Overview

First order circuits, as their name implies, are modeled mathematically in the time domain by a first order differential equation. In this lab we will be concerned, for the most part, with the *steady state response* of first order circuits to *sinusoidal* inputs. This allows us to model the circuit using an impedance analysis approach, which results in a governing equation for the circuit which is algebraic. Specifically, we will characterize the circuit by its magnitude response as a function of frequency.

**Before beginning this lab, you should be able to:**

- Perform basic measurements using Digital Mult Meters (DMMs) and oscilloscopes.
- Use DC power supplies and function generators
- Write the differential equation governing first order passive electrical circuits. (Module1.1.)
- Identify the time constant of a first order system. (Module1.1.)
- Analyze first order circuits using the impedance method to determine system outputs in phasor form. (Module1.2.)
- Analytically estimate the magnitude response and cutoff frequency of first order electrical circuits. (Module 1.3.)
- Express the magnitude response of a system in terms of decibels. (Module 1.3.)

**After completing this lab, you should be able to:**

- Use the function generator to generate time-varying signals
- Use the oscilloscope to measure time-varying signals and calibrate oscilloscope probes
- Experimentally measure the step response of a first order electrical circuit and identify the time constant of the circuit from the measured step response;
- Experimentally measure the frequency response of a first order electrical circuit and identify the cutoff frequency from the measured frequency response;
- Use experimental data to estimate unknown parameters in a mathematical model of a first order electrical circuit.

**This lab exercise requires:**

- EE 352 Analog Parts Kit
- Breadboard
- Function Generator, oscilloscope
- DMM
- DC power supplies
Symbol Key:

- **Demo**: Demonstrate circuit operation to teaching assistant; teaching assistant should initial lab notebook and grade sheet, indicating that circuit operation is acceptable.
- **Analysis**: Analysis; include principle results of analysis in laboratory report.
- **Matlab**: Matlab numerical analysis; include results of analysis and/or simulation in laboratory report.
- **Pspice**: PSPICE simulation; include simulation results in lab report.
- **Data**: Record data in your lab notebook.

I. **Bench Inventory**

In your lab notebook, record the manufacturer’s name and model number of the equipment at your workstation. Items to be inventoried include:

- Oscilloscope
- Digital Multimeter (DMM)
- Function Generator
- Power supply

Additional equipment used in later experiments should be listed with your lab notes for that experiment. It is extremely important to document the equipment used in an experiment; any knowledgeable engineer should be able to replicate your experimental procedure, including the equipment used, from the notes in your lab notebook. (In general, the serial number of the equipment being used for an experiment should be recorded as well. We will forgo this level of detail.)

Also inventory the probes and connectors at your workbench. These do not have to be listed in your lab notebook, but you should have at least two each of the following:

- Oscilloscope probes
- BNC to BNC connectors

In addition to the above, each student is required to supply for their own use:

- Experiment Board, such as a Proto Board.
- Supply of resistors, capacitors, potentiometer, diodes, transistors, operational amplifiers (OPAMP), etc.
- Computation (Lab) Notebook - National 43-648
- Ball-point Pen - Black Ink
II. Function Generator and Oscilloscope

We will often be concerned with the dynamic response of circuits in EE 352. For that reason, it will be necessary to generate and measure time-varying signals. We will primarily use the function generator and oscilloscope to generate and measure these signals. This experiment is intended to re-acquaint you with the basic operation of these devices.

Abbreviated manuals for most of the available lab equipment are located in a file cabinet near the middle of the lab. The following instructions are intended as guidelines to help you to understand the operation of the function generator and oscilloscope. Feel free, however, to expand upon the procedures listed as you investigate the accuracy, appropriate frequency ranges, and/or general characteristics of equipment and components.

Pre-lab: None.

