RC Circuits

Purpose

To examine the change in voltage in an RC circuit

Equipment

- ♦ 1 capacitor with a capacitance of **about** $C = 0.02\ \mu\text{F}$ (attached to a dual-binding post)
- ♦ 1 Resistor with resistance of $100\ k\Omega$
- ♦ 1 Extech DMM
- ♦ 1 PASCO 850 Interface
- ♦ 1 Voltage Sensor
- ♦ 4 short banana-to-banana leads

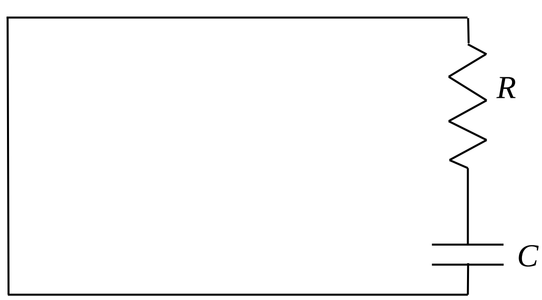
TAs will need a meter that measures capacitance.

Verify that you have all of the equipment listed. Notify your TA if anything is missing.

Introduction

Capacitors have many practical applications (camera flashes, smoothing AC ‘ripples’ on the DC supplied by power supplies, windshield wipers, etc.). There are several types of capacitor, but all types include plates separated by an insulator. As we saw in Electricity II, capacitors can hold charge. The more charge that a capacitor holds, the higher the voltage across it becomes. For a given capacitor, the amount of charge stored is directly proportional to the voltage across the plates; $\text{charge stored} \propto \Delta V \Leftrightarrow Q = \text{constant} \times \Delta V$. The constant here is called ‘capacitance’ and is defined $C \equiv \frac{Q}{\Delta V}$. (The units of capacitance are $\text{Farads} = \frac{\text{Coulombs}}{\text{volts}}$.)

In the lab, you will look at the voltage across a capacitor as it loses charge. What kind of voltage change across a capacitor should you expect? The simplest answer is that as Q decreases, then ΔV must decrease so as to keep $C \equiv \frac{Q}{\Delta V}$ constant. The real question then becomes; “what will we do physically to make Q decrease ($\Leftrightarrow \Delta V$ decrease)? The answer is that we’ll connect one plate of the capacitor to the other as in the following diagram;



We expect a current to flow (through the resistor) from one plate to the other. Some theoretical work leads us to expect current to be $I(t) = I_0 e^{-\frac{t}{RC}}$ where I_0 is a constant and t is the time between the moment the current was I_0 and the current moment. Looking at dimensions: [Resistance·Capacitance] = [Resistance] · [Capacitance] $= \frac{\text{volts}}{\text{amp}} \cdot \frac{\text{coulomb}}{\text{volt}} = \frac{\text{coulomb}}{\text{amp}} = \frac{\text{charge}}{\text{charge/time}} =$ time. Thus, the dimensions of RC are the dimensions of time. Since RC is also a constant, $\tau = RC$ is called the 'time constant' of the circuit.) This constant is an important one: it controls the rate of discharge of the capacitor (through the resistor). Because $\Delta V = RI$, the voltage across the capacitor is $\Delta V(t) = RI_0 e^{-\frac{t}{\tau}} \equiv \Delta V(0)e^{-\frac{t}{\tau}}$ (where $\Delta V(0) \equiv RI_0$). $\Delta V(t) = \Delta V(0)e^{-\frac{t}{\tau}}$ doesn't look as neat as $I(t) = I_0 e^{-\frac{t}{\tau}}$ but it is the relation that you'll verify experimentally. **How can you change the time constant if the capacitance of the circuit is fixed? [1]**. If we succeed in measuring the time constant during the experiment, we'll have verified that $\Delta V(t) = \Delta V(0)e^{-\frac{t}{\tau}}$.

The relation $\Delta V(t) = \Delta V(0)e^{-\frac{t}{\tau}}$ says that the voltage drops <u>asymptotically to zero</u> as $t \to \infty$. We might ask the question: "how long do we have to wait until the voltage across the capacitor is zero?" but the answer will be "After an infinite time". **Initially, how large is $\frac{\Delta V(t)}{\Delta V(0)}$? After an infinitely long time, what is the value of $\frac{\Delta V(t)}{\Delta V(0)}$? [2]** Saying that "the time t for $\frac{\Delta V(t)}{\Delta V(0)}$ to be zero will be $t = \infty$" is always true but doesn't allow us to see the fact that some voltage decays are very fast and others are slower. We can characterize the rate of voltage decay by saying how long we have to wait for $\Delta V(t)$ to become a certain fraction of its initial value. To pursue this, we need to recall that,

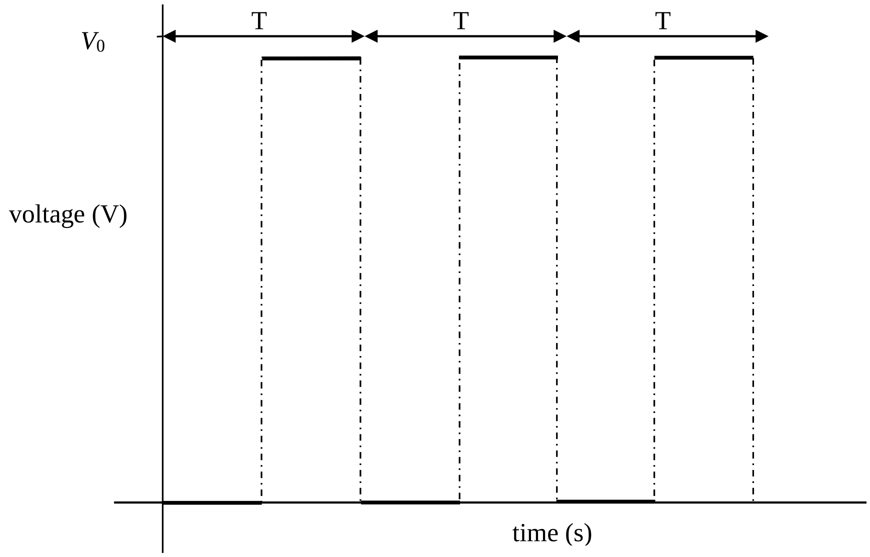
$$\frac{\Delta V(t)}{\Delta V(0)} = e^{-\frac{t}{\tau}}.$$

Suppose that we want to know how long we have to wait until $\frac{\Delta V(t)}{\Delta V(0)}$ becomes $\frac{1}{20}$. We'll call that time $t_{1/20}$ and have $\frac{\Delta V(t_{1/20})}{\Delta V(0)} = \frac{1}{20}$. This will allow us to solve for $t_{1/20}$. **Find $t_{1/20}$ in terms of τ. Will $t_{1/20}$ be changed if the time constant for the circuit is increased? If it changes, explain how. [2]**

The choice of the fraction $\frac{\Delta V(t)}{\Delta V(0)}$ is arbitrary. We could choose it to be $\frac{1}{2}$ and usually do when dealing with radioactive decay. If we make this choice then the time for the voltage to fall to half of its initial value is called the half-life (and is written $t_{1/2}$). There is a relation between half-life and time constant that can be shown using $\frac{\Delta V(t)}{\Delta V(0)} = e^{-\frac{t}{\tau}}$. If $t = t_{1/2}$ then $\frac{\Delta V(t_{1/2})}{\Delta V(0)} = \frac{1}{2}$. **Now use $\frac{\Delta V(t)}{\Delta V(0)} = e^{-\frac{t}{\tau}}$ to show that $t_{1/2} = \tau \ln 2$.**

