Laboratory Manual

for

AC Electrical Circuit Analysis

(Part Two)

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1

The Oscilloscope

Objective

This exercise is of a particularly practical nature, namely, introducing the use of the oscilloscope. The various input scaling, coupling, and triggering settings are examined along with a few specialty features.

Theory Overview

The oscilloscope (or simply *scope*, for short) is arguably the single most useful piece of test equipment in an electronics laboratory. The primary purpose of the oscilloscope is to plot a voltage versus time although it can also be used to plot one voltage versus another voltage, and in some cases, to plot voltage versus frequency. Oscilloscopes are capable of measuring both AC and DC waveforms, and unlike typical DMMs, can measure AC waveforms of very high frequency (typically 100 MHz or more versus an upper limit of around 1 kHz for a general purpose DMM). It is also worth noting that a DMM will measure the RMS value of an AC sinusoidal voltage, not its peak value.

While the modern digital oscilloscope on the surface appears much like its analog ancestors, the internal circuitry is far more complicated and the instrument affords much greater flexibility in measurement. Modern digital oscilloscopes typically include measurement aides such as horizontal and vertical cursors or bars, as well as direct readouts of characteristics such as waveform amplitude and frequency. At a minimum, modern oscilloscopes offer two input measurement channels although four and eight channel instruments are increasing in popularity.

Unlike handheld DMMs, most oscilloscopes measure voltages with respect to ground, that is, the inputs are not floating and thus the black, or ground, lead is **always** connected to the circuit ground or common node. This is an extremely important point as failure to remember this may lead to the inadvertent short circuiting of components during measurement. The standard accepted method of measuring a non-ground referenced potential is to use two probes, one tied to each node of interest, and then setting the oscilloscope to subtract the two channels rather than display each separately. Note that this technique is not required if the oscilloscope has floating inputs (for example, in a handheld oscilloscope). Further, while it is possible to measure non-ground referenced signals by floating the oscilloscope itself through defeating the ground pin on the power cord, this is a safety violation and should not be done.

Equipment

(1) DC power supply model:________________ srn:__________________
(1) AC function generator model:________________ srn:__________________
(1) Digital multimeter model:________________ srn:__________________
(1) Oscilloscope, Tektronix MDO 3000 series model:________________ srn:__________________

Components

(1) 10 kΩ actual:__________________
(1) 33 kΩ actual:__________________

Schematics and Diagrams

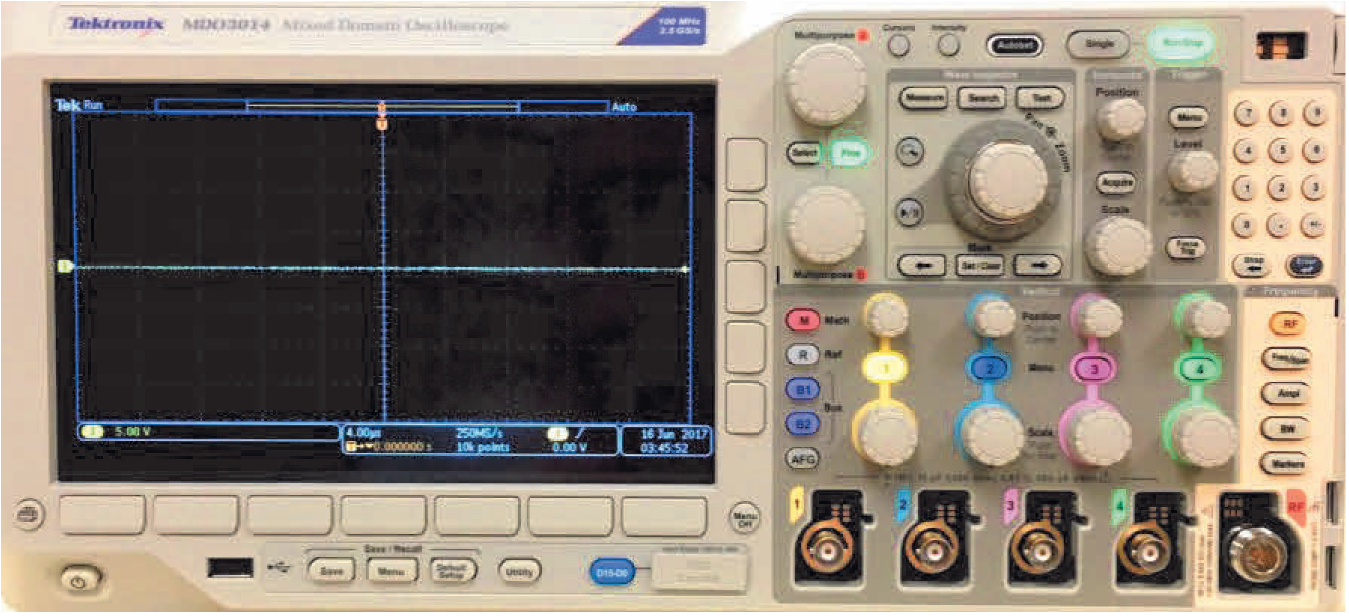

Figure 3A.1

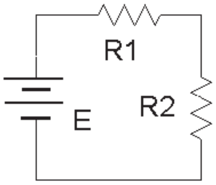

Figure 3A.2

Procedure

1. Figure 3A.1 is a photo of the face of a Tektronix MDO 3000 series oscilloscope. Compare this to the bench oscilloscope and identify the following elements:
   - Channel one through four BNC input connectors.
   - RF input connector and settings section.
   - Channel one through four select buttons.
   - Horizontal Scale (i.e., Sensitivity) and Position knobs.
   - Four Vertical Scale (i.e., Sensitivity) and Position knobs.
   - Trigger Level knob.
   - *Math* and *Measure* (in *Wave Inspector*) buttons.
   - *Save* button (below display).
   - *Autoset* button.
   - *Menu Off* button.

