Unit 6 Lab Report Instructions

Unit Lab Report [40 points]

Use the following section titles in your report. Images, text or equations plagiarized from the internet are not allowed! Remember to write your report *alone* as collaborating with a lab partner will make you both guilty of plagiarism. **Please label your lab report sections:**

- **Title [0 points]** – A catchy title worth zero points so make it unique and fun.

- **Mini-Report [10 points]:** ***{4-6 paragraphs, ~2 double-spaced pages}***
  Choose **one** of the following sections about which to write your mini-report. You are given the choice so that you may decide which topic you feel most comfortable/knowledgeable.

  <u>Week 11 Section 4:</u> specific oscilloscope RLC measurements, or <u>Week 12 Section 3:</u> mutual inductance "radio"

  Write a "mini-report" for one particular section of the lab manual. Describe what you did succinctly, and then what you found accurately. Then explain what the result means and how it relates to some of the concepts in the previous section. *You must write using sentences & paragraphs; bulleted lists are unacceptable.* ***Please label your mini-report sections:***

  - **Abstract:** Write 2-3 sentences about the goals of this section. Describe the concepts you were investigating and how the experimentation you performed allowed you to investigate these concepts. Write 2-3 sentences summarizing the procedure. Write 2-3 sentences summarizing the results and what the results mean with regard to the concepts you were investigating. *It is best to write the abstract last*. [2 points]

  - **Procedure:** Do not provide a lot of specific details, but rather you should summarize the procedure so that a student who took the course a few years ago would understand what you did. Do NOT write bullet points, but explain what you did in sentences/paragraphs(s). [2 points]

  - **Results:** Provide a description of the data you obtained such as data tables. Restate any measured values, calculated slopes of lines-of-best-fit, etc. Do not *interpret* your results, save any interpretation for the discussion. Here you will be graded on the accuracy of your work so be sure to provide the grader well-labeled data along with the correct units of measurement. [3 points]

  - **Discussion:** Analyze and interpret the results you observed/measured in terms of some of the concepts and equations of this unit. It is all right to sound repetitive with other parts of the report, but be thorough and complete in your analysis of the experiment. [3 points]

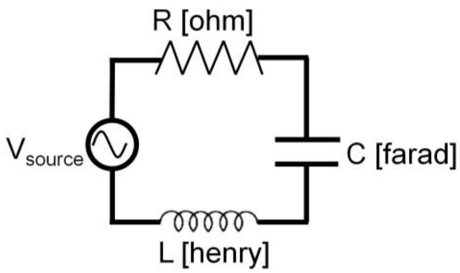
- **Open-Ended Discussion [10 points]** – ***{1-2 paragraphs, ~1 page double-spaced}***
  Choose **one** of the open-ended experiments from the two weekly activities to write about. Describe your experimental goal and the question you were trying to answer. Explain the ideas you came up with and what you tried. If your attempts were successful, explain your results. If your attempts resulted in failure, explain what went wrong and what you would do differently in the future. *You must write using sentences & paragraphs; bulleted lists are unacceptable.*

- **Graphs [5 points] - {attach to your typed report}** Graphs must be neatly hand-drawn <u>during lab</u> on graph paper. Your graphs must fill the entire page (requires planning ahead), include a descriptive title, labeled axes, numeric tic marks on the axes, and unit labels on the axes. If instructed to calculate the slope of the line-of-best-fit, write it directly on the graph.
  - **Week 11: none**
  - **Week 12: 4-12**

- **Take-Home Quizzes [2x5 points = 10 points] - {attach after your Graphs}**

- **Selected Worksheet Pages [5 points] - {attach after your Take-Home Quizzes }**
  Your TA will choose which pages you need to hand in.

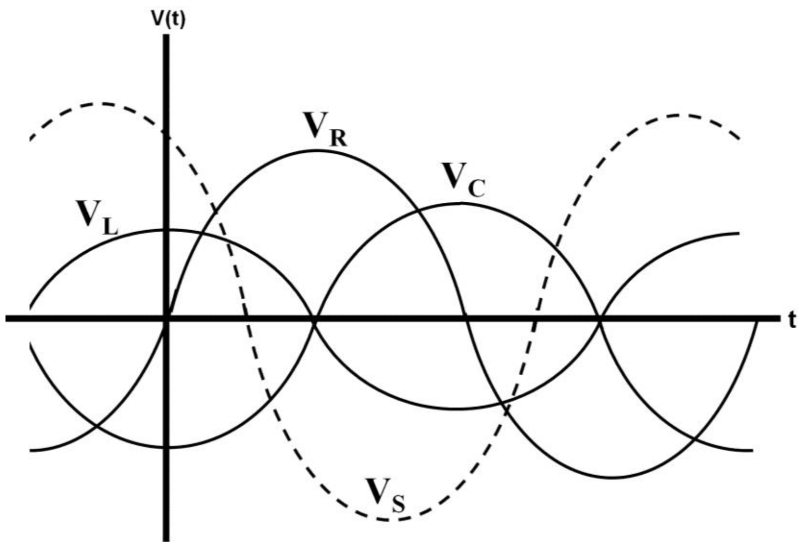
Week 11 Pre-Lab: RLC Circuit - AC Source



Just as the RC circuit with a sinusoidal source had sinusoidal voltages containing phase shifts, so too does the RLC circuit with sinusoidal source. You will need to understand the following (underived) time dependent formulae for RLC component voltages:

$$V(t)_{\text{source}} = V_{\substack{\text{source}\\\text{amplitude}}} \sin\left(\omega_{\text{drive}} t + \phi_{\text{shift}} + \pi\right) \qquad V(t)_{\text{resistor}} = \frac{R}{Z} V_{\substack{\text{source}\\\text{amplitude}}} \sin\left(\omega_{\text{drive}} t\right)$$

$$V(t)_{\text{capacitor}} = \frac{\mathrm{X}_C}{Z} V_{\substack{\text{source}\\\text{amplitude}}} \sin\left(\omega_{\text{drive}} t - \frac{\pi}{2}\right) \qquad V(t)_{\text{inductor}} = \frac{\mathrm{X}_L}{Z} V_{\substack{\text{source}\\\text{amplitude}}} \sin\left(\omega_{\text{drive}} t + \frac{\pi}{2}\right)$$



This graph shows that the resistor voltage has no phase shift as its graph goes through the origin. The capacitor voltage is phase shifted by $\pi/2$ from the resistor voltage while the inductor voltage is phase shifted by $\pi/2$ from the resistor voltage (in the opposite direction from the capacitor voltage). Finally, the source voltage is the negative sum of the other components $V_{\text{S}}(t) = -V_{\text{R}}(t) + -V_{\text{C}}(t) + -V_{\text{L}}(t)$ (due to conservation of energy). The phase shift of the source is more complicated depending on the parameters of the circuit: inductance L and capacitance C. This formula is provided later.

The voltage across each component oscillates at the same frequency as the driving frequency of the source, ω_{drive}. The properties of inductor and capacitor are frequency dependent, which makes the circuit respond differently to different driving frequencies. This causes there to be a specific frequency where the circuit has the largest possible current. This is the *resonant frequency,* ω_{resonant}.

The total circuit impedance (the circuit's total "resistance") is $Z = \sqrt{R^2 + (\mathrm{X}_L - \mathrm{X}_C)^2}$ [Ω]. The capacitive reactance (the capacitor's "resistance") is time dependent, $\mathrm{X}_C = \dfrac{1}{\omega_{\text{drive}} C}$ [Ω]. If you increase the driving frequency, X_C will decrease (inversely proportional). The inductive reactance (the inductor's "resistance") is time dependent also, $\mathrm{X}_L = \omega_{\text{drive}} L$.

If you increase the driving frequency, X_L will increase (linearly proportional). Since increasing the driving frequency causes X_C to decrease while X_L increases, then there is a specific driving frequency when they are equal, $\mathrm{X}_C = \mathrm{X}_L$. When this happens, the total circuit impedance is a minimum $Z_{\min} = \sqrt{R^2 + (\mathrm{X}_L - \mathrm{X}_C)^2} = R$, and this particular driving frequency therefore allows the most current to flow through the circuit. This is called the *resonant frequency*.

One may derive this *very important* resonant frequency in terms of only the capacitance and inductance of the circuit (does not depend on resistance): $\mathrm{X}_C = \mathrm{X}_L \rightarrow \dfrac{1}{\omega_{res} C} = \omega_{res} L \rightarrow \omega_{res} = \dfrac{1}{\sqrt{LC}}$.

The phase shift formula for the source voltage is $\phi_{\text{source}} = \tan^{-1}\left(\dfrac{\mathrm{X}_L - \mathrm{X}_C}{R}\right)$. Also, note that the familiar Ohm's law I=V/R can be used as a pneumonic for the formula for the current in the RLC circuit $I_{\substack{\text{current}\\ \text{amplitude}}} = \dfrac{V_{\substack{\text{source}\\ \text{amplitude}}}}{Z}$.

As an example, imagine an RLC circuits (sinusoidally driven) with the following parameters. If R = 0.5 [Ω], L = 0.010 [H], C = 0.10 [F], $V_{\text{source amplitude}}$ = 3 [V] and f_{drive} = 10 [Hz]. Then,

- $\omega_{\text{drive}} = 2\pi f_{\text{drive}} = 62\,[1/\text{s}]$
- $\mathrm{X}_C = \dfrac{1}{\omega_{\text{drive}} C} = 0.16\ [\Omega]$
- $\mathrm{X}_L = \omega_{\text{drive}} L = 0.62\ [\Omega]$
- $Z = \sqrt{R^2 + \left(\mathrm{X}_L - \mathrm{X}_C\right)^2} = 0.68\ [\Omega]$
- $\phi_{\text{source}} = \tan^{-1}\left(\dfrac{\mathrm{X}_L - \mathrm{X}_C}{R}\right) = 0.74\ [\text{radians}]$
- $V(t)_{\text{source}} = V_{\substack{\text{source}\\ \text{amplitude}}} \sin\left(\omega_{\text{drive}} t + \phi_{\text{shift}} + \pi\right) = 3\sin\left(62t + 0.74 + \pi\right)\ [\text{V}]$
- $V(t)_{\text{resistor}} = \dfrac{R}{Z} V_{\substack{\text{source}\\ \text{amplitude}}} \sin\left(\omega_{\text{drive}} t\right) = 2.2\sin\left(62t\right)\ [\text{V}]$
- $V(t)_{\text{capacitor}} = \dfrac{\mathrm{X}_C}{Z} V_{\substack{\text{source}\\ \text{amplitude}}} \sin\left(\omega_{\text{drive}} t - \dfrac{\pi}{2}\right) = 0.71\sin\left(62t - \dfrac{\pi}{2}\right)\ [\text{V}]$
- $V(t)_{\text{inductor}} = \dfrac{\mathrm{X}_L}{Z} V_{\substack{\text{source}\\ \text{amplitude}}} \sin\left(\omega_{\text{drive}} t + \dfrac{\pi}{2}\right) = 2.7\sin\left(62t + \dfrac{\pi}{2}\right)\ [\text{V}]$
- $I_{\substack{\text{current}\\ \text{amplitude}}} = \dfrac{V_{\substack{\text{source}\\ \text{amplitude}}}}{Z} = 4.4\ [\text{A}]$

Notice that at this driving frequency, of the three circuit components, the inductor has the largest voltage amplitude and would appear the largest on the oscilloscope screen.

