AC Magnitude and Phase

Objectives:
Today's experiment provides practical experience with the meaning of magnitude and phase in a linear circuits and the use of phasor algebra to predict the response of a linear system to a sinusoidal input. Using the digital oscilloscopes, we can better understand the true implications of amplitude and phase.

Pre Lab:
- Read and understand Hambley Sections 5.1 through 5.4
- For \( v(t) = 160 \cos (180\pi t + 60) \) determine:
  1. \( V_{\text{max}} \)
  2. The phase angle \( \theta \).
  3. The angular frequency \( \omega \).
  4. \( V_{\text{rms}} \)
  5. The phasor voltage \( V \)

Part A: RC Circuit Measurements

Procedure:
1. Set the output impedance of the function generator to Hi-Z mode.
2. Using any method, set the waveform generator for 500mV pk-pk using a 250 Hz sine wave.
3. Measure the 1k\( \Omega \) resistor using the Fluke 45 as an Ohmmeter. Measure the 1\( \mu F \) capacitor using the universal bridge on the instructor’s table. Enter these values on the data sheet.
4. Construct the RC circuit illustrated in Figure 1. Use the BNC to “micrograbber” cables to make component connections (remember to check that the amplification factor for CH1 and CH2 are 1x). When using the probes, use common sense precautions to avoid damaging the sensitive contacts and clips.

Figure 1. The first positive peak for \( v_1 \) occurs before the first positive peak of \( v_2 \) so \( v_1 \) leads \( v_2 \). The difference in time determines the phase difference between \( v_1 \) and \( v_2 \): \(-\phi = \frac{t_1 - t_2}{T} \cdot 360^\circ\). You can also look at the time difference between zero crossings if it’s hard to tell exactly where the peaks of the sine waves occur.
5. The display itself has a natural coarseness, which can be reduced by selecting the Average function. Try to use as few samples as possible to avoid long delays while moving from one display to another. Set both channels to the same Volts/Division setting. Averaging is a way to pull a repetitive signal out of the background noise. It works better than a bandwidth limit or brightness control because the bandwidth is not reduced. The simplest averaging is smoothing (number of averages = 1). The oscilloscope acquires the signal every 5 ns. The smoothing function uses two acquisitions to display one signal. The Average function (number of averages >1) requires a stable trigger. The trigger is what tells the scope when to display the signal. It is constantly acquiring the signal, but doesn’t let you see it until the signal meets some criteria you set using the trigger controls.

6. Which channel appears to display the greater peak magnitude? Use the measure function to determine the Voltage pk-pk amplitudes for both channels, and record in the data sheet.

7. AC Phasor analysis can determine the Complex Gain as a function of radian frequency. Use measured values of your resistor and capacitor components to determine theoretical gain. Measure the frequency in Hz using your oscilloscope and calculate the radian frequency. Record the frequency, radian frequency, and theoretical gain value on your data sheet. Show all calculations in your lab report.

\[ Gain = \frac{V_2}{V_1} = \frac{1/j\omega C}{R + 1/j\omega C} = \frac{1}{1 + j\omega RC} \]

8. Calculate the ratio of the CH1 and CH2 pk-pk measurements to determine the measured gain and record on your data sheet.

Figure 2: The RC Circuit
9. We can also measure the phase. Position the time cursors on corresponding zero crossings (or peaks) of the CH-1 and CH-2 waveforms. Determine the time difference $\Delta t$ between the waves. Indicate which channel arrives at the reference point first--this channel is said to "lead". Record these values on the data sheet.

10. The measure function displays the wave periods. Record the period on the data sheet.

11. The phase shift, $\theta$, is related to the time shift, $\Delta t$, that you observe on the oscilloscope. $T$ is the period of the waveform.

$$\theta = \frac{\Delta t}{T} \times 360^\circ = \Delta t \times f \times 360^\circ$$

Record the measured phase value on the data sheet.

