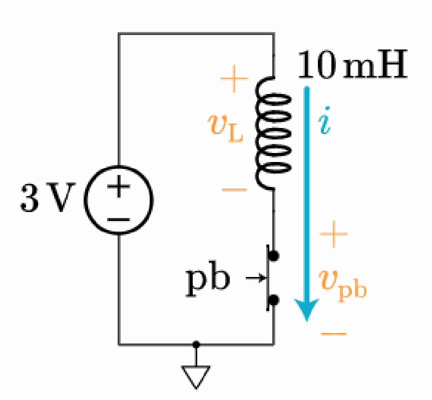

Figure 3 RL circuit at time > 0

The current can be expressed as:

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

The integral from 0 to t go until we release the switch. Putting the values:

$$i(t) = \frac{3V}{10mH}t = 300 \text{ amps/second} \quad (3)$$

When we release the switch at t = 2ms, the current is reached 600mA. The voltage can be expressed as using (1):

$$V = L * \frac{-600mA}{0} = \text{-infinity} \quad (4)$$

In ideal circumstances, the voltage mathematically will go to infinity. However, in real cases, the current cannot change instantaneously.

Still, we see an abrupt voltage spike, and in real applications, the designer must foresee this phenomenon and prevent this.

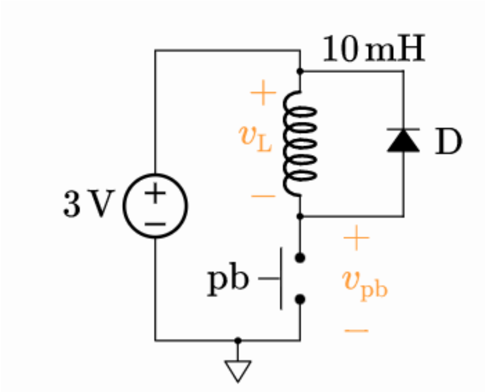

Figure 4 Simplified Inductance Kickback protection circuit

In our case, the voltage spike can be simulated with a transformer circuit. An inductor can be represented as two inductors electromagnetically coupled with a core. We could only use an inductor, but we can conveniently manipulate the output voltage.

Software Implementation:

The proposed circuitry can be seen in Figure 5.

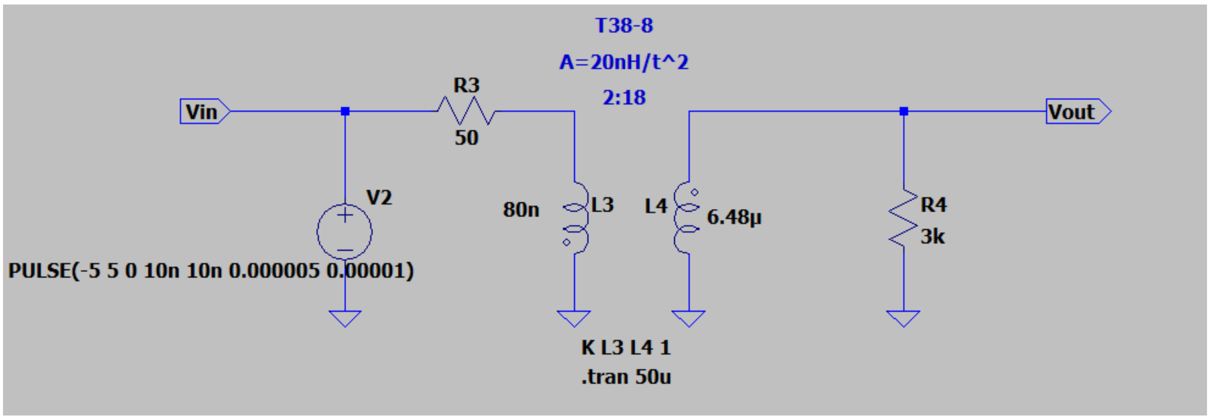

Figure 5 The Software Lab Circuit

According to Faraday's Law of Induction:

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s} \tag{5}$$

We can express the relationship between inductance and the winding values as:

$$L = A_l * n^2 \quad (6)$$

Where A_l is the inductance per turn and n is the turn number. To choose the inductor values according to the desired output:

$$\frac{L_p}{L_s} = \left(\frac{V_p}{V_s}\right)^2 \quad (7)$$

Compliance with the formulas, we have 10/15 and 10/20 voltage ratios. Hence the inductor ratios must be between 1/9 and 1/16.

