

Power Amplifier

Order Code PAMP

The Vernier Power Amplifier allows you to drive loads with ± 10 V and currents up to 1 A. It works with any input waveform, including DC, sine, square, triangle, and sawtooth waveforms. The Power Amplifier can drive a variety of loads, such as speakers, lamps, small DC motors, and RLC circuits. These circuits typically draw more power than the signal source can deliver. The Power Amplifier makes it possible to drive these heavy loads.

- Works with LabQuest, LabPro, and SensorDAQ. Can also be used with most function generators.
- Can provide a steady, linearly controlled DC output for driving loads like DC motors, and precise AC waveforms for driving things like speakers.
- Current limited to protect against overload and shorting.
- Current monitor function allows you to log real-time load current.
- Class A-B Push-Pull Amplifier provides low distortion.

What is included with the Power Amplifier?

The Power Amplifier comes in box containing the following:

- Power Amplifier unit
- Power Supply
- Audio/LabQuest cable
- Current sense and LabPro input cable
- This booklet



Note: This product is to be used for educational purposes only. It is not appropriate for industrial, medical, research, or commercial applications.

What is the Power Amplifier used for?

Some circuits require more current than can be delivered by the output of LabQuest, LabPro, or other signal sources. The Vernier Power Amplifier amplifies an existing signal so that it can be used to drive a speaker, a coil, an RLC circuit, a motor, a resistor for heating experiments, electrolysis apparatus or other experimental apparatus. A list of suggested activities is found at the end of this booklet.



How the Power Amplifier Works

The Vernier Power Amplifier is a DC-coupled amplifier capable of delivering 1 A at 10 V. In many applications, the amplifier will simply increase the amplitude of the input signal. This is true for audio-frequency applications.

In other applications a much lower frequency output is desired. Since many audio sources are not DC-coupled, the Power Amplifier includes a novel pulse-width-modulated (PWM) input to create extremely low-frequency waveforms and DC offsets. The output of the PWM section is added to the input of the amplifier. For example, an experiment might demand a signal of a few hertz. A typical signal generator cannot create an output at that frequency, but the Power Amplifier can generate such a waveform when driven with the correct PWM signal.

Finally, a current-sensing resistor allows monitoring of the output current. This signal is available at the current-sense output connector. When this output is connected to an analog input of a LabQuest or LabPro, a calibrated, autoID current sensor is detected by software.

What you need to use the Power Amplifier

The Power Amplifier requires an input signal source to function; it does not create any waveforms without input. Most commonly it is used with a Vernier LabQuest, but it can also be used with a Vernier LabPro, or with any AC or DC signal source that does not exceed 12 V. The Power Amplifier provides both current and voltage gain so that larger loads can be driven than is possible with the signal source alone. The output of the Power Amplifier can be connected to a speaker, a test circuit such as an RLC circuit, or any device that requires a controlled AC or DC signal.

A current sense port allows monitoring of the current through the output stage of the Power Amplifier. Connect this to a LabQuest or LabPro analog input.

Connections on the Power Amplifier

The Power Amplifier has several connectors used to control and monitor the output. The primary input is the 3.5 mm audio-style port on the back panel. The secondary input is the BTA receptacle on the back panel that serves as both an input from LabPro and as a current sense output. The two output terminals on the front panel are used to connect the load circuit. The negative (black) terminal is connected to ground via a 0.1-ohm resistor. The red terminal can range between ± 10 V.



The front of the Power Amplifier, showing the output terminals, the Power Indicator LED, and the On/Off Switch



The back of the Power Amplifier, showing the Power Connector, the Audio/LabQuest Connector, and the BTA Connector.

Use Power Amplifier with LabQuest App



Power Amplifier connected to a LabQuest audio out connector

The Power Amplifier requires a LabQuest with 1.2 or newer system software. LabQuest 1.3 or newer is recommended. Launch the LabQuest Power Amplifier App by selecting it in the home menu. If it is not present in the home menu, see www.vernier.com/labquest/updates/ for information on updating your LabQuest.

The Power Amplifier App includes waveform options of sine, triangle, square wave, ramp up, and ramp down and DC.

