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ECE 2100H Experiment V

AC Circuits

# Introduction

## Purpose

In this laboratory exercise you will apply techniques learned in class to solve circuits in which the inputs are sinusoidal. This technique makes use of transforms and involves complex arithmetic, but is generally much easier to use than techniques that directly solve differential equations. Remember, these are really just shortcuts for solving the differential equations that arise from Kirchhoff's laws and the current-voltage relationships for the resistor, capacitor, and inductor.

## Background

This laboratory exercise will use sinusoidal inputs. Since the circuits used here are linear, the outputs will also be sinusoidal and of the same frequency as the input. Although this is a somewhat restrictive class of problems, it is a very useful class. To elaborate, let us look at general circuit analysis. In any circuit, we will have signals of some sort entering the circuit at one or more points, and being detected, measured, or used at one or more points. These signals are not always sinusoids. However, the signals are always voltages or currents, and as such are always continuous functions of time. In fact, they are always what are called "well behaved functions".

 This behavior is a mathematical characteristic; an important consequence is that one can apply Fourier's (pronounced 4-E-A) theorem and break down the signal into its components (the so-called Fourier components). The components are sine waves at different frequencies with different amplitudes and phases, and the sum of these sinusoids gives the original function. If you think about it, it is an amazing idea that any waveform can be achieved by adding up sine waves.

 Having the Fourier components, one can apply superposition, solve the problem using phasor techniques for each of the sinusoidal components, and add the solutions to obtain the final answer. Thus, theoretically at least, one can solve any problem, no matter how complex, by a diligent application of these ac circuit analysis techniques. But there is more to it than just this. With this mathematical underpinning, one can begin to look at problems in a different way. An engineer will often speak of working a problem in the frequency domain instead of the time domain.

This frequency domain appears to be a mystical world, not quite real, where some numbers can be squared to obtain negative numbers. Actually, the frequency domain is merely a mathematical technique for thinking about and solving problems in a simpler way. As with any new approach, it can be difficult at first. The first step is to believe that it works. This lab is intended to convince you that it does. The remaining steps are left for later.

 Take care in this laboratory to interpret your readings correctly. There are three ways in which we refer to sinusoidal amplitudes. One way is to refer to the amplitude of a sinusoid, that is, the coefficient of a sinusoidal operator like the sine or cosine. This is also referred to as the zero-to-peak value. The second way is called the "peak-to-peak" value, and is twice the zero-to-peak value. The peak-to-peak value is what is usually read off the oscilloscope, since this is the most accurate measurement you can make on the display. The "rms" (root-mean-square) value refers to the square root of the mean value of the squared waveform. This is very useful for power calculations, and for sinusoids it is equal to the zero-to-peak value divided by. Most meters will read RMS values when measuring ac signals.

## Methodology/Components Required

 1/4 watt Resistors (number required in parentheses):

1[k] (2) 2.2[k] (2)

2.7[k] (1) 3.9[k] (1)

Capacitors:

0.01[F] (1) 150[pF] (1) 0.022[F] (1)

0.1[F] (2) 1[F] (1) 0.033[F] (1

# Pre-Lab

Step 1. Find the output vout(t) of the circuit in Figure 1, as explained in that step. Use phasor domain techniques, but then convert to the time domain to get vout(t).

Step 6. Find the ac and dc components of the output vout(t) of the circuit in Figure 2, as explained in that step. Use phasor domain techniques, but then convert to the time domain to get vout(t).

Questions. There are several calculations in the Questions section that you might want to work on before you arrive in the lab, but these will not be graded as part of the Pre-Lab assignment.

# Results and Discussion

1. Examine the circuit in Figure 1. This is a reasonably simple circuit, by most standards. However, without phasor techniques the solution is difficult to obtain. In doing your calculations, assume that a signal source with a 50[] Thévenin resistance is applied to the input. Assume that the signal at the input is a sinusoid with a frequency of 3[kHz] and an amplitude of 10[Volts peak-to-peak] (abbreviated as 10[Vpp]). Calculate, using phasor techniques, the magnitude and the phase shift of the output signal with an open circuit at the output. Remember that the frequency given here is *f*, and is not the angular frequency, **. You will need to convert to angular frequency to use the phasor technique. Record these values in Table 1. Note that the phase shift refers to that phase measured with respect to the signal at the input.