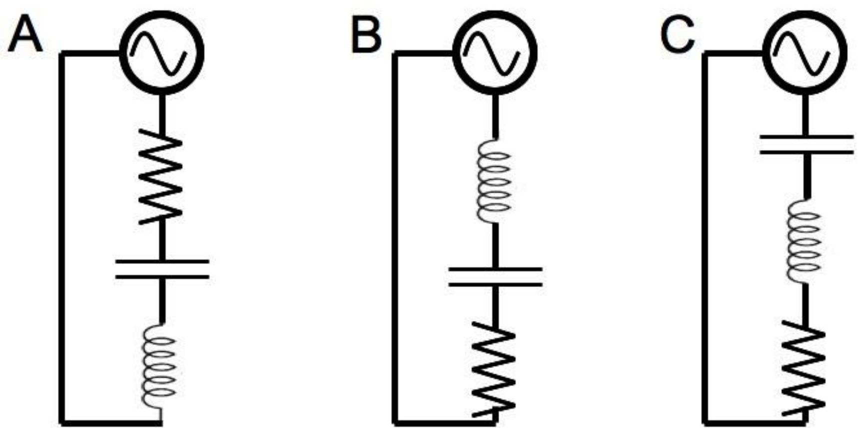
Week 11 Lab: RLC Circuit - AC Source

Students Absolutely Must Learn…

- How to use the sinusoidal solutions of the RLC circuit components and what they mean (including phase shifts).
- How to relate the RLC circuit current to other circuit parameters especially the circuit impedance.
- How conservation of energy and calculus explain the $\pi/2$ phase shifts.
- How to determine the resonance features of the RLC circuit and how the various parameters affect resonance.
- Advanced oscilloscope techniques.

Section 1: measuring with two oscilloscope channels

In electronics, you may use the oscilloscope to simultaneously measure the voltage of two *adjacent* components. Connecting your inductor, capacitor and resistor in series should be done with some consideration of which components you will measure with your oscilloscope since you only have two channels to measure with. The three circuit configuration examples below and the questions that follow are used to illustrate this point



¿ **1-1** ***Middle Ground Measurements***

In which circuit(s) is it impossible to simultaneously measure the voltages of the inductor and resistor?

In which circuit(s) is it impossible to simultaneously measure the voltage of the source and resistor?

If you wire and RLC circuit, are you always make any measurement you need, or do you sometimes need to exchange components?

¿ 1-2
In circuit B, which pairs of components cannot be separately measured on the oscilloscope with a middle ground technique? (*You are free to choose the location of the oscilloscope ground.*)

¿ 1-3
In circuit C, which pairs of components can be separately measured on the oscilloscope with a middle ground technique? (*You are free to choose the location of the oscilloscope ground.*)

! Depending on which two components you wish to measure, you often have to rearrange the actual components.

¿ 1-4
Sketch a circuit configuration along with the proper placement of the three oscilloscope leads (red 1, red 2 and ground) in order to be able to separately measure the time dependence of the solenoid and resistor simultaneously.

¿ 1-5
Sketch a circuit configuration along with the proper placement of the three oscilloscope leads (red 1, red 2 and ground) in order to be able to separately measure the time dependence of the source and resistor simultaneously.

Section 2: calculus explains $\pi/2$ phase shifts

The explanation of the 90° phase shifts of the inductor and capacitor voltages from the resistor voltage can be explained using calculus.

Conservation of energy for the sinusoidally driven RLC circuit gives:

$$V_{\text{source}}(t)+V_{\text{L}}(t)+V_{\text{R}}(t)+V_{\text{C}}(t)=0.$$

Substituting Ohm's Law $V_{\text{R}}(t)=I(t)\cdot R$, the definition of inductance $V_{\text{L}}(t)=L\frac{dI(t)}{dt}$ and the definition of capacitance $V_{\text{C}}(t)=\frac{Q(t)}{C}$ gives:

$$V_{\text{source}}(t)+\underbrace{L\frac{dI(t)}{dt}}_{\text{inductor term}}+\underbrace{R\cdot I(t)}_{\text{resistor term}}+\underbrace{\frac{Q(t)}{C}}_{\text{capacitor term}}=0.$$

First notice that the time dependence of the inductor is related to the resistor by a time derivative,

$$V_{\text{source}}(t)+\underbrace{L\frac{dI(t)}{dt}+R\cdot I(t)}_{\substack{\text{The inductor voltage is}\\ \text{proportional to the time}\\ \text{derivative of the resistor voltage.}}}+\frac{Q(t)}{C}=0.$$

All time dependent quantities of the circuit are oscillating sinusoidally including $Q(t)$ and $I(t)$. Since the resistor voltage is described by a sine function, $V(t)_{\text{resistor}}=V_{\substack{\text{resistor}\\ \text{amplitude}}}\sin(\omega_{\text{drive}}t)$, the current is as well, $I(t)=I_{\text{amp}}\sin(\omega_{\text{drive}}t)$. Since

$$V_{\text{L}}(t)=L\frac{dI(t)}{dt}=L\cdot\omega_{\text{drive}}\cdot I_{\text{amp}}\cos(\omega_{\text{drive}}t),$$

so the inductor voltage must be described by a cosine function. But the cosine function is shifted from the sine function by $\pi/2$,

$$L\cdot\omega_{\text{drive}}\cdot I_{\text{amp}}\cos(\omega_{\text{drive}}t)=L\cdot\omega_{\text{drive}}\cdot I_{\text{amp}}\sin\left(\omega_{\text{drive}}t+\frac{\pi}{2}\right).$$

Thus calculus has explained the 90° phase shift of the inductor voltage relative to the resistor voltage.

Next remember the definition of current $I(t)=\frac{dQ(t)}{dt}$ to find that

$$V_{\text{source}}(t)+\underbrace{L\frac{dI(t)}{dt}}_{\text{inductor term}}+\underbrace{R\frac{dQ(t)}{dt}}_{\text{resistor term}}+\underbrace{\frac{Q(t)}{C}}_{\text{capacitor term}}=0.$$

Notice that the second two terms on the right hand side show that the time dependence of the capacitor voltage is related to the antiderivative of the resistor voltage,

$$V_{\text{source}}(t) + L\frac{dI(t)}{dt} + \underbrace{R\frac{dQ(t)}{dt} + \frac{Q(t)}{C}}_{\substack{\text{The capacitor voltage is}\\ \text{proportional to the antiderivative}\\ \text{of the resistor voltage.}}} = 0$$

Since the resistor voltage is described by a sine function, $V(t)_{\text{resistor}} = V_{\substack{\text{resistor}\\ \text{amplitude}}} \sin(\omega_{\text{drive}}t)$, the capacitor voltage must be described by a **negative** cosine function, the antiderivative of the sin function. But the negative cosine function is also phase shifted from the sine function by π/2,

$$-\cos(\omega_{\text{drive}}t) = \sin\left(\omega_{\text{drive}}t - \frac{\pi}{2}\right).$$

¿ 2-1

Use the fact that $\frac{dI(t)}{dt} = \frac{d^2Q(t)}{dt^2}$ and use calculus explain in a different way why the inductor voltage is phase shifted from the resistor voltage by π/2. Begin with

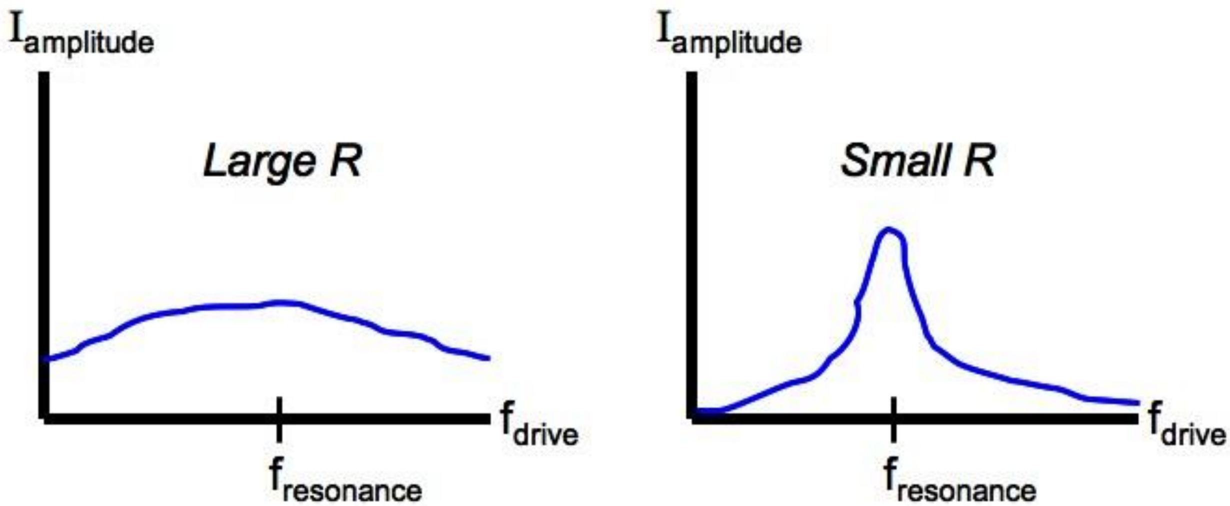
$$V_{\text{source}}(t) + \underbrace{L\frac{d^2Q(t)}{dt^2} + R\cdot\frac{dQ(t)}{dt}} + \frac{Q(t)}{C} = 0$$ **and** $Q(t) = -Q_{\text{amp}}\cos(\omega_{\text{drive}}t)$**.**

¿ 2-2

Use calculus to explain why the capacitor voltage is phase shifted from the inductor voltages by π.

