INDUCTIVE REACTANCE IN AC

Objectives

You will connect several ac inductive circuits and make measurements and observations regarding their important electrical characteristics.

In completing these projects, you will connect circuits, make measurements, perform calculations, draw conclusions, and be able to answer questions about the following items related to inductive reactance:

- Relationship of L, induced voltage, and inductive reactance
- Relationship of frequency to inductive reactance
- The X_L formula
- Solving for L when X_L and frequency are known

Project/Topic Correlation Information

PROJECT	TEXT CHAPTER	SECTION	RELATED TEXT TOPIC(S)
41 Induced Voltage	13	13-2	Review of Faraday's and Lenz's Laws
		13-3	Self-Inductance
42 Relationship of X_L to L and Frequency	14	14-4	Relationship of X_L to Inductance Value
		14-5	Relationship of X_L to Frequency of AC

SPECIAL NOTE:

For this project, and all the following projects that require *setting* or *measuring* ac voltages (or currents), assume that the rms values are desired, unless specified otherwise.

Inductive Reactance in AC

Induced Voltage

PROJECT 41

Name: ______________________ Date: ____________

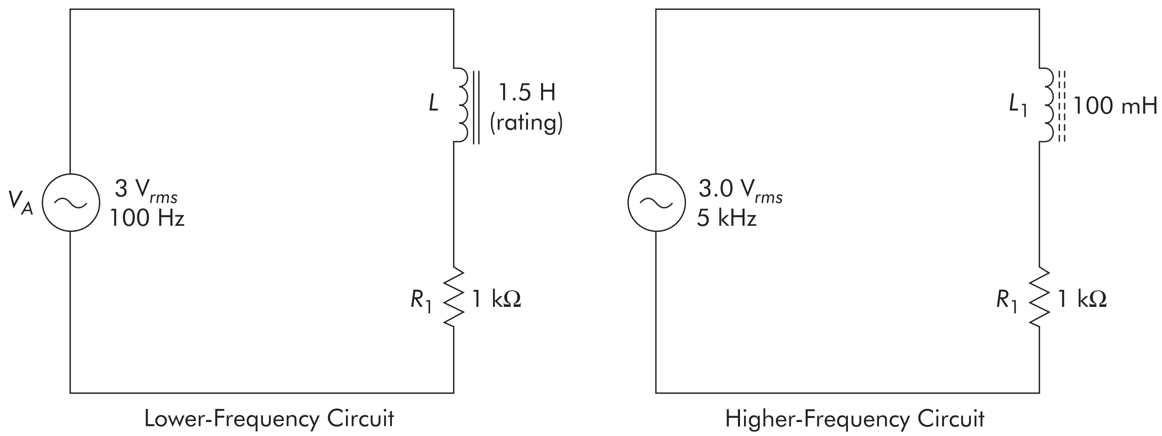


FIGURE 41-1

PROJECT PURPOSE To illustrate the circuit effects of inductor counter-emf by noting the difference in circuit current when dc is applied to the inductor circuit, and again when ac is applied.

PARTS NEEDED

- ☐ DMM
- ☐ VVPS (dc)
- ☐ Low voltage ac source (function generator, approximately 7 VAC)
- ☐ CIS
- ☐ Inductor, 1.5 H, 95 Ω (or approximate)
- ☐ 100 mH
- ☐ Resistor 1 kΩ

SPECIAL NOTE:

The methods used during this project are used to illustrate the concept of back emf and are not a precise scientific method of measuring or calculating exact values of back emf. Also remember that the ac equivalent of a given dc value is the "effective" (rms) value of ac.

PROCEDURE

1. Connect the initial circuit as shown in Figure 41-1.

2. Measure the ac voltage source that will be used for this demonstration. Next, connect the VVPS to the circuit and adjust the dc input V to a value that matches the ac voltage you will be using in a later step.

OBSERVATION ac source equals ____________________ V_{rms}.

dc source connected to circuit set to ____________________ V.

3. Measure V_1 (dc voltage across R_1) and calculate circuit dc current.

OBSERVATION (Using lower f circuit components) (Using higher f circuit components)

I (dc) = ______________________ mA. I (dc) = ______________________ mA.

CONCLUSION The circuit current is limited only by the dc resistance of R_1 and ________________.

4. Remove the dc source, connect the 3 V_{rms} ac source and measure V_1. Now calculate the circuit ac current.

OBSERVATION Lower f Higher f

I (ac) = ______________________ mA. I (ac) = ______________________ mA.

