Physics NYB

Experiment: Impedance, Phase and Resonance in an Alternating Current RLC in Series Circuit

Introduction:

The current is the same for all elements in a series RLC circuit and defined by expression:

$i = i_0 \sin \omega t$

The voltages are: resistor: $v_R = v_{0R} \sin \omega t$
ideal inductor: $v_L = v_{0L} \sin(\omega t + \pi/2)$
capacitor: $v_C = v_{0C} \sin(\omega t - \pi/2)$
emf: $v = v_0 \sin(\omega t + \varphi)$

inductive reactance: measured: $X_L = v_{0L} / i_0$ calculated by theory: $X_L = \omega L$
capacitive reactance: -- " -- $X_C = v_{0C} / i_0$ -- " -- $X_C = 1/\omega C$
impedance: -- " -- $Z = v_0 / i_0$ -- " -- $Z = [(X_L - X_C)^2 + R^2]^{½}$
phase angle: $\varphi = \tan^{-1}[(X_L - X_C)/R]$

If the angular frequency of the AC source "ω" is the same as the *natural circular frequency* of the circuit $\boldsymbol{\omega_0 = 1/(LC)^{1/2}}$ the amplitude of the current $\boldsymbol{i_0}$ is maximum and the circuit is said to ***resonate***.

Part A: Impedance and Phase Relationships

Procedure:

1) Connect the circuit with RLC series shown in figure 1. Select R = 100 Ω(*check by multimeter*), L = 39 mH, and C = 0.20 μF. Note that the inductor has an internal resistance, R_L. Its value is printed*(check it)* on the plastic mount of the inductor. Write those values on your data sheet. The AC emf is that of signal generator in the Pasco 550 interface. Set the output to "sine wave" with an amplitude of 5.0 V and a frequency of 2500 Hz. Connect a voltage probe across the resistor and connect it to channel A of the interface. You *will use the voltage across the resistor to monitor the evolution of current since the current "**i**" is in phase with "* $\mathbf{v_R}$*"*. The amplitude of current ($\boldsymbol{i_0}$) is found by dividing the resistor voltage amplitude by 100(*checked value*).

2) Follow by connecting a second voltage probe across the capacitor and plug it to channel B of the interface. Keep the same order of polarity with that of sensor A (*connect the same color of "wire up" for the two sensors, see fig.1*).

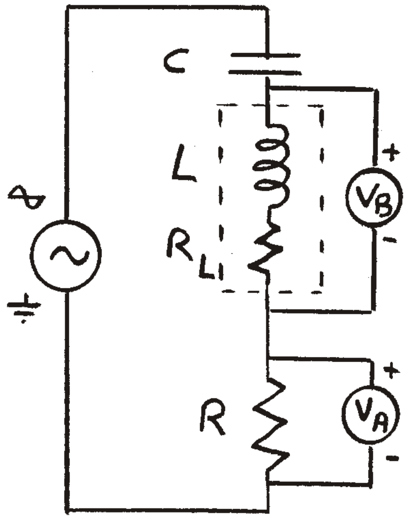


Figure 1

3) Set up ***the oscilloscope*** in Capstone to display the voltage across the resistor (V_A) and the voltage across the inductor (V_B) *on the same window*. Record both voltages, trigger them and adjust the time scale so that you see one or two complete stable cycles on the screen.

4) Use the coordinate tool, as shown below, to measure the ***period*** **for each *of the two signals***, the ***amplitude*** $\boldsymbol{i_o}$ *(=v_{0R}/R, probe A)* of current in the circuit and the ***phase shift*** between them.

5) Move the voltage sensor (V_B) from the capacitor to the inductor and repeat steps 3 and 4.

6) Move the voltage sensor (V_B) from the inductor to the AC source and repeat steps 3 and 4.

Measurements:

1) Use the Coordinate Tool to *measure the amplitudes of voltage* and *period (T) of both curves*. Adjust the scales of the graph as necessary to get the best possible values. Print the graph, label it C,L,S; note V_A on the graph of current (i.e. resistor voltage) and V_B on the other one.

2) Measure the phase difference φ between the two voltages measured by V_A and V_B as follows:
   - Use the coordinate tool to measure the time at which the cycle starts for V_A . Call it t_A. Do the same for V_B and call it t_B.
   - Calculate $\Delta t = t_A - t_B$.
   - Calculate the phase shift in radians as: $\varphi = 2\pi \Delta t / T$

   Note that in some cases Δt and φ will be positive and in other cases, negative. In the example shown in the diagram, as $t_A < t_B$, they are both negative.