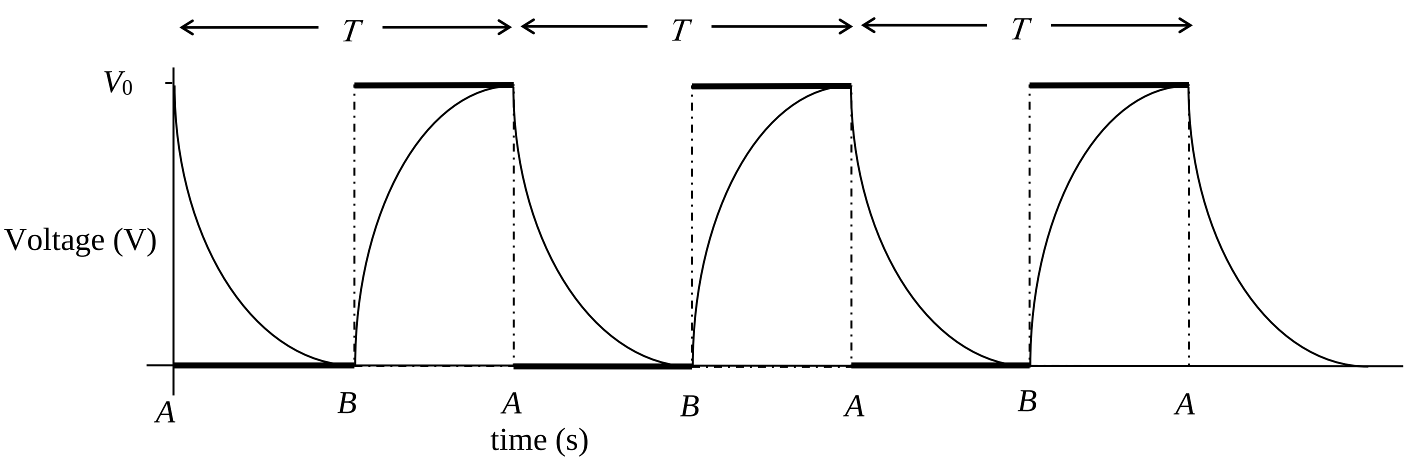
Another common choice is the fraction $\frac{1}{e}$. If so, $\Delta t = \tau$. Since $\frac{\Delta V(t)}{\Delta V(0)} = \frac{1}{e} \approx 0.36788 \ldots$ $\Delta t = \tau$ is the time taken for the voltage to decay to about 36.788% of its initial value.

The half-life for the circuit we build will be very short (about a thousandth of a second). Instead of looking at a capacitor discharging once, we'll charge & discharge it many times using square waves from a signal generator. These are waves in which the voltage spends half a cycle at one voltage and the other half at another voltage. (In the following diagram, generator voltage $V_G = V_G(t)$ alternates between zero and a voltage that we call V_0.)



The period of the square wave is T. The vertical lines are dotted because they are not really part of the square wave. (They appear if the voltage sensor across the capacitor cannot make measurements often enough.)

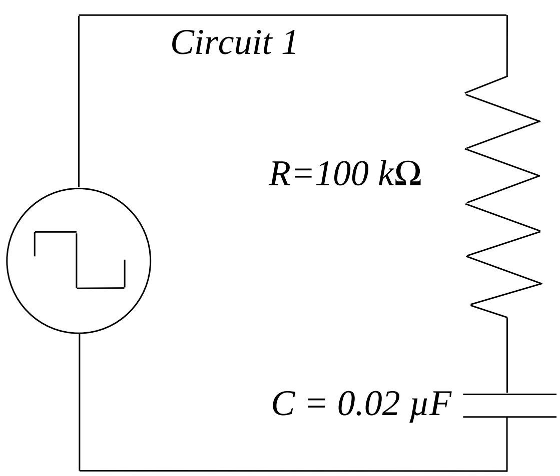
The next diagram shows graphs of both the voltage across the signal generator $V_G(t)$ versus time, and voltage across the capacitor $V_C(t)$ versus time. (Bold straight lines denote the square wave from the generator and dot-dashed lines indicate the abrupt voltage change that will appear.) The generator voltage has period T and changes polarity after <u>half</u> of a period. Solid exponential lines denote the response of the capacitor to $V_G(t)$.



The point $t = 0$ is the point on the furthest left that is marked 'A'. At points marked 'A', the voltage across the capacitor is as large as it will become. After points 'A', the capacitor begins to discharge and the voltage across it drops. The voltage approaches some voltage asymptotically. (It won't necessarily approach zero. In your experimental setup and in the diagram above, the voltage across the capacitor will seem to approach zero but you shouldn't worry unless this voltage is far from zero.) At points marked '*B*', the generator changes voltage and again, the voltage across the capacitor approaches a voltage asymptotically. This time the voltage approached is a maximum. (My diagram above makes this maximum voltage look like V_0 but experimentally, the asymptotic approach will be to some smaller voltage.) At the next '*A*', the generator voltage drops to zero and the cycle repeats.

As time approaches any point *B*, the voltage across the capacitor decays. However, it does not look as if the voltage has 'fully' decayed by the time that the voltage from the signal generator changes at point *B*. (The fact that the slope of the capacitor voltage is not zero suggests this.) Remember that this voltage decay is asymptotic so that the slope would decrease a little more if the capacitor was left undisturbed. Similarly, it does not look as if the capacitor has 'fully' charged at any time marked '*A*' but the signal generator disturbs it before the slope gets near zero. Both the charging and the discharging of the capacitor are asymptotic and will not happen in any finite time. But if we don't disturb the capacitor (by letting the signal generator change voltage), both the charging & discharging will be visibly more complete.

In the previous diagram, half the period of the generator (during which a single voltage decay occurs) is about 4τ so the period of square waves from the signal generator is $T \approx 8\tau$. We'd get a better idea of the voltage being asymptotically approached if we used square waves of a longer period. How long? We want the voltage across the capacitor to be 'small' enough. Recall $\frac{\Delta V(t)}{\Delta V(0)} = e^{-\frac{t}{\tau}}$. **What is the ratio of the voltage after $t = 20\tau$ to the initial voltage across the capacitor? [2]** The implication is that we should use a low frequency such as $f_{\text{low}} = \frac{1}{20\tau}$ at which to measure time constants.
The circuit that you'll build in the lab is;



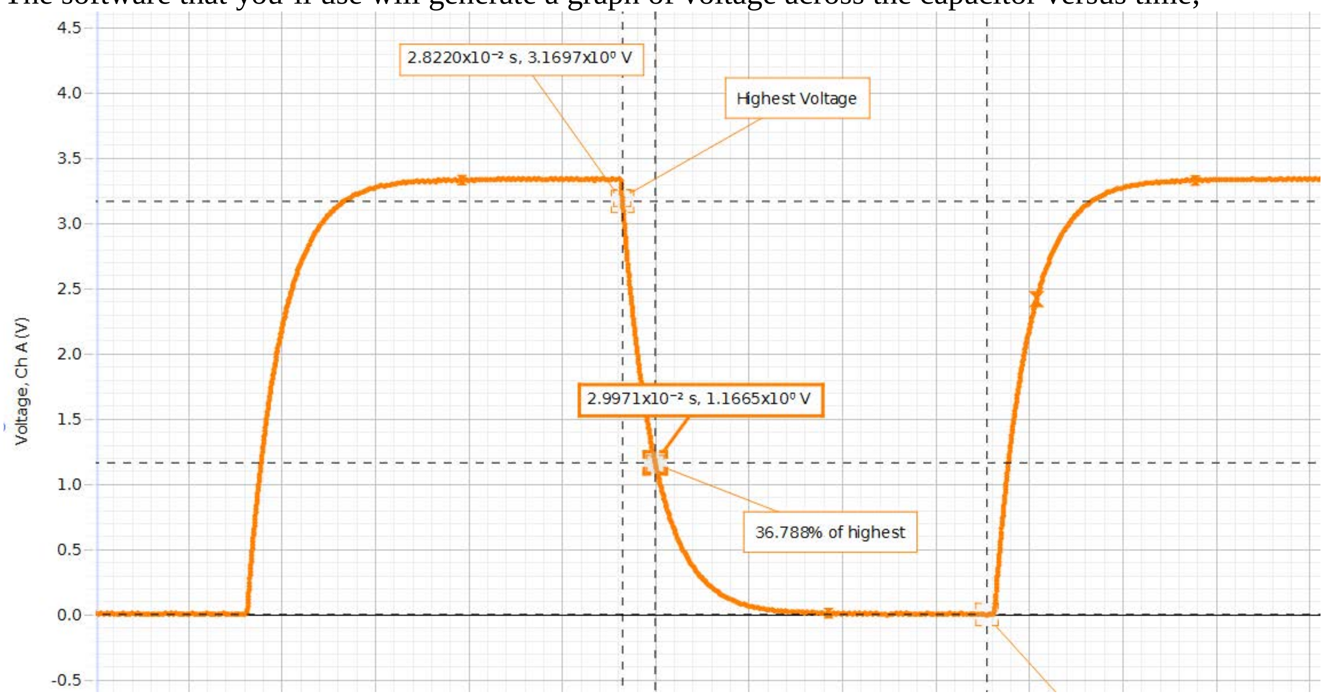
Find the approximate time constant for circuit one. (Use the nominal resistance and capacitance for your calculation.) **[1]** Given the preceding time constant, **what approximate frequency corresponds to T = 20τ? [1]**