CONCLUSION The inductor developed a back emf that opposes the changing current. Discount the small dc resistance of the coil. The current that flowed with dc applied was equivalent to having a V_A of ____________ V across a circuit resistance of 1 kΩ. When the same value of ac voltage was applied to the circuit, a current flowed that would be equivalent to applying only _________ V across the circuit resistance. The effect simulated was as if there must be a back emf of approximately _________ V.

NOTE ➤ This disregards any R in the circuit and assumes that the total limiting effect on the current is due to back emf.

Inductive Reactance in AC

Relationship of X_L to L and Frequency

PROJECT 42

Name: ______________________________ Date: ______________

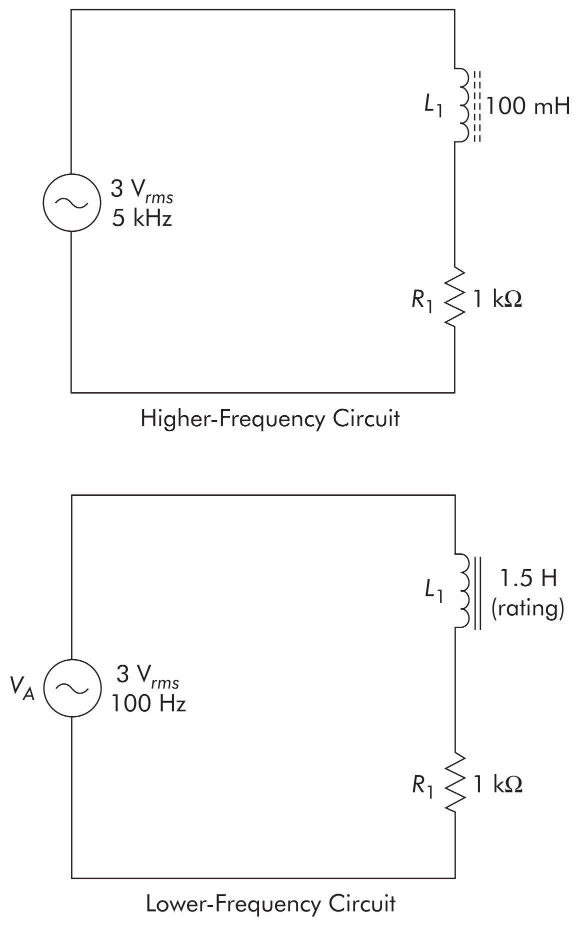


FIGURE 42-1

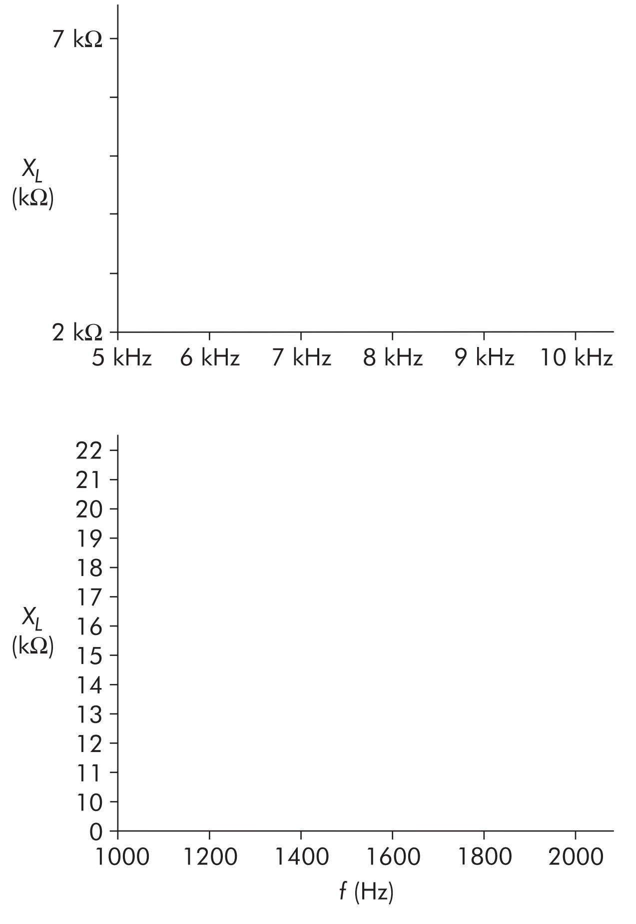


FIGURE 42-2 X_L versus f (sample graph coordinates)

NOTE If using a different value of L than shown, renumber the y-axis of the graph, as appropriate. Use separate graph paper for drawing these graphs.