Section 3: extra lab techniques

An RLC circuit has a resonant driving frequency $f_{\text{resonance}}$ that maximizes the circuit current amplitude. Therefore, a plot of the current amplitude vs. driving frequency will show peak current amplitude at the resonant driving frequency. However, this graph can appear different depending on whether a large or small resistance is used in the circuit:



The sharpness of the resonance peak is measure by the quality factor Q. The larger the quality factor, the sharper the peak. Q is found to be given as

$$Q = \frac{\omega_{\text{resonance}} \cdot L}{\text{R}}.$$

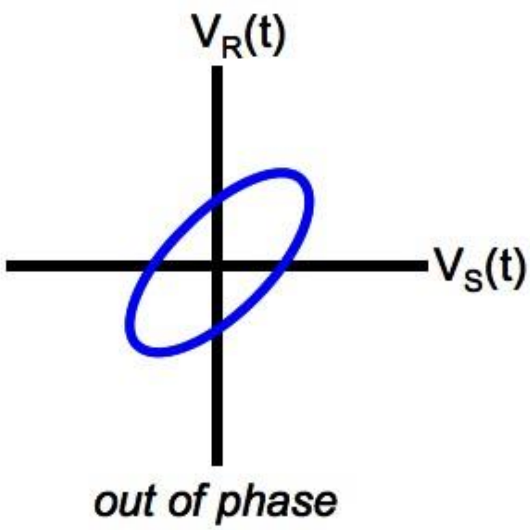
¿ 3-1
What are the units of *Q*?

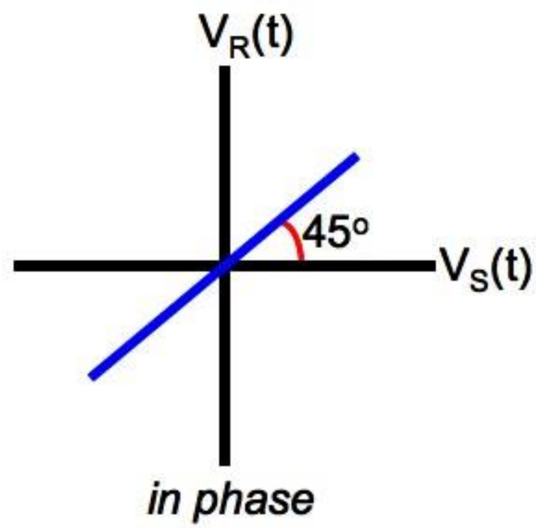
¿ 3-2
Say you were building a circuit that needed to operate at many possible driving frequencies, and you wanted to avoid shorting out the components with a large current. Should you use a larger or smaller resistance?

¿ 3-3
Say you were building a circuit that needed to operate at one specific frequency (near resonance), and you wanted to maximize the current through the circuit to do some work. Should you use a larger or smaller resistance?

In today's lab you usually want to use as small of a resistance as possible (while still being safe) in order to obtain a nice sharp peak in the current amplitude. This will make it easier to find the resonance frequency. However, it is not always desirable to have a large quality factor. In some mechanical systems (bridges, buildings, etc.) a pronounced response to a driving frequency can cause destruction.

The most accurate way to find $f_{resonance}$ is to utilize the fact that at resonance, $V_R(t)$ and $V_{source}(t)$ are exactly in phase with each other with equal amplitudes. You should place each of these voltages on your oscilloscope channels and examine an XY formatted display. The resonance frequency is easily found because you will see an ellipse when $V_R(t)$ and $V_{source}(t)$ are out of phase and a diagonal line when they are in phase. You see a straight line when they are in phase because both voltages must reach zero simultaneously.





Note that if R is chosen small enough, the resistance of the very long wire of the solenoid may become an appreciable resistance of the circuit. When this occurs, the amplitude of the resistor voltage will be smaller than the source voltage amplitude so that you will see a different angle of tilt (not 45°) of the in phase resonance line shown above. This is because

$$V_{\text{source}} + V_{\text{R}} + V_{\substack{\text{resistance of} \\ \text{real solenoid}}} + V_{\text{L}} + V_{\text{C}} = 0.$$

Section 4: specific oscilloscope RLC measurements

Construct an RLC circuit driven by a sinusoidal driving voltage of $V_{\substack{\text{source}\\\text{amplitude}}} = 5$ [V] with $f_{\text{drive}} = 10{,}000$ [Hz], $R = 1$ [kΩ] , $C = 0.1$ [μF], and $L = 50$ [mH]. The frequency and resistance values were not randomly selected, but were determined so that R, χ_C and χ_L are of the same order of magnitude (check if you like). This means that $V_{\text{R,amp}}$, $V_{\text{C,amp}}$ and $V_{\text{L,amp}}$ will also be of the same order of magnitude. This "cheat" is only for this, your first time so you learn the measurement techniques better. Later you will need to be able to analyze two components on your oscilloscope when their voltages are drastically different.

¿ 4-1

Why must you hook up the entire circuit before setting the source voltage on the function generator? Why not just hook the function generator directly to the oscilloscope and set its properties first?

! You must keep this driving frequency the same as you are answering different questions (until told otherwise) because the properties of the circuit change with driving frequency.

¿ 4-2

It is often the case that components in a circuit become disconnected at bad solder joints even though you cannot see this with the unaided eye. What can you do experimentally to make sure that your RLC circuit is still conducting current through all its connections *without disconnecting the circuit*? {Hint: what information can the ohmic component give you?}

¿ 4-3

Quickly measure the voltage amplitudes of each component separately using a single channel of your oscilloscope. Double check that your source voltage amplitude is 5 [V] first.

¿ 4-4

Now use two-channel observations to simultaneously measure the resistor voltage and the inductor voltage to determine their respective phase shift. Don't forget that one channel should be inverted when using a middle ground configuration.

¿ 4-5

Now use two-channel observations to simultaneously measure the resistor voltage and the capacitor voltage to determine their respective phase shift.

¿ 4-6

Now use two-channel observations to simultaneously measure the inductor voltage and the capacitor voltage to determine their respective phase shift.

¿ 4-7

Now use two-channel observations to simultaneously measure the resistor voltage and the source voltage to determine their respective phase shift in seconds.

¿ 4-8

Theoretical calculations: Use the labeled values for inductance, capacitance and resistance that you have in your circuit as well as your actual driving frequency to calculate the following RLC circuit parameters in SI units.

χ_C

χ_L

Z

$\omega_{resonance}$

$f_{resonance}$

¿ 4-9

Comparing theory and observation: Use your results from the previous question along with your observed source voltage amplitude (should still be 5 [V]) to theoretically calculate the voltage amplitudes of the resistor, inductor and capacitor in SI units. Then compare each of these theoretically computed amplitudes to your previous observations.

Power: Since $P_{\text{resistor}} = I \cdot V_{\text{resistor}} = \dfrac{(V_{\text{resistor}})^2}{R}$,

the power converted to heat by the resistor oscillates in time as a squared sine function:

$$P_{\text{R}}(t) = \frac{V_{\text{R}}^2(t)}{R} = \frac{V_{\text{R, amp}}^2}{R} \sin^2(\omega_{\text{drive}} t).$$

The average value of a squared sine function over a complete oscillation cycle is 0.5:

$$average\left[(\sin(\omega_{\text{drive}} t))^2\right] = \frac{1}{2}.$$

This means that the power consumed by the resistor averaged over time is

$$P_{\text{R, average}} = \frac{V_{\text{R, amplitude}}^2}{2R}.$$

¿ 4-10

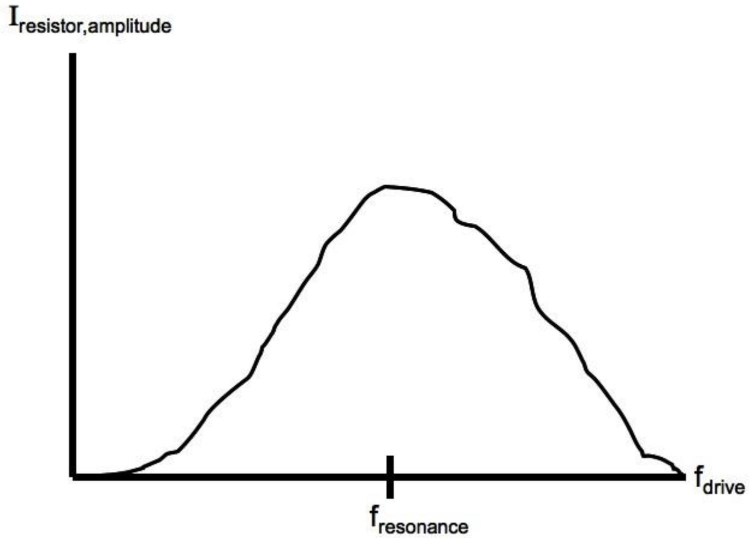
Use this formula to find the average power loss of your circuit in SI units.

¿ 4-11

When the driving frequency is at resonance, the voltages of the source and resistor are equal and in phase. Use this fact to search the range of driving frequencies for the resonant driving frequency using the technique described in section 4 of this lab. Compare this observed value to your predicted value.

¿ 4-12

Collect data of $I_{\text{amplitude}}$ vs. f_{drive} and record below. Then graph the data on separate graph paper. A slightly incorrect example (on purpose so you can't just copy) with a larger resistance is shown to help guide you.



Section 5: authentic assessment

One solenoid and each of the four capacitors on the capacitor board allows you to construct four unique RLC circuits (not counting the resistance possibilities). You need to find the four resonant frequencies of each of these RLC circuits using the method described in section 4 on the phase relationship between the resistor and source voltages. Use the same solenoid as a different group so that you can compare answers.

! The inductor and capacitor voltage amplitudes can be larger than the source voltage amplitude. Voltages over 20 [V] can cause nasty shocks, and very large currents can be generated near resonance in circuits with a large quality factor Q. You should approach any circuit with care, not touching the components while the circuit is powered. In designing a circuit, one must either use a large resistance to limit the dangerous currents near resonance, or have a firm theoretical understanding of the maximum currents that the circuit can produce, while still proceeding with caution.

If you are uncomfortable having another student check your work, please ask your TA.

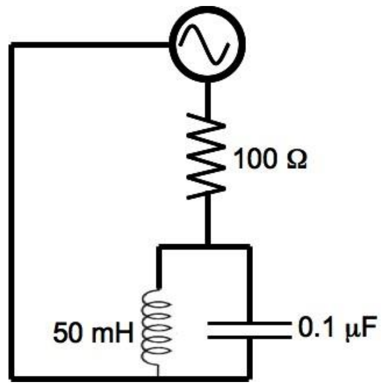
¿ 5-1

Show a student in a different group that you can successfully measure the resonance frequency of an RLC circuit (four circuits, compare your data with theirs). Once you are successful, have them sign below. Note: if someone is stuck, please give them advice!

"Yes, I have seen this student successfully find the resonance frequencies of four RLC circuits. Their results match mine. Either they are doing it right or we are both wrong in the same way!"

Student Signature:____

Section 6: open-ended



Pretend that you are an old-timey inventor. You have already discovered the coiled wire device (now called inductor) and the metallic parallel plates device (now called capacitor). Resistors were discovered by a competitor of yours. It is still a sore subject around the workshop.

