Performance:
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Physics 212-7

Scopes and Transformers

NAME: ________________________________ ☐

STUDENT ID ________________________________ ☐

LAB PARTNER(S): ________________________________ ☐

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Check the box next to the name of the person to whose report your group's data will be attached.

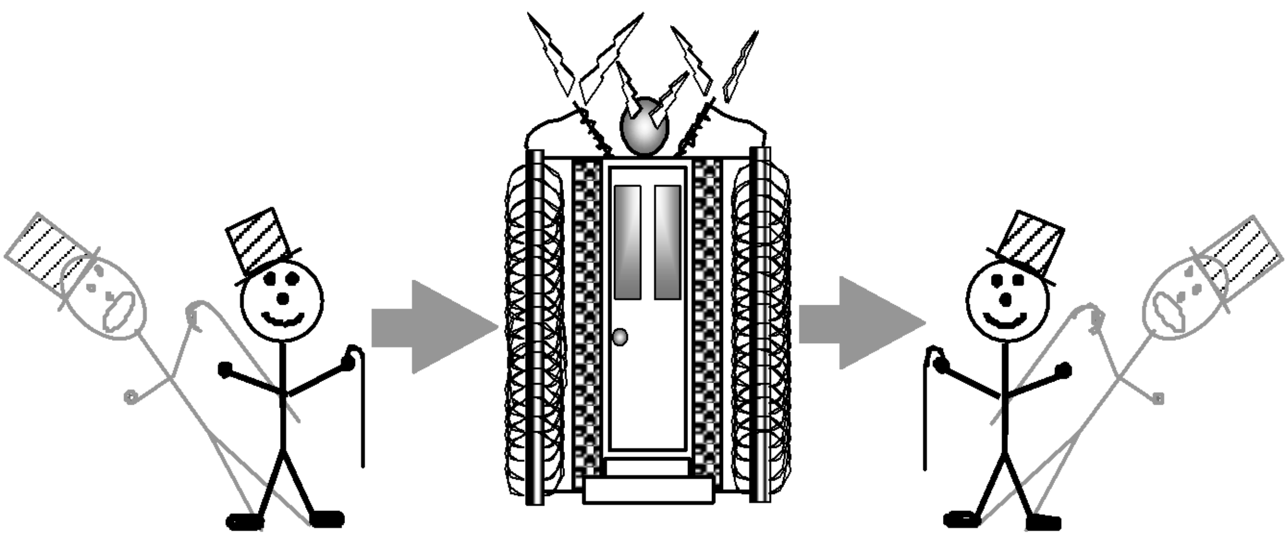
LAB SECTION: ________________________

INSTUCTOR: ________________________

DATE: ________________________

TABLE: ________________________

(YOU WILL BE TAKEN 3 POINTS IF TABLE IS VACANT.)



The Amazing Transformer!

Written by Beda, Hearn, Hertzog, Makins & Weissman, modified by Xia Huanxin for ZJUI

Physics Lab 212-7

Equipment List
Oscilloscope with BNC-to-dual banana jack adapters connected to CH1 and CH2 inputs
Function generator
One basin of banana plug cables per lab table
47 ohm resistor mounted on dual banana plugs
DMM
5 m long wires (2)
Tape (electrical)
White plastic tube, approximately 10 cm
Iron core to place inside tube
Differential Amplifier
2 DC power supplies per room to power differential amplifiers
Circuit board

Computer File List
Capstones file "212-07 Loop Test"

Physics Lab 212-7

Scopes and AC Signals

Investigation 1: Scopes

To find out
- How to use an oscilloscope

Preview
- Connect an oscilloscope to a function generator and see what happens
- Measure the characteristics of an AC signal

Activity 1 Oscilloscope Operation

One of the most common instruments used in examining dynamic circuits is the oscilloscope. In earlier labs, you used a computer program to plot the output of a voltage probe versus time. The oscilloscope performs a similar function but is a far superior device. For one thing, the computer program is too slow for the more interesting high-frequency circuits that we will soon investigate. For another, the oscilloscope offers a new functionality called *triggering* which is extremely important for observing and measuring oscillating, periodic signals.