2. Note the numerous buttons along the bottom and side of the display screen. These menu buttons are context-sensitive and their function will depend on the most recently selected button or knob. Menus may be removed from the display by pressing the *Menu Off* button (multiple times for nested menus). Power up the oscilloscope. Note that the main display is similar to a sheet of graph paper. Each square will have an appropriate scaling factor or weighting, for example, 1 volt per division vertically or 2 milliseconds per division horizontally. Waveform voltages and timings may be determined directly from the display by using these scales.

3. Select the channel one and two buttons (yellow and blue) and also press the *Autoset* button. (Autoset tries to create reasonable settings based on the input signal and is useful as a sort of "panic button"). There should now be two horizontal lines on the display, one yellow and one blue. These traces may be moved vertically on the display via the associated Position knobs. Also, a trace can be removed by deselecting the corresponding channel button. The Vertical and Horizontal Scale knobs behave in a similar fashion and **do not** include calibration markings. That is because the settings for these knobs show up on the main display. Adjust the Scale knobs and note how the corresponding values at the bottom of the display change. Voltages are in a 1/2/5 scale sequence while Time is in a 1/2/4 scale sequence.

4. When an input is selected, a menu will pop up allowing control over that input's basic settings. One of the more important fundamental settings on an oscilloscope channel is the *Input Coupling*. This is controlled via one of the bottom row buttons. There are two choices: *AC* allows only AC signals through thus blocking DC, and *DC* allows **all** signals through (it does **not** prevent AC).

5. Set the channel one Vertical Scale to 5 volts per division. Set the channel two Scale to 2 volts per division. Set the Time (Horizontal) Scale to 1 millisecond per division. Finally, set the input Coupling to DC for both input channels and align the blue and yellow display lines to the center line of the display via the Vertical Position knob (note that pushing the vertical Position knobs will automatically center the trace).

6. Build the circuit of figure 3A.2 using E=10 V, R1=10 kΩ and R2= 33kΩ. Connect a probe from the channel one input to the power supply (red or tip to the positive terminal, black clip to ground). Connect a second probe from channel two to R2 (again, red or tip to the high side of the resistor and the black clip to ground).

7. The yellow and blue lines should have deflected upward. Channel one should be raised two divisions (2 divisions at 5 volts per division yields the 10 volt source). Using this method, determine the voltage across R2 (remember, input two should have been set for 2 volts per division). Calculate the expected voltage across R2 using measured resistor values and compare the two in Table 3A.1. Note that it is not possible to achieve extremely high precision using this method (e.g., four or more digits). Indeed, a DMM is often more useful for direct measurement of DC potentials. Double check the results using a DMM and the final column of Table 3A.1.

8. Select AC Coupling for the two inputs. The flat DC lines should drop back to zero. This is because AC Coupling blocks DC. This will be useful for measuring the AC component of a combined AC/DC signal, such as might be seen in an audio amplifier. Set the input coupling for both channels back to DC.

9. Replace the DC power supply with the function generator. Set the function generator for a one volt peak sine wave at 1 kHz and apply it to the resistor network. The display should now show two small sine waves. Adjust the Vertical Scale settings for the two inputs so that the waves take up the majority of the display. If the display is very blurry with the sine waves appearing to jump about side to side, the Trigger Level may need to be adjusted. Also, adjust the Time Scale so that only one or two cycles of the wave may be seen. Using the Scale settings, determine the two voltages (following the method of step 7) as well as the waveform's period and compare them to the values expected via theory, recording the results in Tables 3A.2 and 3A.3. Also crosscheck the results using a DMM to measure the RMS voltages.

10. To find the voltage across R1, the channel two voltage (V_{R2}) may be subtracted from channel one (E source) via the *Math* function. Use the red button to select the *Math* function and create the appropriate expression from the menu (ch1 – ch2). This display shows up in red. To remove a waveform, press its button again. Remove the math waveform before proceeding to the next step.

11. One of the more useful aspects of the oscilloscope is the ability to show the actual waveshape. This may be used, for example, as a means of determining distortion in an amplifier. Change the waveshape on the function generator to a square wave, triangle, or other shape and note how the oscilloscope responds. Note that the oscilloscope will also show a DC component, if any, as the AC signal being offset or "riding on the DC". Adjust the function generator to add a DC offset to the signal and note how the oscilloscope display shifts. Return the function generator back to a sine wave and remove any DC offset.

12. It is often useful to take precise differential measurement on a waveform. For this, the bars or cursors are useful. Select the *Cursors* button toward the top of the oscilloscope. From the menu on the display, select *Vertical Bars*. Two vertical bars will appear on the display (it is possible that one or both could be positioned off the main display). They may be moved left and right via the Multipurpose knobs (next to the Cursors button). The *Select* button toggles between independent and tandem cursor movement. A read out of the bar values will appear in the upper portion of the display. They indicate the positions of the cursors, i.e., the location where they cross the waveform. Vertical Bars are very useful for obtaining time information as well as amplitudes at specific points along the wave. A similar function is the Horizontal Bars which are particularly useful for determining amplitudes. Try the Horizontal Bars by selecting them via the Cursors menu again (holding the *Cursors* button will bring up the menu).

13. For some waveform parameters, automatic readings are available. These are accessed via the *Measure* button. Press *Measure*, select *Add Measurement*, and page through the various options using the Multipurpose b knob. Select *Frequency*. Note that a small readout of the frequency will now appear on the display. Multiple measurements are possible simultaneously. **Important:** There are specific limits on the proper usage of these measurements. If the guidelines are not followed, erroneous values may result. **Always** perform an approximation via the Scale factor and divisions method even when using an automatic measurement!

