First Order Circuits

Motivation:

In this lab, we will study first order circuits with capacitors and inductors.

Related Lecture Content:

- First Order Circuits
- Operators

Experiment:

Please fill out the experimental report while going through the lab and submit it to the TA by the end of the lab for grading.

Part 1

Connect a 10 nF capacitor in series with a 10 kΩ resistor as shown in Figure 1. Capacitors are passive two-terminal electrical components used to store electrical energy temporarily in an electric field. The orientation in which the capacitor is connected does not matter.

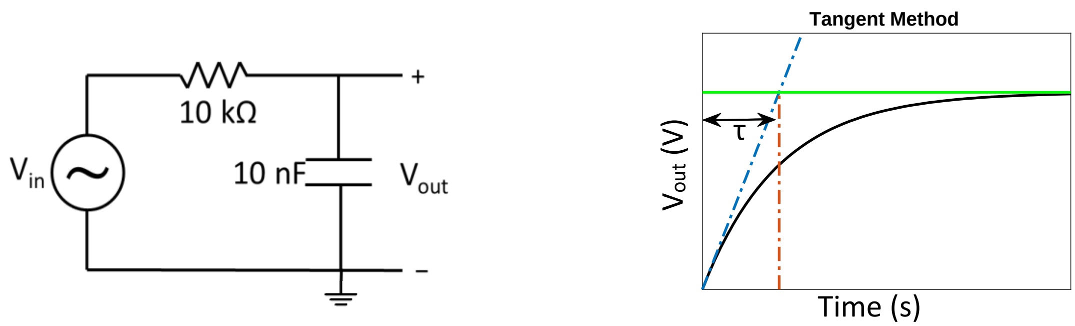

Figure 1: RC Circuit and Time Constant Using the Tangent Method

Let V_{in} be a 5 V step function; one way to generate such a function is to apply a 2.5 V amplitude square function with a DC offset of 2.5 V. Make sure that the frequency is small enough so that the signal can reach steady state. In this experiment, a frequency of around 500 Hz is suitable. Measure both the input V_{in} and the output V_{out} voltages using the oscilloscope.

1.1 Measure the values of the resistor and capacitor using the LCR meter, calculate the time constant τ of the circuit.

1.2 Using the oscilloscope and the tangent method shown in Figure 1, what is the time constant τ of the circuit? Change the vertical and horizontal scales of the oscilloscope display to get an accurate value. How does it compare with your calculated value?

1.3 Write down an expression for V_{out} (t) using your measured values.

Connect a 470 µH inductor in series with a 42.2 Ω resistor as shown in Figure 2. Let V_{in} be a 4 V step function; measure both the input voltage V_{in} and the output voltage V_{out} using the oscilloscope. Since the function generator's internal resistance of 50 Ω is comparable to the rest of the circuit, you will observe a delay τ for the V_{in} to reach steady state.

1.4 Using the oscilloscope, what is the time constant τ of the circuit? Note that the time constant τ is the same for both V_{in} and V_{out}.

1.5 Based on the resistors and inductor in the circuit, calculate the time constant τ of the circuit. Since both resistors in the circuit are comparable, you need to include the 50 Ω resistance of the function generator in series with the circuit in your calculations. How does τ compare with your measured value?

1.6 Write down an expression for V_{out} (t) using your measured values.

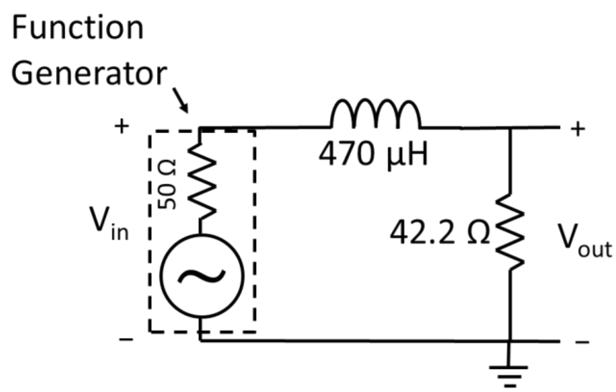

Figure 2: RL Circuit

Part 2

As you saw in the previous lab and lectures, it is possible to do math operations on input signals such as take their sum or difference using resistive op-amp circuits. This can be expanded to more advanced operations, and you can take the derivative or the integral of the signal using first order op-amp circuits. A basic differentiator circuit can be designed using an op-amp, a capacitor and a resistor as shown in Figure 4. The op-amp pin arrangement is shown below for your convenience.

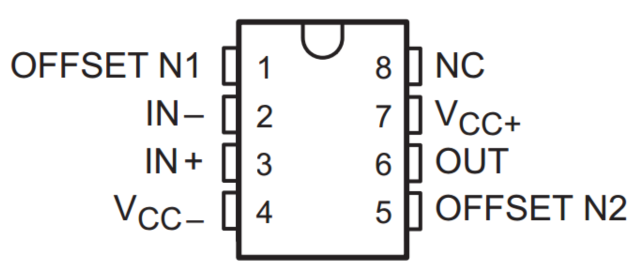

Figure 3: µA741 Op-amp Pin Numbering and Assignment

The input signal to the differentiator is applied to the capacitor. The capacitor blocks any DC content so there is no DC current flow to the amplifier summing point, resulting in zero output DC voltage. The capacitor only allows AC type input voltage changes to pass through.

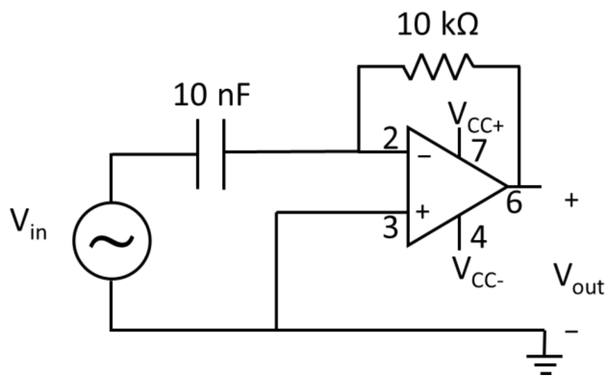

Figure 4: Differentiator Circuit

2.1 Build the circuit shown in Figure 4, with a 10 nF capacitor, a 10 kΩ resistor and the µA741 op-amp used before. Set $V_{CC\pm}$ to ±15 V and apply a sine waveform as the input signal with a 500 Hz frequency, 3 V peak-to-peak and 1 V DC offset. Monitor both the input and output signals with the oscilloscope. Since this is a differentiator circuit, what form do you expect the output signal to be? What form do you observe?

2.2 Compare the frequencies of both input and output signals.

2.3 Compare the peak-to-peak voltages of both input and output signals. What is the gain?

2.4 What is the DC offset of the output signal?

2.5 Change the input signal to a sawtooth waveform (be careful - not a triangle waveform) while keeping the rest of the variables unchanged; observe both input and output signals. What are the two slopes of the input in units of V/ms?

2.6 Based on your circuit and input signal, what are the two theoretically expected output voltages?

2.7 Add a 1 nF capacitor in parallel to the 10 kΩ resistor, and observe the output signal. What are the two output voltages?