Lab 2: Circuit Loading, RC and RL Circuit Introduction

Goal

The goal is to understand circuit loading and measure equivalent source resistance of a signal generator. The second part of the lab, the goal is to understand basic RC and RL circuit concepts.

Objectives 1

1. Measure circuit loading effect due to load resistance for a signal generator and power supply

2. Calculate equivalent source resistance for a signal generator and power supply

3. Discuss discrepancies in observations and calculations.

Objectives 2

1. Observe the transient response of RC and RL circuits

2. Relate oscilloscope measurements to properties of RC and RL circuits

Expectations

1. You are expected to take detailed notes during each step outlined in the procedure that can be used during the lab report write-up.

2. You are expected to provide a neat table of the data that you measured where you clearly label what each data set is and include units for all measured quantities.

3. You are expected to clearly record the measured values of any components that you use.

4. You are expected to clearly record the detail related to images captured by the oscilloscope.

5. You are expected to make your final plots in a program such as Excel. Make sure that your data points appear clearly on the plots, that all axes are clearly labeled and have units.

6. If it is possible to compare your measurements with an expectation or a prediction, you are expected to do so in your lab report

7. You are expected to answer the questions encountered in this manual as well as discuss exercises given during the lectures in your lab write up.
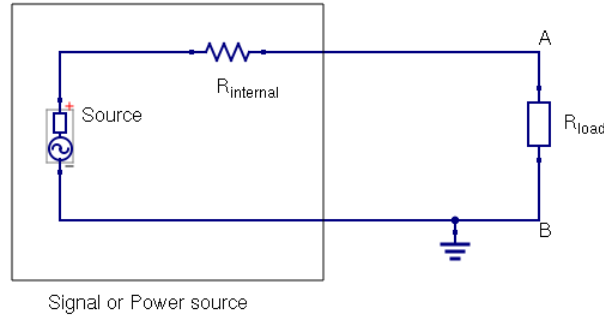
Figure 1: Load R_{load} connected to a power source or a signal generator with internal resistance, $R_{internal}$
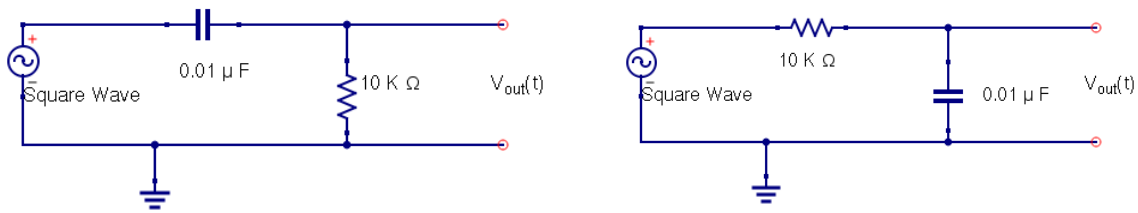

Figure 2: Left: RC based differentiator. Right: RC based integrator.

Introduction to Concepts : Circuit Loading

Attaching a load to a power source or signal generator causes the output voltage to drop due to equivalent source resistance leading to undesirable effects. The concept of equivalent internal resistance applies to all sorts of sources; batteries, voltage dividers, signal sources (oscillators, amplifiers, etc.). All these devices have an equivalent source resistance. Attaching a load with resistance less than or comparable to the internal resistance will reduce the output considerably. This reduction of output by the load is called "circuit loading". It is important to have $R_{load} \gg R_{internal}$ (see Figure 1) to minimize this effect. You will calculate the internal resistance of a signal generator at two different frequencies.

Introduction to Concepts : RC and RL Circuits

Simple RC based differentiator and integrator (Figures 2) will be used to measure the time constant of a RC circuit. The output signal of such a RC circuit is proportional to $e^{-t/RC}$. The output signal for a square wave signal is shown in Figure 3. The time it takes for the output signal to reach the one half of the input voltage after a rising (or failing) edge is called $t_{1/2}$,

$$t_{1/2} = RC \cdot \ln(2)$$

This equation can be used to estimate the time constant (RC).

For a RL (resistor+inductor) circuit (Figure 4), the $t_{1/2}$ for a RL circuit,
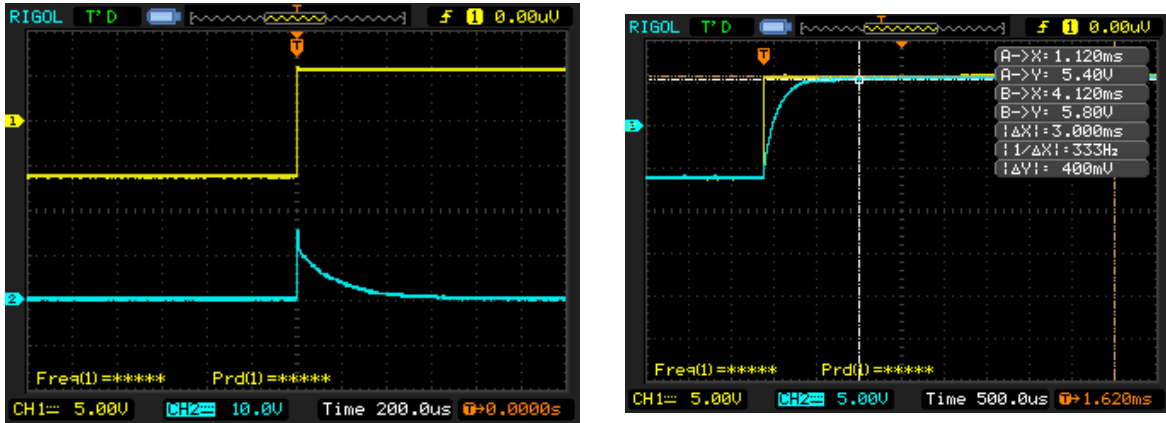
$$t_{1/2} = L/R \cdot \ln(2)$$