14. Finally, a snap-shot of the screen may be saved for future work using the USB port and a USB memory stick via the *Save Menu* button. The pop up menu has options for saving the image as well as the trace data or setup info. Select *Save Screen Image* to save a bit mapped graphics file that can be used as is or processed further in a graphics program (for example, inverting the colors for printing). The .PNG format is recommended.

Data Tables

V_{R2}	Scale (V/Div)	Number of Divisions	Voltage Scope	Voltage DMM
Oscilloscope				
Theory	X	X		

Table 3.1

	Scale (V/Div)	Number of Divisions	Voltage Peak	Voltage RMS
E Oscilloscope				
E Theory	X	X		
V_{R2} Oscilloscope				
V_{R2} Theory	X	X		

Table 3A.2

	Scale (S/Div)	Number of Divisions	Period	Frequency
E Oscilloscope				
E Theory	X	X		

Table 3A.3

2

Capacitive Reactance

Objective

Capacitive reactance will be examined in this exercise. In particular, its relationship to capacitance and frequency will be investigated, including a plot of capacitive reactance versus frequency.

Theory Overview

The current – voltage characteristic of a capacitor is unlike that of typical resistors. While resistors show a constant resistance value over a wide range of frequencies, the equivalent ohmic value for a capacitor, known as *capacitive reactance*, is inversely proportional to frequency. The capacitive reactance may be computed via the formula:

$$X_c = -j\frac{1}{2\pi fC}$$

The magnitude of capacitive reactance may be determined experimentally by feeding a capacitor a known current, measuring the resulting voltage, and dividing the two, following Ohm's law. This process may be repeated a across a range of frequencies in order to obtain a plot of capacitive reactance versus frequency. An AC current source may be approximated by placing a large resistance in series with an AC voltage, the resistance being considerably larger than the maximum reactance expected.

Equipment

(1) AC function generator model:________________ srn:__________________
(1) Oscilloscope model:________________ srn:__________________

Components

(1) 1 μF actual:__________________
(1) 2.2 μF actual:__________________
(1) 10 kΩ actual:__________________

Schematics

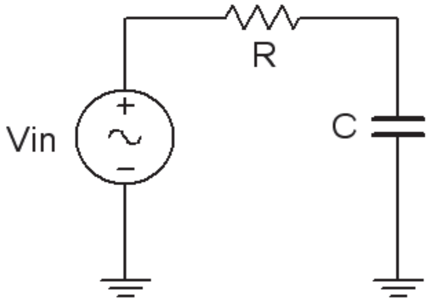

Figure 4.1

Procedure

Current Source

1. Using figure 4.1 with Vin=10 V p-p and R=10 kΩ, and assuming that the reactance of the capacitor is much smaller than 10k and can be ignored, determine the circulating current using measured component values and record in Table 4.1.

Measuring Reactance

2. Build the circuit of figure 4.1 using R=10 kΩ, and C=1 μF. Place one probe across the generator and another across the capacitor. Set the generator to a 200 Hz sine wave and 10 V p-p. Make sure that the *Bandwidth Limit* of the oscilloscope is engaged for both channels. This will reduce the signal noise and make for more accurate readings.

3. Calculate the theoretical value of Xc using the measured capacitor value and record in Table 4.2.

4. Record the peak-to-peak capacitor voltage and record in Table 4.2.

5. Using the source current from Table 4.1 and the measured capacitor voltage, determine the experimental reactance and record it in Table 4.2. Also compute and record the deviation.

6. Repeat steps three through five for the remaining frequencies of Table 4.2.

7. Replace the 1 μF capacitor with the 2.2 μF unit and repeat steps two through six, recording results in Table 4.3.

8. Using the data of Tables 4.2 and 4.3, create plots of capacitive reactance versus frequency.

Data Tables

$i_{\text{source (p-p)}}$	

Table 4.1

Frequency	X_C Theory	$V_{C(p-p)}$ Exp	X_C Exp	% Dev
200				
400				
600				
800				
1.0 k				
1.2 k				
1.6 k				
2.0 k				

Table 4.2

Frequency	X_C Theory	$V_{C(p\text{-}p)}$ Exp	X_C Exp	% Dev
200				
400				
600				
800				
1.0 k				
1.2 k				
1.6 k				
2.0 k				

Table 4.3

Questions

1. What is the relationship between capacitive reactance and frequency?

2. What is the relationship between capacitive reactance and capacitance?

3. If the experiment had been repeated with frequencies 10 times higher than those in Table 4.2, what would the resulting plots look like?

4. If the experiment had been repeated with frequencies 10 times lower than those in Table 4.2, what effect would that have on the experiment?

3

Inductive Reactance

Objective

Inductive reactance will be examined in this exercise. In particular, its relationship to inductance and frequency will be investigated, including a plot of inductive reactance versus frequency.

Theory Overview

The current – voltage characteristic of an inductor is unlike that of typical resistors. While resistors show a constant resistance value over a wide range of frequencies, the equivalent ohmic value for an inductor, known as *inductive reactance*, is directly proportional to frequency. The inductive reactance may be computed via the formula:

$$X_L = j2\pi fL$$

The magnitude of inductive reactance may be determined experimentally by feeding an inductor a known current, measuring the resulting voltage, and dividing the two, following Ohm's law. This process may be repeated a across a range of frequencies in order to obtain a plot of inductive reactance versus frequency. An AC current source may be approximated by placing a large resistance in series with an AC voltage, the resistance being considerably larger than the maximum reactance expected.