The precise moment at which you begin taking measurements of the decaying voltage is not significant. To see this, suppose that the we begin measuring at time $t_1 \neq 0$. Since $\Delta V(t) = \Delta V(0)e^{-\frac{\Delta t}{\tau}}$ then, $\Delta V(t) = \Delta V(0)e^{-\frac{(t-0)}{\tau}} = \Delta V(0)e^{-\frac{(t-t_1+t_1)}{\tau}} = \left[\Delta V(0)e^{-\frac{t_1}{\tau}}\right]e^{-\frac{(t-t_1)}{\tau}}$. If we define $(\Delta t)_1 \equiv t - t_1$ then $\Delta V(t) = \left[\Delta V(0)e^{-\frac{t_1}{\tau}}\right]e^{-\frac{(\Delta t)_1}{\tau}}$. But $\Delta V(0)e^{-\frac{t_1}{\tau}}$ is just a constant. The factor $e^{-\frac{(\Delta t)_1}{\tau}}$ is the only factor that depends on time. (Actually, $\Delta V(0)e^{-\frac{t_1}{\tau}}$ is the voltage at a time t_1 and is often called $V(t_1)$ or simply V_1.) **Will this decay still be an exponential function of time? Will the time constant have changed? Explain**. **[2]** The implication is that the moment at which you begin taking measurements of the decaying voltage is not significant.

Suppose that we want to find the capacitance of the capacitor and suppose that we can measure time constants. If we use an ohmmeter to measure resistance then $\boldsymbol{C = \frac{\tau}{R}}$ can be used to find the capacitance. During the experiment, you will find a best-fit curve (that is expected to be exponential). The equation of the best-fit curve will give you the time constant.

At any moment, there is a difference between the voltage across the signal generator (square wave) and the voltage across the capacitor (exponential increase and decrease). **Identify the component of circuit 1 across which the voltage must appear**. **Identify the parts of the cycle at which the current is smallest.**

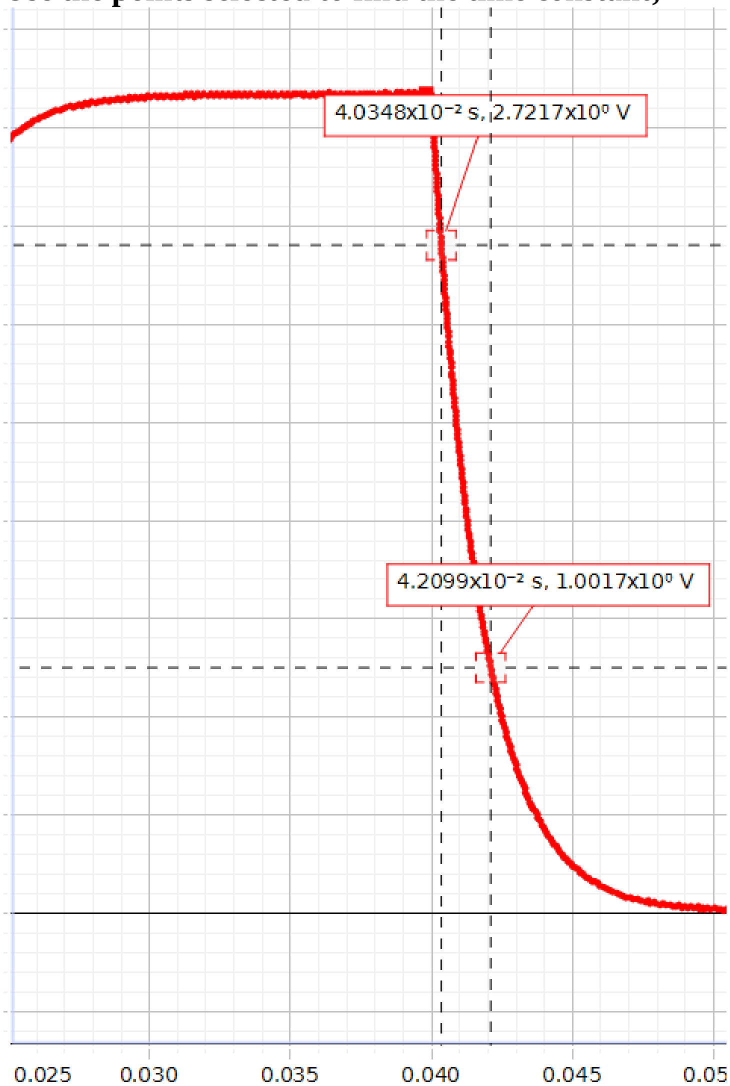
The software that you'll use will generate a graph of voltage across the capacitor versus time;



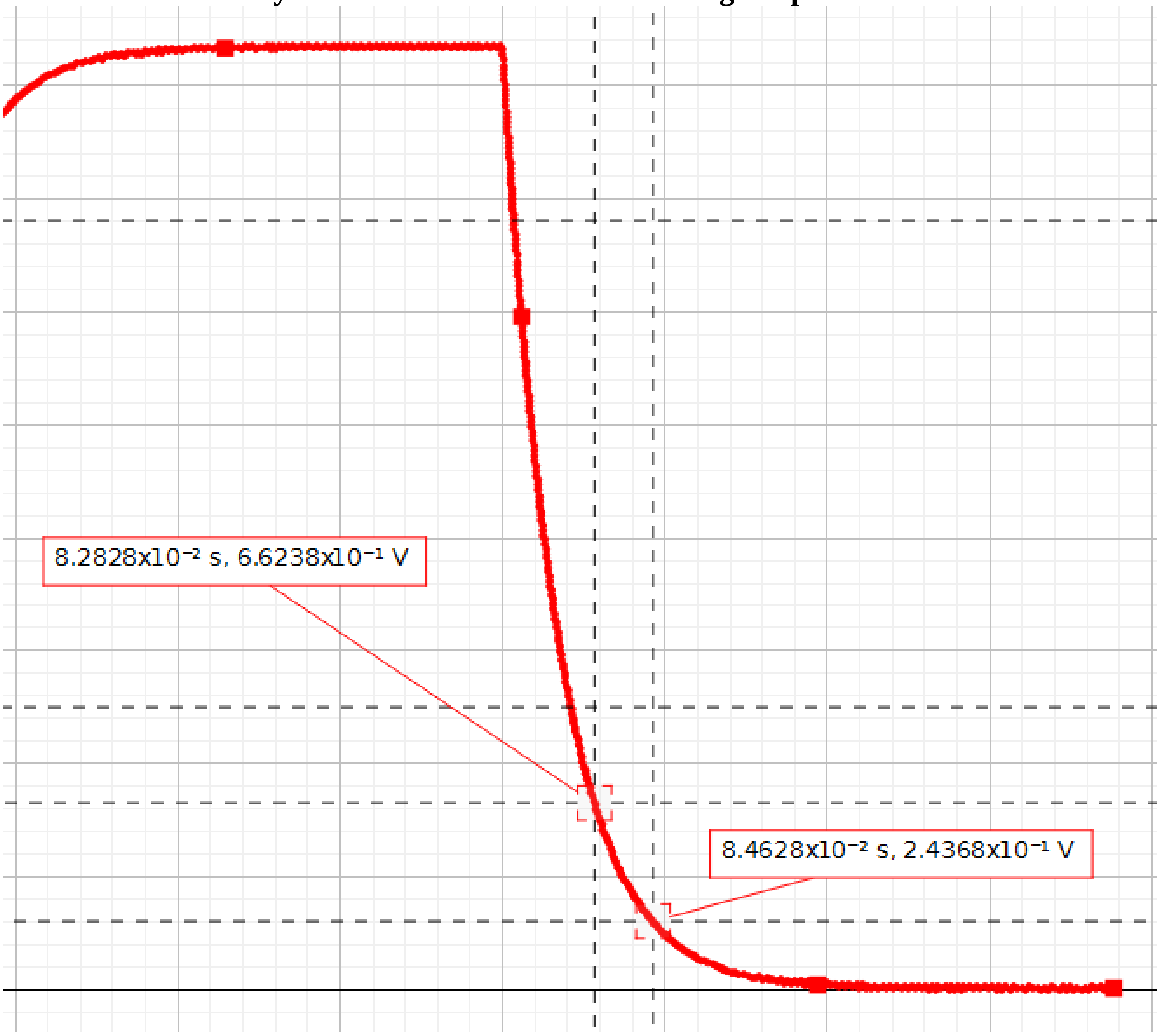
The software also has an annotation tool that you can use to put comments on your graph.