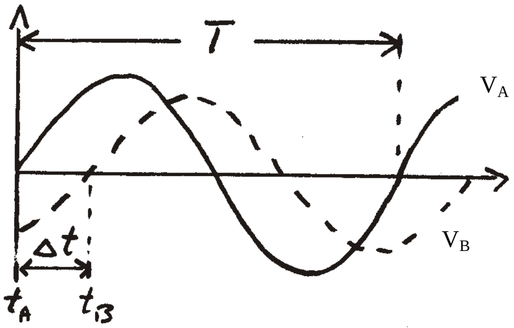


Figure 2: The graph of V_B is shifted right side (as in figure) if the phase shift of V_B is negative ($\varphi < 0$); it is shifted left side if $\varphi > 0$

3) Repeat steps 1 to 2 for the graph of voltage across the inductor and for the graph of AC output voltage.

5) Calculate the values of X_L, X_C, and Z from the measured values of i_0, v_{0C},v_{0L} and v_0 by using the relations between magnitudes. (Calculate i_0 as the ratio V_A / 100(*checked value*).

6) Calculate the theoretical reactance values (X_L and X_C) for a frequency f= 2500 Hz. Use these values to draw to scale a phasor diagram for the impedance of this circuit. (Note that the resistance used in this calculation must be the sum of the resistance of the resistor R plus the resistance of the inductor R_L.) Calculate the impedance, Z, and the phase angle, φ, between the current and the voltage of the AC signal generator.

Table 1 (f=2500Hz) R= ; R_L= ; L= ; C= ;

	Current ***i***	Voltage v_C	Voltage v_L	Source Voltage v
Period T				
Amplitude	i_o =	v_{oC} =	v_{oL} =	v_o =
Δt				
φ				

Conclusions:

1) Do the *phase constants* for v_L and v_C match the theory? (N.B. Recall that for the inductor, what you have measured as v_L includes the effect of the resistance of the inductor R_L , too).

2) Do the theoretical and measured values for X_L, X_C, Z and φ agree with each other?

Part B: Resonance

Procedure and Analysis:

1) Change the frequency of the signal generator to 200 Hz. Display the AC Output Voltage (V_B) and Resistor Voltage (V_A) on the scope. Maximize the scope window. Trigger on Channel A at zero volts with rising signal. Start data accumulation and adjust the time scale so that you see one or two complete cycles.

2) Plot a graph of both data sets. Use the coordinate TOOL to measure the amplitude of V_R. Divide its value by 100 to get the current amplitude (i_0). Check that the amplitude of the AC Output Voltage is $V_B = 5.0$ V. Measure the phase shift as described in Part A. Do not print the graph.

3) Repeat for the same procedure for following frequencies: 200, 500, 800, 1100, 1400, 1600,1700, 1800, 1900,2000, 2300, 2600 and 3000 Hz. Record all data; frequency, i_0, Δt(*with sign*) and φ in a well organized table on your data sheet.

4) Plot two graph; ***i_0* vs. *f*** and ***φ* vs. *f***. From these graph, determine the resonant frequency, f_0.

5) Calculate the theoretical value of f_0.

Tab. 2 Amplitude of Source Voltage $\boldsymbol{v_0=5V}$

Freq.(Hz.)	3000	2600	2300	2000	1900	1800	1700	1600	1400	1100	800	500	200
i_0 (A)													
Δt (s)													
φ (rad)													

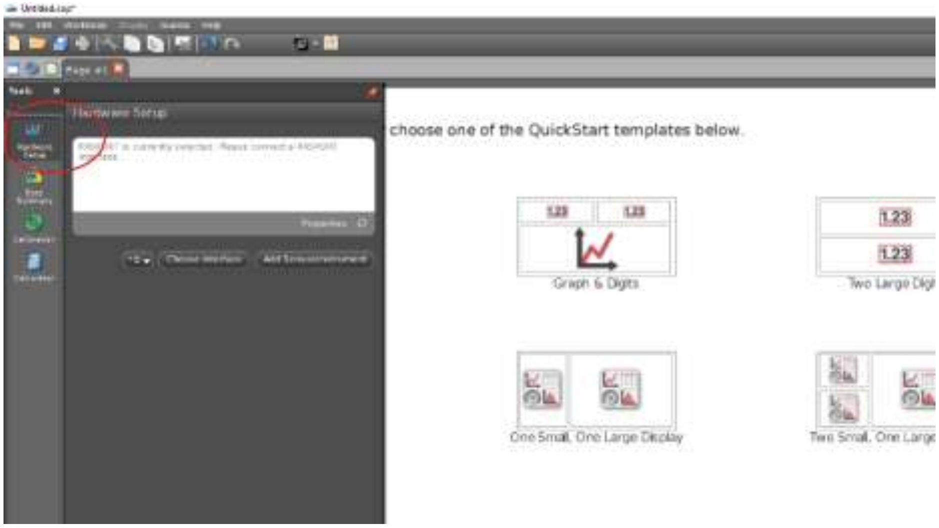
Conclusions:

1) What happens to the current amplitude and phase angle as the frequency is changed from low frequency through the resonant frequency to higher frequencies?

2) Compare the measured resonant frequency with the theoretical value.

Appendix: Capstone and the RLC series circuit

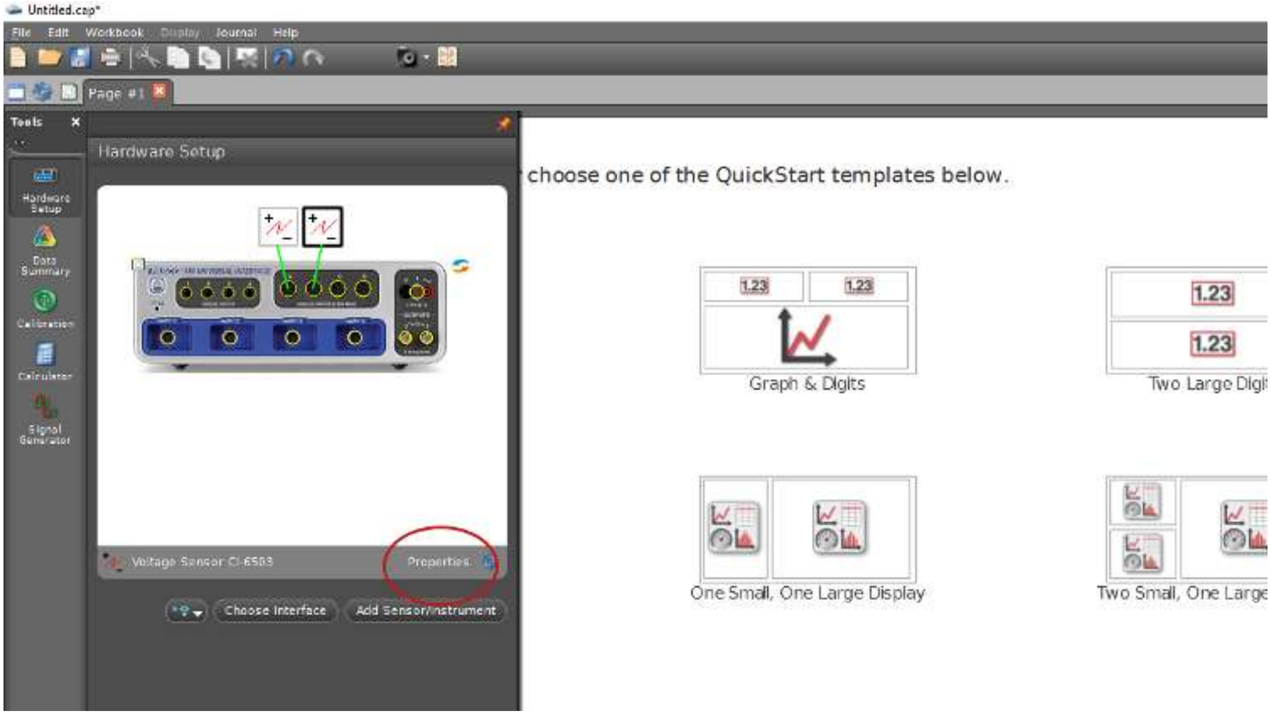
Click on **Hardware Setup** in the upper left-hand corner (fig.3). If the interface is on, but still the software cannot see it, reboot the machine:



choose one of the QuickStart templates below.