For the sine, square wave, ramp and triangle waveforms, you can set the frequency with the keyboard, with the up and down arrow keys, and with the slider. The slider provides an easy way to change the frequency: tap to the right or left of the slider control to double the current setting, or drag the control to change the frequency smoothly. The V_{DC} control is only used for the DC waveform.

The Power Amplifier App can be run simultaneously with LabQuest App. For example, the current sense output of the Power Amplifier is used with the LabQuest App, while the control of the Power Amplifier is retained by the Power Amplifier App. To switch between them, choose each by name in the LabQuest home menu. This way you can control the output of the Power Amplifier while simultaneously recording the current in LabQuest App.

Use Power Amplifier with LabQuest and Logger Pro



Power Amplifier connected to a LabQuest and a computer

Control of the Power Amplifier from the computer requires Logger Pro 3.8 and LabQuest 1.3 (or newer versions).



LabQuest sensors dialog with Power Amplifier controls

The Power Amplifier control dialog is accessed from the LabQuest sensors dialog. Click the LabQuest icon in the toolbar to summon this dialog. Next, click on the Power Amplifier button. This will display the Power Amplifier controls. You can adjust Power Amplifier output during data collection by leaving this window open. For the sine, square wave, ramp and triangle waveforms, you can set the frequency with the keyboard, with the X2 and $\div 2$ buttons, and with the slider. The V_{DC} control is only used for the DC waveform.

Use Power Amplifier with LabPro and Logger Pro

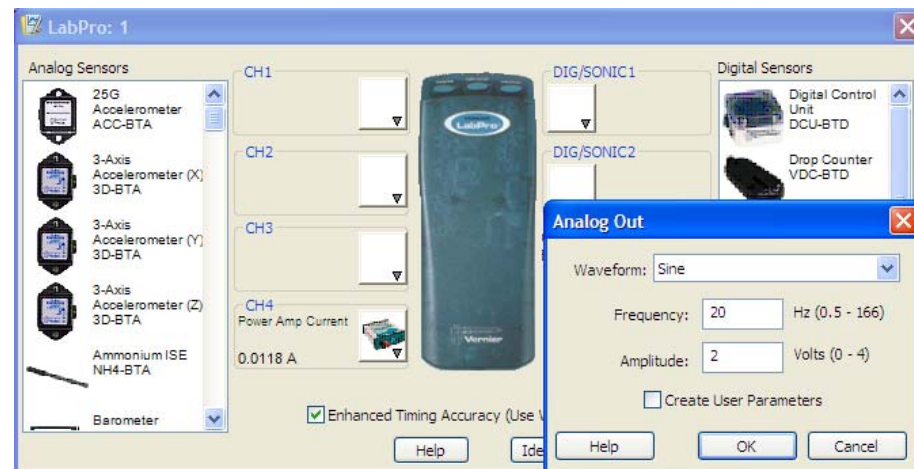


Power Amplifier connected via the BTA cable to CH 4 of a LabPro

LabPro includes an analog-output function for generating low-frequency waveforms and DC offsets. The Power Amplifier can be used to amplify that output so that larger loads can be used. The analog output is available only on CH4 of LabPro.

Follow these steps to set up Logger Pro for use with the Power Amplifier:

- Connect the supplied BTA cable between the current sense output on the Power Amplifier and CH4 on LabPro.
- Connect any other sensors, such as voltage probes, to other inputs.
- Launch Logger Pro 3. Logger Pro will detect the current sensor of the Power Amplifier.
- Enable analog out by choosing Set Up Sensors ► LabPro from the Experiment menu. Click the CH4 menu in the resulting sensors dialog, and select Analog Out. Select a waveform, frequency, and amplitude. A gain of a factor of two is applied to the LabPro input, so that a LabPro output of 1 V results in a Power Amplifier output of 2 V.
- Close the dialog boxes.
- Set data collection rate and duration as needed.



LabPro sensors dialog with the analog output controls

Hint: If you enable user parameters in this dialog, the frequency and amplitude will be controllable by Parameter Controls. Choose Parameter Controls from the Insert menu to add these to your Logger Pro session. These controls will let you modify the frequency and amplitude during data collection, without going through the Analog Out dialog box.