PROJECT PURPOSE To observe the relationship of X_L to L by changing L_T, and to frequency by applying various frequencies to an inductor circuit, and by measuring the changing circuit parameters.

PARTS NEEDED

- ☐ DMM
- ☐ Function generator or audio oscillator
- ☐ CIS
- ☐ Inductor, 1.5 H, 95 Ω (2) (or approximate)
- ☐ 100 mH (2)
- ☐ Resistor 1 kΩ

SPECIAL REMINDER:

The inductors used in the lower-frequency circuit of this project, *and a number of projects following this one*, are iron-core, filter-choke-type inductors. Under normal operating conditions, this inductor has dc current as well as ac signal components present. The manufacturer has rated the inductance value based on the normal operating environment for this type of inductor. *Students and instructors* should be aware that this inductor will exhibit "apparent" inductance values quite different from the manufacturer's rating under the varying operating conditions in our projects. Because the inductor is used under different conditions from those specified by the manufacturer, such factors as "incremental permeability" enter into the results in terms of how much acting inductance the inductor appears to have. Also, the voltage dropped by the inductor is due to the inductor's impedance—not just its reactance. Add into this scenario the tolerances of component values, variances in calibration of signal sources, test equipment, and so on, and it is obvious that results will vary from those that would result if the inductor were acting at the rated value.

PROCEDURE

1. Connect the initial circuit as shown in Figure 42-1.

2. Set the function generator to a frequency of 100 Hz for the lower f circuit or to 5,000 Hz for the higher f circuit and set V_A from the source to 3 V. Measure V_1 and calculate the circuit current. Next, measure V_L and calculate X_L by Ohm's Law ($X_L = V_L/I$).

OBSERVATION

Lower f	Higher f
V_A = ______ V.	V_A = ______ V.
V_1 = ______ V.	V_1 = ______ V.
I = ______ mA.	I = ______ mA.
V_L = ______ V.	V_L = ______ V.
X_L = ______ Ω.	X_L = ______ Ω.

CONCLUSION Since this is a simple series circuit, the current through the inductor is the same as the current through the ______.

3. Insert a second inductor (the same type as L_1). You should now have a series circuit of L_1, L_2, and R_1. With the same frequency and V_A as step 2 above, measure V_1, calculate I, measure the voltage across the total inductance of L_1 and L_2, then calculate X_L total.

OBSERVATION

Lower f	Higher f
V_A = ______ V.	V_A = ______ V.
V_1 = ______ V.	V_1 = ______ V.
I = ______ mA.	I = ______ mA.
V_{L_T} = ______ V.	V_{L_T} = ______ V.
X_{L_T} = ______ Ω.	X_{L_T} = ______ Ω.

CONCLUSION Connecting a second inductor of nearly equal value as L_1 in series with L_2 caused the total inductance to approximately (*double, halve*) ________________. In analyzing the results of step 2 and comparing with this step, we conclude that doubling total inductance caused the total inductive reactance (X_L) to approximately (*double, halve*) ____________________. We therefore conclude that inductive reactance (X_L) is (*directly, inversely*) ____________________ proportional to inductance (L). Increasing L causes X_L to (*increase, decrease*) ____________________ at any given frequency.

4. Remove L_2 and replace with a jumper. For the lower f circuit, change the input frequency to 1,000 Hz and keep V_A at 3 volts. For the higher f circuit, change the input frequency to 10,000 Hz, keeping V_A at 3 volts. Measure V_1, calculate I, measure V_L, and calculate X_L.

OBSERVATION

Lower f	Higher f
V_A = ____________ V.	V_A = ____________ V.
V_1 = ____________ V.	V_1 = ____________ V.
I = ____________ mA.	I = ____________ mA.
V_{L_1} = ____________ V.	V_{L_1} = ____________ V.
X_L = ____________ Ω.	X_L = ____________ Ω.

CONCLUSION Increasing the frequency caused the inductive reactance (X_L) to (*increase, decrease*) ________________________. If this had been a perfect inductive circuit, would X_L have increased the same number of times as frequency was increased? ___________. We conclude that inductive reactance is (*inversely, directly*) ____________________ proportional to f (frequency). If the frequency were decreased to one-half its original value, then theoretically the X_L would (*increase, decrease*) ____________________ to (*double, one-half*) ____________________ its original value.

