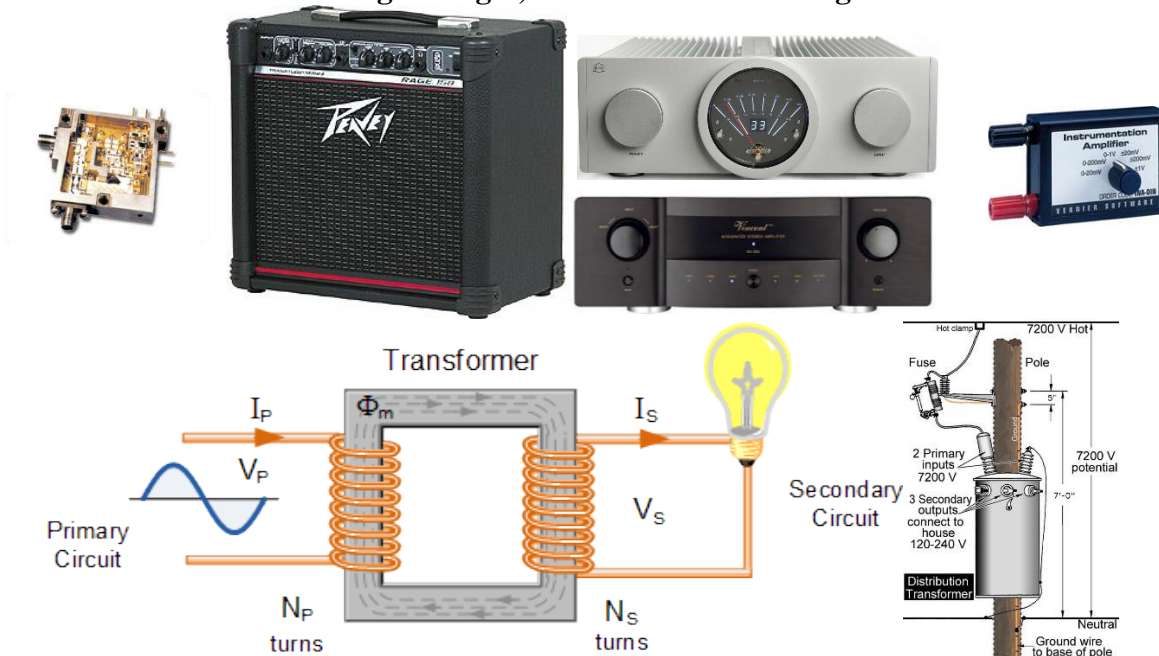


## Class #21: Experiment Transformers & Amplifiers Making Voltages, Current & Power Larger



**Purpose:** In this experiment we will discuss ways in which transformers and amplifiers can increase voltages, currents and power in electrical circuits.

Background: Before doing this experiment, students should be able to

- Review online background materials.
- Build and operate simple circuits on a Protoboard.
- Measure the voltages and determine the currents using a math channel in simple Protoboard circuits using Analog Discovery
- Analyze simple circuits consisting of combinations of resistors, especially voltage dividers.
- Do a transient (time dependent) simulation of circuits using LTspice
- Review the background for the previous experiments.

Learning Outcomes: Students will be able to

- Incorporate transformers in circuits built and simulated and determine conditions under which they successfully perform the functions they are designed for.
- Build, simulate and analyze circuits using operational amplifiers in either inverting or non-inverting configurations.

Resources Required:

- LTspice
- Matlab with activation for RPI students
- Analog Discovery and Parts Kit

Helpful links for this experiment can be found on the course website under Class #21.

### Pre-Lab

*Required Reading:* Before beginning the lab, at least one team member must read over and be generally acquainted with this document and the other **required reading** materials.

*Hand-Drawn Circuit Diagrams:* Before beginning the lab, hand-drawn circuit diagrams must be prepared for all circuits either to be analyzed using LTspice or physically built and characterized using Analog Discovery.

**Due:** At the beginning of Class #23

## Background Reading & Viewing

### Transformers

- <http://www.electronics-tutorials.ws/transformer/transformer-basics.html>
- <https://en.wikipedia.org/wiki/Transformer>
- Modeling Transformers in LTspice: <https://www.youtube.com/watch?v=kJDahaWfobw>

### Operational Amplifiers

- [https://en.wikipedia.org/wiki/Operational\\_amplifier\\_applications](https://en.wikipedia.org/wiki/Operational_amplifier_applications)
- [http://www.electronics-tutorials.ws/opamp/opamp\\_1.html](http://www.electronics-tutorials.ws/opamp/opamp_1.html)
- <http://www.allaboutcircuits.com/textbook/semiconductors/chpt-8/introduction-operational-amplifiers/>

## Part A – Transformer Simulation

In reading the information in the links above (or just about any other reference on transformers), we see that the governing equations are usually written something like the following, where P and S refer to the primary and secondary windings of the transformer.

