

UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE

Department of Electrical and Computer Engineering

EXPERIMENT 6 – IMPEDANCE

OBJECTIVES

In this laboratory exercise you will verify the magnitude and phase relationships between AC voltage and current for: a resistive load, an inductive load, and a capacitive load. You will compare the impedances calculated to the impedances calculated from the measured voltage across and current through the device at several frequencies.

MATERIALS/EQUIPMENT NEEDED

Oscilloscope
Waveform Generator
Resistors: 5.1 Ω , 1 k Ω
Capacitor: 0.01 μ F
Inductor: 10 mH

INTRODUCTION

Until now in your study of circuits, Ohm's law has referred to the relationship between current, voltage and resistance in DC circuits. In AC (alternating current) circuits Ohm's law remains unchanged; however, the quantities in the relationship assume new meaning. Resistance is replaced by Z (a complex quantity known as impedance) while DC current and voltage are replaced by complex phasors, I and V, that represent sinusoidal current and voltage in the frequency domain. Ohm's law in the frequency domain is:

$$Z = \frac{V}{I} \text{ (ohms)}$$

Initially, AC circuits were solved in the time domain with differential equations, a tedious and nearly impossible method for complicated circuits. However, in 1897 Charles Steinmetz, an engineer with General Electric, recognized that linear circuits excited by a sinusoidal source can be solved algebraically in the frequency domain where impedance, voltage, and current are complex phasors. Linear circuits are those containing elements of constant value (i.e. they do not vary with time, voltage, or current). For the circuit components; R, L and C, the impedance is defined by the equations below:

$$\begin{aligned}Z_R &= R \\Z_L &= j\omega L \\Z_C &= 1/(j\omega C)\end{aligned}$$

Observe that the impedance for a resistor is real, and therefore, the current through a resistor is in phase with the voltage across it. For the inductor the j in the numerator of Z_L causes the voltage to lead the current by 90° , while for the capacitor, the j in the denominator of Z_C causes the current to lead the voltage by 90° . This can be remembered with a simple jingle well known to electrical engineers (ELI the ICE man). The interpretation is: (ELI) voltage leads current in an inductor and (ICE) current leads voltage in a capacitor. The magnitude of Z_L , ωL , is referred to as inductive reactance, and the magnitude of Z_C , $1/\omega C$, is referred to as capacitive reactance.

PRELAB

1. For the circuit shown in Figure 6-1, calculate and record the magnitude and phase of the impedance for each of the devices and frequencies shown in Tables 6-1, 6-2 and 6-3. This should be done using the three equations described in the introduction. For these calculations replace the 5.1Ω resistor with a short. Its impedance is so small compared to the device impedance that no significant error will result. It has been included as a current sensing resistor, allowing the display of the load current waveform on the oscilloscope.

Note: The frequencies listed in Tables 6-1, 6-2, and 6-3 are in Hertz, and must be converted to radians to calculate the device impedance. Observe that only the columns for the calculated values are to be filled out. The remaining columns will be filled out during the lab procedure or during post lab calculations.