5. Make a graphic plot of X_L versus f from 1,000 Hz to 2,000 Hz for the lower f circuit or from 5,000 to 10,000 Hz for the higher f circuit. Use graph coordinates similar to those shown in Figure 42-2. Make graphs on separate graph paper.

NOTE ➤ Calculate X_L for each 200 Hz or each 1,000 Hz change, as appropriate. See optional steps 9 and 10 for an alternative approach.

OBSERVATION

Lower f	Higher f
X_L at 1,000 Hz = ____________	@ 5 kHz = ____________ kΩ.
X_L at 1,200 Hz = ____________	@ 6 kHz = ____________ kΩ.
X_L at 1,400 Hz = ____________	@ 7 kHz = ____________ kΩ.
X_L at 1,600 Hz = ____________	@ 8 kHz = ____________ kΩ.
X_L at 1,800 Hz = ____________	@ 9 kHz = ____________ kΩ.
X_L at 2,000 Hz = ____________	@ 10 kHz = ____________ kΩ.

CONCLUSION Did X_L act like it is directly related to f? ________.

Optional Steps

6. Use the appropriate version of the $X_L = 2\pi fL$ formula to find the apparent L of the inductor for the operating conditions used in step 2.

NOTE ➤ Use the X_L value found by Ohm's Law in step 2 when solving for L.

OBSERVATION

Lower f Calculated apparent	Higher f Calculated apparent
L = ____________________ H.	L = ____________________ mH.

CONCLUSION Is the calculated (apparent) inductance different from the manufacturer's rated value for this inductor? ________. What do you think the inductance value would appear to be if the inductor were operated under the conditions used by the manufacturer when rating the inductor? ________ H.

7. Use the appropriate version of the $X_L = 2\pi fL$ formula to find the apparent L_T of the series inductors for the operating conditions used in step 3.

NOTE ➤ Use the X_L value found by Ohm's Law in step 3 when solving for L_T.

OBSERVATION

Lower f Calculated apparent	Higher f Calculated apparent
L_T = ____________________ H.	L_T = ____________________ mH.

CONCLUSION Is the calculated (apparent) total inductance different from the manufacturer's rated value for these inductors? ________. What do you think the total inductance value would appear to be if the inductors were operated under the conditions used by the manufacturer when rating these inductors? ________ H.

8. Use the appropriate version of the $X_L = 2\pi fL$ formula to find the apparent L of the inductor for the operating conditions used in step 4.

NOTE ➤ Use the X_L value found by Ohm's Law in step 4 when solving for L.

OBSERVATION

Lower f Calculated apparent	Higher f Calculated apparent
L = ____________________ H.	L = ____________________ mH.

CONCLUSION Is the calculated (apparent) inductance different from the manufacturer's rated value for this inductor, in this case? _________. Is it different under step 4's operating conditions than it was for step 2? ________. If so, what might account for the difference?

____.

9. Use Excel (or another) spreadsheet and set up a chart similar to the one shown below for charting the data collected in step 5.

PROJECT: RELATIONSHIP OF X_L TO FREQUENCY (Data derived from Project 42, step 5 data)				
	A	B	C	D
1	**Frequency**	**Mfg Rated**	**Calc X_L**	**Calc X_L**
2	**Setting (Hz)**	***L* in H**	**X_L formula**	**From Measurements**
3	1st Freq (Hz)	*L* rating (H)	= 6.28*A3*B3	$= V_L/I$
4	2nd Freq (Hz)	*L* rating (H)	= 6.28*A4*B4	$= V_L/I$
5	(etc.)	(etc.)	(etc.)	(etc.)
6	(etc.)	(etc.)	(etc.)	(etc.)
7	(etc.)	(etc.)	(etc.)	(etc.)

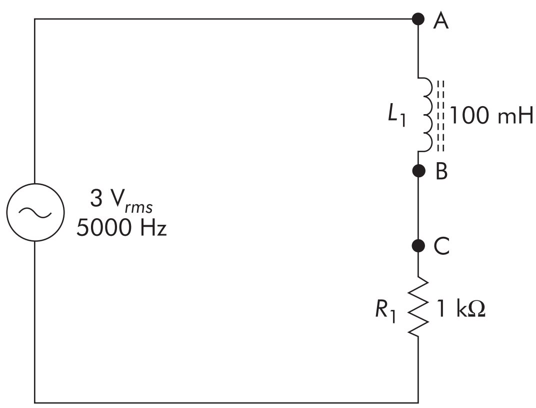
10. Use the spreadsheet chart graphing capability to create a line graph showing frequency as the x-axis and X_L as the y-axis data. Show a line graph for both the X_L formula results (column C) and the X_L from measurements results (column D) on the same graph. Appropriately label the graph using the titling and labeling capabilities of the spreadsheet program.