12. We interpret the negative sign in the theoretical phase expression as revealing that the output "lags behind" the input. That is, the input should lead the output. Describe in your lab report if this is what you observed? What would be implied by an output that leads the input?

Part B: $RL$ Circuit Measurements

1. Using any method, set the waveform generator for 200mV pk-pk using a 50 kHz sine wave.

2. Measure the 470$\Omega$ resistor using the Fluke 45 as an Ohmmeter. Measure the inductor using the universal bridge on the instructor’s table. Make sure the bridge is set to Auto and 1 kHz when you take your measurement. Enter this value on the data sheet.

3. Construct the $RL$ circuit illustrated in Figure 2. Use the BNC to “micrograbber” cables to make component connections, (remember to check that the amplification factor for CH1 and CH2 are 1x). When using the probes, use common sense precautions to avoid damaging the sensitive contacts and clips.

4. Which channel appears to display the greater peak magnitude? Use the measure function to determine the Voltage pk-pk amplitudes for both channels, and record in the data sheet.

5. Use AC phasor analysis to determine the voltage gain, which is the ratio of the output impedance divided by the total series impedance. Show all calculations in your lab report.

$$Gain = \frac{V_2}{V_1}$$

Using the voltage divider rule, $V_2 = V_1 \left(\frac{j\omega L}{R + j\omega L}\right)$. Dividing through both sides by $V_1$ yields the complex gain for the circuit: $Gain = \frac{V_2}{V_1} = \frac{j\omega L}{R + j\omega L}$. This gain is sometimes called the “transfer function” since if we know the input voltage Phasor $V_1$, we can determine the output voltage magnitude and phase at any frequency. Try changing the frequency of the function generator signal, $V_1$. What happens to the amplitude of the output waveform $V_2$ when you decrease the frequency? When you increase it?
6. Use your measured component values to calculate the theoretical complex gain. Record these theoretical magnitude and phase on the data sheet. Show all calculations in your lab report.

7. Calculate the ratio of the CH1 and CH2 pk-pk measurements to determine the measured gain magnitude and record on your data sheet.

8. Measure the phase. Position the time cursors on corresponding zero crossings (or peaks) of the CH-1 and CH-2 waveforms. Determine the time difference \( \Delta t \) between the waves. Indicate which channel arrives at the reference point first--this channel is said to "lead". Record values on the data sheet.

9. The measure function displays the wave periods. Record the period on the data sheet.

10. The phase shift, \( \theta \), is related to the time shift, \( \Delta t = t_1 - t_2 \), that you observe on the oscilloscope. \( T \) is the period of the waveform.

\[
- \theta = \frac{\Delta t}{T} \times 360^\circ = \Delta t \times f \times 360^\circ
\]

Record the measured phase value on the data sheet.

11. We interpret the negative sign in the theoretical phase expression as revealing that the output "lags behind" the input. That is, the input should lead the output. Describe in your lab report if this is what you observed? What would be implied by an output that leads the input?
Data Sheet

Part A: RC Circuit Measurements

Nominal 1kΩ resistor value__________  Nominal 1µF capacitor value__________

Which channel has the great peak magnitude? CH-1    CH-2   (Circle One)

CH-1 ___________________   CH-2 ____________________

 f ______________   ω ______________

Theoretical Gain ________________   Measured Gain ________________

Theoretical Phase ________________

Δt ________________   Which channel leads? _________

T ________________   Measured Phase ________________

Part B: RL Circuit Measurements

Nominal 470Ω resistor value__________  Nominal 1 mH inductor value__________

Which channel has the great peak magnitude? CH-1    CH-2   (Circle One)

CH-1 ___________________   CH-2 ____________________

 f ______________   ω ______________

Theoretical Gain ________________   Measured Gain ________________

Theoretical Phase ________________

Δt ________________   Which channel leads? _________

T ________________   Measured Phase ________________

Your Name_____________________________  Lab Instructor___________________

Partner Name___________________________  Date___________________________