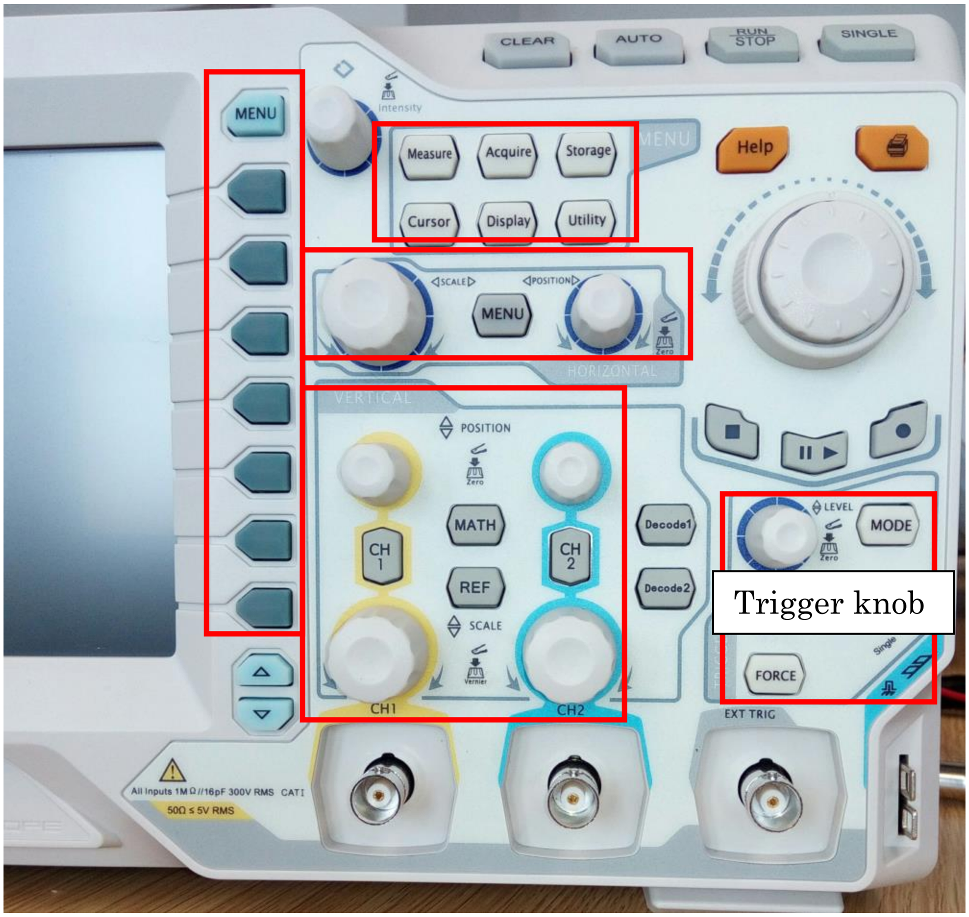


Figure 1. The oscilloscope

The front panel of the oscilloscope (or "scope" for short) is depicted in Figure 1. The screen is a liquid crystal panel on which a waveform is displayed. You can think of this waveform as a visual trace that travels across the screen horizontally, from left to right, at a constant rate.

At the bottom of the scope are three input plugs, two of which are labeled **CH1** and **CH2** (the CH stands for 'Channel'). If a signal is connected to either of these inputs, its voltage can be displayed as a function of time: as the oscilloscope trace proceeds from left to right across the screen, its *vertical* position at each moment is determined by the voltage appearing on the selected input plug. The signals attached to CH1 and CH2 can be made to appear or disappear from the display by toggling the **CH1** and **CH2** buttons. Study your oscilloscope and Figure 1 to become familiar with the controls.

Before we proceed any further with our investigation of the oscilloscope, let us have it display a signal. The function generator illustrated in Figure 2 allows you to produce AC voltage signals in a variety of shapes, frequencies, and amplitudes. With the function generator, you can choose frequencies between 1 μHz and 30 MHz, and amplitudes from 0 volts to about 10 volts.

Figure 2. The function generator

1. Set up the function generator to produce a signal.
   - Turn on the device using the power switch on its front panel.
   - Set the frequency of the function generator to **355 Hz** by using top blue button (the column of unlabeled buttons of the right-hand edge of the screen) and the digital panel.
   - Make sure the waveform is set to a sine wave.
   - Set the **AMPLITUDE** by using the second top blue button and the digital panel. Set the amplitude to **5 V (10 Vpp)**.

2. Connect the signal to the oscilloscope.
   - Connect the **CH1** of the function generator to the **CH1** input of the scope. Press the **Output1** button on the function generator.