Figure 3: Left: Differentiator output (blue) for square wave input (yellow) . Right: Integrator output (blue) for square wave input (yellow).
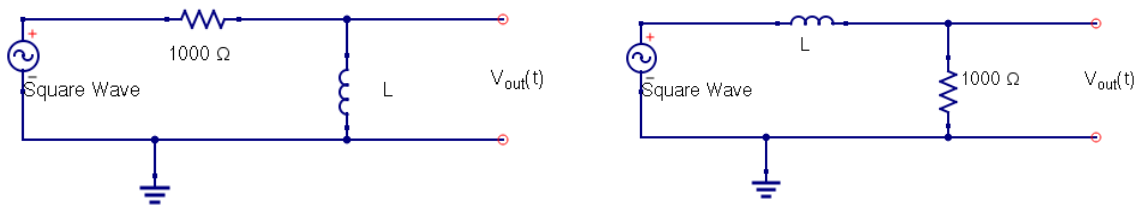

Figure 4: Left: RL based integrator. Right: RL based differentiator.

Where L is inductance in unit Henry. This equation can be used to estimate the time constant (L/R). In both RC and RL circuits, the output signal charges to 63% or discharges to 37% during the time interval equal to the time constant of the circuit. This property can also be used to measure the time constant of a RC or RL circuit using an oscilloscope.

Preliminary Lab Questions

You will find useful to complete the preliminary lab questions before starting the procedure. For circuit loading,

1. If the voltage across the source (Figure 1) when no load is connected across A and B is V_{open} and the voltage across A and B when a load is connected is V_{load}, derive an equation for V_{load} using V_{open}, R_{load}, and R_{internal}

2. Using the above relation find the equation for $\frac{V_{\text{load}}}{V_{\text{open}}}$

You will find useful to complete the preliminary lab questions before starting the RC and RL circuit procedure.

1. Obtain equations for output signal, V(t) for RC and RL circuits shown in Figures 2 and 4

2. Derive the equations $t_{1/2} = RC \cdot \ln(2)$ and $t_{1/2} = L/R \cdot \ln(2)$

3. Show that, in both RC and RL circuits, the output signal charges to 63% or discharges to 37% during the time interval equal to the time constant of the circuit.

Equipment and Parts for Circuit Loading

1. Power supply (EXTEC 18 V DC power supply)

2. Signal generator (Instek GFG-8216G)

3. Oscilloscope (RIGOL DS11002E) and a BNC cable

4. Two multimeters

5. BNC T-junction to banana cable

6. two pairs of banana cables

You will also need the following components in order to carry out this lab. It makes more sense to get them as you need them, rather than all at once before the start of the lab.

1. A resistor box (RC box)

2. Connecting wires

Equipment and Parts for RC and RL Circuits

1. Signal generator (Instek GFG-8216G)

2. Oscilloscope (RIGOL DS11002E) and two BNC to crocodile cables

3. Two multimeters

4. RLC meter

5. proto-board

You will also need the following components in order to carry out this lab. It makes more sense to get them as you need them, rather than all at once before the start of the lab.

1. A resistor box (RC box)

2. RLC board

3. 0.01 μF capacitor

4. 10 KΩ, 1 KΩ resistors

5. proto-board connecting wires

6. few pairs of banana cables

Procedure

Precaution: Use two multimeters for voltage and resistance measurements. Do not use the multimeter to measure resistance when signal generator is connected to the RC box. You can use the range button to adjust the ohm scale of the multimeter to measure the resistance to better precision.

Signal Generator Internal Resistance at 50 Hz

1. Set the signal generator to sinusoidal wave and frequency to 50 Hz

2. Using the oscilloscope set the peak amplitude to 2.8V

3. Verify frequency and amplitude of the signal using the oscilloscope

4. Save an image from the scope (**use bitmap format**)

5. Measure the output voltage of the signal generator with no load resistor connected using the multimeter (**AC mode**).

6. Verify the value displayed in the multimeter by comparing to the oscilloscope measurement. Note that multimeter displays the **rms** value of any AC signal.

