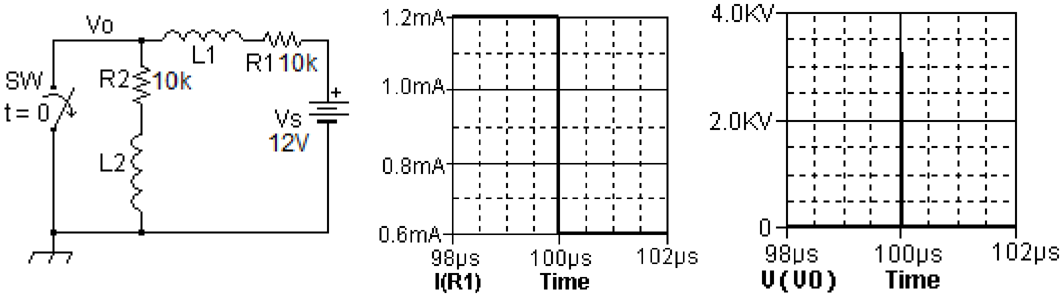
Experiment 34: Inductive Impulse Voltage

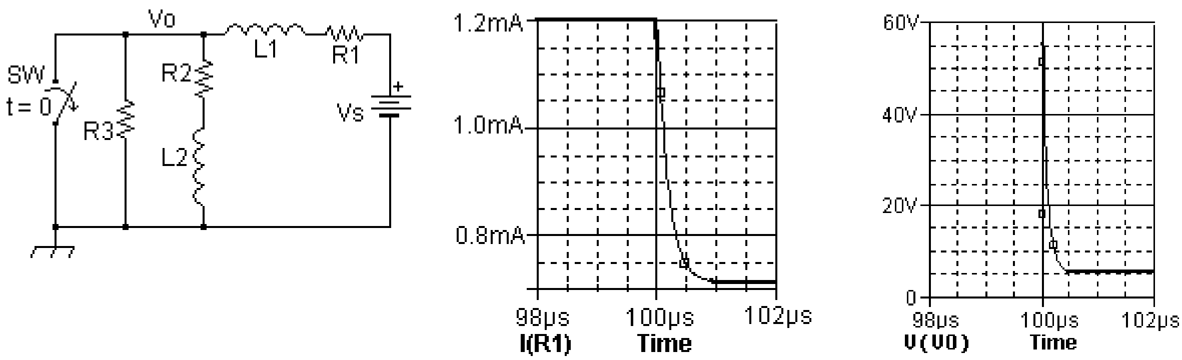
Introduction

Switching operations in inductive circuits can produce voltage impulses, short duration and possibly high amplitude voltage spikes. Consider the circuit below. Before the switch opens the circuit current is 1.2 mA, limited by R1. The instant the switch opens the current drops to 0.6 mA, limited by R1 plus R2. The rapid change in current creates a voltage impulse across L1, as shown in the graphs below.



The magnitude of the voltage is over 3000 V and the duration is very short. This is because inductors oppose a change of current. L2 acts like an open circuit initially, so that L1 is discharging into a very high resistance, which means a very short discharge time constant and large voltage amplitude. This impulse may be modeled by the Dirac delta function.

A load resistance, R3, is connected across the switch in the circuit below. The discharge time constant is increased and the magnitude of the peak voltage is decreased to about 55 volts. The magnitude of the exponential voltage spike increases as the value of R3 is increased. Some of the energy stored in L1 is discharged into R3. Note the circuit and graphs below.



Objectives

This experiment uses a transistor as an electronic switch. Its breakdown voltage is 40 V, so the amplitude of the voltage spike must be less than that. The impulse response for two different values of load resistors will be measured and analyzed. One objective is to show that the duration of the exponential spike decreases, and the voltage magnitude increases, as the value of the load resistor increases.

Procedure

Equipment and Parts

Power supply, Function Generator. Oscilloscope with X10 probes, Breadboard.
L1 = 100 mH,   L2 = 100 mH.   Transistor = 2N3904 or equivalent.
Resistors: 2.2 KΩ, three 1 KΩ, all ¼ watt, 5%.

1. Measure and record the resistance of the inductors, Rw1 and Rw2.

   Rw1: ______________   Rw2: _____________

   Resistor and inductor values don't need to be measured (except for the resistance of the inductors). Their labeled values will be used in the analysis.   The objective of this experiment is to show that an impulsive response is produced by the inductive load.

2. Connect the circuit in Figure A below. Set the function generator to produce a 5 V peak-to-peak, 1 KHz square wave, with a plus 2.5 V offset.