Use Power Amplifier with Function Generator

The Vernier Power Amplifier can be used with most function generators. Connect the function generator to the 3.5 mm input using a mono connector only. A stereo connector may enable the PWM features of the Power Amplifier with undesirable results. When used with this input, the Power Amplifier applies a factor of ten gain to the input signal. The input is DC-coupled.



Connect a function generator to the Power Amplifier with a mono audio cord

Use Power Amplifier with SensorDAQ and LabVIEW



SensorDAQ is a lab interface for use with LabVIEW and engineering education. The analog output on SensorDAQ is on the screw terminal connections. It has a 0 to 5 volt output. There are two ways to make the connection from SensorDAQ to the Power Amplifier:

Make the connection via the BTA connector. Use a cable with a BTA connector on one end and bare wire on the other. Vernier sells this cable as order code CB-BTA. We will send you one cable per PAMP on request to info@vernier.com. Pin 1 on the BTA plug (the farthest from the tab) should be wired to the #9 screw terminal (analog out) on the SensorDAQ. Pin 2 on the BTA plug base of the connector should be wired to the #10 screw terminal (ground). Using this connection, the Power Amplifier will increase the voltage by a factor of 2. The advantage of this method of connection is better resolution on the analog output, since you are using the full range of the SensorDAQ analog output. A sample VI showing how to control the SensorDAQ analog output is included in the SensorDAQ Examples folder.

Make the connection via the 3.5 mm input using a mono connector. The tip of the connector should be wired to the #9 screw terminal (analog out) on the SensorDAQ.

The base of the connector should be wired to the #10 screw terminal (ground). Using this connection, the Power Amplifier will increase the voltage by a factor of 10. This means that you should only use SensorDAQ analog output settings up to one volt. This method allows you to simultaneously use the BTA connector on the Power Amplifier to connect to the SensorDAQ. You can then read the current sensor built into the Power Amplifier with SensorDAQ.



SensorDAQ connection to screw terminals and mono plug

Technical Details of Power Amplifier Operation

LabQuest Audio (3.5 mm connector) Input

- DC coupled between tip and sleeve of 3-conductor connector
- Frequency range DC to 15 kHz.
- Overall gain 10X
- Input impedance 10 k Ω .
- If using this input with a source other than LabQuest, use a mono cable so the PWM input on the ring will be grounded.

LabQuest Pulse Width Modulation Input

- Pulse Width Modulation (PWM) signal input between ring and sleeve of 3.5 mm connector.
- This is used for producing a DC offset or pure DC output with a LabQuest.
- This input is designed for the LabQuest PWM output only.

BTA Analog Input

- DC coupled and has a total gain of 2X to the output.
- Input impedance is 50 k Ω .
- Maximum input $\pm 12V$ without damage.
- This input is on pin 1, or the yellow wire, of the BTA Cable (see www.vernier.com/probes/specs/pinout.html for details)

BTA Current Sensing

- There is a 0.1-ohm resistor between the black terminal and ground. Current measurements are based on the voltage drop across this resistor.

Input DC Blocking

Some signal sources contain an undesirable DC offset. Since the Power Amplifier is DC-coupled in order to produce DC signals, any offset will be amplified alongside an AC waveform. To block unwanted DC signals, add a 1- μF non-polarized capacitor in series to the input.

Output Circuit

The Vernier Power Amplifier has an analog Class A/B push pull output section that will drive currents up to 1 A at frequencies from DC to over 10KHz. It has a soft current limit, intended as a safety net. Do not connect the Power Amplifier to a load that would require more than 1 A. Load current can be calculated by dividing the output voltage by the resistance of the load or dividing the wattage of the load by the operating voltage.

The output is bipolar but not differential or balanced. In other words, the black terminal is at approximately zero volts and the red swings positive and negative. A current sense resistor of 0.1Ω is between the black terminal and true ground.

Grounding Concerns

The unit is not grounded through the external power connections, so any external voltage source applied to the black terminal will find its way back to ground through the LabQuest or LabPro. This is not of any concern when driving floating loads (a load with only two leads and each connected ONLY to the Power Amplifier terminals.)