**Table 1.** Output signal measurements for circuit 1

|  |  |  |
| --- | --- | --- |
|  | Magnitude | Phase shift |
| Calculation |  |  |
| Measurement with 10X probe |  |  |
| Measurement with 1X probe |  |  |
| Measurement with multimeter |  | ////////////////////////////////////////////////// |



**Figure 1.** First of Two AC Circuits.

1. Calibrate the probes by connecting them to the calibrating signal on the front of the oscilloscope. Adjust the probes so that the square wave on the screen is indeed square.
2. Build the circuit in Figure 1. Connect the signal generator to the oscilloscope and set the signal generator for a sinusoidal signal with a frequency of 3[kHz] and an amplitude of 10[Vpp]. Now remove the signal generator from the oscilloscope and connect it to the circuit input *vin*. Use the 10X probes to measure the magnitude and phase shift of the output signal using the oscilloscope. Repeat this measurement with the oscilloscope probe in the 1X position. Record your measured values in Table 1.
3. Compare your measurements, with and without the 10X probe, to your calculations. Which measurements were more accurate? Calculate the impedance of the 150[pF] capacitor at this frequency. Use this information to explain your results.
4. Repeat the magnitude measurements with the multimeter instead of the oscilloscope. Record your measured values in Table 1. Compare with your previous measurements and explain any discrepancies.
5. Examine the circuit in Figure 2. Assume that the combination of the voltage source *v1* and the 50[] resistor is a signal source with a 50[] Thévenin resistance, and *v2* is a dc power supply set to –7[V]. Assume that *v1* has a frequency of 10[kHz] and an amplitude of 5[Vpp]. Solve for the magnitude and phase shift of the ac component and the dc component of the signal with an open circuit at the output. You will need to use superposition to complete this step. Remember that for dc sources, capacitors can be thought of as open circuits. Record your answers in Table 2.
6. Build the circuit in Figure 2. Note two things in particular. First, the 50[] resistor should not be added with a discrete component. That is, do not use a resistor from your kit since this is an internal characteristic of the signal generator. Second, note that the dc source must be included as a floating supply. The dc source contained within the signal generator cannot be used as a floating supply. If you are using electrolytic capacitors, it is important that you observe the proper biasing polarity: connect the positive side of the capacitor towards ground since *v2* is negative. Use the 10X probes to measure *vout*. Use *v1* as your phase reference. Repeat this measurement with the oscilloscope probe in the 1X position. Record your results Table 2.

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**Table 2.** Output signal measurements for circuit 2

|  |  |  |  |
| --- | --- | --- | --- |
|  | Magnitude | Phase | DC Component |
| Calculation |  |  |  |
| Measurementwith 10X probe |  |  |  |
| Measurementwith 1X probe |  |  |  |

1. The output of the circuit in Figure 2 has both a dc and an ac component. That is, your output waveform will be a sinusoid added to a constant value; the constant value is the dc component. Measure the dc component of the output. To do this you may want to make use of the ac/dc coupling feature of the oscilloscope.

**Conclusions**

1. The input to the oscilloscope can be modeled as a 1[M] resistor in parallel with a capacitor in the range of about 20[pF]. When the scope probe is properly calibrated, it can be modeled as a 9[M] resistor in parallel with a capacitor having a capacitance 1/9th that of the oscilloscope input capacitance. When you calibrate the probe, you are in fact adjusting the probe capacitance so that it has the correct value. If the scope probe is not properly calibrated, is an error introduced into your measurement? What is the nature of the error? Is there also an error in dc measurements made using the scope probe?
2. Repeat the calculation of the output voltage of the circuit in Figure l assuming that the oscilloscope is connected to the circuit output. Repeat this calculation again assuming that the oscilloscope ***and the scope probe*** are connected to the circuit output. In which case is the circuit loading more of a problem? Why?
3. Assume that the scope probe is connected to the oscilloscope. Calculate the impedance of the scope probe and oscilloscope combination at the terminals of the scope probe. Do this calculation for a signal frequency of 3[kHz] and 10[kHz]. If the probe and oscilloscope were connected to a circuit output, for which frequency would the circuit loading be more of a problem? Why?