I choose two points during a voltage decay got using circuit 1. You have seen above that the choice of an initial point is not significant. I selected a data point after I was sure that the voltage had begun to decay: $(2.8220 \times 10^{-2}$ s, 3.1697×10^{0} V). Then I calculated 36.788% of 3.1697 V and got 1.1661 V. It turns out that this voltage is not among the data so I selected one with a voltage near what I wanted: $(2.9971 \times 10^{-2}$ s, 1.1665×10^{0} V). The time taken for the voltage to fall to (about) 36.788% of the maximum is $2.9971 \times 10^{-2} - 2.8220 \times 10^{-2}$ s $= 0.1751 \times 10^{-2}$=0.001751 s.

Use the points selected to find the time constant;

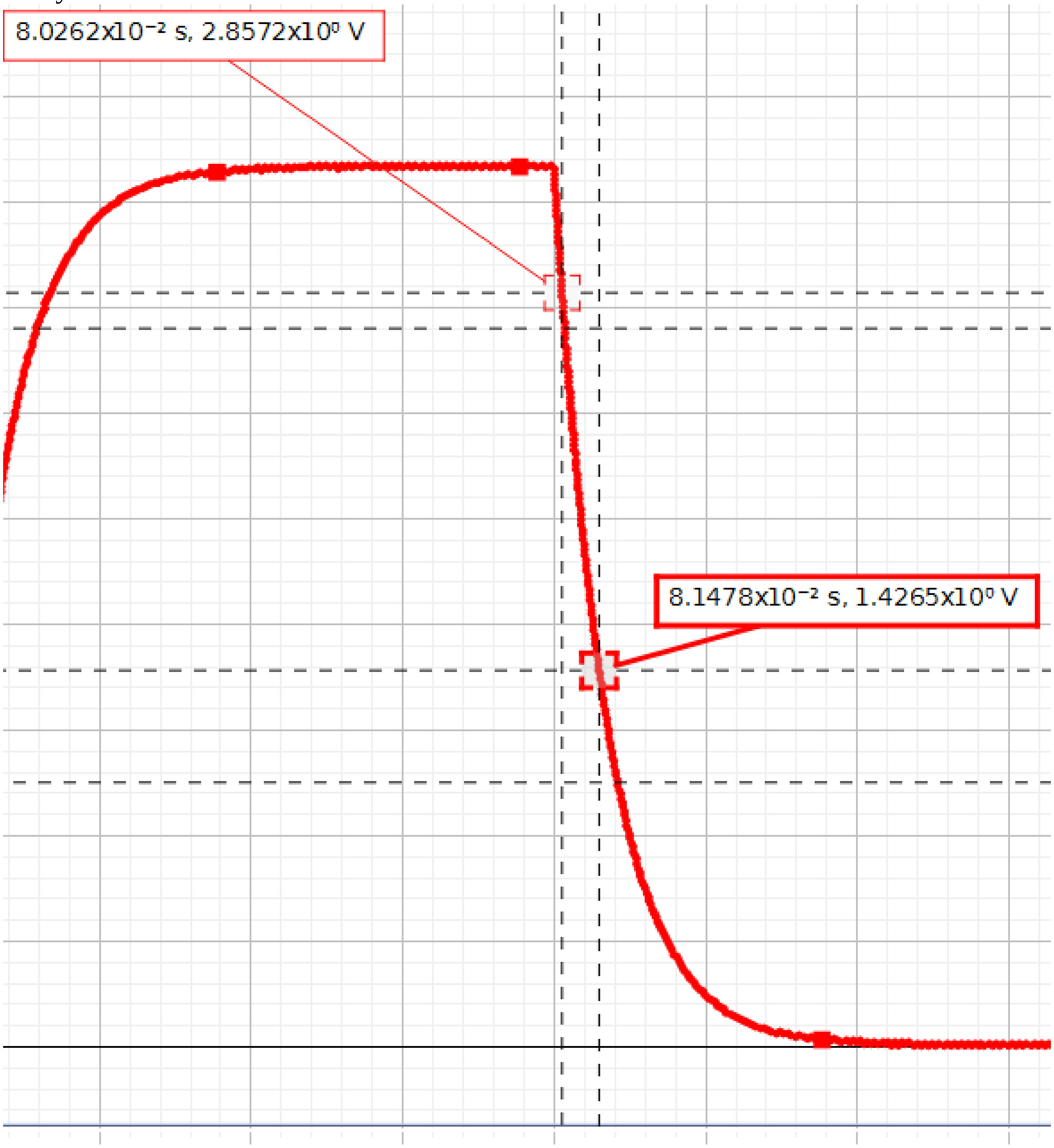


Here is another decay: calculate the time constant using the points selected.



In principle, it shouldn't matter where the two points are selected: near the start of the decay or near the end of the decay. In practice, the end of the decay is 'noisy' (as is the end of the charging of the capacitor). By this, I mean that the voltage jumps around unexpectedly and the chance of selecting one of these unexpected points is quite high. When you get a graph as above, zoom in on the end of a decay and you'll see what I mean!

We could characterize the rate of decay using "half-life" as we do in the case of radioactive decay.



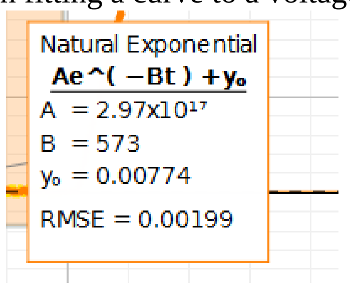
This time we choose an initial point (corresponding to voltage 2.8572×10^0 V). Then we look for a point with voltage 1.4286×10^0 V. The nearest voltage in the data-run is 1.4265×10^0 V and using it, $t_{1/2} = (8.1478 - 8.0262) \times 10^{-2} = 0.1216 \times 10^{-2}$s.

The same RC circuit was used to produce the preceding graphs that gave both the time constant and half-life. You also found a relation between time constant and half-life. **Do the time constant and half-life given by the graphs agree with the relation you found previously? Show your answer using the data above. [2]**

CURVE FIT

One weakness of using just two points in the calculation of the time constant is that many more points were actually gathered and are being ignored. A voltage decay in the graphs above lasts for about $0.002s$. Data was gathered at a sampling rate of 1 MHz. **About how many data points were collected during the decay?** The natural question is if the time constant calculated from the decay would be different if other points were selected.

Rather than reject most of those data-points and just use two for a calculation of the time constant, curve fitting uses most of them. The Capstone software makes this quite easy. When in the lab, you'll fit the decay data to the curve $\Delta V = Ae^{-Bt} + y_0$. **If we expect $\boldsymbol{\Delta V(t) = \Delta V(0)e^{-\frac{t}{\tau}}}$ then what do we expect the fitting procedure to give for $\boldsymbol{y_0}$? [1] Given that $\boldsymbol{t}$ is time [in seconds], what do we expect to get for $\boldsymbol{B}$? What units do you expect for $\boldsymbol{B}$? [2]** (Capstone won't give units!) When fitting a curve to a voltage decay, the software gave:



