Class #22: Experiment
Building and Testing a Transformer
AKA Coupled Inductor

Figure 1

Purpose: In this experiment we will build a simple transformer by winding several turns of magnet wire around a ferrite core and then test its properties.

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
- Build, simulate, analyze and test circuits using transformers (aka coupled inductors).
- Build, simulate and test a Joule Thief, demonstrating that it can power an higher voltage LED (V_F > 3V) using 1.5V (possibly from a battery).

Resources Required:
- LTspice
- Matlab with activation for RPI students
- Analog Discovery and Parts Kit
- Ferrite Core
- Magnet Wire
- Sandpaper and Sanding Square or Block (to protect table tops)

Helpful links for this experiment can be found on the course website under Class #22.

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 #24

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
- Joule Thief: https://en.wikipedia.org/wiki/Joule_thief, http://rimstar.org/sdenergy/joule_thief.htm and others

Part A – Building and Testing a Transformer

The overall goal is to build a simple transformer (see Figure 1) with the same number of windings on the primary and secondary. The easy way to do this is to wind both coils at the same time. This is done by creating a pair of wires and then winding both the primary and secondary by threading the combination of the two wires around the core about 20 times. Leave about 5 cm of wire at each end for connections.

Magnet wire is insulated with enamel. To make contact, you must remove about 1cm of enamel from each end of the wire. Us the sandpaper provided but ***please do not sand on the table top***! Us the small plastic square provided to protect the Formica table surface. Check to be sure that you have removed enough enamel to make good contacts by checking the resistance of the coils. You must also identify the primary and secondary, which also requires checking wire resistance. Once you have identified the primary and secondary coils, be sure to mark at least one coil with tape or something that will not rub off.

Next, plug the transformer into your Protoboard and then check to be sure it is well connected. Often, it will look connected but not really be making good contact. Complete the circuit below, which was drawn for simulation with LTspice. The 2.2Ω resistor must be included because the resistance of the primary inductor is too small for the Analog Discovery Function Generator to drive. The load resistor is 47Ω, selected to be a standard value. You do not need the values of the inductances shown, but they are the measured values for a transformer built according to these directions. The ferrite core may not be the same and you may have a different number of turns, so use these values only as a general guide. For the experiment and simulation that follow, save and annotate all plots.

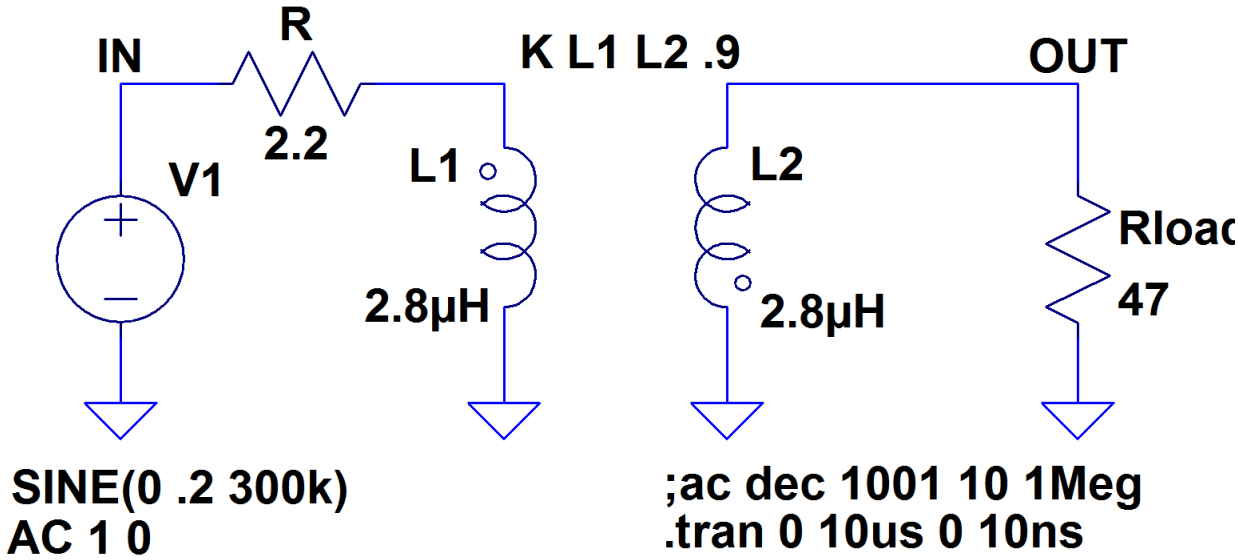

Figure A-1

1. Starting at a frequency around 300kHz and an amplitude of 200mV, test the circuit by measuring the primary and secondary voltages vs time. Note that these measurements are across the coils not at the source. Use these measurements to demonstrate that the transformer is working as it should. Check both the voltage and current ratios. It is not necessary to address the input impedance yet.
2. Once you are sure the transformer is working, you should also make a second set of measurements (for completeness) of the source voltage and the primary voltage.

Part B – Transformer Simulation

Set up the simulation circuit shown above (Figure A-1) using the estimated values for the inductances, unless you have access to an impedance bridge and can measure the inductances. It is also possible to estimate the inductance value if you know the dimensions and magnetic permeability of the ferrite. An example of a ferrite core inductor calculator: http://coil32.net/online-calculators/ferrite-torroid-calculator.html. If you have access to an impedance bridge and the spec sheet for the ferrite core, you should do both the measurements and calculation.

3. Repeat all measurements made with the transformer you constructed.
4. Using your annotated plots, compare the two sets of measurements.
5. Using your annotated plots, demonstrate that the input impedance of the transformer is approximately what is predicted by the ideal transformer equations.

Part C – Joule Thief (Optional)

When you complete the experiment and simulation of your transformer, you can build a Joule Thief, using your transformer as a coupled inductor. Read over the information provided above on the Joule Thief. If you do not have a 1.5V battery, you can use one of the DC power supplies set to output 1.5V. Once you get your circuit to work, measure the voltages across the LED (also the collector voltage to ground) and the transistor base voltage to ground.

6. What is the oscillation frequency and demonstrate that the voltage across the LED is large enough to turn it on. Use a green, blue or white LED if possible.

Part D – Task List

- Plot and annotate transformer primary and secondary voltages and primary and secondary currents at 300kHz for the transformer you built.
- Plot and annotate the function generator voltage and the primary voltage at 300kHz.
- Plot and annotate transformer voltages and currents and the sinusoidal input voltage at 300kHz from your LTspice simulation.
- Using your annotated plots, compare the two sets of measurements
- Using your annotated plots, check the validity of the input impedance equation.
- (Optional) Build and test the Joule Thief

Part E – Reflection

Take a moment to reflect on what you have learned in this experiment. Then describe how well your transformer works and how you can predict or measure the inductances of the primary and secondary windings.