PART 10

Story Behind the Numbers

Inductive Reactance in AC

Name: ______________________________ Date: ______________



NOTE ➤ Prior to performing this project and the upcoming projects that will use inductors, be sure to read the **Special Notes to Students and Instructors** at the beginning of Part 9. For this project you will use the higher-frequency circuit option; therefore, pay attention to the cautions regarding DMM measuring limitations (frequency limits). If you are using a DMM, be sure it is rated to properly read voltages at the frequencies required in this project. If a scope is to be used, observe the critical ground connection precautions necessary to prevent shorting out components.

GENERAL INFORMATION In this project, you will first look at how inductance value affects circuit inductive reactance. Then, you will change circuit source frequency over a range of frequencies to see how frequency affects inductive reactance for a given circuit setup.

Procedure

1. Connect the initial circuit as shown.
2. With 3 volts applied voltage and the signal source set at 5,000 Hz, measure V_{R_1} and calculate the circuit current. Record this data in the appropriate locations on the Data Table.
3. Measure V_L and calculate X_L, using Ohm's Law (V_L/I). Record this value on the Data Table, as appropriate.
4. Turn off the signal source. Remove the circuit jumper between circuit points B and C. Insert a second 100-mH inductor at circuit points B and C, so as to have two 100-mH inductors in series.
5. Turn on the signal source, making sure that the circuit applied voltage is set at 3 V and the source frequency is still set at 5,000 Hz.

6. Measure V_{R_1}, calculate circuit current, and record data on the Data Table.
7. Measure V_{L_T} (voltage across both inductors in series) and calculate X_{L_T} using Ohm's Law. Record data, as appropriate, on the Data Table.
8. Turn off the signal source. Return the circuit configuration to the original one-inductor "initial" circuit setup using the inductor whose value is rated at 100 mH.
9. Now, make a "frequency run" for this circuit as follows:
   a. Set the signal source to a frequency of 5,000 Hz and its output voltage to 3 V.
   b. Use the techniques you used earlier to measure V_{R_1}, calculate circuit I, measure V_L, and calculate X_L.
   c. Measure and record data on Data Table 2, as indicated, to show inductive reactance for each new frequency setting from 5,000 Hz to 10,000 Hz in 1,000-Hz steps. That is, record values you determined at 5,000 Hz, 6,000 Hz, 7,000 Hz, and so on.
10. Create a line graph showing X_L versus frequency (f) over the frequency run. Use f settings along the **x-axis**, and let the **y-axis** represent the X_L values.
11. After completing the Data Table and creating the graph, answer the Analysis Questions and produce the brief Technical Lab Report to complete the project.

NOTE ➤ If your instructor wants you to perform measurements and analysis on both the higher-frequency circuit(s) and the lower-frequency circuit(s), perform steps 1–10 a second time, using the correct components and frequency settings. Record data, as appropriate, in the Data Table, and create graphs for both types of circuits.

Analysis Questions

NOTE Answers to these Analysis Questions should be clearly numbered and documented on separate sheets of paper with your name and the date at the top of each page. These answer sheets are to be turned in with the rest of the project documentation, as appropriate.

1. Why was the circuit inductive reactance greater with the two inductors in series than it was with the single inductor?
2. From the data in Data Table 1, use the appropriate version of the $X_L = 2\pi fL$ formula and calculate the "apparent" *inductance* of the single-inductor used in the initial circuit. Show your work.
3. From the data in Data Table 1, use the appropriate version of the $X_L = 2\pi fL$ formula to find the *total inductance* of the two inductors in series. Show your work.
4. Was the inductance of the two-inductor circuit approximately two times the inductance of the one-inductor circuit? Was the total inductive reactance of the two-inductor circuit approximately two times the inductive reactance

Data Table 1

Component and Parameter Identifiers	Higher *f* (1 inductor) $V_A = 3\ V_{rms}$; @ $f = 5{,}000$ Hz Parameter Values
L_1 rated (H)	0.1
R_1 color code (Ω)	1000
V_{R_1} measured (V_{rms})	
I (ac) calculated (mA)	
V_L measured (V_{rms})	
X_L calculated (kΩ)	
Component and Parameter Identifiers	**Higher *f* (2 series inductors) $V_A = 3\ V_{rms}$; @ $f = 5{,}000$ Hz Parameter Values**
L_1 rated (H)	0.1
L_2 rated (H)	0.1
R_1 color code (Ω)	1000
V_{R_1} measured (V_{rms})	
I (ac) calculated (mA)	
V_{L_T} measured (V_{rms})	
X_{L_T} calculated (kΩ)	

of the single inductor circuit having the same circuit voltage applied and frequency parameters?