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \sqrt{\frac{L_S}{L_P}} = \frac{1}{a} \quad \frac{I_S}{I_P} = \frac{N_P}{N_S} = \sqrt{\frac{L_P}{L_S}} = a \quad Z_{IN} = \left(\frac{N_P}{N_S}\right)^2 Z_L = a^2 Z_L$$

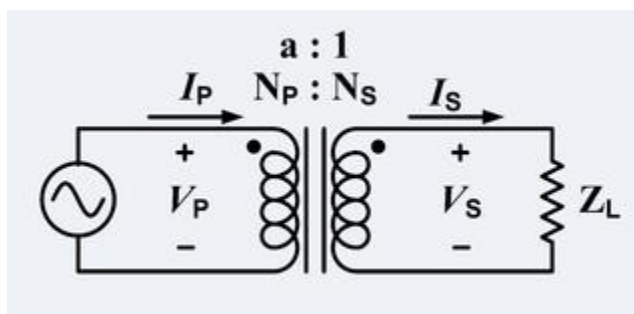
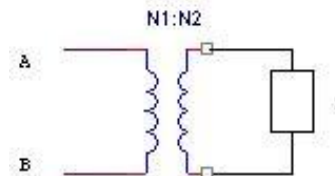


Figure A-1

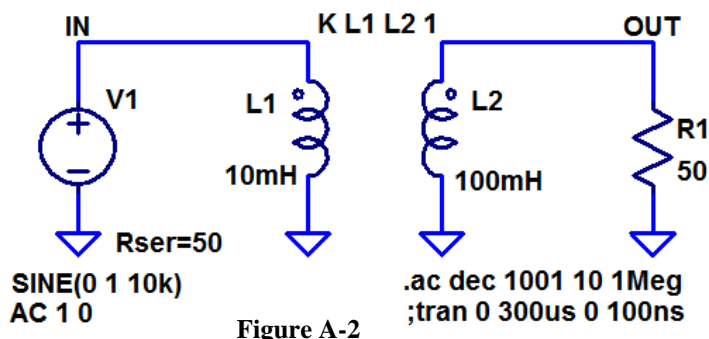
Unfortunately, there is no standard for expressing simply how the turns-ratio shows up in these expressions. Some people define the ratio as primary to secondary (as above) and some as secondary to primary. On the formula sheets for this class, we have the second definition.

$$a = \frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \sqrt{\frac{L_2}{L_1}} \quad Z_{in} = Z_{AB} = \frac{Z}{a^2}$$



Thus, in this experiment, we will not use the letter *a* to represent the turns-ratio, just the ratio itself. Whenever you use formulas like this, be sure to carefully check definitions.

To test out these equations, set up the simulation below using LTspice. Note that there is no transformer symbol in LTspice. Rather, one must construct it using two inductors, as is explained in the YouTube video listed above. Note also that this circuit shows the voltage source with an internal series resistance, even though there is no resistor symbol. Both transient and AC simulations are setup. Begin by doing the transient case. The first equation to test is the voltage ratio. For all plots, use a linear vertical scale.



1. Run the simulation and plot both the input and output voltages as functions of time. Save and annotate your plot and show that the voltage ratio works.
2. Next, plot the currents through the primary and secondary inductors. Save and annotate your plot and show that the current ratio works.

The third equation tells us that the impedance we see looking into the primary of the transformer will be the load resistance multiplied by  $\frac{N_p^2}{N_s^2}$

3. To test this equation, you must determine the input impedance by plotting the ratio of  $V_p$  divided by  $I_p$ . Because the current oscillates around zero, there will be some times for which this ratio is not accurately determined, but, if you have set things up properly, the ratio should be consistent with the third equation above, except possibly for its sign. It is likely the resistance will come out negative, which will be due to the reference direction for positive current for the inductor. You can ignore the sign, in this case.

You should see that all three equations work, so the inductor is behaving as it should at this frequency. Now, switch to the AC sweep. You should see that all three expressions hold for a limited frequency range.

4. Plot, save and annotate  $V_p$  and  $\frac{N_p}{N_s} V_s$ ;  $\frac{N_p}{N_s} I_p$  and  $I_s$ ; and  $\frac{N_p^2}{N_s^2} \frac{V_p}{I_p}$  for the range of frequencies from 10Hz to 1MHz.
5. What determines the range of frequencies for which the transformer works as designed?