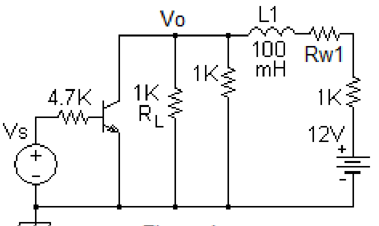


Figure A

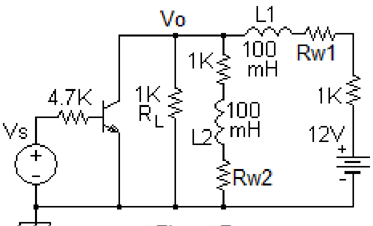
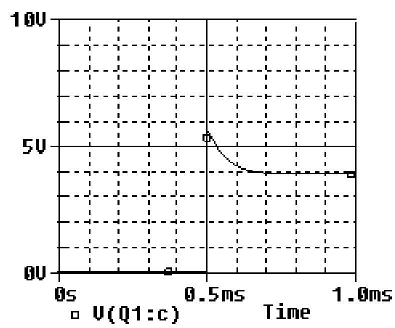


Figure B

3. Connect channel 1 of the oscilloscope to the function generator and channel 2 to measure Vo. Trigger on channel 1.



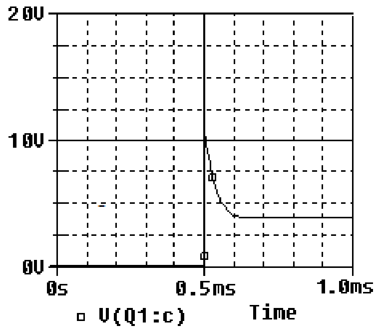
4. Adjust the oscilloscope's time per division and volts per division to observe about one cycle of the Vo waveform on channel 2.

5. Measure and record the peak amplitude of the positive pulse, V_P, (about 1.8 V in the graph on the right), the time constant, τ , and the steady state voltage, V_{SS} (4.9 V in the graph on the right). This is a surge voltage similar to that in experiment 33.

   V_P __________ τ __________ V_{SS} ___________

6. Connect the circuit in Figure B above (add the inductor L2 to the load circuit). Set the function generator to produce a 5 V peak-to-peak, 1 KHz square wave, with a plus 2.5 V offset.

7. Connect channel 1 of the oscilloscope to the function generator and channel 2 to measure Vo. Trigger on channel 1. Adjust the oscilloscope's time per division and volts per division to observe about one cycle of the Vo waveform on channel 2, as shown on the right.



8. Expand the oscilloscope display by adjusting the volts per division, time per division, and trigger controls to most accurately measure the peak amplitude of the positive pulse, V_P, its decay time constant, τ, and steady state voltage, V_{SS}.

V_P __________ τ __________ V_{SS} ___________

9. Turn off power supply and change the value of R_L to 2.2 KΩ. Turn on the power supply. Expand the oscilloscope display by adjusting the volts per division, time per division, and trigger controls to accurately measure the peak amplitude of the positive pulse, V_P, its decay time constant, τ, and steady state voltage, V_{SS}. Record below.

V_P __________ τ __________ V_{SS} ___________

10. Turn off power supply and change the value of R_L to 3.3K. Turn on the power supply. Expand the oscilloscope display by adjusting the volts per division, time per division, and trigger controls to accurately measure and record the peak amplitude of the positive pulse, V_P, its decay time constant, τ, and steady state voltage, V_{SS}.

V_P __________ τ __________ V_{SS} ___________

Analysis

1. Calculate the theoretical response of the circuit in Figure A and compare the results to your measurements in procedure step 5.

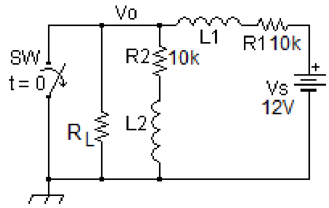
2. Calculate the theoretical response of the circuit in Figure B with R_L equal to 1 KΩ. Compare results to your measurements in procedure step 8.

3. Simulate the circuit in Figure B with R_L equal to 2.2 KΩ and 3.3 KΩ or use a math program such as *Maple* or *MATLAB*.

   Compare your results to the measurements in steps 9 and 10. Explain how the results show that the response approaches an impulse as the value of R_L increases.

Maple Example: Inductive Impulse Voltage

Response for $R_L = \infty$.




```
> restart;
> with(inttrans);
> I1:=(12/s+0.12e-3)/(20000+.2*s);
> V1:=I1*(10000+.1*s);
> V1t:=invlaplace(V1,s,t);
```

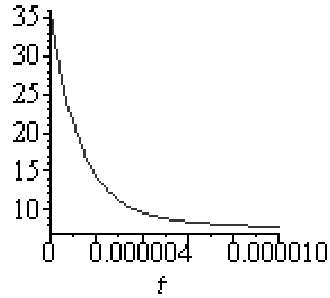
$$V1t := 0.00006000000000 \operatorname{Dirac}(t) + 6.$$

Response for R_L = 30K.

```
> I2:=(12/s+0.12e-3)/(10000+.1*s+(30000*(.1*s+30000))/(60000+.1*s));
> V2:=I2*(30000*(.1*s+30000))/(60000+.1*s);
> V2t:=invlaplace(V2, s, t);
```

$$V2t := 7.200000000 + 7.200000000 e^{-5.00000\,10^5\,t} \left(4. \cosh\left(3.162277660\,10^5\,t\right) - 3.162277660 \sinh\left(3.162277660\,10^5\,t\right)\right)$$

```
> plot(V2t, t = 0 .. 0.1e-4);
```



The area under the pulse is calculated below. It can be shown that as the value of R_L approaches infinity, the area approaches the strength of the impulse of .00006 volt-seconds.

```
> int(V2t-7.2,t=0..infinity);
```

0.0000480000000