3. Display the signal.
   - Turn on the oscilloscope and press the **AUTOSET** button. This causes the scope to set its internal parameters to reasonable values for the signal you have connected.
   - You should see a stable sinusoidal wave form on the scope's screen. If not, ask your instructor for assistance.

Try adjusting the **SCALE** knob, and see how the displayed signal and scale values change (the yellow words on the left bottom of the screen for vertical, white words on the top of the screen for horizontal). For example, if you set the **SCALE** knob so that the horizontal scale is 50 ms (m = 10^{-3}) per division, the horizontal time axis displays a total of 10 div x 50 ms/div, i.e., 0.5 seconds. If the **SCALE** knob is adjusted so that the vertical scale is 5 V per division, then a total vertical range of 40 V is obtained. Note the little arrow that appears along the left hand edge of the display. This arrow indicates the position of 0 V. You can move the signal up and down on the screen using the CH1 VERTICAL **POSITION** knob, and as you see, the little arrow moves as well.

Theory Calculation

If we set the oscilloscope display to 0.5 ms per division, how many horizontal divisions would one cycle of a 355 Hz signal occupy? (Hint: first calculate the period of a 355 Hz signal.)

4. Set the oscilloscope scales.
   - Adjust the horizontal **SCALE** knob until the information line at the bottom of the display indicates **500 µs**; this is the same as 0.5 ms per division.
   - Adjust the vertical **SCALE** knob until the signal is nicely displayed; note the information line indicates how many volts per vertical division for channel 1.

5. Measure the signal.
   - Measure the number of horizontal divisions (including fractions of a division) between two adjacent peaks of the waveform. For more accuracy, measure more than one cycle and divide by the number of cycles measured.

   Number of horizontal divisions ________ [divs/cycle]

Q1 How many horizontal divisions does one cycle of this signal occupy? Did the experimental results agree with your theoretical calculation? If not, record the reason why here.

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6. Set a random signal.
   - Cover the frequency display of the function generator and give the knob a few quick random turns.

7. Determine the frequency of the signal.
   - Using your knowledge of the time scale of the scope, convert the number of divisions measured above to time, and record this value (the period).

     Period ________ [sec/cycle]

   - Calculate the frequency of the signal.

     Frequency ________ [Hz] or [cycles/sec]

Q2 Does the measured frequency agree with the set frequency? If they do not agree well, go back over your measurements and reconcile all differences.

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8. Determine the peak-to-peak voltage difference of the signal.
   - Using your knowledge of the voltage scale of the scope and the vertical position of 0 V, determine the highest and lowest voltages achieved by the signal:

     Highest voltage achieved ________ [V]

     Lowest voltage achieved ________ [V]

   - The peak-to-peak voltage is defined as the total voltage range covered by the signal. Take the difference of the high and low voltages you found to determine this range:

     Peak-to-peak voltage difference ________ [V]

Fortunately, the digital scope you are using has the ability to make the above measurements for you. If you press the **MEASURE** button at the top of the scope, you will see a new menu of items appear in the text column to the right of the display. You can affect each of the five menu items by pressing the column of unlabeled buttons of the right-hand edge of the screen. The measurement menu enables you to make all simultaneous measurements of your signal by making the **Display All** is on.

9. Use the scope's measurement features to determine again the period, frequency, and peak-to-peak voltage of the signal.

   Period ________ [sec/cycle]

   Frequency ________ [Hz]

   Peak-to-peak voltage difference ________ [V]

Q3 Do the scope's measured values agree with the ones you determined before?

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It is important to understand the concept of oscilloscope *triggering*, which is the key to a stable display of a periodic waveform. The scope continuously samples the input signal and has to be told at which point in time to begin its left-to-right display. What it does is wait for the input voltage to achieve a certain *trigger threshold*; when this trigger voltage is reached, the scope displays a snapshot of the signal on screen, capturing a window of times both *before and after* the trigger occurred. It then waits for a small amount of *holdoff time* before looking for another trigger point in the input signal and updating the display with a new snapshot of data. Each set of data appears on screen with the trigger point at the *same* horizontal location. The trigger point thus provides a time reference for the display, much as the 0 V position serves as a voltage reference.

A small arrow at the top edge of the graph indicates the horizontal position of the trigger point. The trigger threshold voltage is indicated by another small arrow, along the right-hand edge of the graph, and its value is printed on the right hand side of the information line. You can adjust this voltage using the **TRIGGER LEVEL** knob. Try changing it. You will see that at the trigger point in *time*, the signal height is always at the trigger voltage. The result is that successive snapshots of a *periodic* signal will be displayed right on top of each other, making a stable waveform.