Despite the ungrounded output, take care when driving any load that is part of another electrical system, such as a robotic device or computer peripheral. If you have any doubts about ground loops, connect the black Power Amplifier terminal to your system ground. The Power Amplifier current sensor may give false readings with two ground paths but this connection method reduces the chances of any damage to your LabQuest or LabPro. Running the LabQuest on battery power (and not connected to a computer host) also reduces the chance of ground currents returning through the LabQuest. Any time your LabQuest or LabPro unit is connected to a computer with a USB cable it is connected to that computer's ground which, in turn, is probably grounded to the building's power system ground through the AC plug.

Stability

The Power Amplifier output section uses distributed feedback to achieve accuracy and DC stability. The feedback circuits have been designed to be stable with a wide range of loads but highly reactive loads with very low resistance may present a high enough Q to incite oscillation. When driving reactive loads you should always have at least a few ohms in series. This is also good protection against an over-current condition.

Current Sensor Output

The Power Amplifier contains a current sensor that can be read by a LabQuest, LabPro, SensorDAQ, or Go!Link. Connect the supplied BTA cable between the Power Amplifier and the interface. When the Power Amplifier is turned on, the current sensor will be detected by the data-collection software. The bandwidth of the current sensor is not as high as the amplifier since it is a trade-off between noise and several other factors.

For the current sensor to read correctly all of the current that passes through the load must return through the black terminal. For this reason, loads that have a ground connection will not allow reliable current measurements. In particular, do not use a simple 10-V Voltage Probe, VP-BTA, with the Current Sensor, because the Voltage

Probe will ground part of the circuit. Instead, use a Differential Voltage Probe, DVP-BTA.

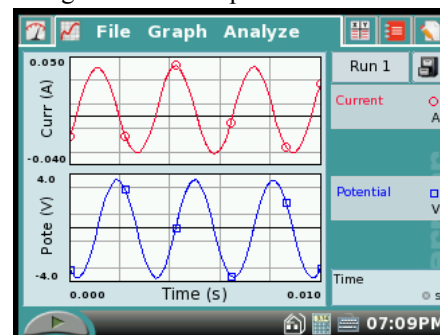
Suggested Accessories

Vernier LabQuest (LABQ), Vernier LabPro, or SensorDAQ
Logger *Pro* (LP)
Power Amplifier Speaker Accessory (PASS-PAMP)

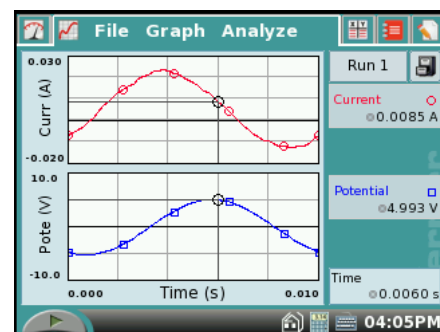
Sample Experiments

RC, RL and RLC Circuits

Construct a series circuit of a resistor, capacitor and inductor. Drive the circuit with a sine wave, and measure the potential across various components. Study the phase and amplitude relationships between current and potential across components. The current and voltage graphs below were made with an RC circuit with a $4.7 \mu\text{F}$ capacitor, and a 100Ω resistor. The frequency of the Power Amplifier was set to 319 Hz because that was calculated as the frequency where the current should be 45° out of phase with the voltage across the capacitor.



The current and voltage graphs below were made with an RLC circuit with a 0.067 H inductor, a $4.7 \mu\text{F}$ capacitor, and a 100Ω resistor.



The calculations using the component values would predict that the current would lead the voltage by 70 degrees and the result matches this well.