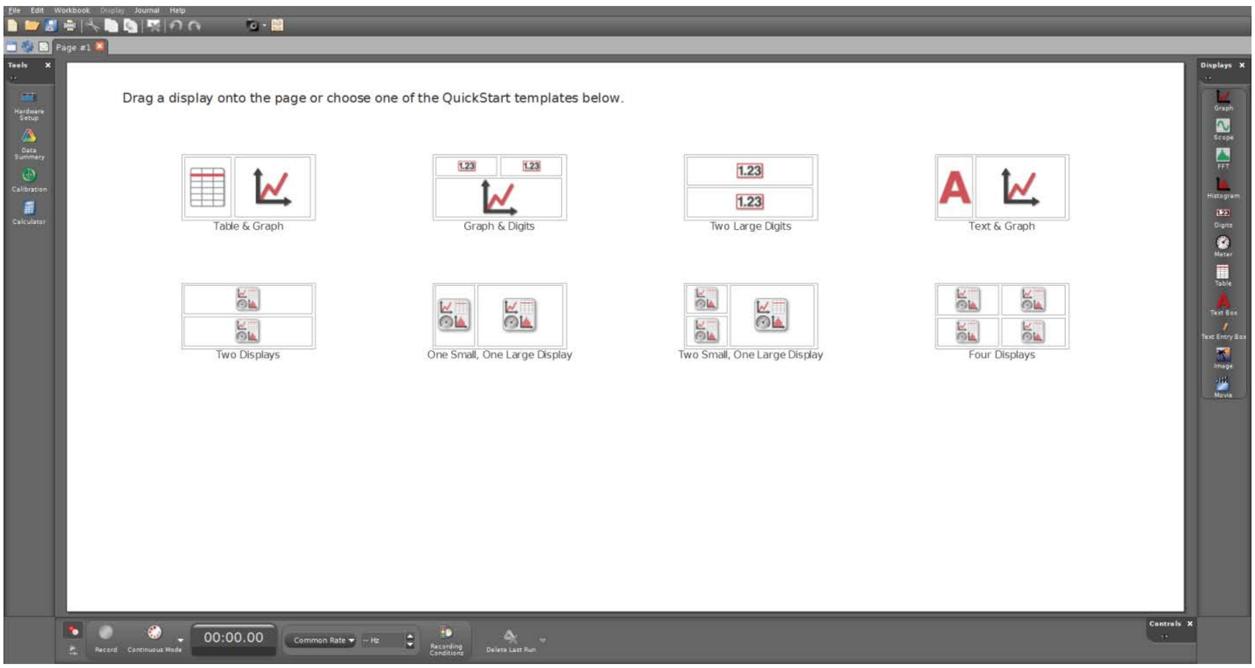
The RMSE is the root mean square error (sample standard deviation). This is a measure of the difference between the data and the curve being fit. The smaller it is the better! **What was the time constant for the curve-fit data above? [1]**

RC Circuits
Paul MacAlevey © Spring 2017

Instructions

Measure the resistance of the resistor with nominal resistance of **100Ω**. **Record** this resistance in your report. **[1]** Your TA will measure the capacitance of your capacitor using a capacitance meter. **Record** its measured capacitance in your report. **[1]** You will need to use these measured values in order to calculate your approximate time constant for the RC circuit. ***Use these measured values to calculate the approximate time constant.*** **Record it in your report. [1]**

- Connect the 850 interface to computer using a USB cable
- Switch on the interface
- Launch Capstone software. (A shortcut to Capstone is on the Desktop.)
- The Capstone screen should look like:

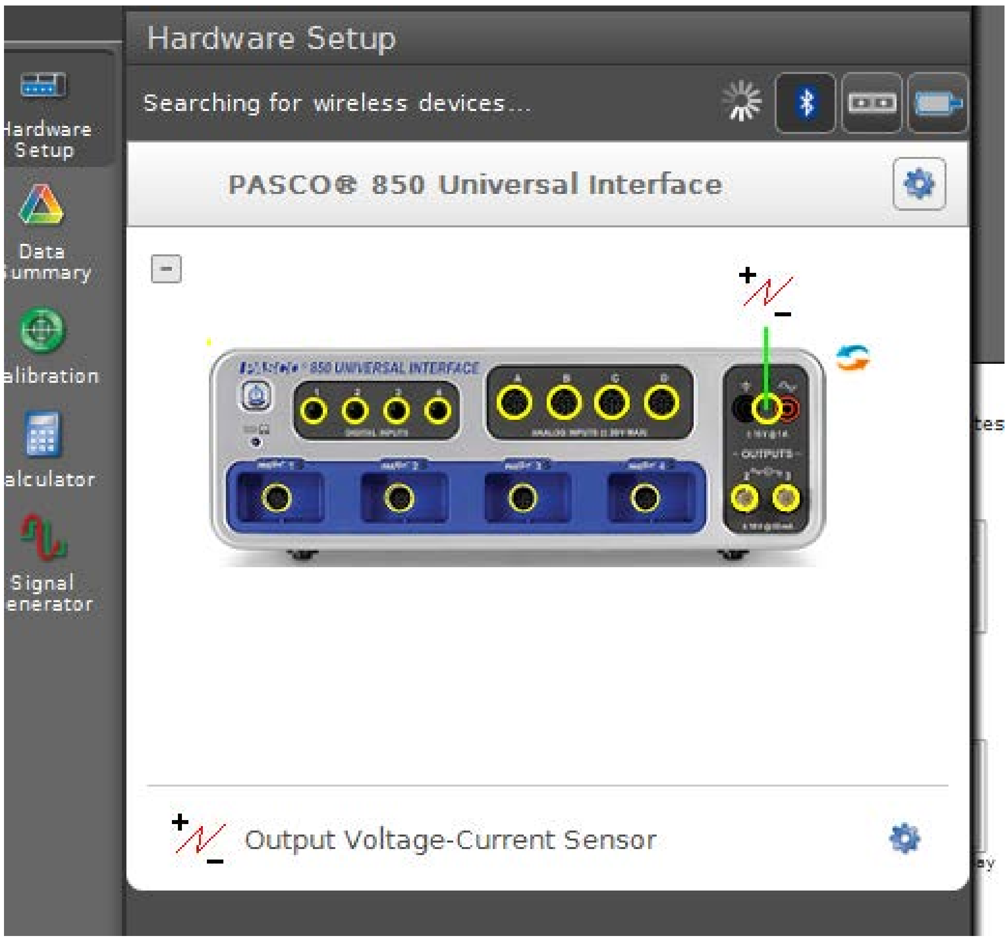


- The Tools palette is on the left of the Capstone screen. Click "Hardware Setup"  from the Tools palette
- You should get a picture of the interface like;

- Output 1 is the output from a signal generator that is built into the interface.

- Click on "Output 1" on the picture of the interface. A dropdown list appears. Select "Output Voltage-Current Sensor". This sensor is built into the interface and detects voltage and current at Output 1. You have just associated the Output Voltage-Current Sensor with Output 1 so that the Capstone software 'knows' about this sensor.

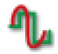
- The picture of the interface becomes;