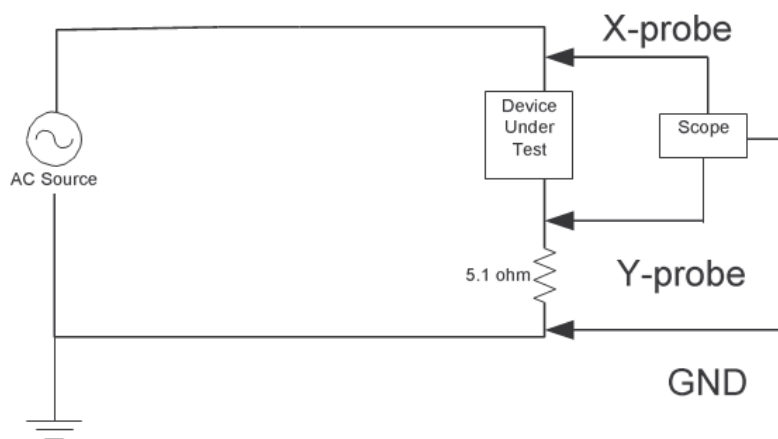


Figure 6-1 Impedance measuring setup

PROCEDURE

Measuring Impedance of a Resistor

1. Construct the circuit shown in Figure 6-1. Place the $1\text{k}\Omega$ resistor in the location labeled Device Under Test.
2. Adjust the y- channel gain of the oscilloscope to one of the more sensitive setting. From the oscilloscope you can read either peak-to-peak values and convert to RMS or read RMS values directly.
3. Set the waveform generator to produce a 1kHz sinusoid wave.
4. Start with the waveform generator output amplitude turned all the way down.
5. Slowly increase the amplitude on the waveform generator until suitable clean waveforms can be obtained on the oscilloscope. Record all settings.
6. Measure and record the voltage V_{rms} at all of the indicated frequencies in Table 6-1.
7. I_{rms} must be calculated from the measured RMS voltage across the 5.1Ω sensing resistor.

Measuring Impedance of Reactive Devices

1. For reactive devices, as the frequency of the signal is changed, the impedance equations predict that the relationship between current through and voltage across the device will change. When measuring current and voltage for reactive devices, freely adjust the ranges on the oscilloscope, and the amplitude of the signal from the waveform generator so that signal levels are readily measured by the oscilloscope.
2. Remove the $1\text{k}\Omega$ resistor from the circuit, and insert the capacitor in its place.
3. Fill in the data columns in Table 6-2 for the capacitor current and voltage at all of the indicated frequencies. Be sure to observe and record the phase relationship between the voltage across and the current through the device. You may assume the voltage across the device has a phase of zero and record only the phase of current relative to the phase of voltage as the phase angle of current.
4. Replace the capacitor with the inductor. Using the same procedure as for the capacitor, fill in the data columns in Table 6-3 for the inductor current and voltage at all of the indicated frequencies.
5. Finally, measure the DC resistance of the resistor, capacitor and the inductor with an ohmmeter. Record your measurements.

Note: In Table 6-1, all impedance values must include a magnitude and phase. The phase of impedance is the angle by which current leads voltage. On the oscilloscope if the current waveform is shifted to the left of the voltage waveform by angle θ the current leads the voltage by that angle and the phase of the impedance is angle θ .

DATA/OBSERVATIONS

Table 6-1: Resistor Impedance Results

Frequency (kHz)	Theoretical	Measured		
	Z_R	V_R	I_R	Z_R
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

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Table 6-2: Capacitor Impedance Results

Frequency (kHz)	Theoretical	Measured		
	$ Z_C \angle \phi$	V_C	I_C	$ Z_C \angle \phi$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

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Table 6-3: Inductor Impedance Results

Frequency (kHz)	Theoretical	Measured		
	$ Z_L \angle \phi$	V_L	I_L	$ Z_L \angle \phi$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

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POST-LAB

Post-Lab questions must be answered in each experiment's laboratory report.

1. Prepare all data for analysis. Remember that device current was determined by measuring the voltage across the current sensing resistor and dividing by the resistance of that resistor. Be sure that RMS values were recorded. If not, P-P values can be converted to RMS with the following equation:

$$V_{rms} = \frac{V_{pp}}{2\sqrt{2}}$$

2. Enter the numbers from your data tables into a spreadsheet program. At each frequency, determine and record the percent error between the measured and theoretical values for resistance and for both the magnitude and phase of impedance for each reactive device. The following is the equation for this calculation:

$$\%error = \frac{measured - theoretical}{theoretical} \times 100$$

3. For the 1kΩ resistive device plot a single graph showing both the theoretical and measured impedance vs. frequency. Since the frequency range is small a logarithmic scale is not required. For each of the reactive loads plot two graphs, one showing the theoretical and measured values of impedance magnitude vs. frequency and the other showing the theoretical and measured values of impedance phase vs. frequency. Clearly label each curve and import these graphs into your write-up.
4. At high and low frequencies what differences can you see in the measured vs. the theoretical impedances in each component?
5. Do the ohmmeter measurements help to account for some of the differences between the theoretical and measured values? Explain.
6. Does the fact that the current sensing resistor was assumed to be zero in the calculations of impedance account for any of the measurement errors observed? Explain.

Be sure to include all items from the post-lab exercise above in your written lab report.