The transformer in the software lab has a ratio of 2/18 with the primary and the secondary inductances as 80nH and 6.48uH, respectively. As for the load resistor, I used 3k ohm.

The square wave is generated with 10n rise and fall time, %50 duty cycle, and 100kHz frequency.

Hardware Implementation:

I changed the inductor and the load resistor values in the hardware implementation. I used a 3-27 turn ratio transformer with a 330k load resistor. The chosen inductor core is T38-8, Al = 20nH/t^2. The inductor values are 180nH and 14.58uH.

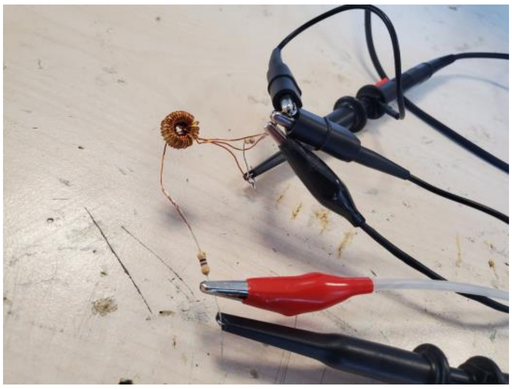

Figure 6 The Hardware Circuit

Results:

Software Results:

The input and output waveforms can be seen in Figure 7.

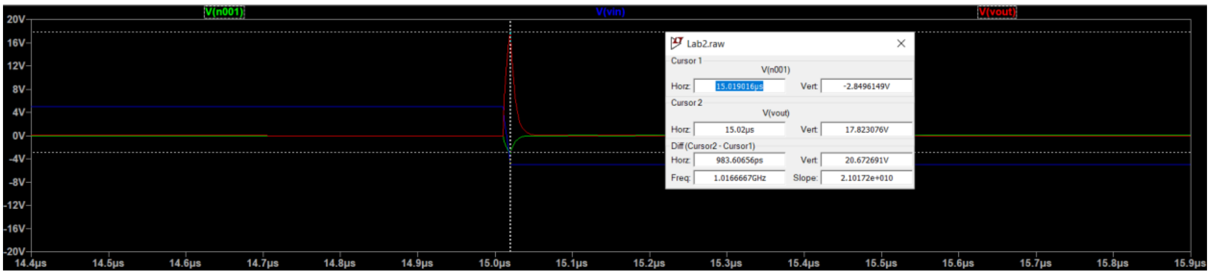

Figure 7 Waveforms

The blue line is the input voltage of a 10Vpp square wave with a 100kHz frequency. The red line is the output voltage, 17.82V.

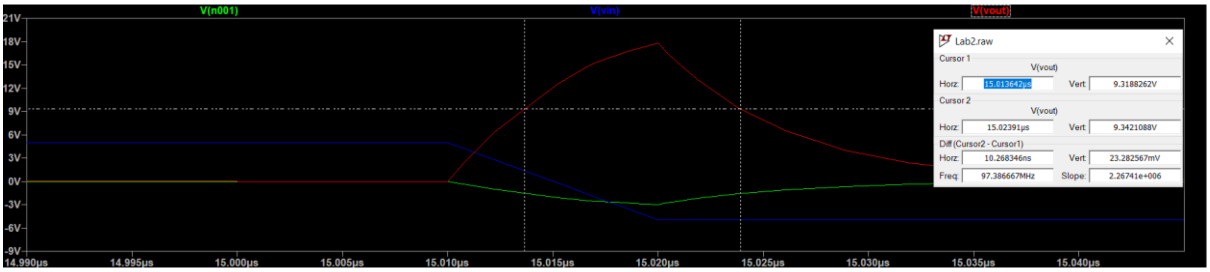

Figure 8 FWHM of the spike

The FWHM of the spike is 10.26ns, which is far less than 90ns.