Equipment

(1) AC function generator model:________________ srn:__________________
(1) Oscilloscope model:________________ srn:__________________
(1) DMM model:________________ srn:__________________

Components

(1) 1 mH actual:__________________
(1) 10 mH actual:__________________
(1) 10 kΩ actual:__________________

Schematics

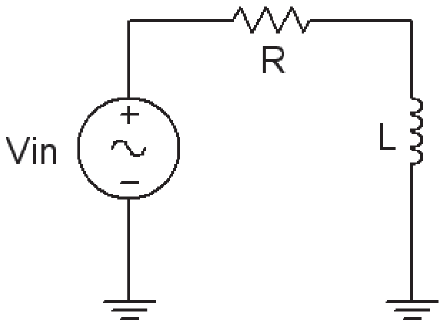

Figure 5.1

Procedure

Current Source

1. Using figure 5.1 with Vin=10 V p-p and R=10 kΩ, and assuming that the reactance of the inductor is much smaller than 10k and can be ignored, determine the circulating current using measured component values and record in Table 5.1. Also, measure the DC coil resistances of the inductors using an ohmmeter or DMM and record in Table 5.1.

Measuring Reactance

2. Build the circuit of figure 5.1 using R=10 kΩ, and L=10 mH. Place one probe across the generator and another across the inductor. Set the generator to a 1000 Hz sine wave and 10 V p-p. Make sure that the *Bandwidth Limit* of the oscilloscope is engaged for both channels. This will reduce the signal noise and make for more accurate readings.

3. Calculate the theoretical value of X_L using the measured inductor value and record in Table 5.2.

4. Record the peak-to-peak inductor voltage and record in Table 5.2.

5. Using the source current from Table 5.1 and the measured inductor voltage, determine the experimental reactance and record it in Table 5.2. Also compute and record the deviation.

6. Repeat steps three through five for the remaining frequencies of Table 5.2.

7. Replace the 10 mH inductor with the 1 mH unit and repeat steps two through six, recording results in Table 5.3.

8. Using the data of Tables 5.2 and 5.3, create plots of inductive reactance versus frequency.

Data Tables

$i_{source(p-p)}$	
R_{coil} of 10 mH	
R_{coil} of 1 mH	

Table 5.1

Frequency	X_L Theory	$V_{L(p-p)}$ Exp	X_L Exp	% Dev
1 k				
2 k				
3 k				
4 k				
5 k				
6 k				
8 k				
10 k				

Table 5.2

Frequency	X_L Theory	$V_{L(p-p)}$ Exp	X_L Exp	% Dev
10 k				
20 k				
30 k				
40 k				
50 k				
60 k				
80 k				
100 k				

Table 5.3

Questions

1. What is the relationship between inductive reactance and frequency?

2. What is the relationship between inductive reactance and inductance?

3. If the 10 mH trial had been repeated with frequencies 10 times higher than those in Table 5.2, what effect would that have on the experiment?

4. Do the coil resistances have any effect on the plots?

4

Series R, L, C Circuits

Objective

This exercise examines the voltage and current relationships in series R, L, C networks. Of particular importance is the phase of the various components and how Kirchhoff's voltage law is extended for AC circuits. Both time domain and phasor plots of the voltages are generated.

Theory Overview

Each element has a unique phase response: for resistors, the voltage is always in phase with the current, for capacitors the voltage always lags the current by 90 degrees, and for inductors the voltage always leads the current by 90 degrees. Consequently, a series combination of R, L, and C components will yield a complex impedance with a phase angle between +90 and -90 degrees. Due to the phase response, Kirchhoff's voltage law must be computed using vector (phasor) sums rather than simply relying on the magnitudes. Indeed, all computations of this nature, such as a voltage divider, must be computed using vectors.

Equipment

(1) AC function generator model:________________ srn:__________________
(1) Oscilloscope model:________________ srn:__________________

Components

(1) 10 nF actual:__________________
(1) 10 mH actual:__________________
(1) 1 kΩ actual:__________________

Schematics

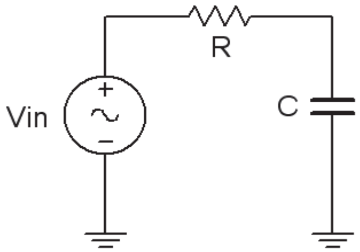

Figure 6.1

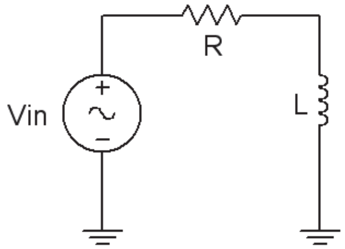

Figure 6.2

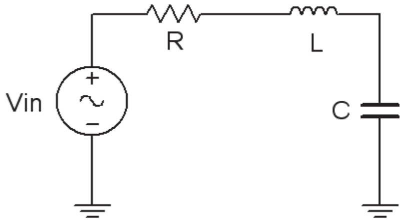

Figure 6.3

Procedure

RC Circuit

15. Using Figure 6.1 with Vin=2 V p-p sine at 10 kHz, R=1 kΩ, and C=10 nF, determine the theoretical capacitive reactance and circuit impedance, and record the results in Table 6.1 (the experimental portion of this table will be filled out in step 5). Using the voltage divider rule, compute the resistor and capacitor voltages and record them in Table 6.2.

16. Build the circuit of Figure 6.1 using R=1 kΩ, and C=10 nF. Place one probe across the generator and another across the capacitor. Set the generator to a 10 kHz sine wave and 2 V p-p. Make sure that the *Bandwidth Limit* of the oscilloscope is engaged for both channels. This will reduce the signal noise and make for more accurate readings. Also, consider using *Averaging* for the acquisition mode, particularly to clean up signals derived using the *Math* function.

17. Measure the peak-to-peak voltage across the capacitor and record in Table 6.2. Along with the magnitude, be sure to record the time deviation between V_C and the input signal (from which the phase may be determined). Using the *Math* function, measure and record the voltage and time delay for the resistor ($V_{in} - V_C$). Compute the phase angle and record these values in Table 6.2.

18. Take a snapshot of the oscilloscope displaying V_{in}, V_C, and V_R.

19. Compute the deviations between the theoretical and experimental values of Table 6.2 and record the results in the final columns of Table 6.2. Based on the experimental values, determine the experimental Z and X_C values via Ohm's law ($i=V_R/R$, $X_C=V_C/i$, $Z=V_{in}/i$) and record back in Table 6.1 along with the deviations.