Non-ohmic light bulb and Ohm's Law

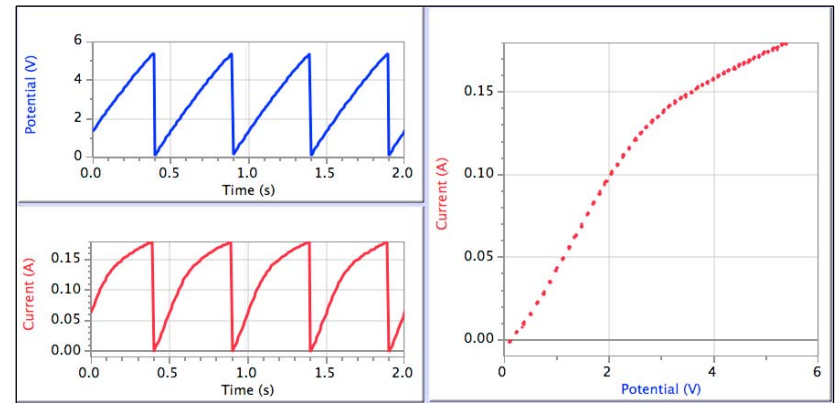
The ramp waveform can be used to quickly measure the I-V (current-voltage) characteristics of circuit components.



Connect the output of the Power Amplifier across a device such as a light bulb or resistor. Use Logger *Pro* or LabQuest to plot the current through the component versus the potential across it. It is particularly interesting to compare a light bulb to a resistor.



Here are results using a #50 lamp. Note that the current vs. time graph does not match the potential vs. time graph. At the right is a graph of the current vs. potential, showing the non-linear (non-ohmic) behavior of the lamp.



Resonance Experiments Using the Power Amplifier Accessory Speaker (PAAS-PAMP)

Vernier sells an accessory speaker for use with the Power Amplifier (order code PAAS-PAMP). Below are some experiments that can be done using this speaker. These experiments can be done with many different speakers. The advantages of the Vernier Power Amplifier Speaker Accessory are that has a mounting post on the speaker and the speaker cone will move through a larger distance than most.

Observing standing waves and harmonics

1. Place the speaker on the table and connect the Power Amplifier.
2. Attach the threaded hook screw to the driver plate. (Note: a small spacer is included with the equipment. It can be placed between the hook screw and the driver plate to elevate the hook screw.) Attach the elastic string to the hook screw.
3. Attach the other end of the elastic to a ring stand.
4. Move the speaker box to create tension in the string.
5. Use the software to generate a sine wave with a 4 V amplitude and a frequency of around 15 Hz.
6. Adjust the tension in the string until you have a standing wave for the fundamental frequency.
7. Double the frequency. Describe the change in the standing wave.
8. Triple the fundamental frequency. Describe the change in the standing wave.
9. Try quadrupling the frequency.



Measuring the speed of a wave on an elastic string

1. Place the speaker on the table and connect the Power Amplifier.
2. Attach a Dual-Range Force Sensor to a ring stand.
3. Attach the threaded hook screw to the driver plate.
4. Attach the elastic string to the hook screw post on the speaker.
5. Attach the other end of the string to the force sensor.
6. Move the speaker box to create tension in the string.
7. Use the software to generate a sine wave with an amplitude of 4 V and a frequency about 15 Hz.
8. Adjust the tension in the string until you have a standing wave of the fundamental frequency.
9. Use the data collection software to determine the tension in the string.
10. Knowing that the speed of the wave is equal to frequency multiplied by the wavelength, determine the speed of the wave.

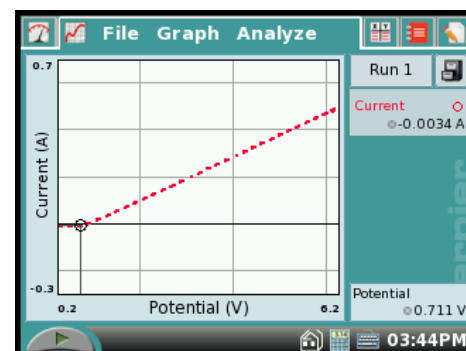
Observe resonance on a spring

1. Attach the threaded hook screw to the driver plate.
2. Attach the speaker to a ring stand with the speaker facing down.
3. Attach one end of the spring to the hook screw on the speaker.
4. Attach a weight to the other end of the spring.
5. Knowing the spring constant of the spring and the mass of the weight, calculate the period and frequency with which the mass will oscillate.
6. Use the software to generate a sine wave with an amplitude of 4 V and a frequency of about 1 Hz. Observe the motion of the mass.
7. Increase the frequency slightly, e.g., 0.2 Hz. Observe the motion of the mass.
8. Continue to increase the frequency and approach the frequency calculated in Step 4 above.
9. Describe the motion of the weight when that frequency is reached.
10. Repeat the above with another spring and weight combination.