You have begun to combine these new components together in order to observe their compound behavior. You already found that when the inductor and capacitor are combined in series and driven sinusoidally, the circuit produces a special resonant frequency where the current in the circuit is a maximum. This means that civilization can now make electronics that "select" specific driving frequencies and "suppress" frequencies far from resonance.

Now you try combining the inductor and capacitor *in parallel* and drive them sinusoidally (see above figure). What electrical possibilities might this new compound device hold for the future of mankind? Well, use your anachronistic oscilloscope to find out. Try to deduce why this circuit may be said to have an "**anti**resonant frequency", a different kind of effect on the circuit current.

You are allowed to "cheat" by talking to other groups for ideas, but are not allowed to "cheat" by just stating an answer you may already know, looking it up online or asking your TA.

Below you are given three prompts: **hypothesizing/planning, observations/data, calculations/conclusion.** Your job is to figure out the answer using these prompts as your problem-solving model. In the event that you should run out of time, you may not discover the correct answer, but you should make an attempt at each prompt. Grades are based on honest effort.

Your open-ended solution should probably include some of the following items: sketches of circuit diagrams, tables of data, calculations, recorded observations, random ideas, etc.

Write at the prompts on the next page.

¿ 6-1
hypothesizing/planning:

¿ 6-2
observations/data:

¿ 6-3
calculations/conclusion

I, the physics 241 laboratory TA, have examined this student's Weekly Activity pages and found them to be thoroughly completed.

! **TA signature: ____**

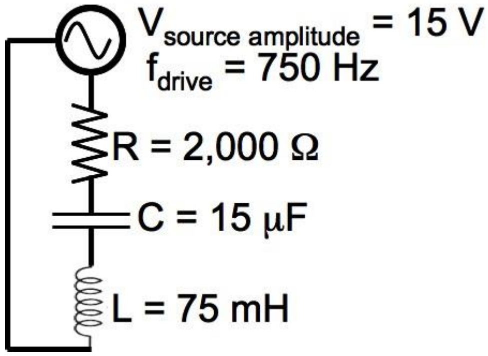
Have you found errors in the manual? Email me to get them fixed: MattLeone@gmail.com

Week 11 Take-Home Quiz

Score:__________ /5

¿ THQ-1 (2-point)

Practice the math for an example of a sinusoidally driven series RLC circuit.



Calculate each of the basic RLC circuit parameters in SI units though not necessarily in the order given (SI units):

χ_C

χ_L

Z

$V_{\text{R,amplitude}}$

$V_{\text{C,amplitude}}$

$V_{\text{L,amplitude}}$

ϕ_{source}

$I_{\text{amplitude}}$

¿ THQ-2 (2-point)

Next write a time dependent equation for each quantity below using the numerical results from the previous question.

$V_{\text{source}}(t)$

$V_{\text{R}}(t)$

$V_{\text{C}}(t)$

$V_{\text{L}}(t)$

$I(t)$

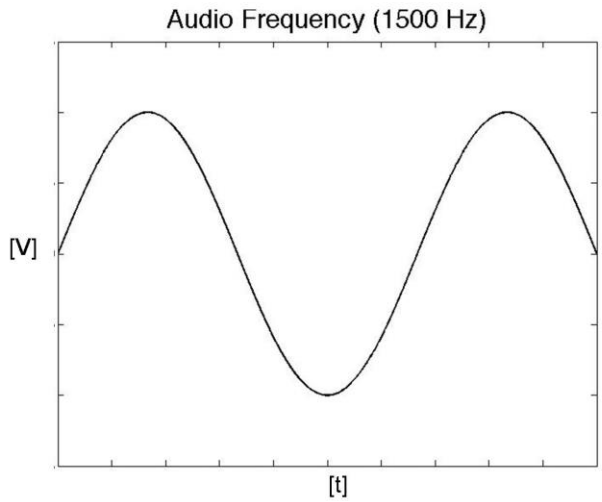
$Q_{\text{cap}}(t)$

¿ THQ-3 (1-point)

What is the resonant driving frequency f_{resonant} of this circuit?

(This page intentionally left blank.)

Week 12 Pre-Lab: RLC Radios



Modulating High Frequency Waves with Low Frequency Waves:

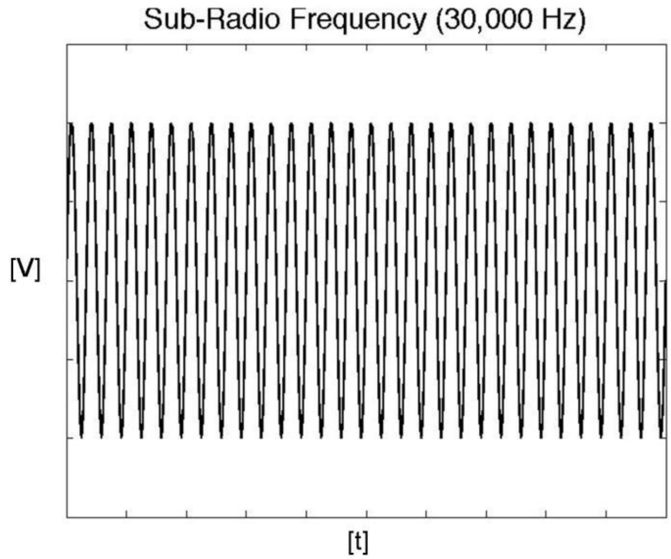
Imagine that you want to transmit a 1,500 [Hz] sound wave from one place to another. Clearly you could *play* the sound and have its vibrations be carried in the air as compression/rarefaction waves. But for long distance transport, you may want to turn the 'sound' into an electronic signal which can be transported with less energy loss along a wire. But if we need to transport the sound to many people (radio) or someone at a changing location (walkie-talkie), we can take advantage of our knowledge of electromagnetism and turn the sound wave into an electromagnetic wave and send the electromagnetic wave through the air. Of course an electromagnetic wave traveling through the air moves at the speed of light because light *is* an electromagnetic wave. We can turn our sound wave into light to transport it.

First investigate transporting sound as oscillating magnetic fields in solenoids, from one solenoid (the transmitter) to another solenoid (the receiver). The two solenoids are not connected in any way so that the oscillating magnetic field inside one solenoid must be made to oscillate within the other solenoid to utilize Faraday's Law of inductance, $\varepsilon_{\mathrm{L}} = -\frac{d\Phi_{\mathrm{B}}}{\mathrm{dt}}$, a process called mutual inductance.

Unfortunately, this wave is alternating much too slowly to induce a large voltage in the receiving solenoid. Remember the equation for mutual inductance, $V_{\substack{\text{induced}\\ \text{in circuit 2}}} = -\frac{\mathrm{dI}_{\text{circuit 1}}}{\mathrm{dt}} M_{1\text{ to }2}$, where M is a constant that describes how much the solenoids overlap. If the current doesn't oscillate rapidly enough, then $V_{\substack{\text{induced}\\ \text{in circuit 2}}}$ is very small.

You might say, "gee, I wish this wave oscillated more quickly to cause a bigger induced voltage in the receiving solenoid." But then it wouldn't be the same sound pitch that you wanted to hear in the first place! Still, it sounds like something you might say since you understand that to utilize Faraday's law, you need rapidly changing magnetic fields.

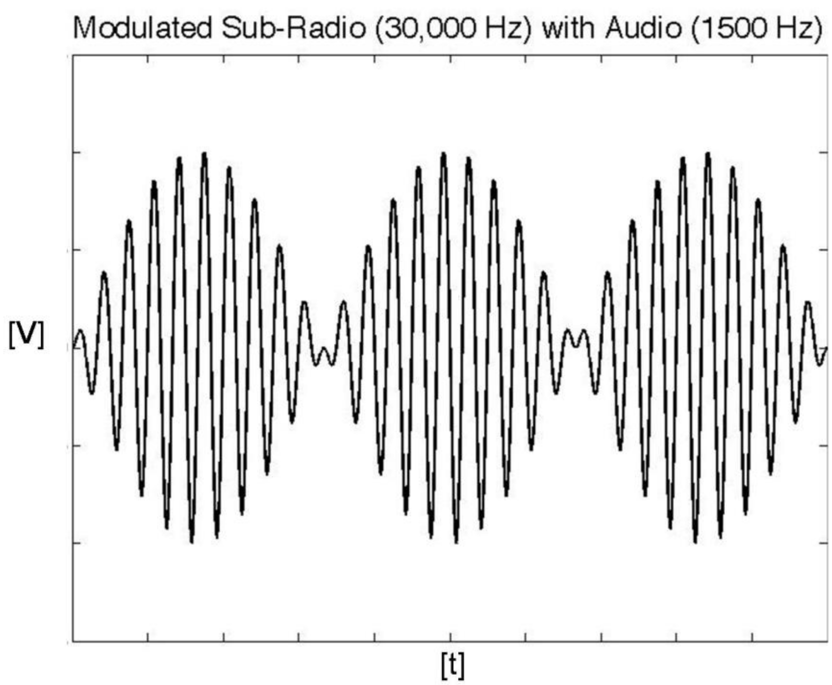
Next examine a wave that oscillates quickly at radio wave frequency or slightly sub-radio frequency.



This isn’t the frequency you want to hear (you are not able to!), but it does oscillate so quickly as to create a large induced voltage in the receiving solenoid. I.e., it oscillates quickly enough to be transmitted into the receiving circuit through the mutual inductance of the “transformer” (overlapping solenoids).

So what to do? There is a low frequency wave that carries the information we wish to transmit but can't, and there is a high frequency wave that we don't care about that is easily transmitted.

The solution is to ***combine*** the two waves together by ***multiplying*** them. This *modulated* wave has the properties of both waves: it carries information about the audio frequency component *and* it oscillates quickly enough to generate a highly induced voltage in the receiver circuit. The following picture shows what a modulated wave looks like.



The *envelope wave* is the low frequency oscillation while the high frequency oscillation is called the *carrier wave*. Together they are the *modulated wave*.