5. From your answers in question 4, what can you describe about the relationship of inductive reactance to inductance value for given circuit inductor(s) at a specific voltage applied and source frequency?

6. From the data in Data Table 2 (the frequency run data), what relationship can you describe about the value of inductive reactance as it relates to frequency for a given circuit configuration?

7. Use the appropriate version of the $X_L = 2\pi fL$ formula and calculate the "apparent" *inductance* of the single-inductor used for the frequency run at the lowest frequency used in the run and at the highest frequency in the run. Show your work.

8. Were the apparent inductance values the same at the lower-frequency end and the higher-frequency end of the run? If not, explain some factors that may have caused this.

9. Describe why your calculated apparent inductance values may differ somewhat from the manufacturer's rated value for these inductors.

Data Table 2

Component and Parameter Identifiers	Higher f	Circuit	(1 inductor)	$V_A = 3\ V_{rms}$	@ f = 5,000–10,000 Hz	
	5,000 Hz	6,000 Hz	7,000 Hz	8,000 Hz	9,000 Hz	10,000 Hz
V_{R_1} measured (V_{rms})						
I (ac) calculated (mA)						
V_L measured (V_{rms})						
X_L calculated (kΩ)						

Technical Lab Report

Write a brief technical lab report summarizing the technical facts learned from this project. The report should be organized to provide the following:

1. An introductory paragraph describing the type of circuit being analyzed and the key parameters that will be discussed relating to this circuit.
2. A section describing the most important characteristics of this type of circuit that were shown via the collected data in the tables and graphs.
3. Any special facts or characteristics about this type of circuit that were highlighted in answering the Analysis Questions.
4. A practical example of how the information learned in this project might help you in operating, troubleshooting, error analysis, or adjusting a circuit of this type in your home setting, in your training program setting, or in a job setting in the real world.
5. A summary statement listing the most positive aspects of the project and any parts of the project that were difficult because of equipment problems or unclear instructions. Include areas that might be improved.

PART 10

Summary

Inductive Reactance in AC

Name: ______________________________ Date: ______________

Complete the following review questions, indicating the appropriate response by placing a check in the box next to the correct answer.

1. The induced voltage and X_L of a coil are directly proportional to
   - ☐ L and R
   - ☐ L/R
   - ☐ L and f
   - ☐ R and f
   - ☐ none of these

2. If frequency is doubled and L is halved, the net resultant X_L will
   - ☐ double
   - ☐ halve
   - ☐ quadruple
   - ☐ remain the same
   - ☐ none of these

3. If two equal inductors that were in series are now parallel connected, the resulting total X_L compared to the original circuit will be
   - ☐ two times greater
   - ☐ one-half as great
   - ☐ four times greater
   - ☐ one-fourth as great

4. As f increases, the rate of change of current
   - ☐ increases
   - ☐ decreases
   - ☐ remains the same

5. The X_L formula shows that inductive reactance is
   - ☐ directly proportional to L and inversely proportional to f
   - ☐ inversely proportional to L and directly proportional to f
   - ☐ neither of these

6. To solve for L when X_L and frequency are known, use the formula
   - ☐ $2\pi f/X_L$
   - ☐ $2\pi X_L/f$
   - ☐ $X_L/2\pi f$
   - ☐ none of these

7. The unit of X_L is the
   - ☐ back emf
   - ☐ ohm
   - ☐ ampere
   - ☐ volt
   - ☐ none of these

8. The opposition that an inductor shows to ac is
   - ☐ purely inductive
   - ☐ purely resistive
   - ☐ a combination of resistance and inductive reactance
   - ☐ none of these

9. The amount of inductive reactance that a given coil exhibits is directly related to
   - ☐ the amount of current
   - ☐ the applied voltage
   - ☐ neither of these

10. If frequency is tripled and inductance halved, the resultant X_L will be
    - ☐ two-thirds of the original
    - ☐ three-halves of the original
    - ☐ six times the original
    - ☐ one-sixth of the original