Lab 4: Transient analysis of RC and LR circuits

1. Objectives

1) Determine the time constants of the 1st order passive filter circuits from the transient response.
2) Learn how to communicate with the scope using Excel.

2. Introduction

The 1st order linear filter circuit can be characterized by the value of its time constant. Sometimes 1st order linear filter circuit is called single time constant network. Of course, the value of time constant can be calculated from the values of the circuit elements, i.e. resistance, capacitance or inductance. Clearly, the circuit component values need to be known with good precision otherwise the estimation of the time constant would be erroneous. In other words, accurate measurements of the R, C and L are required (as you already know the nominal values can be not accurate). Alternatively, the time constant can be measured directly. The time constant unambiguously determines the 1st order circuit’s transient response. Hence measurement of the 1st order circuit transients can serve as a method of determination of the time constant. In this lab we will characterize a differentiating RC (Figure 1a) and an integrating LR circuits (Figure 1b). The time constants will be determined for these circuits through analysis of their transient responses. You will measure R independently using DMM. Values of C and L will be calculated from measured values of the time constants.

![Figure 1](image)

For differentiating RC circuit in Figure 1a.

Assume V1 was kept equal to V0 for a long enough time so the C1 is charged to V0 and current through R1 is zero, hence, voltage across R1 is zero as well. Now, the V1 is changed abruptly to zero, i.e. V1 becomes simply a short circuit. The C1 will send current through R1 using its accumulated energy. In the very first moment this current is V0/R1, i.e. the V0 is applied to R1. Later the current will be getting smaller and smaller until becomes equal to zero (when all energy accumulated in C1 is spent). Accurate temporal shape of the voltage across R1 can be found by solving 1st order differential equation. Solutions to the 1st order differential equations have the following form:

\[ V_R(t) = V_o \exp\left(-\frac{t}{\tau}\right), \]

where \( \tau = R \cdot C \), i.e. is RC circuit’s time constant.
For integrating RL circuit in Figure 1b.
Assume V1 was kept zero for a long time so the current through R1 is zero. If V1 is abruptly changed from zero to V0 the voltage drop across R1 will develop in time according to:

\[ V_R(t) = V_o \left( 1 - \exp\left( -\frac{t}{\tau} \right) \right) \]  

(2)

By virtue of the exponential function, after five time constants the voltage approaches a steady-state value (zero in (1) and V0 in (2)) with 1% accuracy.

In practice, it is easier to display and measure periodical signals. For accurate measurements the excitation source should have a rectangular waveform with the period much larger than the expected circuit time constant. In principle, the time constant can be determined from any pair of points in the response using equation (1) or (2). However the accuracy of this method is usually low due to a number of systematic and random errors. In this lab the time constant for RC and RL circuits will be determined by fitting the recorded experimental transient response to corresponding exponential decays (Appendix A).

3. Preliminary lab
A. Calculate the time constant for an RC circuit with R = 1 kΩ and C = 0.1 μF. Draw the 1st order differentiating and integrating RC circuits. Sketch the corresponding transient waveforms.

B. Calculate the time constant for an LR circuit with R = 1 kΩ and L = 10 mH. Draw the 1st order differentiating and integrating LR circuits. Sketch the corresponding transient waveforms.

4. Experiment
1. Learn how to communicate with the scope and write a screen shot into the Excel file:
Run Microsoft excel (be patient as it will be loading extra modules).

Look for the Agilent toolbar:

In order to capture the picture of the scope screen press the camera button on the Agilent toolbar. This function will then produce an image file that would look similar to the one shown in Figure 2. The waveform, axis settings and any active cursors and measurements are present in this screenshot making it invaluable in a write-up.

In order to obtain the waveform data (i.e. voltage as a function of time in the form of table) use another button in the Agilent toolbar. The required button has a green sine wave with an x,y below it. This function will automatically load oscilloscope screen data into Excel spreadsheet.
1. Measure the real resistance and capacitance value of the nominally 1 kΩ resistor and 0.1 µF capacitor.
   Calculate the expected value of the time constant.

2. Assemble the circuit in Figure 1 (a). Set an input square wave: 1 V amplitude, zero offset and 1 kHz frequency. Display one period of the waveform of the voltage across the resistor on the oscilloscope screen. Obtain the waveform data (voltage vs. time) in Excel. Process this data to get the time constant. See Appendix A for details. Compare the result with the value calculated using nominal resistance and capacitance.

3. Characterization of LR circuit
Repeat part 1 and 2 for the circuit in Figure 1 (b). You might want to use square wave with offset (1 V or slightly more) so the voltage across R is positive.

Report
Perform PSPICE simulation for both circuits in Figure 1. Compare it with the measured data and explain the observed difference.

The report should include the lab goals, short description of the work, the experimental and simulated data presented in plots, the data analysis and comparison followed by conclusions. Please follow the steps in the experimental part and clearly present all the results of measurements.
Appendix A: Calculation of time constant from the transient analysis?

The voltage waveforms in RC circuit under square wave excitation are shown in Figure A1.

The waveforms can be described by equations (1) and (2). The circled curve is the exponential decay of the voltage across the resistor, i.e. plot of Equation (1). In the experiment, record this part of the waveform, and the time constant can be derived in the following way:

Calculate the natural logarithm of that part of the voltage waveform to obtain:

$$\ln(V_R(t)) = \ln V_o - \frac{t}{\tau}$$

This is a linear dependence of $\ln(V_R)$ on time $t$. The time constant $\tau$ can be found form the slope after performing the least-square fit.