RL Circuits and Square Waves

Equipment Needed:

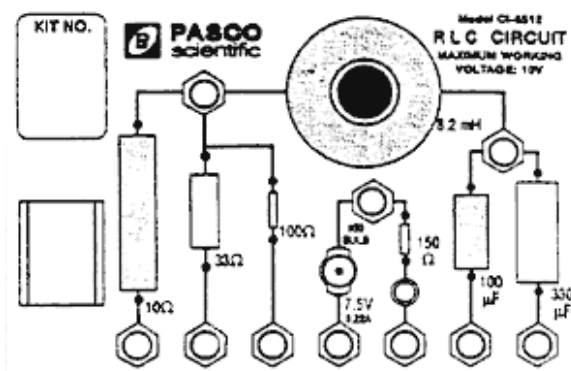|	
1 RLC Circuit Experiment Board	Demo Cart
1 Voltage Sensor Assembly	Demo Cart
1 Multimeter	Demo Cart
1 Computer Interface	

Figure 1: Component Board

Table 1: **Component Values by Circuit Board**

Ckt Board #	Capacitor(μF)		Inductor(mH)	
	100μF	330μF	without core	with core
1	102.5	330	8.06	20.9
2	99.3	330	7.91	20.3
3	104.5	330	7.92	20.3
4	103.3	330	7.92	20.3
5	104.7	330	8.1	20.5
6	103	330	7.9	20.4

Purpose

This experiment displays the voltage across the inductor and the current through the inductor so that the behavior of an inductor can be studied.
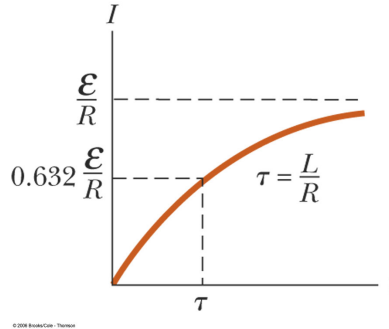
Figure 2: Charge Curve

Theory

When a DC voltage is applied to an inductor and a resistor in series a steady current will be established over time:

$$I_{max} = \frac{V_0}{R}$$

where V_0 is the applied voltage and R is the total resistance in the circuit. But it takes time to establish this steady state current because the inductor creates a back EMF in response to the rise in current. The current will rise:

$$I = I_{max}(1 - e^{-\frac{t}{\tau}})$$

where $\tau = \frac{L}{R}$. The inductive time constants is a measue of how long it takes the current to be established. One inductive time constant is the time it takes for the current to rise to 63% of its maximum value (or fall to 37% of its maximum). The half life $t_{1/2}$, which is the time for the current to rise or fall to half its maximum is related to the inductive time constant by:

$$t_{1/2} = \tau \ln 2$$

The voltage across the resistor is given by:

$$V_R = IR = V_0(1 - e^{-\frac{t}{\tau}})$$

The voltage across an inductor is given by:

$$V_L = -L\frac{dI}{dt} = -V_0 e^{-\frac{t}{\tau}}$$

Thus the voltage across the inductor starts at its maximum and then decreases exponentially. The minus sign indicates that the induced emf from the inductor is opposing the increasing current.

After a time t $\gg \tau$, a steady state current I_{max} is established and the voltage across the resistor is equal to the applied voltage, V_0. The voltage across the inductor is zero. If, after the maximum current is established, the voltage source is turned off, the current will then decrease exponentially to zero while the voltage across the resistor does the same and the inductor again produces a back EMF which decreases exponentially to zero.

2

Summary

DC Voltage applied: DC Voltage turned off:

$$\begin{array}{rlcrl}
I = & I_{max}(1 - e^{-\frac{t}{\tau}}) & \qquad & I = & I_{max}e^{-\frac{t}{\tau}} \\
V_R = & V_0(1 - e^{-\frac{t}{\tau}}) & & V_R = & V_0e^{-\frac{t}{\tau}} \\
V_L = & -V_0e^{-\frac{t}{\tau}} & & V_L = & V_0e^{-\frac{t}{\tau}}
\end{array}$$

At any time, Kirchoff's Loop Rule applies: The algebraic sum of all the voltages around the series circuit is zero. In other words, the voltage across the resistor plus the voltage across the inductor will add up to source voltage.