7. Set the resistance of the RC box to 20 Ω

8. Measure the resistance using the multimeter before connecting to the signal source

9. This will be the resistance value you will use not the face value shown in the RC box.

 Start taking data

1. Measure the output voltage (V_{open}) of the signal generator with no load connected using the multimeter (AC mode).

2. Write down V_{open}

3. Set the resistance of the RC box to 20 Ω

4. Measure the resistance using a multimeter before connecting to the signal generator

5. Write down the resistance value

6. Connect the RC box to the signal generator

7. Measure the voltage across the RC box (V_{load})

8. Write down V_{load}

9. Repeat above steps for RC box resistance set to 30, 50, 75, 100, 200, 500, 750, 1000, 2500, 5000, 10000, 25000, 50000, 100000 ohms

10. Calculate $\frac{V_{load}}{V_{open}}$ for the data set

11. Plot $\frac{V_{load}}{V_{open}}$ vs. R_{load}

12. Find internal resistance, $R_{internal}$ using the condition $R_{internal} = R_{load}$ estimate the value of $R_{internal}$. You will need the equation derived at the preliminary questions section.

13. Compare with signal generator specification printed next to the output

14. Predict the value of R_{load} that gives $V_{load} = 0.7 \cdot V_{open}$

15. Verify your prediction using the oscilloscope

16. Set the signal generator to sinusoidal wave and frequency to 1000 Hz

17. Now repeat steps 1 through 13 at input frequency of 1000 Hz

Time Constant Measurements of RC Circuits

1. Calculate the time constant for the circuit on Figure 2-left

2. Calculate the capacitance (C) of the circuit using time constant measurement.

3. Build the circuit shown on Figure 2-left

4. Set the signal generator to square wave and set $T/2 \sim RC$ where T is the period of the square wave

5. Connect the input and output of the circuit to the oscilloscope

6. Set the peak amplitude to 2.8V at the signal generator

7. Capture the oscilloscope traces of $V_{in}(t)$ and $V_{out}(t)$ signal

8. Set the signal generator to square wave and set $T/2 \sim 1/10 \cdot RC$ where T is the period of the square wave

9. Capture the oscilloscope traces of $V_{in}(t)$ and $V_{out}(t)$ signal

10. Set the signal generator to square wave and set the frequency such that $T/2 \sim 10 \cdot RC$ where T is the period of the square wave

11. Discuss how output $V_{out}(t)$ signal varies with the input frequency

12. Keep the signal generator to square wave and frequency at that $T/2 \sim 10 \cdot RC$

13. Configure the oscilloscope to generate trace similar to Figure 3

14. Measure the $t_{1/2}$ using the oscilloscope

15. Using the $t_{1/2}$ measurement calculate the time constant

16. Capture oscilloscope traces showing the measurement (use cursor feature)

17. Measure the time to charge output signal to 63% of peak signal voltage which is the time constant of the circuit

18. Capture the oscilloscope traces showing the measurement (use cursor feature)

19. Calculate the capacitance (C) of the circuit using time constant measurement.

20. Measure the amplitude of the $V_{in}(t)$ and $V_{out}(t)$ signals and capture the oscilloscope traces showing the measurement (use cursor feature)

21. Now change the input signal to a triangular wave while keeping the same amplitude and frequency. **Do not change the oscilloscope settings**

22. Measure the amplitude of the $V_{in}(t)$ and $V_{out}(t)$ signals and capture the oscilloscope traces showing the measurement (use cursor feature)

23. Now change the input signal to a sin wave while keeping the same amplitude and frequency. **Do not change the oscilloscope settings**

24. Measure the amplitude of the $V_{in}(t)$ and $V_{out}(t)$ signals and capture the oscilloscope traces showing the measurement (use cursor feature)

25. Discuss the relationship between the rise rate (ramp rate) of input signal and amplitude of the output signal, $V_{out}(t)$

26. Build the circuit on Figure 2-right

27. Repeat steps 4 through 19

28. Use the RLC meter to measure the capacitance of the capacitor used in the circuit

29. Compare different measurements of time constants and capacitance using percent errors

Time Constant Measurements of RL Circuits

1. Calculate the time constant for the circuit shown on Figure 4-left

2. Calculate the inductance (L) of the circuit using time constant measurement.

3. Set the signal generator to square wave and set the frequency such that $T/2 \sim 10 \cdot L/R$ where T is the period of the square wave

4. Using the oscilloscope set the peak amplitude to 2.8V

5. Build the circuit shown on Figure 4-left, use the inductor in the RLC board.

6. Connect the input and output of the circuit to the oscilloscope

7. Configure the oscilloscope to generate trace similar to Figure 3

8. Measure the $t_{1/2}$ using the oscilloscope

9. Calculate the time constant using $t_{1/2}$ measurement

10. Capture oscilloscope traces showing the measurement (use cursor feature)

11. Measure the time it takes to charge output signal to 63% of peak signal voltage which is equal to the time constant of the circuit

12. Capture the oscilloscope traces showing the measurement (use cursor feature)

13. Calculate the inductance (L) of the circuit using time constant measurement.

14. Build the circuit on Figure 4-right

15. Repeat steps 6 through 13

16. Use the RLC meter to measure the inductance of the inductor used in the circuit and compare with your measurement from RL circuit.

References