Week 12 Lab: RLC Radios

Students Absolutely Must Learn…

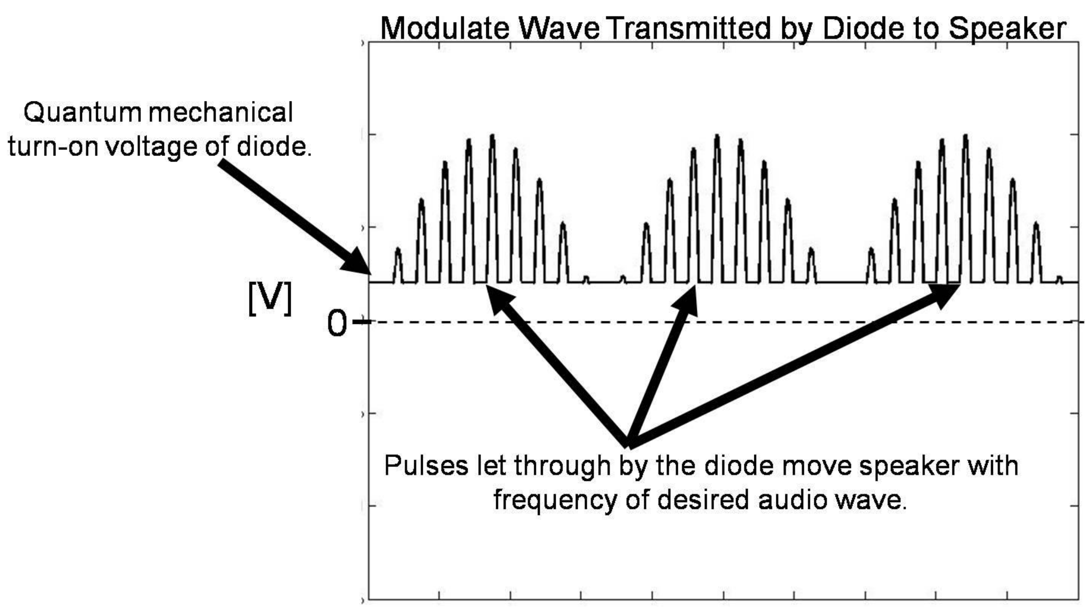
- How the RLC circuit's resonance may be used in technology.
- How to modulate a carrier wave and envelope.
- Advanced oscilloscope techniques.

Section 1: introducing the equipment

In today's lab, we would like to transmit a modulated sound wave transmitted by one solenoid into another "receiving" solenoid. We will use a capacitor in the second "receiving" circuit to make an RLC "receiving" circuit. By changing the capacitor of the "receiving" circuit, we can adjust its resonant frequency. Therefore, we will be able to "tune" our "receiver" to a particular radio frequency.

Now you would like to listen to your transmitted wave. But there is a huge problem. Whenever the wave is positive, it causes an upward force on the speaker, and whenever it is negative it causes a downward force on the speaker. The modulated wave is oscillating up and down with the rapid radio frequency, much too fast for the speaker to respond to. It just sits there quivering.

The trick is to add a diode to the output. Remember that a diode is a quantum mechanical component that only allows current to flow in one direction once a turn-on voltage has been reached (determined by the semiconductor band gap energy). This will allow only positive voltage to reach the speaker.



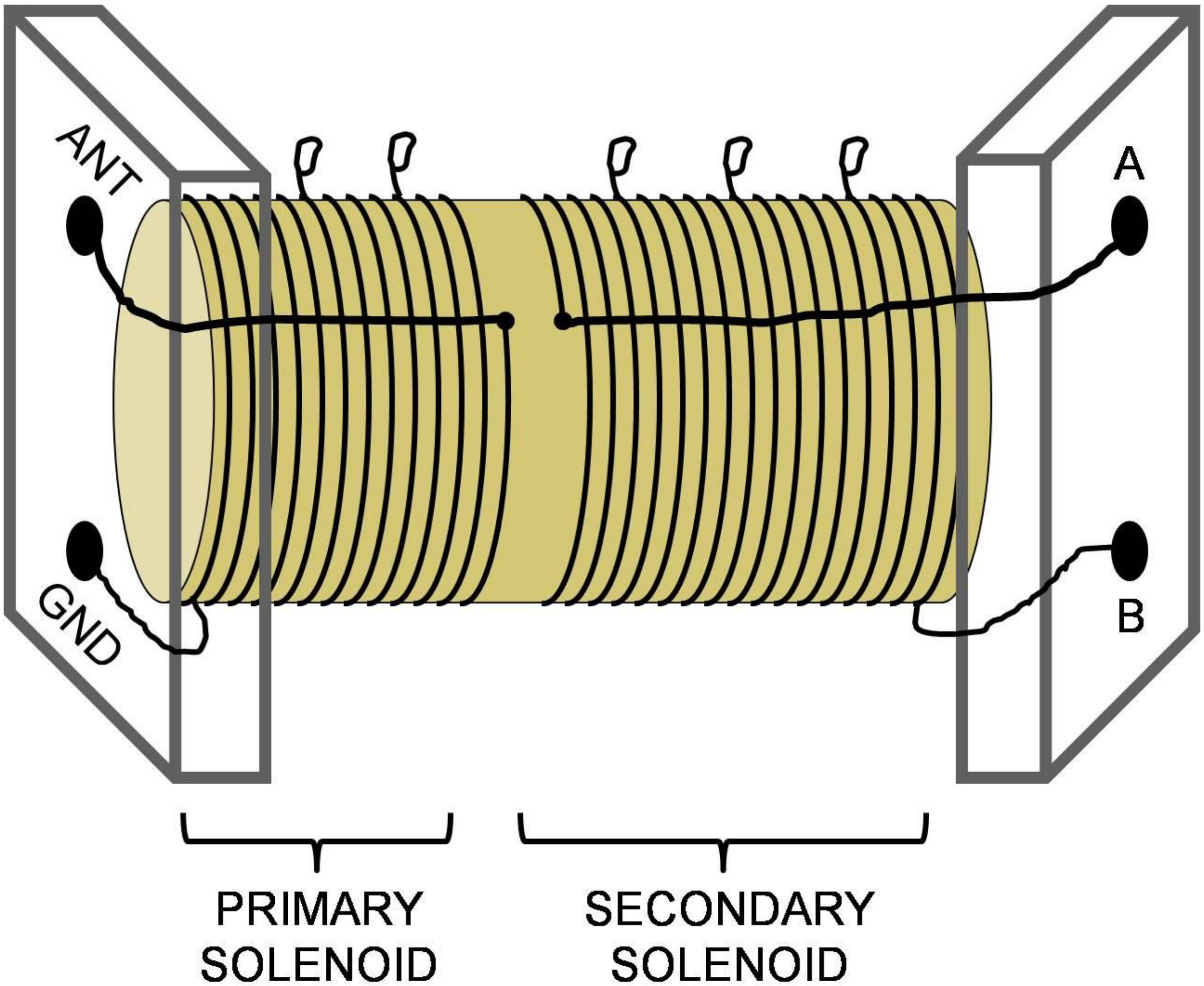
The speaker now gets pushed out a maximum distance at the maximum amplitude of the pulse and relaxes at the minimum.

¿ 1-1

Would you be able to hear the speaker if the direction of the diode in the circuit was reversed? Explain your answer?

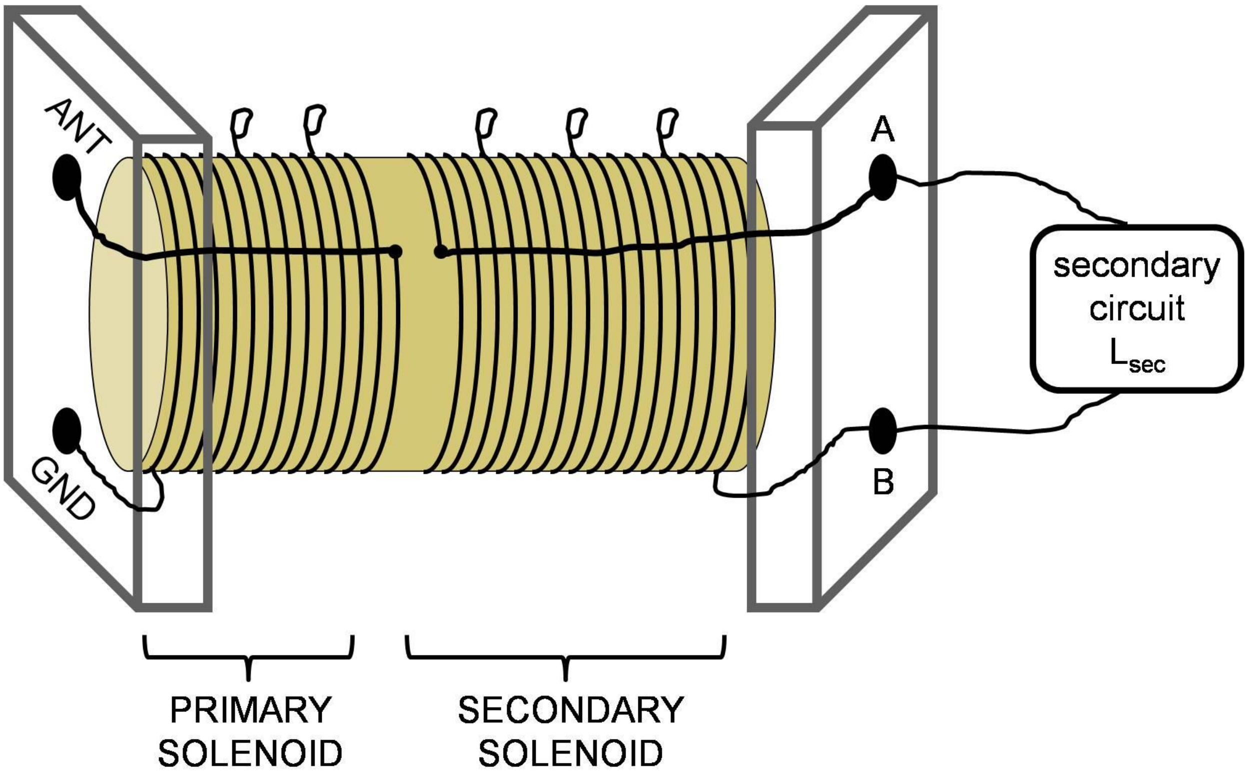
! Never insert the speaker directly into your ear without first verifying that the sound level is safe.