Procedure

1. Connect the circuit as shown in Figure 3.

2. Connect the DIN plug of the voltage sensor to channel A on the interface box. Connect the banana plugs of the voltage sensor across the capacitor. Make sure the banana plup are not connected where the wires are insulated.
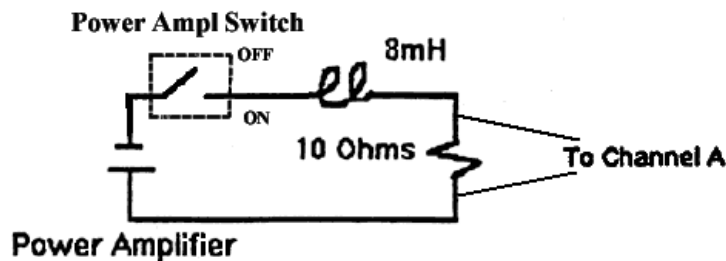

Figure 3: RL Circuit

3. Turn on the interface box and computer. Choose the program "Data Studio" on the computer. Click on "Create Experiment" after the program begins.

4. The `Experiment Setup` window automatically opens. Click on the image of channel A. From the popup list scroll all the way down to select `Voltage Sensor` and click `OK`. Under `Sampling Rate`, choose 25000. This tells the computer how often it should read data during a run.

5. Click on the power output (the rightmost terminal on the image) and a small popup window named `Signal Generator` should open. Select `Square Wave` instead of the default `Sine Wave`. Change the output frequency to $5Hz$. You may keep the default amplitude of $5V$. You do not have to close the `Signal Generator` window when you are done, but you may if you wish to do so.

6. Go back to the `Experiment Setup` window. Click on the `Sampling Option...` to open another popup window. Click on the tab `Automatic Stop`, select `Time` and set it to $1s$. Click `OK`.

7. Close the `Experiment Setup` window. Anytime you wish to make changes to the setup you can click on `Setup` on the to left hand corner of the main window.

8. Under `Display`, you see the item `Graph`. Double click on it and a `Data Source` window opens. Click on `Voltage, ChA (V)` and select `OK`. A blank graph should open.

9. Under `Display`, triple click on `Graph 1` and change its name to "Resistor Voltage".

10. Under `Display`, double click on graph again, this time select `Output Voltage (V)` as your data source. Again triple click to rename the graph to "Output Voltage". Now you are ready for data collection.

Resistor Voltage in an RL Circuit

This portion of the lab will look at the the voltage V_R across the resistor in an RL circuit. Since $I = \frac{V_R}{R}$, the curve you observe is actually proportional to the current flowing through the circuit.

1. Click `Start` and the experiment will begin to run. It will stop automatically after $1s$ based on your earlier setup specification.

2. Under `Data`, double click on `Run #1` under `Voltage, ChA (V)`. A `Data Properties` window opens. Click on the `General` tab and change `Variable Name` to "Resistor Voltage" and click `OK`.

3. Under `Data`, double click on `Run #1` under `Output Voltage (V)`. A `Data Properties` window opens. Click on the `General` tab and change `Variable Name` to "Output Voltage" and click `OK`.

4. You should see a graph similar to Figure 4. You should see the voltage decaying from a positive value to a negative value. Half way between the maximum and the minimum voltage is $V_R = 0$.

5. Find the inductive time constant by first measuring the half-life $t_{1/2}$ on the graph of the voltage versus time.

6. Magnify the decaying part of the curve. Then record the time t_1 at the peak. Then look at the part of the curve where $V_R = 0$, measure the time t_2. The half-life is given by $t_{1/2} = t_2 - t_1$. Record your results in Table 2 below.