Q4 Adjust the trigger voltage so that it is *larger* than the peak signal voltage. What happens to the display? Can you explain this behavior?

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Now that we know how to examine the signals that we put into circuits, we can use that ability to investigate the behavior of coils of wires.

10. Examine other waveforms.
    - Set the function generator to output different types of signals such as a square or a triangular wave.

Q5 Describe the other types of output waveforms. When might these be used instead of a sinusoidal waveform?

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Investigation 2: Transformers

To find out

- How the time-varying current in a coil can cause a time-varying magnetic field that, in turn, causes a time-varying current in a second (and unconnected) coil
- How the number of loops in the secondary coil affects the output voltage
- What happens when you fill the center of a coil with iron?

Preview

- Build a coil around a cylinder and connect it to your AC function generator
- Wrap a second coil around the same cylinder and measure the induced voltage
- Quantitatively investigate the relationship between voltage and the number of turns on the secondary coil
- Investigate the impact of inserting a core with a high magnetic permeability into the coil
- Examine the shape and phase of the induced voltage signal across the secondary coil

Activity 2 Loop to Loop Interactions

In Lab 5 you explored how a current in a wire generates a magnetic field in the region around the wire. You also found that if the wire is wound into a coil, the field is at its maximum at the center of the coil.

In Lab 6 you saw that a changing magnetic field passing through a coil induces an electric current in that coil. Recall the oscillating bar magnet, and the induced current that resulted.

Thus, a current can generate a magnetic field, and a changing magnetic field can generate a current. Suppose you bring two coils together so that their faces are adjacent, as shown in Figure 3. Suppose you then apply an oscillating electrical current to one of the coils with the function generator. What will the voltage across the second coil be as a function of time?

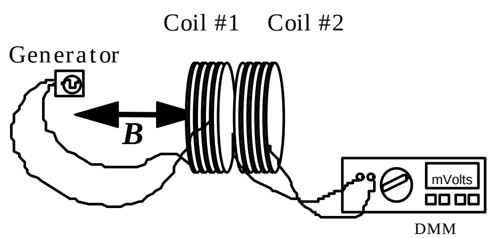


Figure 3. Two coils, wound around the same central cylinder (not shown)

1. Try this experiment.

   - Completely wind one of the two long (5 m) wires around the small tube (packed as closely as you can, **looping the wire on top of itself**). Leave about 15 cm of the wire unwound at both ends so that you can connect the coil to a circuit. Fix a bit of tape to hold the wires in place. Make sure they are wound tightly.

2. Set up the circuit on the *circuit* board.
   - Construct a series circuit containing the following items: the primary coil, the function generator, and a 47 Ω resistor (you can choose not to use the resistor, I think it's useless except for safety).
   - Make sure that the **GND** cable (black tip for BNC-banana cable) from the generator is on the side of the circuit closest to the coil. (The reason for this will only become clear in the final activity.)
   - Make a note to the side of Figure 4 of the direction of the winding and the direction of the flow of positive current through the primary coil for the connections you have just made.

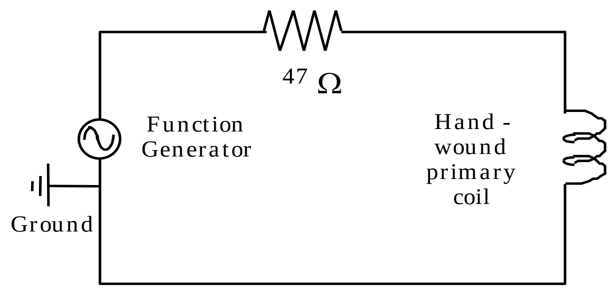
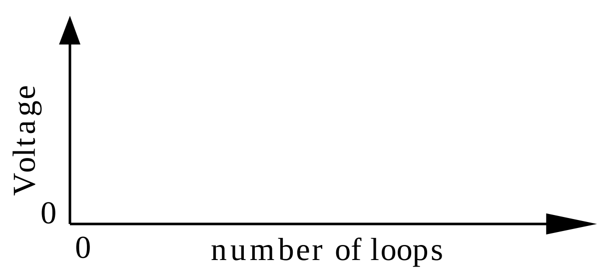


Figure 4. Circuit to drive the primary coil

3. Adjust your circuit.
   - Set the frequency of the function generator to about 90 kHz (you should confirm the exact values of the frequency, since the values affect the results). Set the **AMPLITUDE** of the signal around 10 V (Vpp = 20 V. if you think it's not safe, use a lower voltage.).