Now you will experimentally use a sound wave to modulate a radio frequency wave.
First examine the equipment with two solenoids:

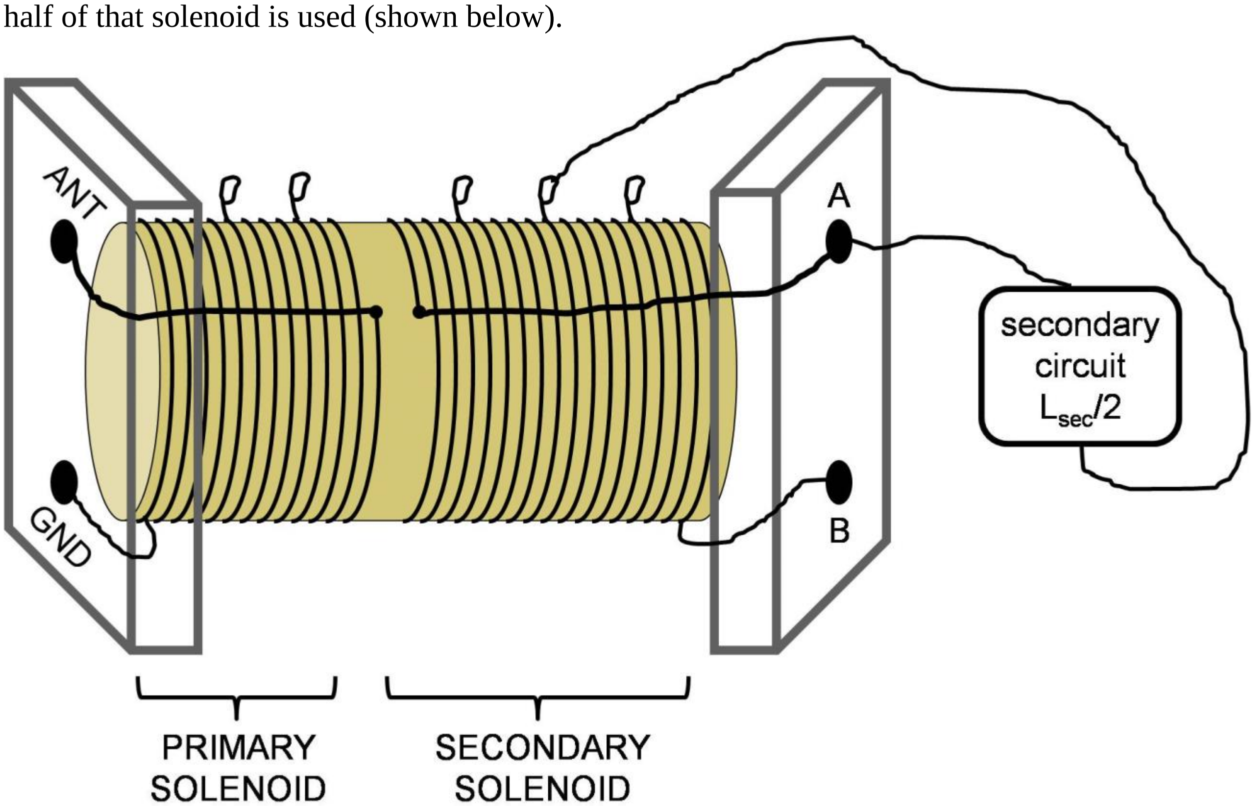


This device allows you to see how two solenoids interact via Faraday's law. There is a small visible gap that separates the two different coils of wire. If you look carefully, you can see that GND connects to the left side of the primary solenoid and ANT connects to the right side of the primary. You can also see that A connects to the left of the secondary and B to the right. In addition to these connections, there are some junctions sticking out of the top of the solenoids. These allow you to use smaller portions of each solenoid if you want less inductance L.

We will always want to use the connections at ANT and A. This forces the current to travel in the parts of the primary and secondary that are adjacent to one another.



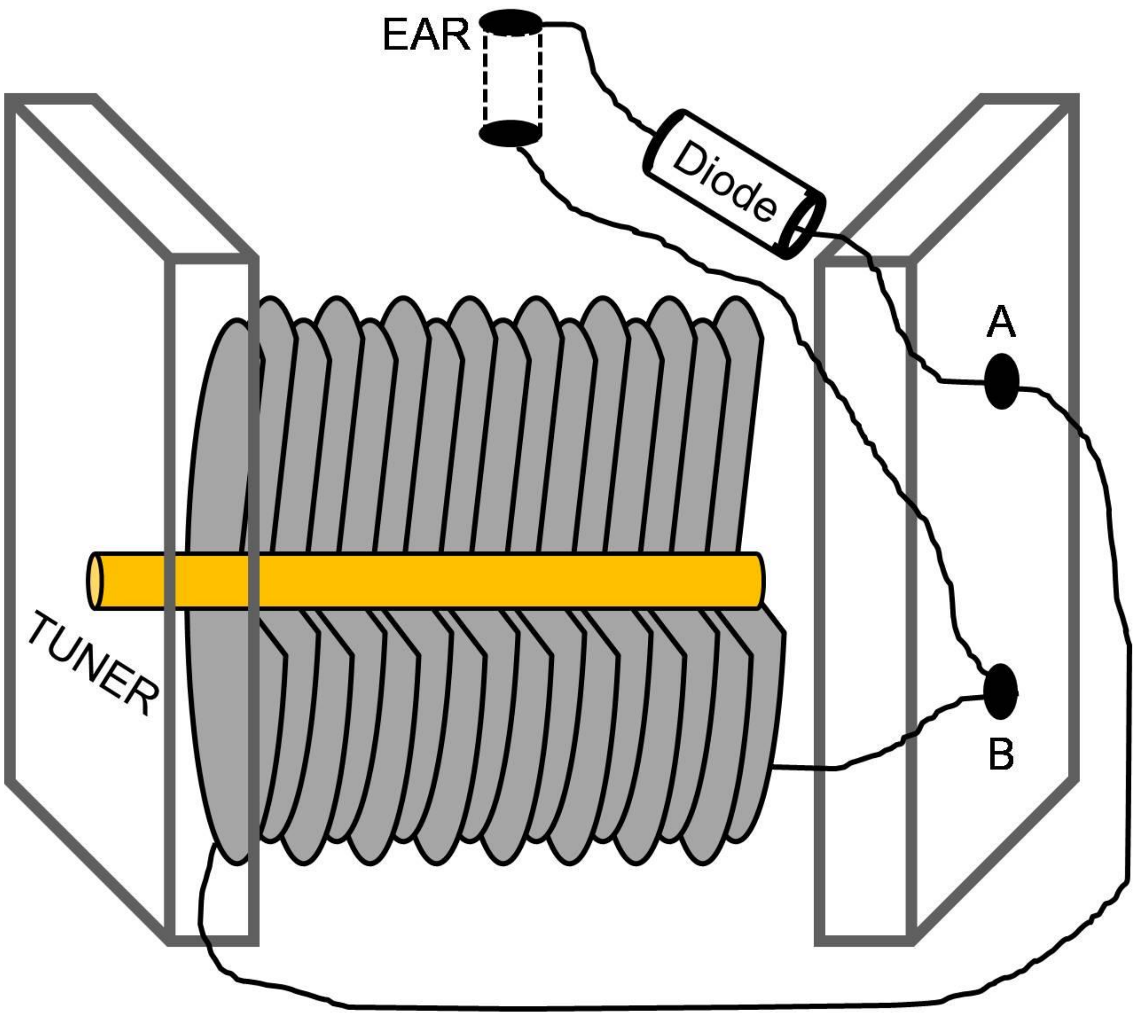
For example, if you wanted to half the inductance of the secondary circuit shown above, you would simply reconnect the B terminal to the midpoint of the secondary solenoid so that only half of that solenoid is used (shown below).



¿ 1-2

How many possible primary solenoid inductances are possible? How many secondary? {Don't forget that the solenoids must remain immediately adjacent to each other.}

Now examine the equipment with the continuously variable capacitance:



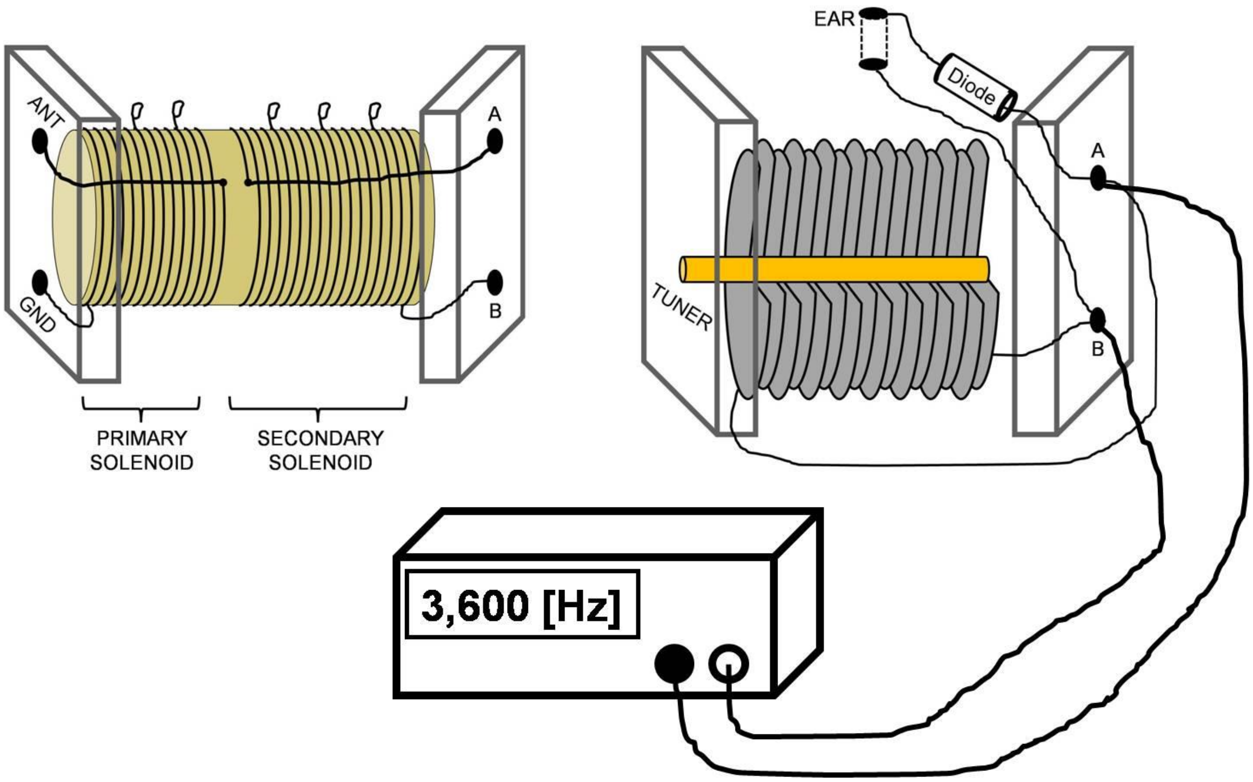
The variable capacitor is made of two sets of overlapping plates. One set can be rotated so that it overlaps more or less with the other set of plates. When they maximally overlap the capacitor has the highest capacitance it can provide. When the plates don't overlap at all, the capacitance is zero.

In addition to the capacitor plates, there is a diode and speaker connector in parallel to the capacitor. Remember that the diode eliminates half the oscillating voltage sent to the speaker.

Now let's be sure you can make the 'sound'. Clean your ear-speaker with alcohol and connect it to the earplug on the capacitor assembly. Set your function generator to 3,600 [Hz]. Connect your function generator to the A and B connections on the variable capacitor assembly as shown below.

Slowly increase the output voltage of the function generator until you can hear the signal.