Figure 3

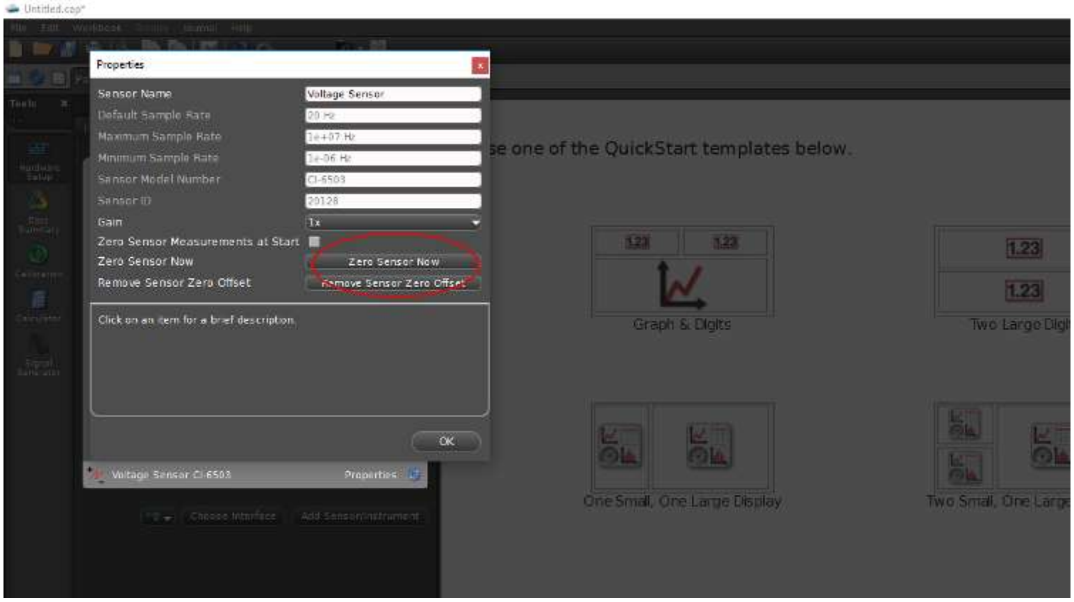
Attach voltage probes of V_A and V_B in **analog channels** 1 and 2 as shown in figure. Under the **properties** (figure 4) dialogue for each sensor (select each in turn), select ***Voltage Sensor.***



choose one of the QuickStart templates below.

Figure 4

For each sensor, click on **Zero Sensor Now** (fig.5) before connecting these in your circuit. This step becomes especially important if you find that, in the course of your measurements, one (or both) of the voltage graph is not symmetric about zero. Click again on **Hardware Setup** to suppress the dialogue.