20. Create a phasor plot showing V_{in}, V_C, and V_R. Include both the time domain display from step 4 and the phasor plot with the technical report.

RL Circuit

21. Replace the capacitor with the 10 mH inductor (i.e. Figure 6A.2), and repeat steps 1 through 6 in like manner, using Tables 6.3 and 6.4.

RLC Circuit

22. Using Figure 6.3 with both the 10 nF capacitor and 10 mH inductor, repeat steps 1 through 6 in similar manner, using Tables 6.5 and 6.6. **Using a four channel oscilloscope:** To obtain proper readings, place the first probe at the input, the second probe between the resistor and inductor, and the third probe between the inductor and capacitor. Probe three yields V_C. Using the *Math* function, probe two minus probe three yields V_L, and finally, probe one minus probe two yields V_R. Assigning *Reference* waveforms can be useful to see all of the signals together. **Using a two channel oscilloscope:** Unfortunately, it will be impossible to see the voltage of all three components simultaneously with the source voltage using a two channel oscilloscope. To obtain proper readings, place the first probe at the input and the second probe across the capacitor in order to see the phase and magnitude of V_C. Then, swap C and L (placing the second probe across the inductor) to see V_L, and finally, swap L and R (with the second probe across R) in order see V_R.

Data Tables

RC Circuit

	Theory	Experimental	% Deviation
X_C			
Z Magnitude			
Z θ			

Table 6.1

	Theory Mag	Theory θ	Exp Mag	Exp Delay	Exp θ	% Dev Mag	% Dev θ
V_C							
V_R							

Table 6.2

RL Circuit

	Theory	Experimental	% Deviation
X_L			
Z Magnitude			
Z θ			

Table 6.3

	Theory Mag	Theory θ	Exp Mag	Exp Delay	Exp θ	% Dev Mag	% Dev θ
V_L							
V_R							

Table 6.4

RLC Circuit

	Theory	Experimental	% Deviation
X_C			
X_L			
Z Magnitude			
Z θ			

Table 6.5

	Theory Mag	Theory θ	Exp Mag	Exp Delay	Exp θ	% Dev Mag	% Dev θ
V_C							
V_L							
V_R							

Table 6.6

Questions

1. What is the phase relationship between R, L, and C components in a series AC circuit?

2. Based on measurements, does Kirchhoff's voltage law apply to the three tested circuits (show work)?

3. In general, how would the phasor diagram of Figure 6.1 change if the frequency was raised?

4. In general, how would the phasor diagram of Figure 6.2 change if the frequency was lowered?

5

AC Superposition

Objective

This exercise examines the analysis of multi-source AC circuits using the superposition theorem. In particular, sources with differing frequencies will be used to illustrate the contributions of each source to the combined result.

Theory Overview

The superposition theorem can be used to analyze multi-source AC linear bilateral networks. Each source is considered in turn, with the remaining sources replaced by their internal impedance, and appropriate series-parallel analysis techniques employed. The resulting signals are then summed to produce the combined output signal. To see this process more clearly, the exercise will utilize two sources operating at different frequencies. Note that as each source has a different frequency, the inductor and capacitor appear as different reactances to the two sources.

Equipment

(2) AC function generators model:________________ srn:__________________
model:________________ srn:__________________
(1) Oscilloscope model:________________ srn:__________________

Components

(1) 100 nF actual:__________________
(1) 10 mH actual:__________________
(1) 1k Ω actual:__________________
(1) 50 Ω actual:__________________

Schematics

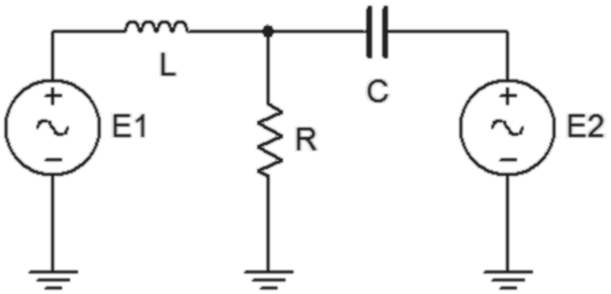

Figure 10.1

Procedure

1. Typical function generators have a 50 Ω internal impedance. These are not shown in the circuit of Figure 10.1. To test the superposition theorem, sources *E1* and *E2* will be examined separately and then together.

Source One Only

2. Consider the circuit of Figure 10.1 with C=100 nF, L=10 mH, R=1 kΩ, using only source *E1*=2 V p-p at 1 kHz and with source *E2* replaced by its internal impedance of 50 Ω. Using standard series-parallel techniques, calculate the voltages across *E1*, R, and *E2*. Remember to include the 50 Ω internal impedances in the calculations. Record the results in Table 10.1.

3. Build the circuit of Figure 10.1 using C=100 nF, L=10 mH, and R=1 kΩ. Replace *E2* with a 50 Ω resistor to represent its internal impedance. Set *E1* to 2 V p-p at 1 kHz, unloaded. Make sure that the *Bandwidth Limit* of the oscilloscope is engaged for both channels. This will reduce the signal noise and make for more accurate readings. Place probe one across *E1* and probe two across R. Measure the voltages across *E1* and R, and record in Table 10.1. Record a copy of the scope image. Move probe two across *E2* (the 50 Ω), measure and record this voltage in Table 10.1.

Source Two Only

4. Consider the circuit of Figure 10.1 using only source *E2*=2 V p-p at 10 kHz and with source *E1* replaced by its internal impedance of 50 Ω. Using standard series-parallel techniques, calculate the

voltages across *E1*, R, and *E2*. Remember to include the 50 Ω internal impedances in the calculations. Record the results in Table 10.2.