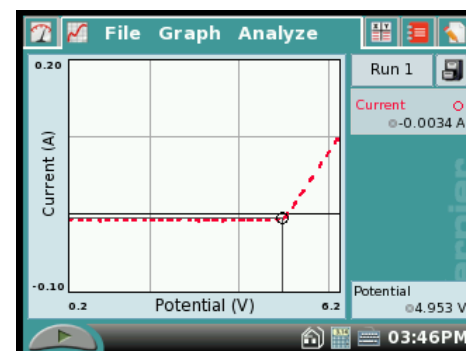


Current vs. Voltage plots for electronic components

The triangle waveform can be used to quickly measure the I-V (current-voltage) characteristics of other electronic components such as diodes, Zener diodes, and transistors. Below are sample graphs made using a diode and a Zener diode.



Current vs. Voltage for a Diode



Current vs. Voltage for a 5.1 V Zener Diode

Bicolor LEDs

Inexpensive bi-color, red/green, LEDs can be driven by the Power Amplifier at various frequencies to show several interesting effects. The LED should be placed in series with a current-limiting resistor, usually a few hundred ohms. The LED will glow red when the current flows one way and green when the current flows the other way. The triangle waveform can be used to drive the LEDs. At low frequencies, the transition can be clearly seen. At higher frequencies the LED appears orange. It is interesting to explore how high the frequency needs to be to trick the eye into seeing just one color. Try moving the bicolor LED quickly while it is being driven by a triangle or sine waveform to see an interesting visual effect. Can you explain what you see?

Use the Power Amplifier as a DC power supply

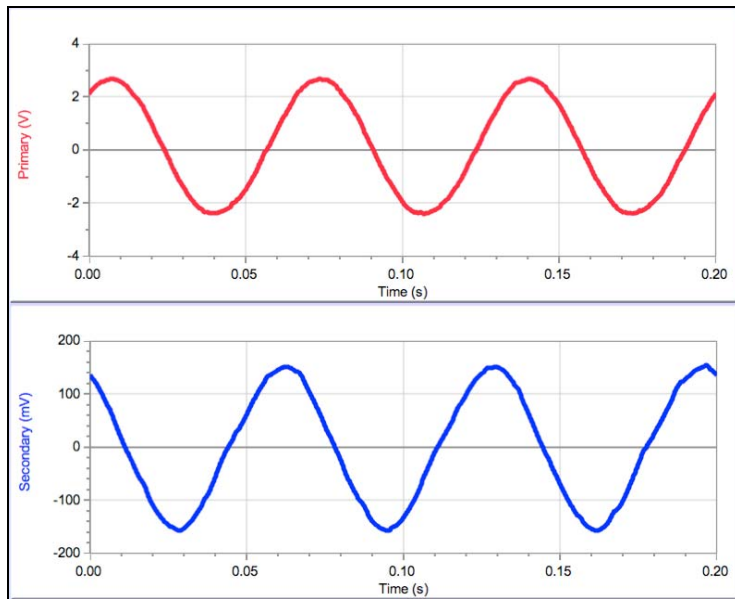
The Power Amplifier can supply a DC voltage up to 10V and a current up to 1A. It can take the place of a DC power supply and offer the advantage of computer control.