! **Ask for help if you have any doubts about the proper operation of these devices.**



¿ 1-3

Give yourself a hearing test. Find the upper end of the frequency range of your hearing (or another student if you do not want to test your own hearing). It may be significantly less than your classmates' if you are older or have suffered hearing loss due to loud noises. Also note any intermediate ranges of hearing loss. Do these frequencies correspond to the kinds of music you listen to (too loudly)?

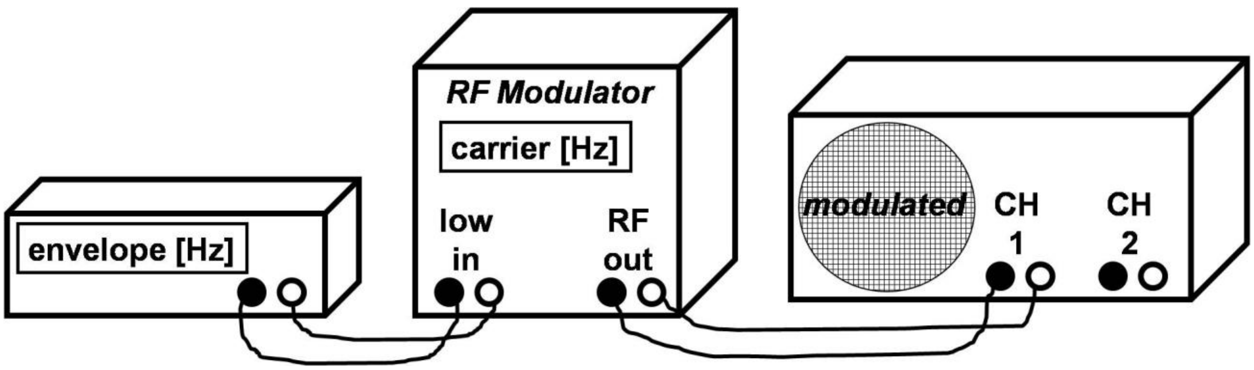
Section 2: the modulated wave

The radio frequency (RF) modulator takes an input envelope wave and modulates it with a rapidly oscillating carrier wave. If you do not input any envelope wave, only the pure carrier wave will be output. Hook your RF modulator directly to the oscilloscope *without* the input envelope wave from the function generator. Use a carrier RF wave of 500,000 [Hz].

¿ 2-1

Use the oscilloscope to determine the period of the 500 [kHz] RF carrier wave. Does this make sense since $T = \frac{1}{f}$?

Now input an audio-frequency signal of 1,000 Hz from your function generator into your RF modulator (shown below). Use a carrier radio-frequency wave of 500,000 [Hz] to create a modulated output wave of 1,000 Hz envelope waves surrounding a 500 kHz high frequency wave.



¿ 2-2

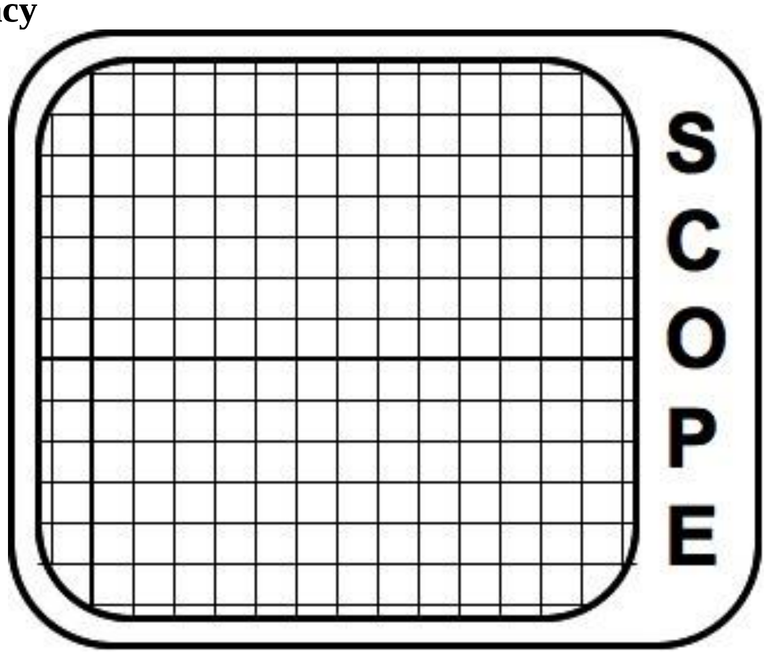
Calculate the period of the envelope wave using $T = \frac{1}{f}$?

Examine the output of this signal on your oscilloscope using two different time ranges so that you can see the audio-frequency signal and then separately the radio-frequency signal. To do this, choose a seconds-per-division setting for the time axis that is appropriate for the time scale of the wave you wish to examine (i.e., use the wave's period to select the seconds-per-division). You may need to press the "run-stop" button to view the wave packets if they appear smeared out on the oscilloscope.

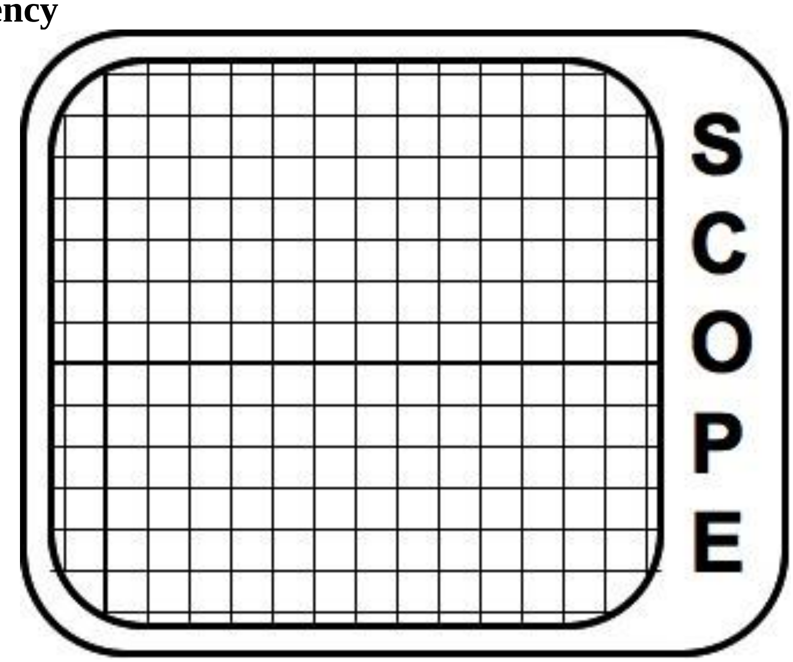
¿ 2-3

Sketch the appearance of the modulated wave at *both* the audio frequency scale and then the radio frequency scale, and record the time scales used to observe the waves. Notice that the RF generator does not necessarily produce a clean RF output as was discussed earlier in this handout. Also, be sure you can hear the envelope waves of the modulated signal in your speaker.

Radio Frequency



Audio Frequency



Section 3: mutual inductance "radio"

Now you will use a sound wave to modulate a radio frequency wave, then use mutual inductance to transmit the radio frequency wave to a separate RLC circuit, and finally listen to the "broadcast" sound wave. Set the capacitor to its maximum setting.

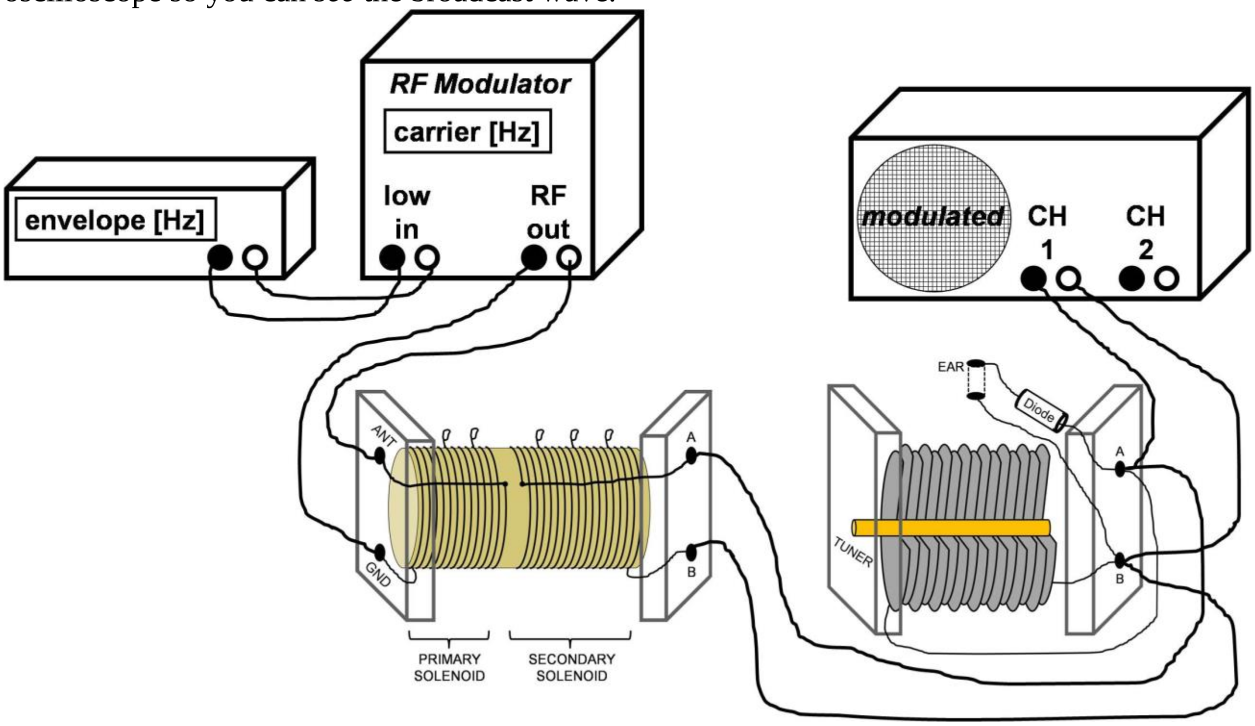
¿ 3-1

First determine the inductances $L_{primary}$ and $L_{secondary}$ of your solenoids using the methods from previous labs. In other words, for each solenoid create an RL circuit driven sinusoidally and monitor the voltage across the resistor and inductor as you vary the driving frequency. Use the appropriate equation to solve for the inductance L. Even with the 10 Ω resistor, you will need to use large driving frequencies as these inductances are very small. Hint: you may need to review section 5 of the week 10 lab. Note: your inductances should be between 1×10^{-5} and 10×10^{-5} [H].

¿ 3-2

Determine the capacitance of the capacitor using methods from a previous lab. Hint: the week 8 lab contained a few methods for doing this. Note: your capacitance should be between $1x10^{-11}$ and $10x10^{-11}$ [F]. Hint: when is the variable capacitor set to maximum capacitance, when the plates are in between each other or some other wrong answer?