5. Replace the 50 Ω with source *E2* and set it to 2 V p-p at 10 kHz, unloaded. Replace *E1* with a 50 Ω resistor to represent its internal impedance. Place probe one across *E2* and probe two across R. Measure the voltages across *E2* and R, and record in Table 10.2. Record a copy of the scope image. Move probe two across *E1* (the 50 Ω), measure and record this voltage in Table 10.2.

Sources One and Two

6. Consider the circuit of Figure 10.1 using both sources, *E1*=2 V p-p at 1 kHz and *E2*=2 V p-p at 10 kHz. Add the calculated voltages across *E1*, R, and *E2* from Tables 10.1 and 10.2. Record the results in Table 10.3. Make a note of the expected maxima and minima of these waves and sketch how the combination should appear on the scope

7. Replace the 50 Ω with source *E1* and set it to 2 V p-p at 1 kHz, unloaded. **Both sources should now be active.** Place probe one across *E1* and probe two across R. Measure the voltages across *E1* and R, and record in Table 10.3. Record a copy of the scope image. Move probe two across *E2*, measure and record this voltage in Table 10.3.

Computer Simulation

8. Build the circuit of Figure 10.1 in a simulator. Using Transient Analysis, determine the voltage across the resistor and compare it to the theoretical and measured values recorded in Table 10.3. Be sure to include the 50 Ω source resistances in the simulation.

Data Tables

Source One Only

	Theory	Experimental	% Deviation
E_1			
E_2			
V_R			

Table 10.1

Source Two Only

	Theory	Experimental	% Deviation
E_1			
E_2			
V_R			

Table 10.2

Sources One and Two

	Theory	Experimental	% Deviation
E_1			
E_2			
V_R			

Table 10.3

Questions

1. Why must the sources be replaced with a 50 Ω resistor instead of being shorted?

2. Do the expected maxima and minima from step 6 match what is measured in step 7?

3. Does one source tend to dominate the 1 kΩ resistor voltage or do both sources contribute in nearly equal amounts? Will this always be the case?

6

AC Thevenin's Theorem

Objective

Thevenin's theorem will be examined for the AC case. The Thevenin source voltage and Thevenin impedance will be determined experimentally and compared to theory. Loads will be examined when driven by both an arbitrary circuit and that circuit's Thevenin equivalent to determine if the resulting load potentials are indeed identical. Both resistive and complex loads will be examined as well as well source impedances that are inductive or capacitive.

Theory Overview

Thevenin's theorem states that any linear single port (i.e., two terminals) network can be replaced by a single voltage source with series impedance. While the theorem is applicable to any number of voltage and current sources, this exercise will only examine single source circuits for the sake of simplicity. The Thevenin voltage is the open circuit output voltage. This may be determined experimentally by isolating the portion to be Thevenized and simply placing an oscilloscope at its output terminals. The Thevenin impedance is found by replacing all sources with their internal impedance and then applying appropriate series-parallel impedance simplification rules. If an impedance meter is available, an easy method of doing this in the lab is to replace the sources with appropriate impedance values and apply the impedance meter to the output terminals of the circuit portion under investigation.

Equipment

(1) AC function generator model:________________ srn:__________________
(1) Oscilloscope model:________________ srn:__________________
(1) Variable frequency impedance meter model:________________ srn:__________________
(1) Decade resistance box model:________________ srn:__________________

Components

(1) 100 nF actual:__________________
(1) 470 nF actual:__________________
(1) 10 mH actual:__________________
(1) 50 Ω actual:__________________

(1) 1.0 kΩ actual:__________________
(1) 1.5 kΩ actual:__________________
(1) 2.2 kΩ actual:__________________

Schematics

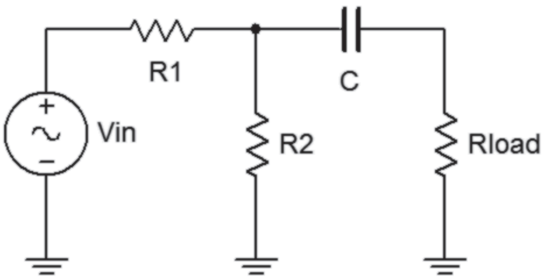

Figure 11.1

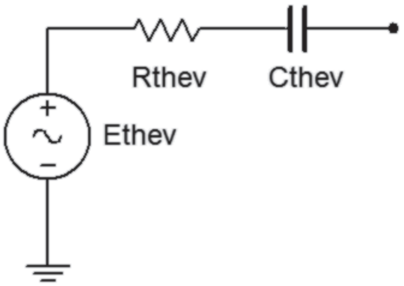

Figure 11.2

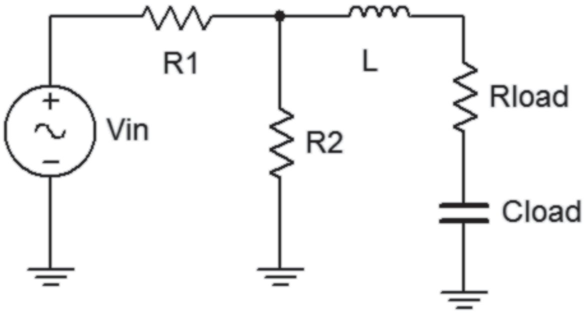

Figure 11.3

Procedure

1. For the circuit of figure 11.1, calculate the voltage across the 1 kΩ load using R1=1.5 kΩ, R2=2.2 kΩ, and C=470 nF, with a 2 V p-p 1 kHz source. Record this value in Table 11.1. Also calculate the expected Thevenin voltage and Thevenin impedance. Record these values in Table 11.2.

2. Build the circuit of figure 11.1 using R1=1.5 kΩ, R2=2.2 kΩ, Rload=1 kΩ and C=470 nF. Set the generator to a 1 kHz sine wave at 2 V p-p. Make sure that the *Bandwidth Limit* of the oscilloscope is engaged. This will reduce the signal noise and make for more accurate readings. Measure the load voltage and record in Table 11.1 as V_{Load} Original.