Prediction

In the next steps, you will wind a secondary coil **right over** the primary coil, so that the magnetic flux that goes through the primary loop will also go through the secondary loop as well. Using what you have learned about induced EMFs in wire loops, sketch the expected voltage across the secondary coil as a function of the *number of loops* in the secondary coil.



4. Now add the secondary coil a loop at a time.
    - First connect both ends of the second 5-meter long wire into two different shunts on the *circuit* board, close to the place where the primary coil is resting.
    - Connect this second (not yet wound) wire to the Digital Multimeter (DMM) or oscilloscope.
    - Set the DMM to read **AC V** (it does not work well above 300 mV on the mV scale) and verify that there is almost no voltage drop across the wire just draped on the board. (On the DMM's dial, AC quantities are those with the sine wave above them.) This reading, of course, corresponds to the null case of a coil with 0 loops. Record this value in Table 1.

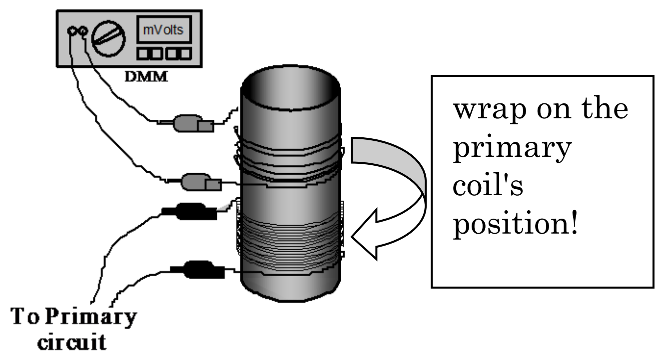


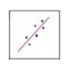
Figure 5. Wrapping the secondary coil

Note that in the next step, you should wind the secondary coil in the same direction as the primary coil and make connections to the DMM so that positive current flows through both the primary and secondary coils in the same direction.

5. Measure induced voltage versus number of loops in the secondary coil.
    - Turn the primary coil and cylinder upright (as shown in Figure 5, actually you'd better lay it on the table). Make sure it is stable, since it should not be moved during the measurements.
    - Prepare to make the secondary windings and record the voltage (as given by the DMM), which is affected by the frequency of the signal, so fix the frequency when you are doing the experiment.
    - Loop the wire around the cylinder once to the point where your fingers are pinching it to the cylinder. This corresponds to one complete loop of the secondary coil. While keeping the rest of the wire out of the way, record the induced voltage in Table 1.
    - Complete Table 1 by winding the secondary coil and recording the induced voltages. Make sure you wrap it tightly right next to (or even on top of) the primary and that you always stop at the point where your fingers are still pinching the beginning of the wire. If you think 1-20 loops data is not enough, record something else.

Secondary Loops	Induced Voltage [V]	If you could not wind 20 loops, you could wind 18, 12 loops and so on, so that your data points won’t be too less.	Secondary Loops (use No. of loops you like)	Induced Voltage [V]
0				
1				
5				
10				
15				
20				

Table 1. Secondary loops and induced voltage data

6. Analyze your data.
   - Build the file “212-07 Loop Test” in the “212 lab files” folder on the desktop to start up the *Capstone* program.
   - A data set table along with a graph will appear. Enter your data from Table 1 by clicking on and typing in the appropriate boxes. The graph will automatically be drawn as you enter your data. Adjust the scale if necessary.
   - Click on the curve fit button  on the toolbar.
   - Select “mx + b” (Linear) in the dialog box that appears (as in Figure 6).
   - You should now see a best fit line through your data points and the formula of the fit.