Lab Procedures:

Using BNC coaxial leads (not the oscilloscope probes), connect the function generator to both channels of the oscilloscope. Both traces should show identical displays. Explore the oscilloscope and function generator controls. Use the function generator to generate various wave shapes (sinusoidal, square, triangular) over the available frequency range, for a range of amplitudes. Expect the display to deteriorate at small amplitudes (mV) and high frequencies (MHz). Make sure that you are comfortable reading time scales and amplitudes from the oscilloscope display.

Examine the effect of the DC - AC coupling of the oscilloscope. Explore the effect of varying the DC offset of the signal. Note that a sine-wave signal with DC offset may give a clipped display.

Discuss your observations in your lab notebook, especially recording the minimum and maximum frequencies and amplitudes at which the waveform begins to deteriorate. This information can become extremely valuable when interpreting results in later lab experiments. A table listing the observations is useful, as are sketches of some representative waveforms.

III. Digital Multimeter (DMM)

The process of making a measurement often has an effect on the parameter being measured. In an electrical circuit, for example, the impedances of voltage measurement devices can be appreciable relative to the impedances of the circuit itself; thus, introducing these impedances can have a significant effect on the currents and voltages in the circuit. This part of the lab assignment is intended to provide a qualitative introduction to these types of effects; a more quantitative approach will be taken in Part V of this assignment.

Pre-lab: None.
Lab Procedures:

Note: Our oscilloscopes are equipped with both ×1 and ×10 probes. (The BNC connectors are ×1 probes, and our oscilloscope probes have both ×1 and ×10 settings.) We will be using the oscilloscope with ×10 probes regularly during the EE 352 labs. It is important to make sure that the oscilloscope itself is set up to read correctly from the ×10 probe, and that the probe is properly calibrated before use.

To set the oscilloscope itself to read properly from the ×10 probe, select the appropriate channel (1 or 2) to be displayed and make sure that the “×10” designation is highlighted on the menu.

Set the switch on the side of the probe to the ×10 setting.

To calibrate the probe itself, connect the probe ground to the ground available on the front of the oscilloscope. Connect the probe to the square-wave generator on the front of the oscilloscope. The scope should display a square wave with an amplitude of 5V. (Be sure to check the amplitude – it is important!) If the displayed square wave does not have “square” edges, adjust the set screw on the side of the probe until the displayed wave is “square”.

Use the Signal Generator to apply a 100 Hz, 4 volt zero-to-peak sine wave to the voltage divider shown in Figure 1. Use the oscilloscope with a ×10 probe to measure $V_{in}$ and $V_o$. With the oscilloscope still connected to $V_{in}$ and $V_o$, use the DMM to measure $V_{in}$. Note any effect on the oscilloscope readings resulting from connecting the DMM to the circuit. Compare the DMM readings with the values measured by the oscilloscope, on the basis of a percentage change in the readings. Increase the frequency; note any discrepancies.

With the oscilloscope still connected to the voltage divider of Figure 1, apply a 200 KHz, 4 volt zero-to-peak sine wave to the circuit. Use the DMM to measure $V_o$. Note any effect on the oscilloscope readings resulting from connecting the DMM to the circuit. Repeat these observations with a square wave input and observe the wave-forms. Comment on your observations in your lab notebook.

Disconnect the oscilloscope from the circuit and replace the 100 KΩ resistors in Figure 1 with 10 MΩ resistors. Use the DMM to measure $V_o$, for a 100Hz, 4 volt zero-to-peak input. Comment on the measured voltage, relative to your expectations.

![Figure 1. Voltage divider circuit for Part III.](image)
IV. Low pass RL circuit

For part I of this lab, consider the circuit shown in Figure 2. The input voltage is \( V_i(t) \) and the output voltage is \( V_o(t) \).

![Figure 2. Low-pass RL circuit.](image)

**Pre-lab:**

(a) Determine an analytical expression for the theoretical amplitude response of the circuit shown in Figure 2. Your response will be a function of frequency \( \omega \), \( R \), and \( L \). Determine the low-frequency \( (\omega=0) \) gain, high frequency \( (\omega\to\infty) \) gain, and the frequency at which the gain \( \left| \frac{V_o}{V_i} \right| = \frac{1}{\sqrt{2}} \) = -3dB (also called the half power point, corner frequency, break frequency, 3dB frequency or cutoff frequency).