3. Remove the load and measure the unloaded output voltage. This is the experimental Thevenin voltage. Record it in Table 11.2.

4. Replace the voltage source with a 50 Ω resistor to represent its internal impedance. Set the impedance meter to 1 kHz and measure the resulting impedance at the open load terminals. This is the experimental Thevenin impedance. Record these values in Table 11.2 and compare with the theoretical values.

5. Using the decade resistance box and capacitor, build the Thevenin equivalent circuit of figure 11.2 and apply the 1 kΩ load resistor. Measure the load voltage and record in Table 11.1. Compare with the values of the original (non-Thevenized) circuit and determine the deviation between the original and Thevenized circuits.

6. To verify that Thevenin's theorem also works with an inductive source and a complex load, repeat steps 1 through 5 in like manner but using figure 11.3 with R1=1.5 kΩ, R2=2.2 kΩ, L=10 mH, Rload=1 kΩ with Cload=100 nF. Set the generator to a 10 kHz sine wave at 2 V p-p. Record results in Tables 11.3 and 11.4.

Data Tables

V_{load} Theory	
V_{load} Original	
V_{load} Thevenin	
% Deviation	

Table 11.1

	Theory	Experimental	% Deviation
$E_{Thevenin}$			
$Z_{Thevenin}$			

Table 11.2

V_{load} Theory	
V_{load} Original	
V_{load} Thevenin	
% Deviation	

Table 11.3

	Theory	Experimental	% Deviation
E_{Thevenin}			
Z_{Thevenin}			

Table 11.4

Questions

1. How does the AC version of Thevenin's theorem compare with the DC version?

2. Would the Thevenin equivalent circuits be altered if the source frequency was changed? If so, why?

3. Based on the results of this exercise, would you expect Norton's theorem for AC to behave similarly to its DC case?

7

AC Maximum Power Transfer

Objective

In this exercise, maximum power transfer to the load will be examined for the AC case. Both the load's resistive and reactive components will be independently varied to discover their effect of load power and determine the values required for maximum load power.

Theory Overview

In the DC case, maximum power transfer is achieved by setting the load resistance equal to the source's internal resistance. This is not true for the AC case. Instead, the load should be set to complex conjugate of the source impedance, the complex conjugate having the same magnitude as the original but with the opposite sign for the angle. By using the complex conjugate, the load and source reactive components will cancel out leaving a purely resistive circuit similar to the DC case. When calculating the true load power, care must be taken to remember that the load voltage appears across a complex load impedance. Only the real portion of this voltage appears across the resistive component, and only the resistive component dissipates power.

Equipment

(1) AC function generator model:_________________ srn:___________________
(1) Oscilloscope model:_________________ srn:___________________
(1) Decade resistance box model:_________________ srn:___________________
(1) Impedance meter model:_________________ srn:___________________

Components

(1) 10 mH actual:___________________
(1) 1k Ω actual:___________________
(1) 50 Ω actual:___________________
(1) 100 nF actual:___________________
(1) 47 nF actual:___________________
(1) 33 nF actual:___________________
(1) 22 nF actual:___________________
(1) 10 nF actual:___________________

Assorted capacitors in the 1 nF region

Schematics

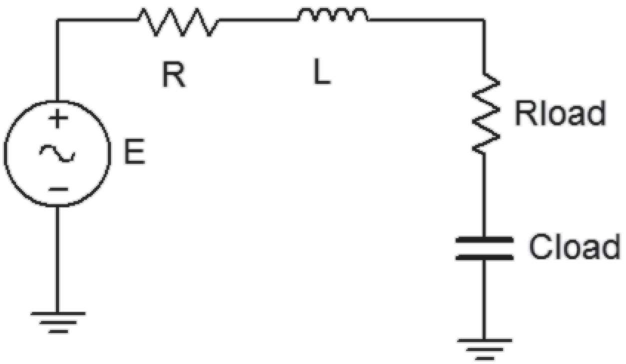

Figure 12.1

Procedure

1. Build the circuit of figure 12.1 using R=1 kΩ and L= 10 mH, but leaving off the load components. Replace the generator with a 50 Ω resistor and determine the effective source impedance at 10 kHz using the impedance meter. Record this value in Table 12.1, including both magnitude and phase. Determine the load impedance which should achieve maximum power transfer according to the theorem and record in Table 12.1. Finally, determine values for R_{load} and C_{load} to achieve this load impedance and record in Table 12.1, also copying the resistance value to the first R_{load} entry of Table 12.2.

Testing R_{load}

2. Replace the 50 Ω resistor with the generator. Insert the decade resistance box in the position of R_{load} and set it to the value calculated in Table 12.1. For C_{load}, use the value calculated in Table 12.1. Use multiple capacitors if necessary to achieve a close value. Set the generator to 10 volts peak at 10 kHz, making sure that the amplitude is measured on the oscilloscope with the generator loaded by the circuit. Make sure that the *Bandwidth Limit* of the oscilloscope is engaged for the channel. This will reduce the signal noise and make for more accurate readings.

3. Measure the magnitude of the load voltage and record in Table 12.2. Also compute the expected load voltage from theory and the load power based on the measured load voltage and record in Table 12.2. Repeat these measurements and calculations for the remaining load resistance values in the table.

Testing C_{load}

4. Return the decade box to the value calculated in Table 12.1. For C_{load}, insert the first capacitor listed in Table 12.3. Repeat step four for each load capacitance in Table 12.3, calculating and recording the required results using Table 12.3.

