Steady-State AC Behavior of Passive Circuit Elements
ECE 2100 Circuit Analysis Laboratory
version 29 March 2022

Equipment and Supplies

<table>
<thead>
<tr>
<th>oscilloscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>function generator</td>
</tr>
<tr>
<td>resistors</td>
</tr>
<tr>
<td>10 Ω (via resistor substitution box)</td>
</tr>
<tr>
<td>500Ω (via resistor substitution box)</td>
</tr>
<tr>
<td>39mH inductor (small black box with banana plugs)</td>
</tr>
<tr>
<td>0.026μF capacitor (via capacitor substitution box)</td>
</tr>
<tr>
<td>banana-to-banana plug cables</td>
</tr>
</tbody>
</table>

Learning Outcomes

Students will:
1. Use a waveform generator to provide a sinusoidal signal;
2. Use an oscilloscope to measure the amplitude and phase of sinusoidal signals; and
3. Experimentally verify the computed and simulated impedance of a resistor, capacitor, and inductor using steady-state time domain measurements.

Pre-Laboratory Assignment (STEPS 1-5)

Resistor Impedance

1. Consider the circuit of Figure 1 with a 16V peak-to-peak 5000 Hz sinusoidal voltage source. Rcsr is a current sampling resistor. **Since the voltage at node 2 will be adjusted to 16V peak-peak, the internal resistance of the waveform generator has no effect on this experiment, and is not included in the schematic.** Resistor Rcsr will enable display of the current i(t) through R1 using an oscilloscope (an instrument that can only display voltage).

Using phasor analysis, find the voltage phasor $V$ across R1 and current phasor $I$ through R1. ASSUME $R_{csr}=0$ in your calculations. NOTE: The voltage source in Figure 1 is a cosine source created by shifting a sine wave by 90 degrees.

2. Simulate the circuit using LTspice® with $R_{csr}=10$ ohms using a transient analysis. Set “Stop Time” to 3 ms, “Time To Start Saving Data” to 1 ms, and “Maximum Time Step” to 0.01 μs. The delay in saving data is to enable the circuit to reach steady state.
   a. Plot $v(t)$ for 1 ms by plotting $v(2)-v(1)$.
   b. Plot $i(t)$ on same plot.
   c. What is the phase relationship between voltage $v(t)$ and current $i(t)$?
      Does it match your pre-lab calculation?
   d. What is the peak amplitude of the current $i(t)$?
      Does it match your pre-lab calculation?
You may notice a small error here… WHY?
e. Plot 1000*(v(1)/10) to show the current i(t) through R1 in mA.
   This is how current i(t) will be measured in lab.
   Note that LTspice® will show units of V instead of mA.

Your final plot for R1 should look like Figure 2.

**Inductor Impedance**

3. Replace R1 with a 39 mH inductor and repeat pre-laboratory steps 1-2. Run the simulation. Does something look strange? Yes… The circuit has not reached steady-state! Change the simulation command to `tran 0 32ms 30ms .01us` and rerun the simulation.

**Capacitor Impedance**

4. Replace R1 with a 0.026 uF capacitor and repeat pre-laboratory steps 1-2.

**Simulation Files**

5. Bring an electronic copy of your simulation files to lab.

---

**Figure 1. Circuit to Measure Steady-State Behavior of a Resistor**

Since the voltage at node 2 is adjusted to be the desired peak voltage, the output resistance of the waveform generator is ignored.
Figure 2. Steady state voltage and currents for the circuit of Figure 1.

Procedures

1. **BE SURE ALL EQUIPMENT IS OFF.**

**Resistor Impedance**

2. Build the circuit of Figure 1 using banana-to-banana cables and resistor substitution boxes. Use the function generator as the voltage source. Since one lead of the oscilloscope is grounded, we cannot directly measure \( v(2) - v(1) \). Connect oscilloscope CH 1 to node 2 (with the ground of the oscilloscope lead connected to the ground of the function generator). We will consider \( v(2) \) to be the voltage across R1; this is not correct, but we can get away with this here (see Analysis question 1). Connect oscilloscope CH 2 to measure \( v(1) \). Note that \( v(1) \) is directly proportional to the current through R1. Setup the scope to display at least two complete waveform cycles. **Verify the frequency (5 kHz) and amplitude (16 V peak-to-peak) at the output of the function generator (node 2).** Find the phase angle between the resistor voltage and current. Compare these experimental results (voltage amplitude, current amplitude, and phase angle) with simulation and hand analysis results (use a table). Find experimental errors using the hand analysis results as the reference.

**Inductor Impedance**

3. Repeat laboratory procedure step 2 after replacing R1 with a 39 mH inductor. Verify the frequency (5 kHz) and amplitude (16 V peak-to-peak) at the output of the function generator (node 2). Compute the actual inductor value using your measurements of circuit voltages and the source frequency. Update your hand analysis and results with this measured value as needed.

**Capacitor Impedance**

4. Repeat laboratory procedure step 2 after replacing R1 with a 0.026 uF capacitor. Verify the frequency (5 kHz) and amplitude (16 V peak-to-peak) at the output of the function generator
Compute the actual capacitor value using your measurements of circuit voltages and the source frequency. Update your hand analysis and simulation results with this measured value as needed.

**Analysis**

1. Why can node voltage $v(2)$ be considered as roughly the same as $v(2)-v(1)$?
2. Sketch phasor diagrams that show phasors $V$ and $I$ for laboratory procedures steps 2-4.
3. What is the primary source of the error between experimental and hand analysis results for this experiment?

**Credits and Copyright**

Adapted from material developed by current and former ECE faculty, including Professor Joseph Kelemen. Thanks to Sepehr Emamian, Masoud Panahi, and Simin Masihi for improvements to this lab.

© 2022 Damon A. Miller. All rights reserved. Not for use outside of ECE 2100.