Induced currents in a coil

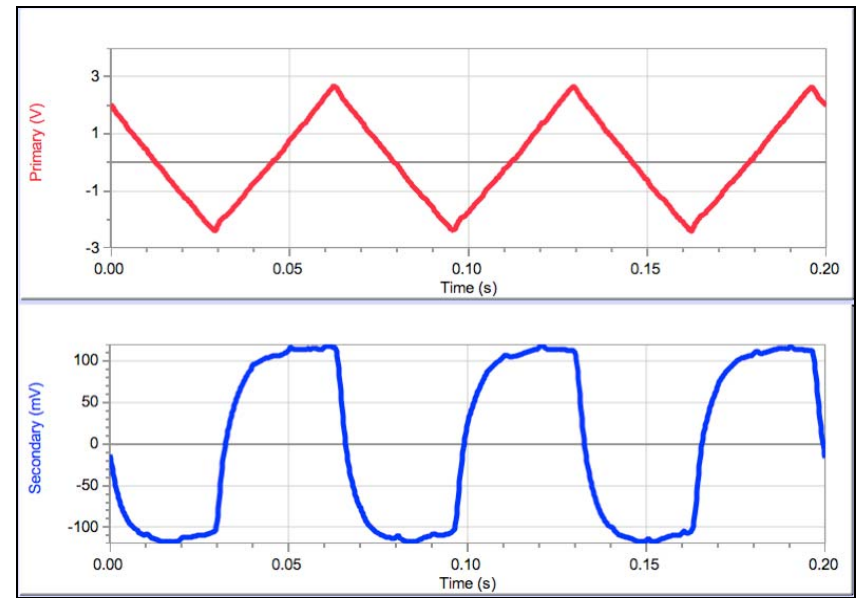
Drive a primary coil with a triangle wave, square wave, or sine wave, and measure the induced potential in a secondary coil. The induced potential is proportional to the rate of change of the current in the primary coil, which means that the coil pair is essentially a machine that finds the derivatives of waveforms.

In these three examples, the potential across the output of the Power Amplifier and primary coil was measured with a Vernier Differential Voltage Probe (DVP-BTA) and the potential across the secondary coil was measured with a Vernier Instrumentation Amplifier (INA-BTA). A second Differential Voltage Probe or the simple Voltage Probe (VP-BTA) could be used instead, but readings will be noisier than those obtained with the Instrumentation Amplifier.

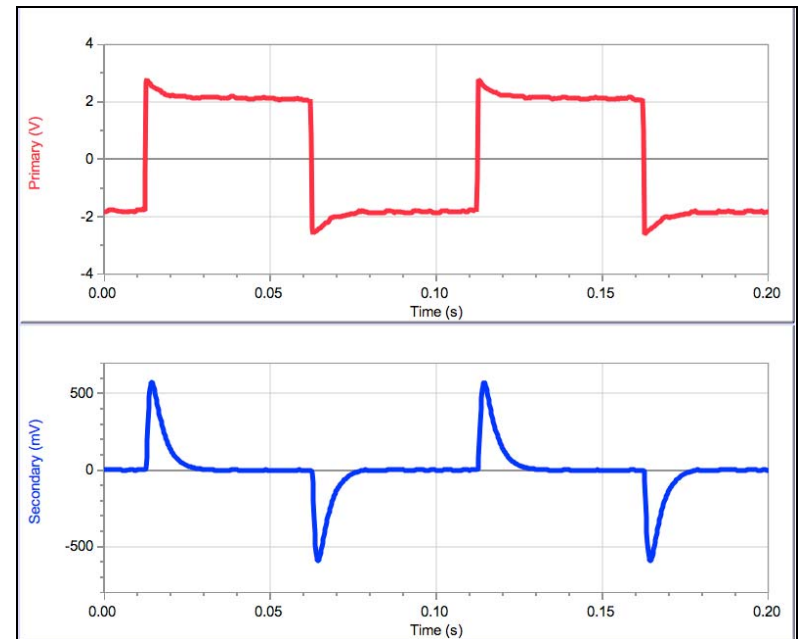
In the example below, a large coil was driven by a sine wave output from the Power Amplifier. A small coil inside the first one has a voltage waveform induced in it. Note that the induced waveform is 90 degrees out of phase with the driving waveform.



Another good demonstration using two coils is to drive the primary with a triangular waveform. What is the waveform of the induced potential?



A square wave is also interesting to study:



Some things to investigate with this apparatus are:

- How does the amplitude of the induced potential depend on the waveform frequency in the primary?
- How does the amplitude of the induced potential depend on the waveform amplitude in the primary?
- How does the shape of the secondary waveform depend on the primary waveform?
- Do you see signs of self-inductance from the primary coil? Hint: compare the waveform from the Power Amplifier with and without the coil connected.

Warranty

Vernier warrants this product to be free from defects in materials and workmanship for a period of five years from the date of shipment to the customer. This warranty does not cover damage to the product caused by abuse or improper used.



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