5. Generate a plot of P_{load} with respect to R_{load} and another of P_{load} with respect to C_{load}.

Data Tables

Z_{source}	
Z_{load}	
R_{load}	
C_{load}	

Table 12.1

Variable R_{load}

R_{load}	V_{load} Theory	V_{load} Exp	P_{load} Exp
100			
400			
600			
800			
1.2 k			
1.8 k			
3 k			
10 k			

Table 12.2

Variable C_{load}

C_{load}	V_{load} Theory	V_{load} Exp	P_{load} Exp
1 nF			
3.3 nF			
10 nF			
33 nF			
47 nF			
100 nF			

Table 12.3

Questions

1. In general, given a certain source impedance, what load impedance will achieve maximum load power?

2. Will achieving maximum load power also achieve maximum efficiency? Explain.

3. If the experiment was repeated using a frequency of 5 kHz, how would the graphs change, if at all?

8

Series Resonance

Objective

This exercise investigates the voltage relationships in a series resonant circuit. Of primary importance are the establishment of the resonant frequency and the quality factor, or Q, of the circuit with relation to the values of the R, L, and C components.

Theory Overview

A series resonant circuit consists of a resistor, a capacitor, and an inductor in a simple loop. At some frequency the capacitive and inductive reactances will be of the same magnitude, and as they are 180 degrees in opposition, they effectively nullify each other. This leaves the circuit purely resistive, the source "seeing" only the resistive element. Consequently, the current will be at a maximum at the resonant frequency. At any higher or lower frequency, a net reactance (the difference between X_L and X_C) must be added to the resistor value, producing a higher impedance and thus, a lower current. As this is a simple series loop, the resistor's voltage will be proportional to the current. Consequently, the resistor voltage should be a maximum at the resonant frequency and decrease as the frequency is either increased or decreased. At resonance, the resistor value sets the maximal current and consequently has a major effect on the voltages developed across the capacitor and inductor as well as the "tightness" of the voltage versus frequency curve: The smaller the resistance, the tighter the curve and the higher the voltage seen across the capacitor and inductor. The Q of the circuit can be defined as the ratio of the resonant reactance to the circuit resistance, $Q=X/R$, which also corresponds to the ratio of the resonant frequency to the circuit bandwidth, $Q=F_0/BW$.

Equipment

(1) AC function generator model:________________ srn:__________________
(1) Oscilloscope model:________________ srn:__________________

Components

(1) 10 nF actual:__________________
(1) 10 mH actual:__________________

(1) 47 Ω actual:__________________
(1) 470 Ω actual:__________________

Schematics

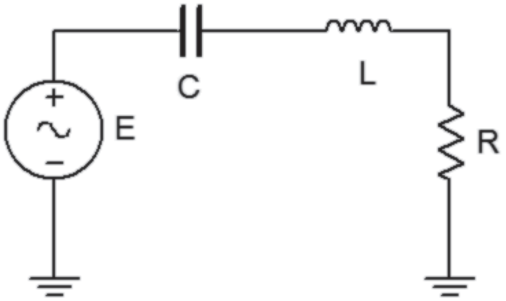

Figure 13.1

Procedure

Low Q Circuit

1. Using Figure 13.1 with R=470 Ω, L= 10 mH, and C=10 nF, determine the theoretical resonance frequency and Q, and record the results in Table 13.1. Based on these values determine the upper and lower frequencies defining the bandwidth, f_1 and f_2, and record them in Table 13.1.

2. Build the circuit of Figure 13.1 using R=470 Ω, L=10 mH and C=10 nF. Place a probe across the resistor. Set the output of the generator to a 1 V p-p sine wave. Set the frequency to the theoretical resonance frequency of Table 13.1. Make sure that the *Bandwidth Limit* of the oscilloscope is engaged for both channels. This will reduce the signal noise and make for more accurate readings.

3. Adjust the frequency in small amounts, up and down, until the maximum voltage is found. This is the experimental resonance frequency. Record it in Table 13.1. Note the amplitude (it should be approximately equal to the source voltage of 1 V p-p). Sweep the frequency above and below the resonance frequency until the experimental f_1 and f_2 are found. These will occur at a voltage amplitude of approximately 0.707 times the resonant voltage (i.e., the half-power points). Record these frequencies in Table 13.1. Also, determine and record the experimental Q based on the experimental f_0, f_1, and f_2.

4. Transcribe the experimental frequencies of Table 13.1 to the top three entries of Table 13.2. For all of the frequencies in Table 13.2, measure and record the voltage across the resistor. Also measure and record the inductor and capacitor voltages. Note that the inductor and capacitor will have to be swapped with the resistor position in order to maintain proper ground reference with the oscilloscope.

5. Based on the data from Table 13.2, plot V_R, V_C, and V_L as a function of frequency.

6. Change R to 47Ω and repeat steps 1 through 5 but using Tables 13.3 and 13.4 for high Q.

Computer Simulation

7. Build the circuit of Figure 13.1 in a simulator. Using AC Analysis, plot the voltage across the resistor from 1 kHz to 100 kHz for both the high and low Q cases and compare them to the plots derived from Tables 13.2 and 13.4. Be sure to include the 50 Ω source resistance and coil resistance in the simulation.

Data Tables

Low Q Circuit

	Theory	Experimental	% Deviation
f_o			
Q			
f_1			
f_2			

Table 13.1

Frequency	V_R	V_C	V_L
f_0=			
f_1=			
f_2=			
1 kHz			
5 kHz			
8 kHz			
12 kHz			
20 kHz			
30 kHz			
50 kHz			
100 kHz			

Table 13.2

High Q Circuit

	Theory	Experimental	% Deviation
f_o			
Q			
f_1			
f_2			

Table 13.3

Frequency	V_R	V_C	V_L
f_0=			
f_1=			
f_2=			
1 kHz			
5 kHz			
8 kHz			
12 kHz			
20 kHz			
30 kHz			
50 kHz			
100 kHz			

Table 13.4

Questions

1. What is the effect of changing resistance on Q?

2. Are the V_C and V_L curves the same as the V_R curves? If not, why?

3. In practical terms, what sets the limit on how high Q may be?