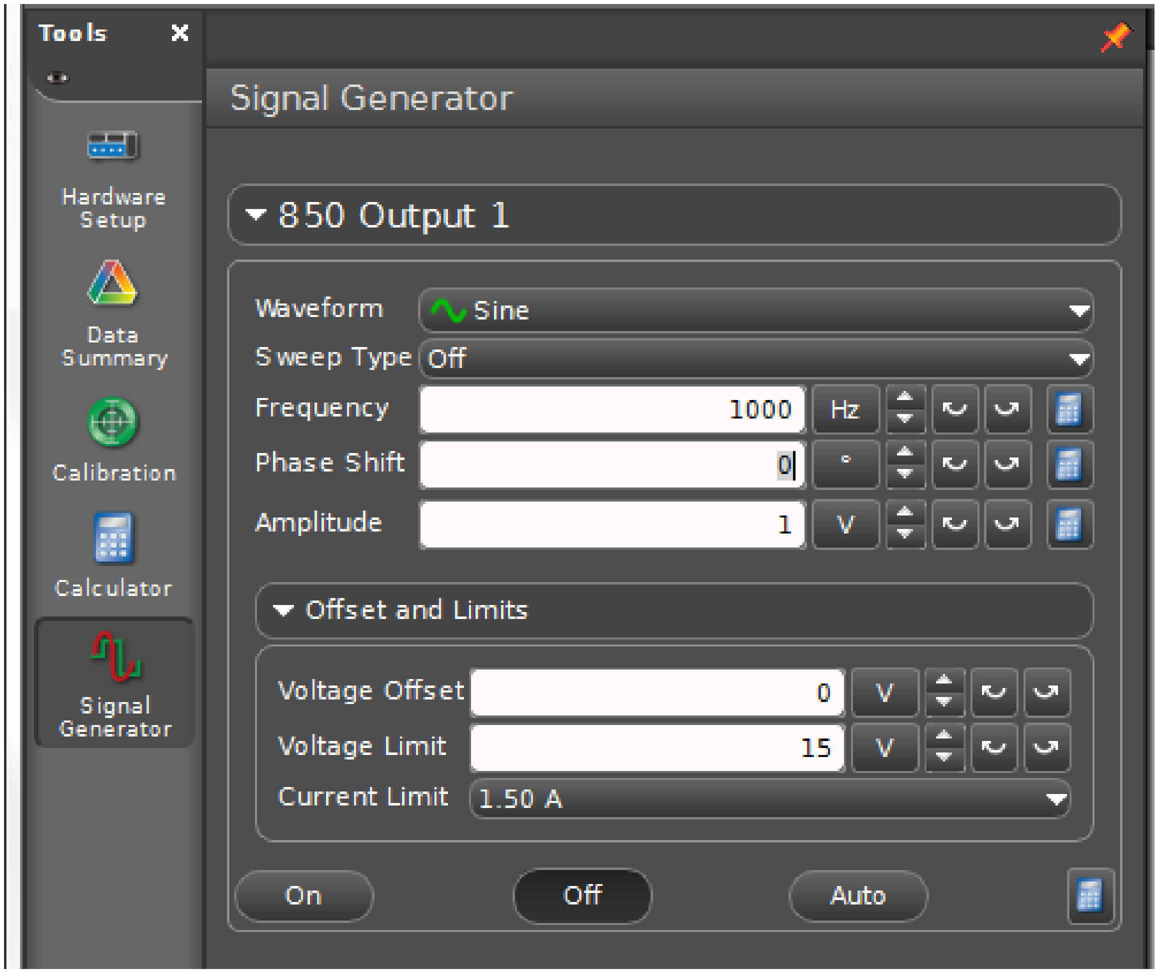


- The default sample-rate for this sensor is 20 Hz but we'll need a larger sample-rate.

• There is a row of controls below the white Display Area;

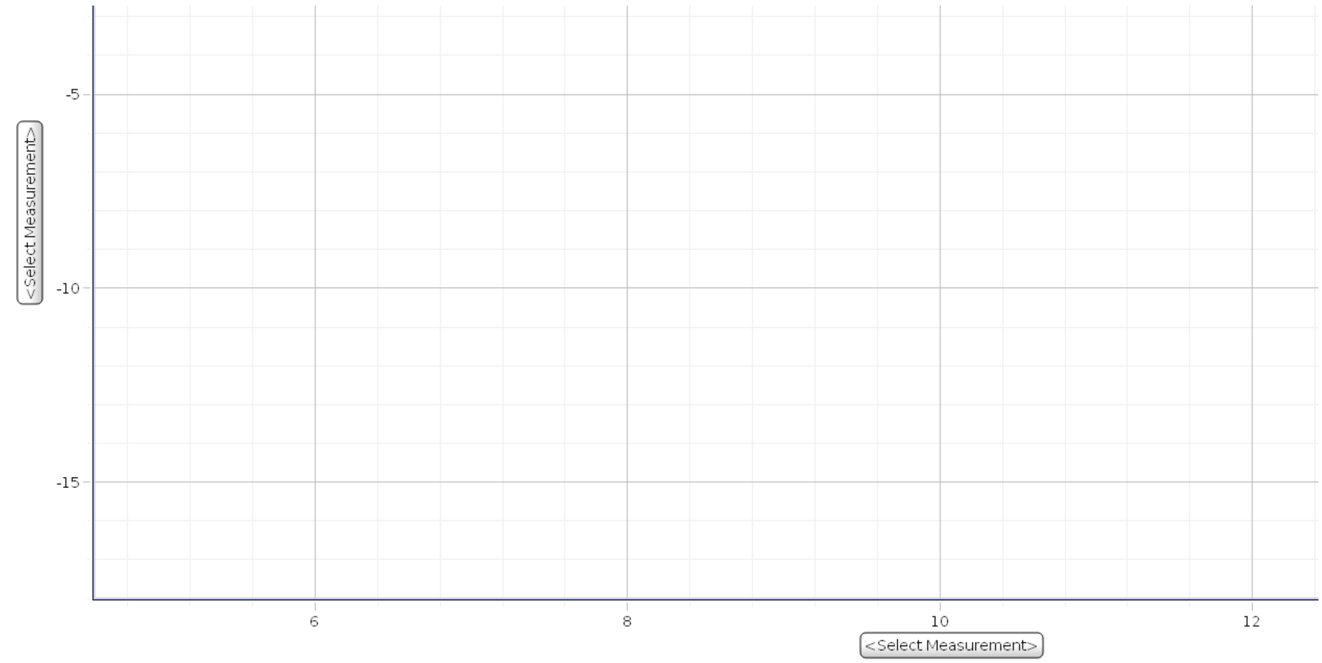
• Use the arrow keys to increase the sample-rate to 1 MHz.

- Click the icon for the signal generator  from the Tool palette.
    - Click on “850 Output 1”.This will open up;

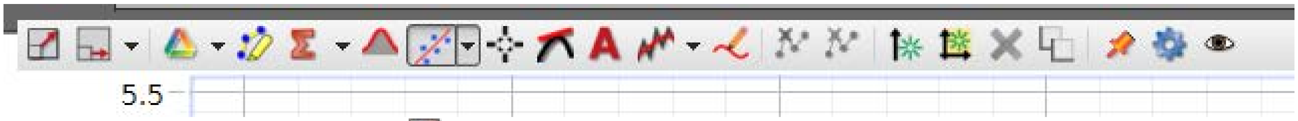


    - Beside “Waveform”, click on . This opens a dropdown. Select the Square wave 
    - Leave the “Sweep Type” off, the “Frequency” at 1000 Hz and the “Phase Shift” at 0.
    - Change the “Amplitude” to 2 V, the “Voltage Offset” to 2 V and the Voltage Limit to 10 V.
    - At the bottom of this dialog, click the AUTO button. (This button switches the signal generator on when you ask the software to record data later.)
    - To finish with this dialog, click the icon for the signal generator  from the Tool palette.

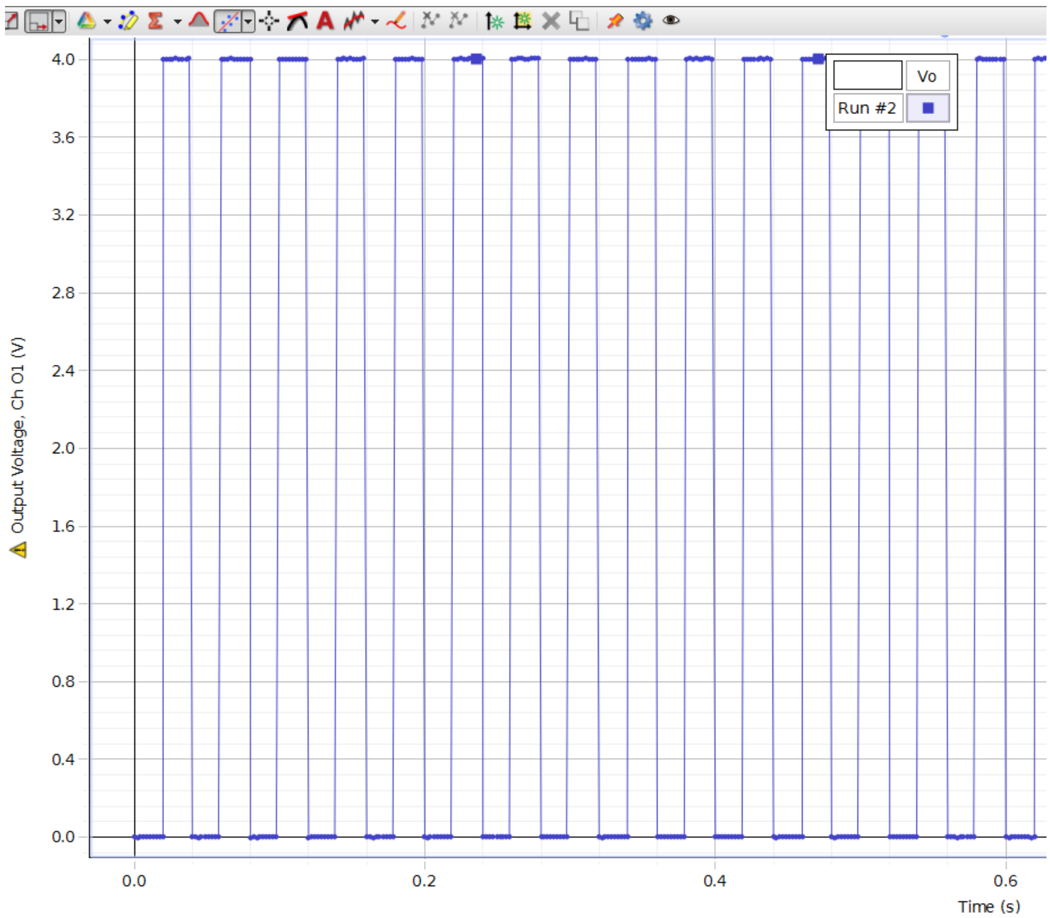
- The largest part of the Capstone screen is a white Display Area. To the right of the Display Area is the Displays palette. Drag the graph icon  from the Displays palette and drop it on the Displays Area.
- This should give you a graph with unnamed axes:



- Click <Select measurement> on the x-axis of the graph. From the dropdown, select "Time (s)"
- Click <Select measurement> on the y-axis of the graph. From the dropdown, select "Output Voltage (V)" under "Output Voltage-Current Sensor".
- You will record some data from the signal generator next. The length of time for which you record data is not very significant. But the more data that is collected by the sensor the harder it will be for the computer to keep up with it.
    - From the row of controls at the bottom of the Capstone screen, click the "Record" button . This switches on the signal generator and makes a graph of voltage at output 1 versus time. The "Record" button turns into a "Stop" button  and your graph fills with data as it is recorded. Press 'stop' soon after you have pressed 'record'. (1/2 s is more than enough time at this sample rate and frequency of the square wave.)
    - If something went wrong when you intended to collect data, you can delete the last run (of data-collection) then press 
- Notice a row of graph tools above your graph;

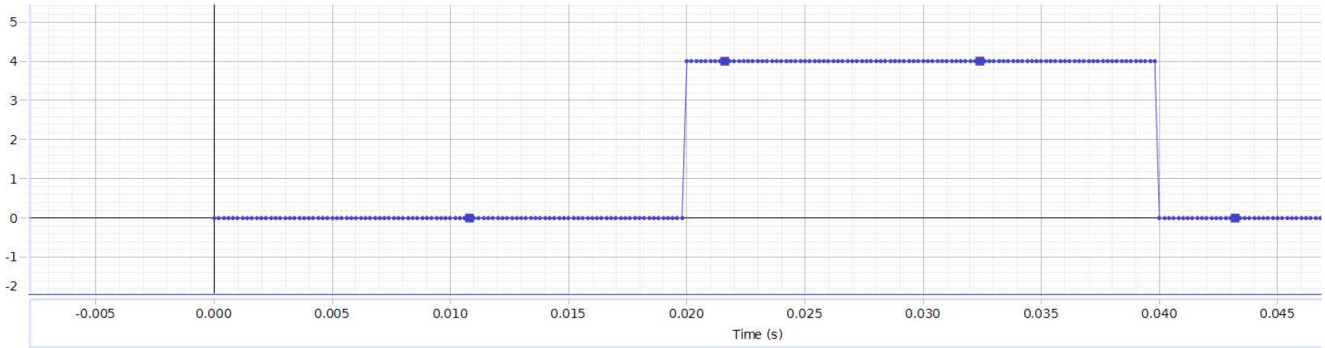


- The first of graph tool ( ) allows you to rescale both axes so that all data is displayed. Click it.
- This should give you a graph such as;

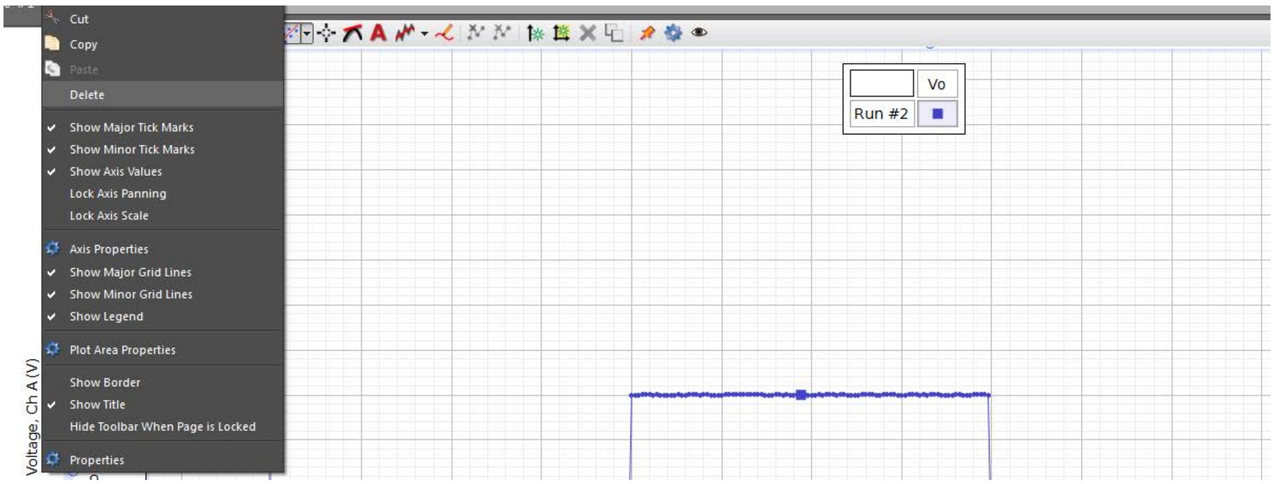


Your cursor looks like a hand  when you hover over the graph. By holding the left mouse button down, you'll be able to drag the graph around the screen. The scroll wheel on your mouse allows you to zoom in or zoom out.

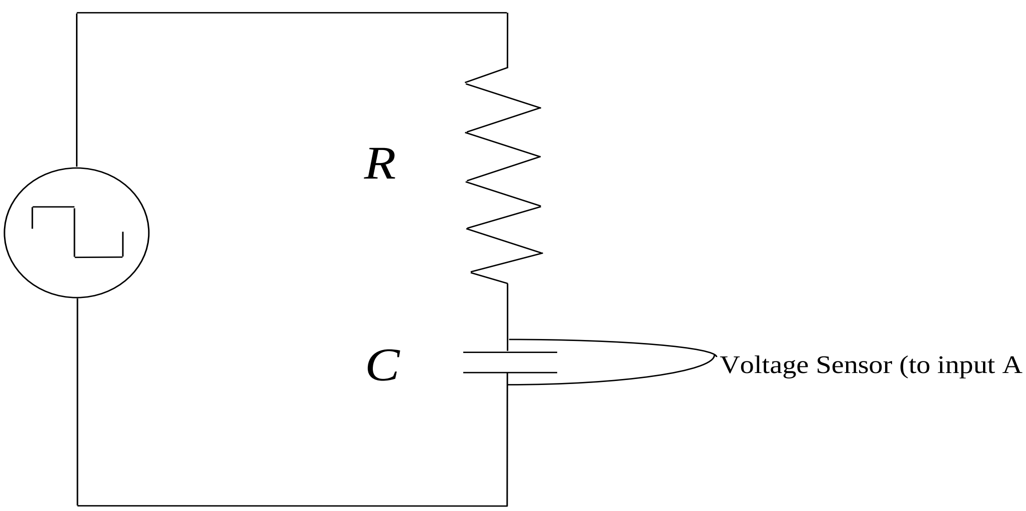
When you move the cursor to an axis, it turns into a double headed arrow; . If you hold down the left button then you can change the axis-scale. This is useful when you want to look closely at part of the graph. For example, you should be able to pick out a cycle of the square wave like this;

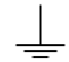


To delete the graph, click on the graph (so that it becomes active). Then go to the "Display" menu and select "Delete".