Choose your favorite audio frequency wave to broadcast and a carrier wave initially 550 [kHz]. Instead of trying to hear the broadcast wave in the secondary circuit, send the output to your oscilloscope so you can *see* the broadcast wave.



¿ 3-3

The secondary circuit is supposed to be an RLC circuit with a resonance frequency. Where is the resistance and why would you want the resistance to be as low as possible?

¿ 3-4

Do you expect the secondary circuit to have a resonant frequency nearer to the audio frequency or the carrier frequency?

¿ 3-5

Calculate the resonant frequency $f_{resonance}$ of the secondary circuit.

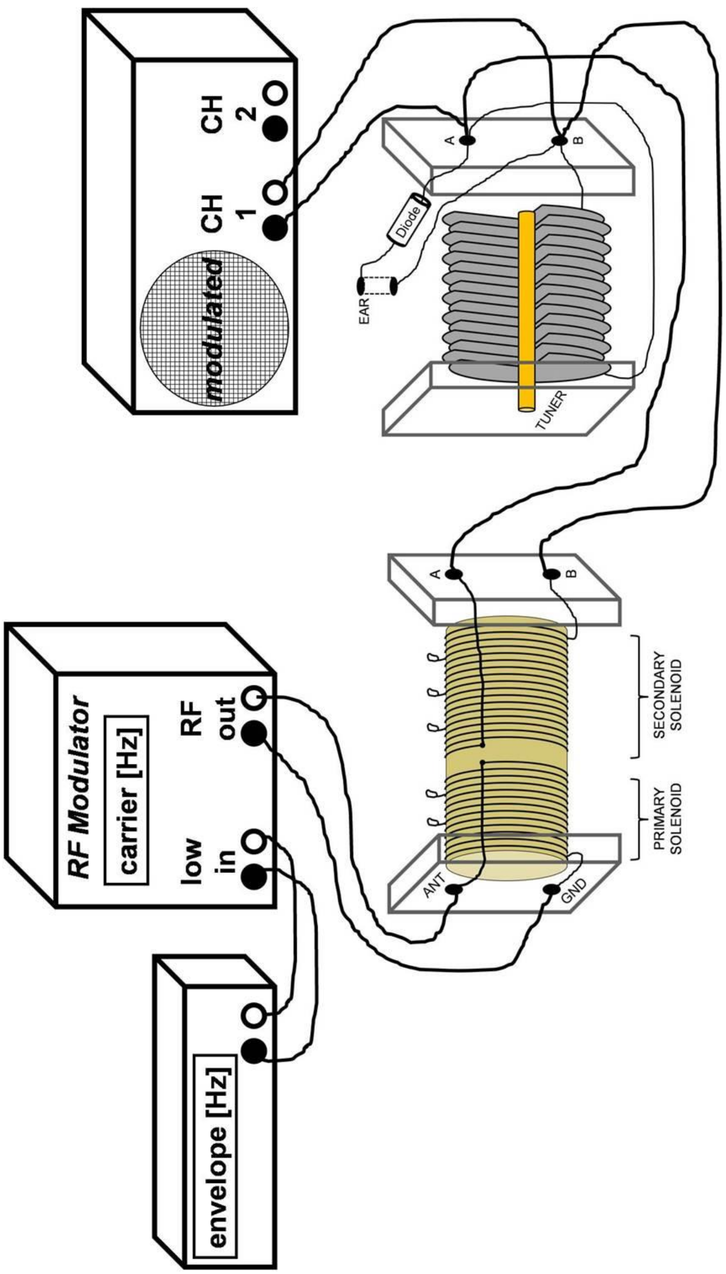
¿ 3-6

Adjust the carrier frequency until a maximum output voltage is determined on the oscilloscope. If it does not match your previous answer, get help. Explain why the carrier wave needs to be at the resonance frequency of the secondary circuit to maximize transmission of the modulated wave.

Now use your earphone to determine that maximum broadcast transmission occurs when the carrier wave is at the resonance of the secondary circuit.

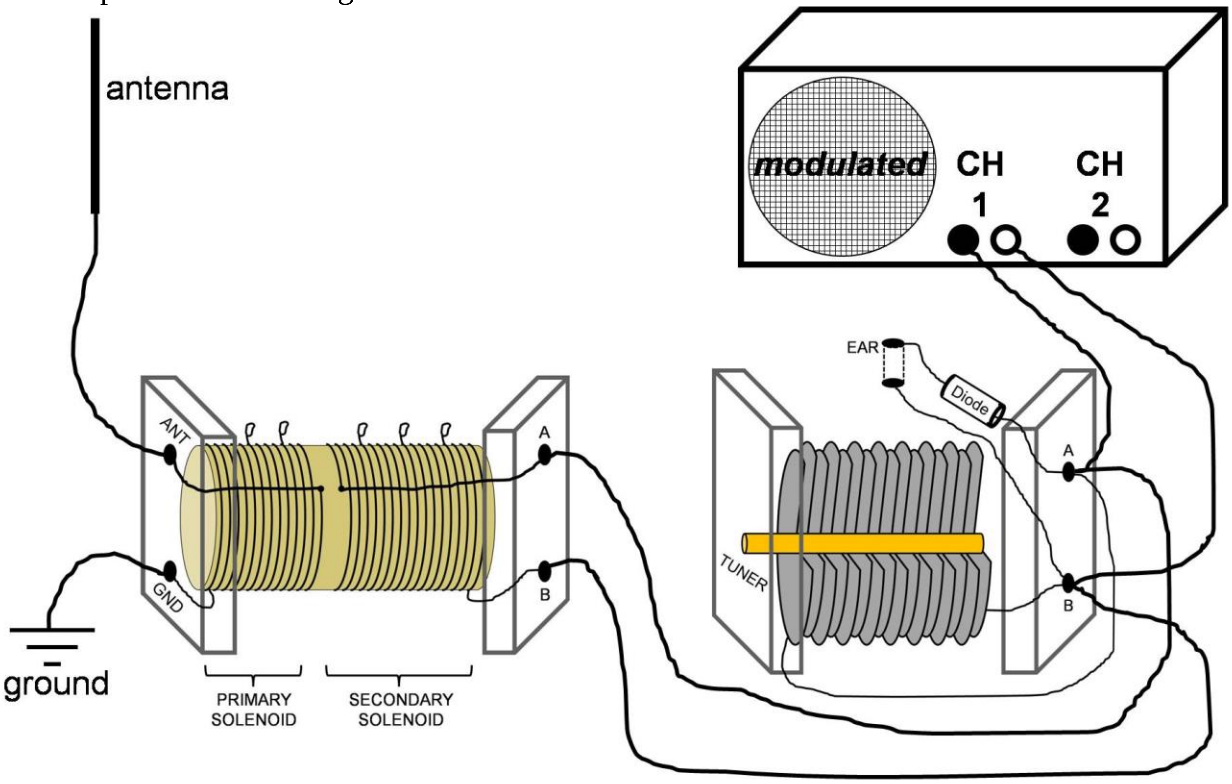
¿ 3-7

Write directly onto the figure below to completely explain how this compound circuit(s) works. You can use labels, text and arrows, and you do not need to write in complete sentences. Note: the oscilloscope has 2x10-12 [F] of capacitance, which is added in series (so sums to the other capacitor). This represents a 10% shift in the receiving circuit's capacitance. This can slightly alter the true resonant frequency that you are trying to measure (and in advanced lab, you would need to include this correction).



Section 4: authentic assessment - real radio wave reception

Now replace the function generator and RF modulator with a real antenna as shown:



Change the secondary solenoid inductance (4 options) and the capacitance (continuous adjustment) to find radio stations which cause the secondary circuit to have a maximum current (large voltage on the oscilloscope).

If you are uncomfortable having another student check your work, please ask your TA.

¿ 4-1
Record the kinds of stations you find.

"Yes, I have seen this student use an RLC circuit to find invisible sound-carrying electromagnetic waves. We then rocked out to some jamming tunes!"

Student Signature:____

Section 5: open-ended

Imagine that you are about to finish a very long semester of electricity and magnetism labs, and that all you have left to do is a single open-ended creative design question.

Using two of the large ~1 [H] solenoids stored in the corner of the room, create your own radio station. Specifically, find a way to transmit unmodulated sound waves created by the function generator from one solenoid *through the air* and listen to the sound using a second solenoid not connected in any way to the transmitting solenoid. Decide on what pitch to broadcast using theoretical predictions based on the numerical values of the components you have on hand. Points are awarded for loudness (not really). Hint: you do not need a carrier wave if you have large enough inductance.

At the following prompts, design an experiment to loudly broadcast *unmodulated* sound waves using two large solenoids among other electronics components. Then implement your experiment and record your observations.

You are allowed to "cheat" by talking to other groups for ideas, but are not allowed to "cheat" by just stating an answer you may already know, looking it up online or asking your TA.

Below you are given three prompts: **hypothesizing/planning, observations/data, calculations/conclusion.** Your job is to figure out the answer using these prompts as your problem-solving model. In the event that you should run out of time, you may not discover the correct answer, but you should make an attempt at each prompt. Grades are based on honest effort.

Your open-ended solution should probably include some of the following items: sketches of circuit diagrams, tables of data, calculations, recorded observations, random ideas, etc.

Write at the prompts on the following page.

Be sure to read the take home quiz before you leave!

¿ 5-1
hypothesizing/planning:

¿ 5-2
observations/data:

¿ 5-3
calculations/conclusion

Be sure to read the take home quiz right now!

I, the physics 241 laboratory TA, have examined this student's Weekly Activity pages and found them to be thoroughly completed.

! **TA signature: ____**

Have you found errors in the manual? Email me to get them fixed: MattLeone@gmail.com

Week 12 ~~Take-Home Quiz~~

Score:____5___ /5

¿ **THQ-1 (5-points)**

! **If you have finished the lab and have time remaining, you should review lab techniques for the lab practical:**

- **Using the DMM to measure:**
    - **voltage**
    - **current**
    - **resistance**
- **Building circuits from schematics:**
    - **series**
    - **parallel**
- **Operation of a DC power supply.**
- **Operation of a function generator:**
    - **square and sin waves**
    - **output frequency**
    - **output voltage amplitude**
    - **DC offset**
- **Oscilloscope general usage:**
    - **middle ground vs bottom ground setups**
    - **time scale**
    - **voltage scale**
    - **where V=0 is on screen**
    - **triggering**
    - **screen capture to USB**
    - **how to get it off French if done so by accident**
- **Oscilloscope measurements (V vs t):**
    - **frequency**
    - **period**
    - **voltage amplitude**
    - **current amplitude (via resistor voltage amplitude)**
- **Oscilloscope measurements (V_x vs V_y):**
    - **RLC resonance**
- **Tricky oscilloscope measurements:**
    - **capacitance**
    - **inductance**