The software results seemed promising since both the output and the FWHM values are between the accepted values.

Hardware Results:

As seen in Figures 9 and 10, the voltage of the spike is 16V at 100kHz frequency, and the FWHM is 48ns. After the changes are made for the hardware lab, the results are applicable for the given task.

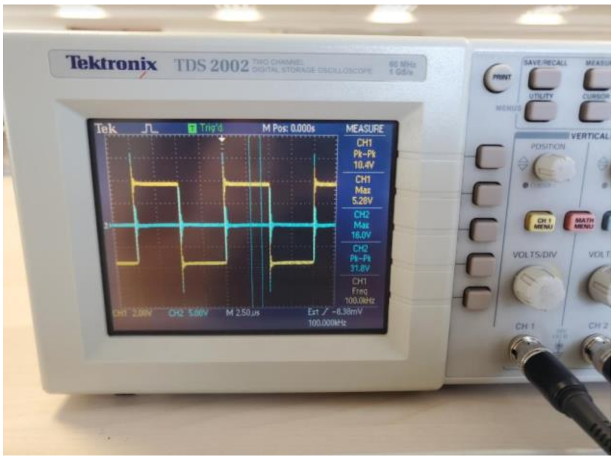

Figure 9 The Hardware results

Figure 10 The FWHM

The frequency is chosen 100kHz because, at higher frequencies, the square wave unstablasizes, and consequently, the voltage spike distorts.

Figure 11 Voltage spike f=500kHz

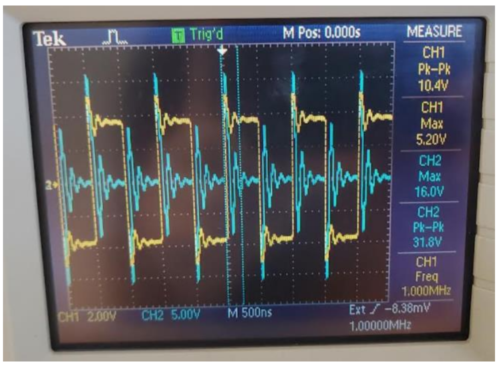

Figure 12 Voltage spike f=1MHz

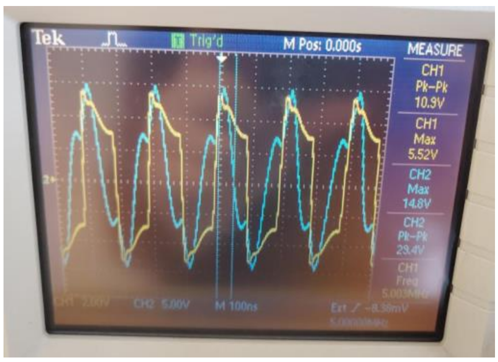

Figure 13 Voltage spike f=5MHz

Conclusion:

The experiment aims to generate a voltage spike with 15V-20V Peak Voltage and less than 90ns of FWHM from a 10Vpp square wave. I used the phenomenon of "inductor kickback" to design my circuit. Rather than using an inductor, I used a transformer to have control over the output spike. I chose the "inductor leakage constant" 1 in the software lab, which means the transformer used in the software lab has no leakage; thus, it was ideal. The winding ratio used was 2/18 with primary and secondary inductances 80nH and 6.48uH, respectively. However, the exact setup I used for the software lab failed in the hardware lab. This is because the transformer has some leakage and inner resistance in real life. Thus to compensate, I increased the winding numbers but still kept the ratio the same. Furthermore, I also increased the load resistance. In the hardware lab, I have used a transformer with a 3/27 winding ratio with primary and secondary inductances 180nH and 14.58uH, respectively, and a load resistor with a value of 330k ohm. The output and the FWHM values are 16V and 48ns which are in the accepted range. To sum up, in this experiment, I learned how to create a voltage spike and get familiar with the transformer concept on the LTSpice software.

References:

Willy McAllister. (2022, March 9). *Inductor kickback*. Spinning Numbers. Retrieved March 11, 2022, from https://spinningnumbers.org/a/inductor-kickback.html