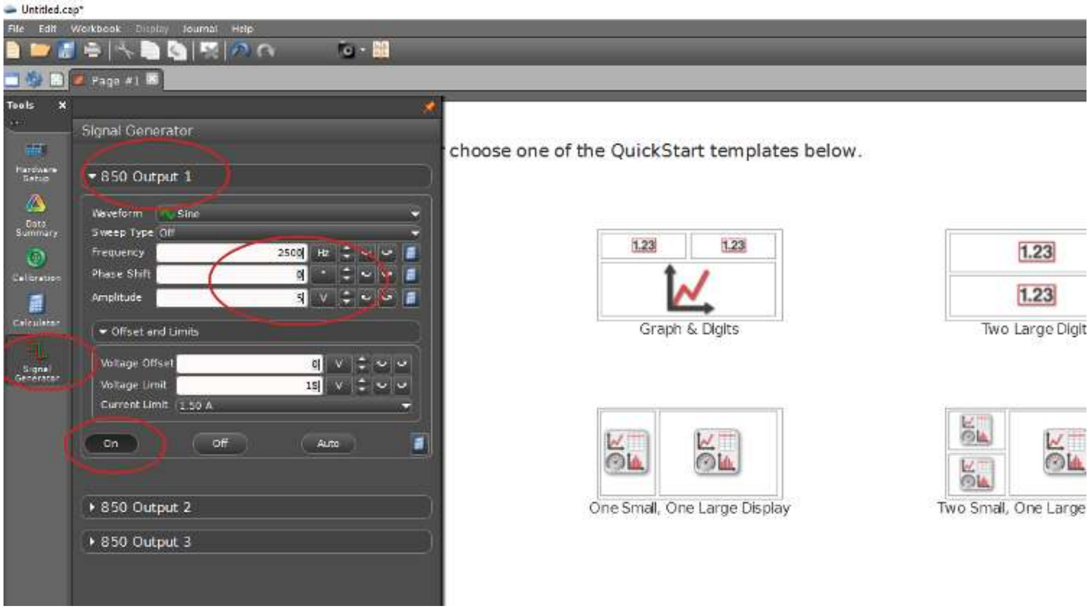
Properties

Sensor Name	Voltage Sensor
Default Sample Rate	20 Hz
Maximum Sample Rate	1e+07 Hz
Minimum Sample Rate	1e-06 Hz
Sensor Model Number	CI-6503
Sensor ID	20128
Gain	1x
Zero Sensor Measurements at Start	☐
Zero Sensor Now	Zero Sensor Now
Remove Sensor Zero Offset	Remove Sensor Zero Offset

Click on an item for a brief description.

Figure 5

To generate a voltage with 5V amplitude and f=2500Hz click on Signal generator on the left. Next, on the interface select frequency and amplitude as shown in figure 6.



Signal Generator

850 Output 1

Waveform	Sine	
Sweep Type	Off	
Frequency	2500	Hz
Phase Shift	0	°
Amplitude	5	V

Offset and Limits

Voltage Offset	0	V
Voltage Limit	15	V
Current Limit	1.50 A	

Figure 6

To display the voltages on the oscilloscope, click on the **Scope** icon in the upper right-hand corner in the **Displays** toolbar. To display the voltage across the 100 Ω resistance, click on **Select measurement** along the left side of the scope(fig 7) , and choose **Voltage Ch A [V]**:

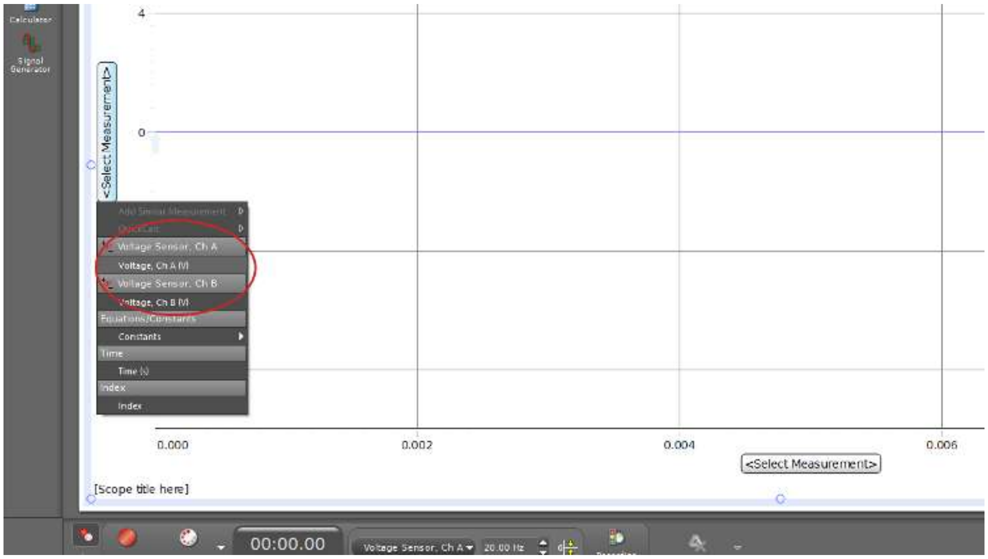


Figure 7

To display the voltage across the capacitance, click on **Voltage Ch A (V)** along the left of the display(fig 8), and select the second voltage under **Add Similar Measurement**:

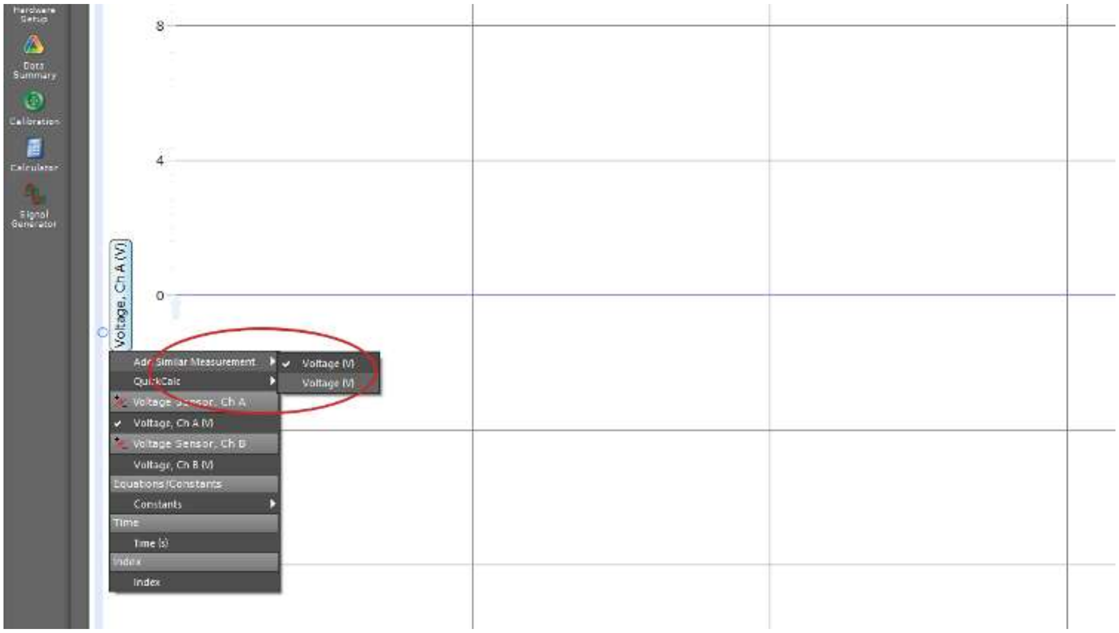


Figure 8

Towards measuring the phase difference between V_A and V_B, you'll need to use the **Coordinate and Delta tool** on the display toolbar (figure9).

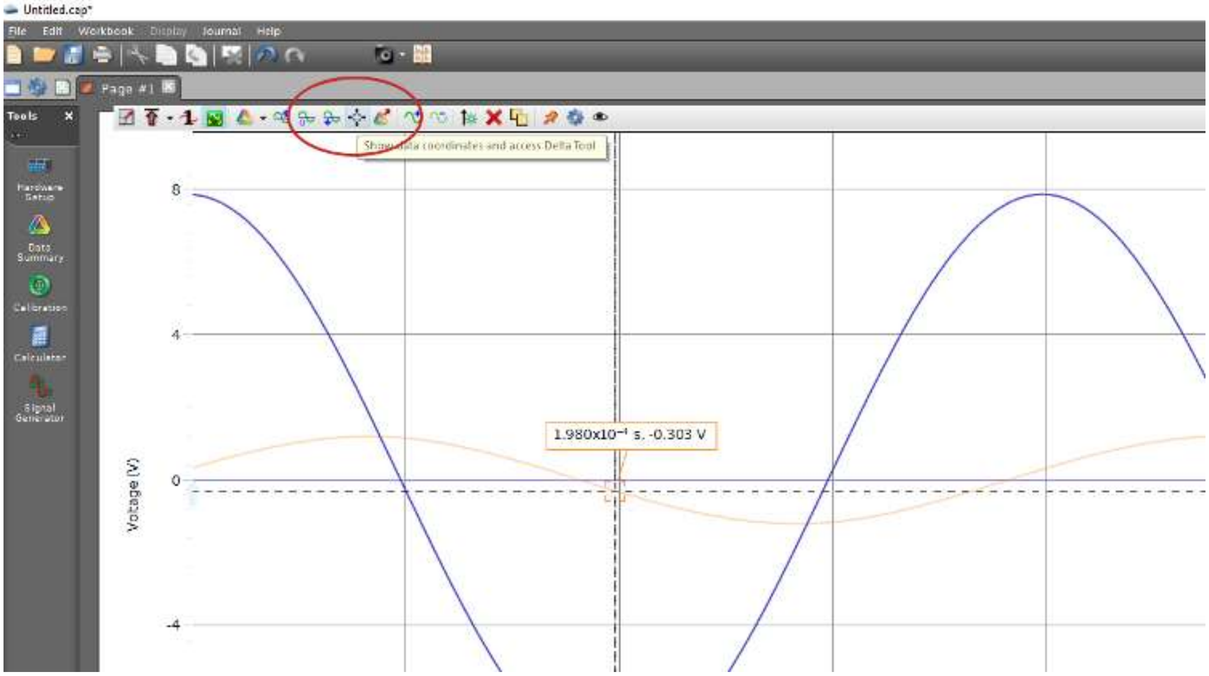


Figure 9