(b) Determine an analytical expression for the time constant of the circuit. What is the relationship between the time constant and the cutoff frequency?

**Lab Procedures:**

Construct the circuit shown in Figure 2 using nominal values of \( R=200\Omega \) and \( L=1\text{mH} \). (Note: Measure the actual values of \( R \) and \( L \) that you use in your circuit using the DMM and the RLC meter. Record these values in your lab notebook for later analysis.)

(a) Measure the amplitude response of the circuit and record the results in your lab notebook. Plot the measured amplitude response as a function of frequency. Be sure to measure the amplitude response at enough different frequencies to allow you to create a meaningful plot.

(b) Using a square wave input, measure the step response of the system. (Note: your input will need to have a low enough frequency to allow the system to reach a steady-state value.) Sketch the step response in your lab notebook; estimate the time constant and steady-state response of the system. Comment on the agreement between the measured step response and the theoretical step response determined in the pre-lab.

Demonstrate operation of your circuit to the Teaching Assistant for both the sinusoidal input and step input cases. Have the TA initial the appropriate page(s) of your lab notebook and the lab checklist.
V. Oscilloscope Characterization

When measuring a quantity, the response of the instrumentation system nearly always has an affect on the measurement. Sometimes this affect is negligible, and at other times it can dominate the measurement. In part II of this lab, we will characterize the frequency response of the oscilloscope.

For this experiment, we will be concerned with the circuits shown in Figures 3 and 4 below. Our goal is to measure the response voltage, $V_o(t)$, of the simple voltage divider shown in Figure 2 to a sinusoidal input $V_{in}(t)$. It will be seen that the oscilloscope introduces loading effects on the circuit which result in potentially erroneous measurements. The loading effects introduced by the oscilloscope will be modeled by the simple first-order circuit shown in Figure 4.

Note: The overall circuit obtained by combining the circuits of Figures 3 and 4 is first order. Thus, the circuit’s response can be characterized by the DC gain and the cutoff frequency or time constant.

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**Pre-lab:** None.

**Lab Procedures:**

Construct the circuit shown in Figure 3. Record the actual values of resistance used in your circuit.

(a) Measure the input and output voltage amplitudes of the circuit of Figure 3 by connecting one channel of the oscilloscope to $V_{in}$ and the other to $V_o$ using X1 BNC and alligator connector cables. Estimate the DC gain and cutoff frequency of the circuit by applying sinusoidal input signals over a range of frequencies from 100 Hz to 1MHz to the circuit and inspecting the magnitude of the output voltage.

(b) Using a square wave input, measure the step response of the system. Estimate a time constant and steady-state response for the system based on the square wave data you acquired. Are these values consistent with the DC gain and cutoff frequency you determined in part (a)?

(c) **Demonstrate operation of your circuit using the X1 probe to the Teaching Assistant for both the sinusoidal input and step input cases.** Have the TA initial the appropriate page(s) of your lab notebook.
(d) Replace the X1 lead with a X10 probe on the channel connected to $V_o$. Adjust the probe, using the square waveform from the oscilloscope front-panel (See manual or TA). Then, using a sine wave input, estimate the DC gain and cutoff frequency of the system with the X10 probe.

(e) Using a square wave input, measure the step response of the system. Estimate a time constant and steady-state response for the system based on the square wave data you acquired. Are these values consistent with the DC gain and cutoff frequency you determined in part (d)?

(f) Demonstrate operation of your circuit using the X10 probe to the Teaching Assistant for both the sinusoidal input and step input cases. Have the TA initial the appropriate page(s) of your lab notebook.

Lab Report:

In your lab report, provide a summary of the results of this lab assignment. You should include, at a minimum, all items indicated on the lab checklist. Append the lab checklist sheet with teaching assistant initials indicating completed lab demos to your report.