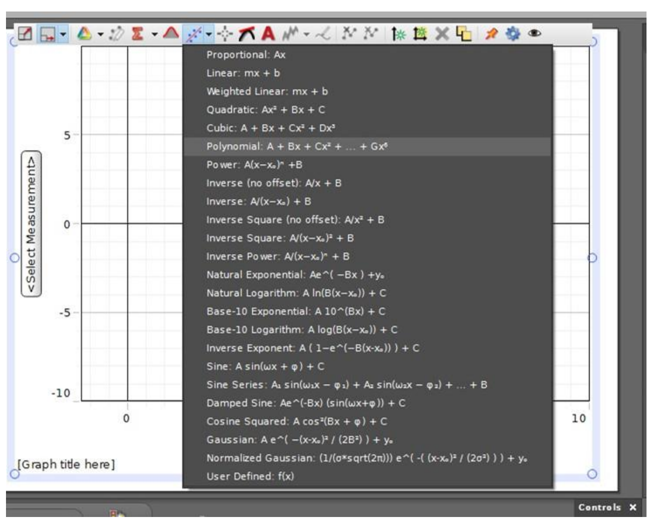


Figure 6. Fitting dialogue box

7. Print/Send your graph.
   - Adjust your graph if necessary to get a good display.
   - **Print/Send...** a copy of your results.

Q6 From the results of this fit, what do you conclude qualitatively about the relationship between the number of loops in the secondary coil and the voltage induced across the secondary coil?

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Q7 How well did your experimental data match your prediction?

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Q8 What practical purpose could you find for the device you have just made?

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Q9 Suppose you used *direct current* (DC) as the source for the primary coil. Would the results of the experiment be the same? Explain why or why not.

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In a moment you will be placing an iron core through your coils. The iron is a soft ferromagnetic material. As you saw in an earlier lab, this means the material will "draw in" the field lines and can even enhance the field strength. This is described by the fact that the magnetic permeability μ is much greater than that of empty space μ_o. Although a transformer core is typically made of laminated sheets of iron, you will actually use a group of iron nails put together, giving the same effect.

Note: the signal frequency will affect the results. Normally, at high frequency, the iron rod may reduce the transformed voltage. While at low frequency, it will enlarge the voltage.

Prediction Remembering the presence of the constant μ_o in the magnetic field equations ($B = \mu_o nI$ for the magnetic field in a solenoid), how will the voltage in the secondary circuit change when the iron core is placed through the coils?

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8. Add a core.
   - Place the iron core through both coils and see what happens to the voltage across the secondary coil.

Q10 Did the effect of the iron core on the secondary circuit agree with your prediction? Give the values of the induced voltage with and without the core?

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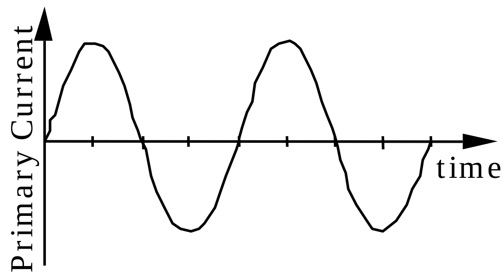
Activity 3 Phases

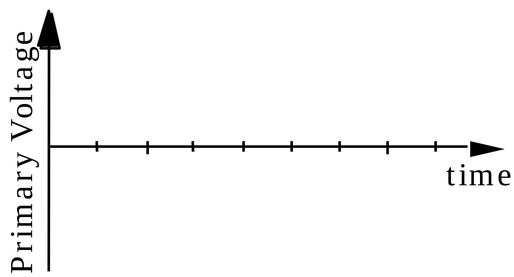
The circuit you have built consists of a resistor in series with an inductor (the primary coil). The coupled combination of the primary and secondary coils forms a transformer. Our final activity investigates how the currents flowing through these various circuit elements are related to the voltages across them.

Theory Calculation

The current provided by the function generator through the primary coil looks like this:



The primary coil is an *inductor*, and a changing current through an inductor generates an induced voltage across its terminals. Consider the current in the primary coil as depicted above. What does the voltage across the primary coil look like? (Neglect the resistance of the primary coil.) Write down an expression for the voltage across an inductor to help you figure out its behavior.



$V_{inductor}$= ___________

To test the analysis you have just made, you first need to observe the current flowing through the primary circuit, as a function of time. The oscilloscope is the right tool for looking at waveforms like this, but it measures voltage rather than current. However, Ohm's Law tells us that the voltage drop across a *resistor* is proportional to current. Monitoring this voltage with our scope will thus tell you how the current is behaving. You next need to compare this waveform with that of the voltage induced on the secondary coil. Your scope makes this comparison easy since the two input channels of the scope allow you to display both waveforms simultaneously. Since the scope's triggering system is tied to one of the signals, the oscilloscope always begins its trace at the same point in the circuit's voltage cycle and this synchronizes the display of the two signals. You can directly observe any phase differences between the waveform of the current in the primary coil and that of the induced EMF in the primary coil.