## Part B – Operational Amplifier Experiment

From the reference materials provided, identify the operational amplifier configurations called inverting and non-inverting amplifiers. Draw the circuits for both, showing where to connect the chips to power (+5V and -5V), ground, etc. Using the OP27 chip, set up the circuits so that they have a gain of 3 or 4 and do not use resistors smaller than 1kΩ. Do an experiment with each of the circuits that demonstrates they work correctly. Use a sinusoidal input voltage source in both cases with a frequency of 1kHz and an amplitude of 500mV. You will likely find information provided by Digilent to be helpful here. Check out their Real Analog educational materials, looking specifically at Chapter 5 on Operational Amplifiers. <https://learn.digilentinc.com/classroom/realanalog/> You should focus on Labs 5.4.1 and 5.4.3. The lab pdf files contain much of the information you need.

6. Before you do either experiment, show your circuit, fully built and ready to go to an instructor or TA Explain what you are trying to demonstrate and why your experiment should work. You must do this before each experiment.

## Part C – Op-Amp Model Simulation

An LTspice model of an op-amp was developed using information from the references listed above. This model has one new component in it – a voltage dependent voltage source. It is found under the name ‘e’ and can be set to have just about any gain (ratio of output to input voltage). You will do this simulation with the rest of the class, setting everything up with guidance from your instructor or TA.

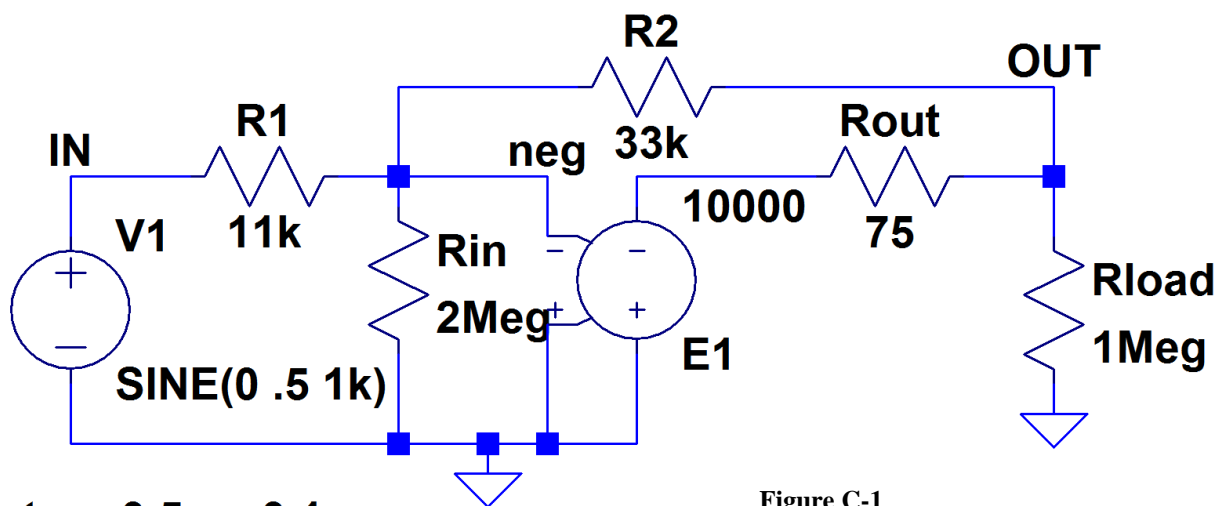


Figure C-1

**.tran 0 5ms 0 1us**

- Run the simulation, plot the output and input voltages as functions of time. Save and annotate your plot and discuss whether or not the model works (does it behave like an op-amp should?).

### Part D – Task List

- Plot and annotate transformer voltage ratio at 10kHz
- Plot and annotate transformer current ratio at 10kHz
- Plot and annotate transformer input impedance at 10kHz
- Plot and annotate the three specified sets of parameters for the frequency range from 10Hz to 1MHz.  
TA/Instructor \_\_\_\_\_
- Design two experiments to study the inverting and non-inverting amplifier configurations using an OP27 op-amp. Have both checked by a TA or instructor before running them.  
Inverting: TA/Instructor \_\_\_\_\_ Non-Inverting: TA/Instructor: \_\_\_\_\_
- Op-amp model simulation

### Part E – Reflection

Take a moment to reflect on what you have learned in this experiment. Then describe how a transformer works and what possibly limits its usefulness. Do the same for operational amplifiers configured as inverting and non-inverting amps. What are the golden rules of op-amps and what evidence have you seen that shows they work?