7. Repeat the experiment one more time with the iron core inserted inside the inductor.
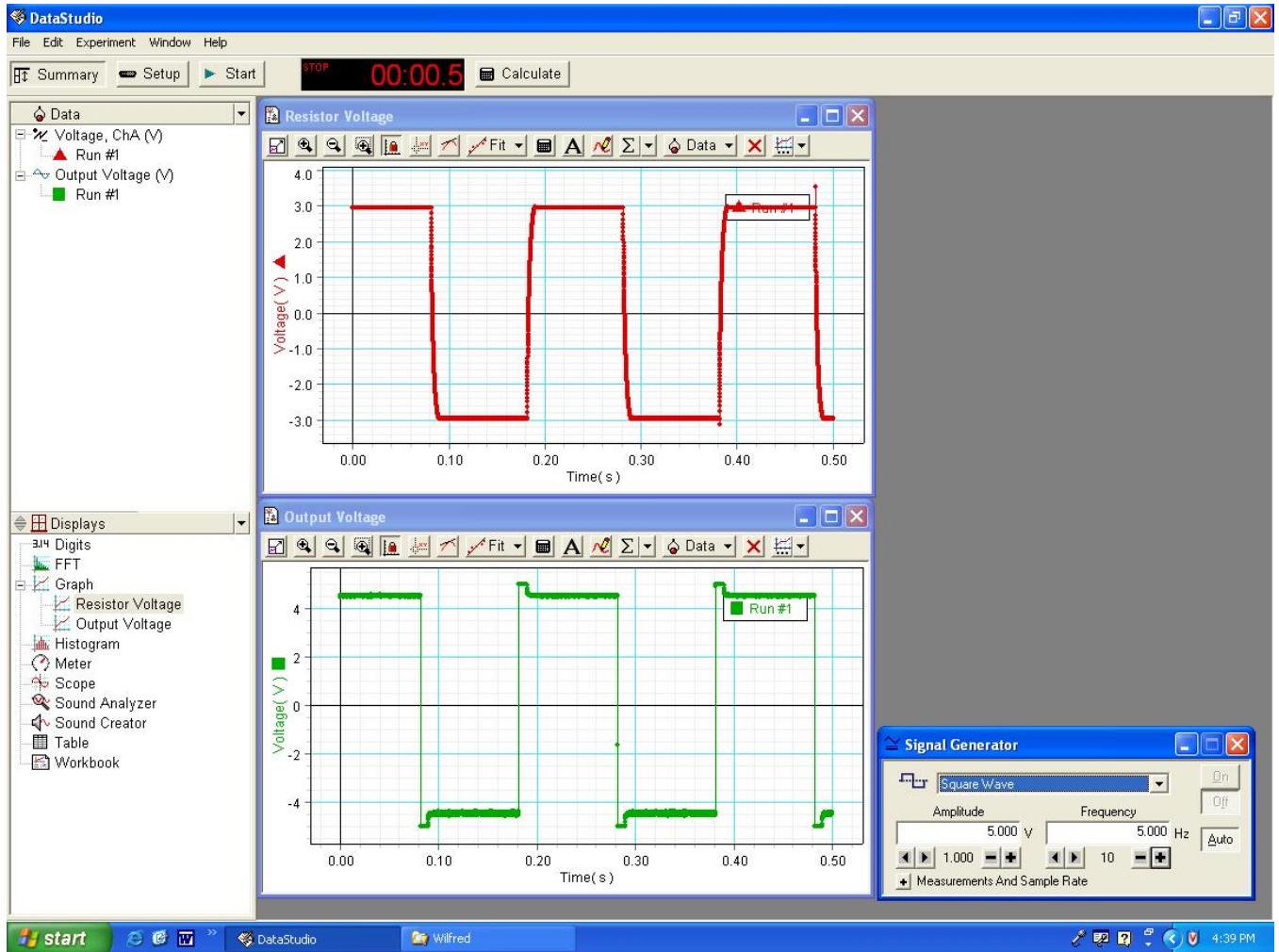
Figure 4: Voltage across the resistor

Table 2: Inductance

	Without Core	With Core
I_{max}		
$R_{resistor}$		
R_{total}		
t_1		
t_2		
$t_{1/2} = t_2 - t_1$		
$\tau_{computer} = \frac{t_{1/2}}{\ln 2}$		
$L_{computer} = \tau_{computer} R_{total}$		
$L_{measured}$		
Percentage Error $L_{computer}$ and $L_{measured}$		

$L_{measured}$ is given in Table 1.