Before you perform your measurement, think about how you will connect the oscilloscope to your circuit. You are planning to have the scope measure the voltage drop across the resistor. That means connecting the scope leads to either side of the resistor. *However one of the scope leads is always connected to ground*, a ground supplied internally in the scope itself. If you make the connection as planned, you will be introducing a second ground point into the middle of the circuit! In order to avoid this dilemma, you will first place a small differential amplifier unit across the resistor, and connect your scope leads to the amplifier output as shown in Figure 7 below. The amplifier will isolate Channel 1's earth ground connection from the circuit. You do not need to know the details of how the amplifier operates, but it is important to remember that an oscilloscope connection will always introduce a ground point into a circuit.

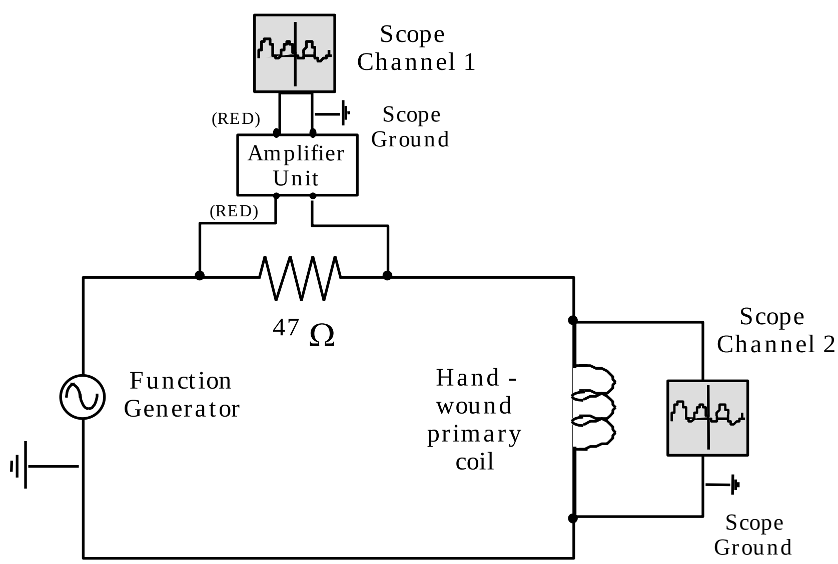


Figure 7.1 Scope connections for measuring the current through the circuit and the voltage across the primary coil

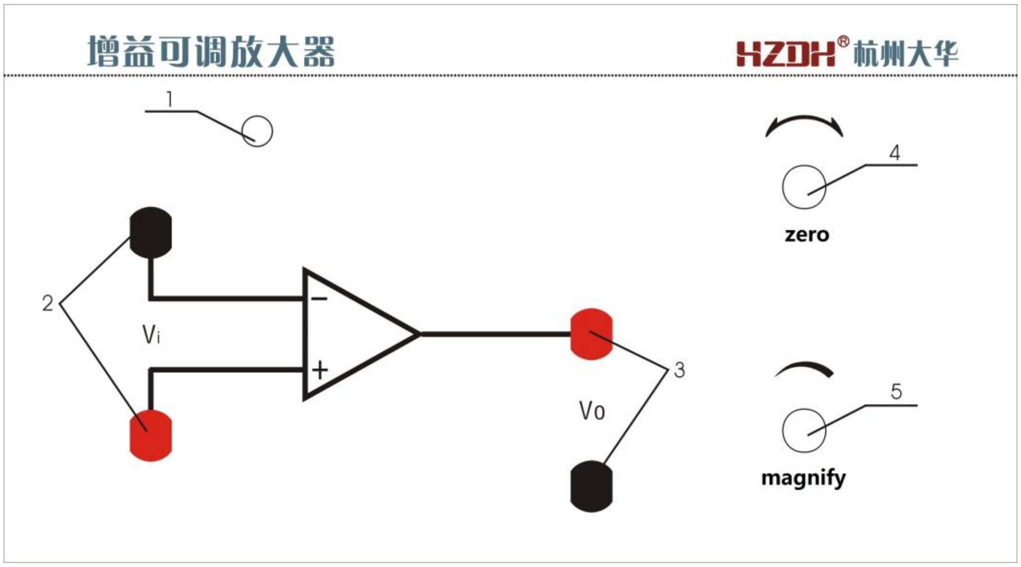


Figure 7.2 the differential amplifier

Note for differential amplifier: amplification: 0~100 times. Input: 0~8V, frequency: <50kHz.

1. Monitor the voltage across the *resistor* using channel 1. This will tell us the phase of the *current* in the circuit.
   - Locate the amplifier unit. It is a small box with two input and two output ports. It also has a **POWER** connection consisting of three leads, which should be connected to banana jacks on the wall near your station. If they are not, ask your instructor for assistance.
   - Connect the **INPUT** ports of the amplifier to each side of the resistor, as shown in Figure 7 (red＋, black－). Connect the function generator side of the resistor to the positive (red) input jack on the amplifier.
   - Connect channel 1 of the oscilloscope to the **OUTPUT** ports of the amplifier. Be sure to connect the red output jack to the red input jack of the scope.

2. Monitor the voltage across the *primary coil* using channel 2.
   - Connect the leads from **CH2** of the oscilloscope so that they measure the voltage across the primary coil, as in Figure 7. Make sure that the ground cable from the oscilloscope is on the same side of the coil as the ground cable from the function generator. (In this way, the two grounds are connected together).
   - Push the **CH2** button to display the new signal.
   - Adjust the scope (**Autoset**) so that it displays a clear trace of both signals. You might want to adjust the vertical positions of the traces to can compare them more easily.

Q11 Did your observations agree with the waveform you drew in the theory calculation? If not, what did you observe?

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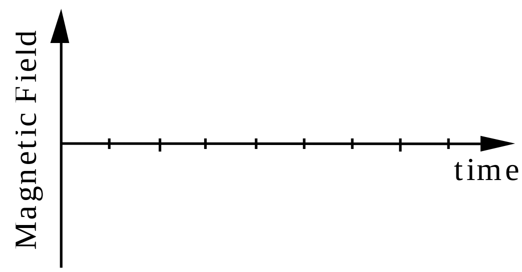
This phase difference between the current in a circuit and the voltage across an inductor is an important characteristic of inductors.

Next we will investigate the time dependence of the voltage across the *secondary* coil. This induced voltage is caused by the magnetic field that is generated in the primary coil, and shared by the secondary coil.

Theory Calculation

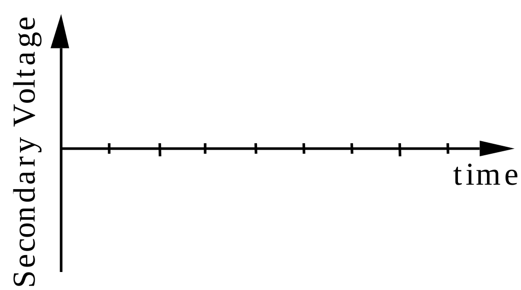
The primary current creates a *magnetic field* in the center of the primary coil. Sketch this field as a function of time. Write down the formula for the field inside a solenoid beside the graph.



$B_{solenoid}$ = ____________

Theory Calculation

The magnetic field you have just sketched induces a *voltage* in the *secondary coil* of the transformer. Sketch the induced voltage as a function of time. Hint: first write down the formula for the induced EMF in the secondary coil.



$EMF_{induced}$ = ____________

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3. Examine the voltage across the *secondary* coil using channel 2.
   - Connect channel 2 of the oscilloscope across the secondary coil instead of the primary coil. Again make sure that the ground cable from the oscilloscope is on the same side of the coil as the ground line from the function generator.
   - Adjust the scope so that you can compare the two waveforms. Channel 1 should still be monitoring the current in the primary circuit.

Q12 Do your observations agree with the waveform you drew in the theory calculation? What is the phase shift between the primary current and the induced EMF? Which one leads the other?

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CLEAN UP CHECKLIST

- ☐ Quit any and all computer programs. Do not turn off the computer.
- ☐ Reset the oscilloscope and function generator to the settings at the beginning of the lab.
- ☐ Turn off the oscilloscope, function generator, and DMMs.
- ☐ Collect the paper onto which data was taken (and annotated) and attach them to one of the lab reports.
- ☐ Unplug all the wires and clean off the *circuit* board. Make your setup look neat for the next group.
- ☐ Staple everything together, make sure you have answered all the questions and done all the activities, make sure the first page is completed with lab partners' names and check boxes. Hand in your work before you leave.