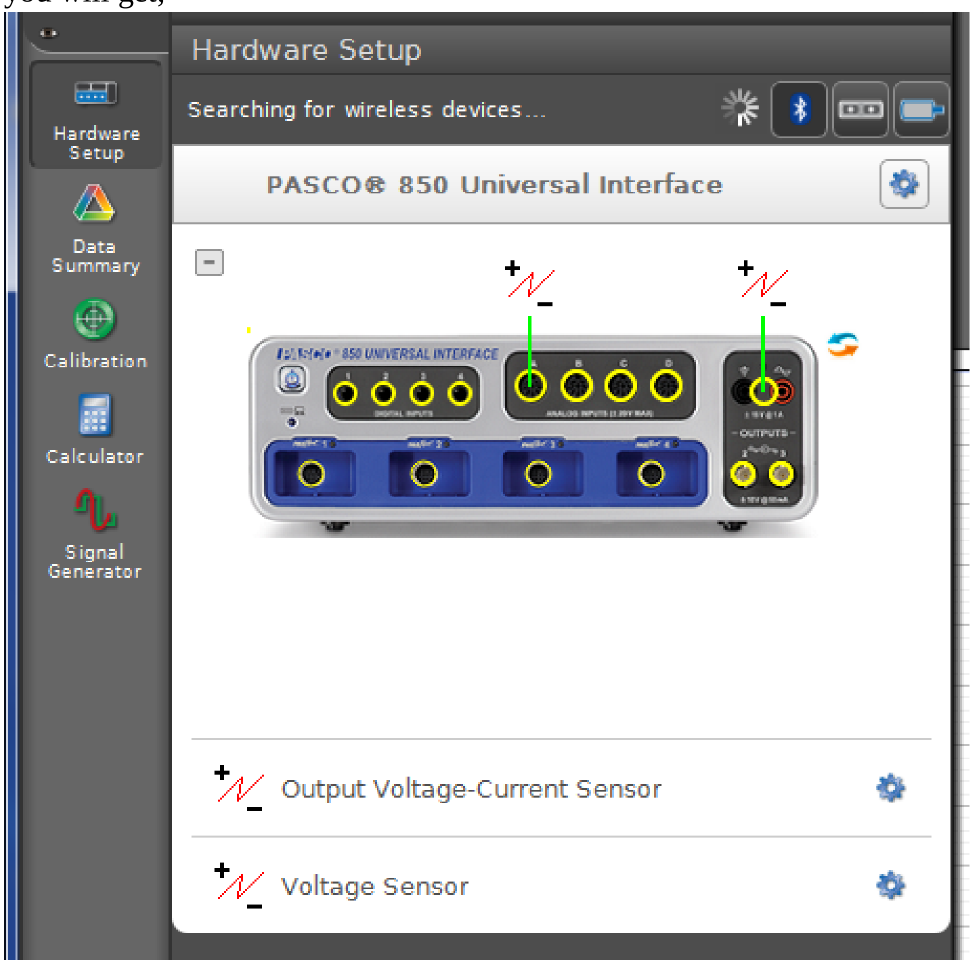
Build circuit 1 using a capacitor (C = 0.02 microF) and a resistor (R = 100 kOhm). *Use banana-to-banana leads to connect the capacitor and resistor to the interface.*



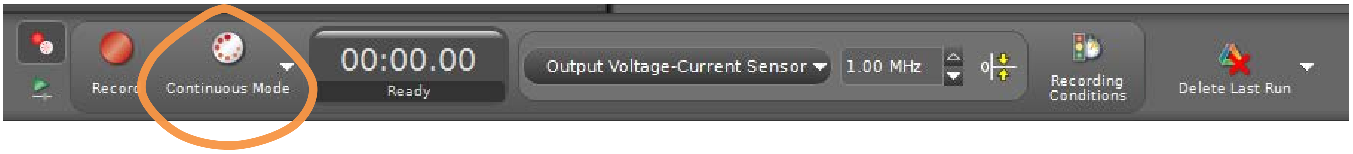
Connect the BNC end of a voltage sensor to analog input A. (We have already told Capstone to associate a voltage sensor with that input.) Connect the alligator clips from the sensor across the capacitor. Connect the black alligator clip from the voltage sensor to the ground  side of the capacitor. Connect the red alligator clip from the voltage sensor to the other side of the capacitor.

- Click "Hardware Setup" from the Tools palette.
  - On the picture of the interface, click on analog input A

  - A dropdown list of sensors will appear. Select Voltage Sensor. After you do, you will get;



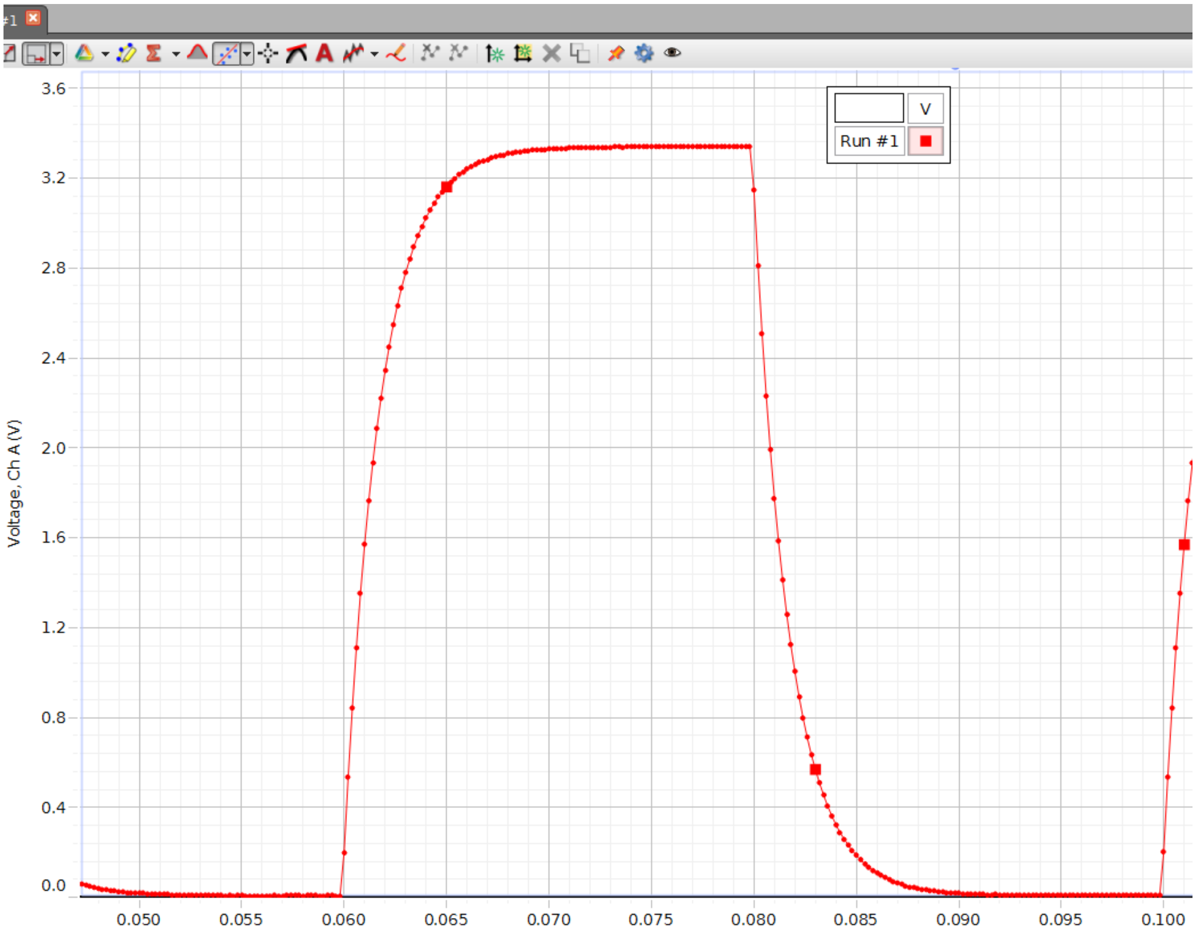
- Click the icon for the signal generator from the Tool palette. Click on “850 Output 1” as before. Change the frequency of the square wave to $f_{\text{low}} = \frac{1}{20\tau_{\text{approx}}}$. (The nominal values give $f_{\text{low}} \approx 25\text{Hz}$ but your values might suggest using a smaller frequency for the square waves.)
- Return to the row of controls below the white Display Area;



  - Click the down arrow to the right of Continuous Mode and select Fast Monitor Mode. The Continuous Mode control will turn into . This will allow the software to take samples at a higher rate than usual.

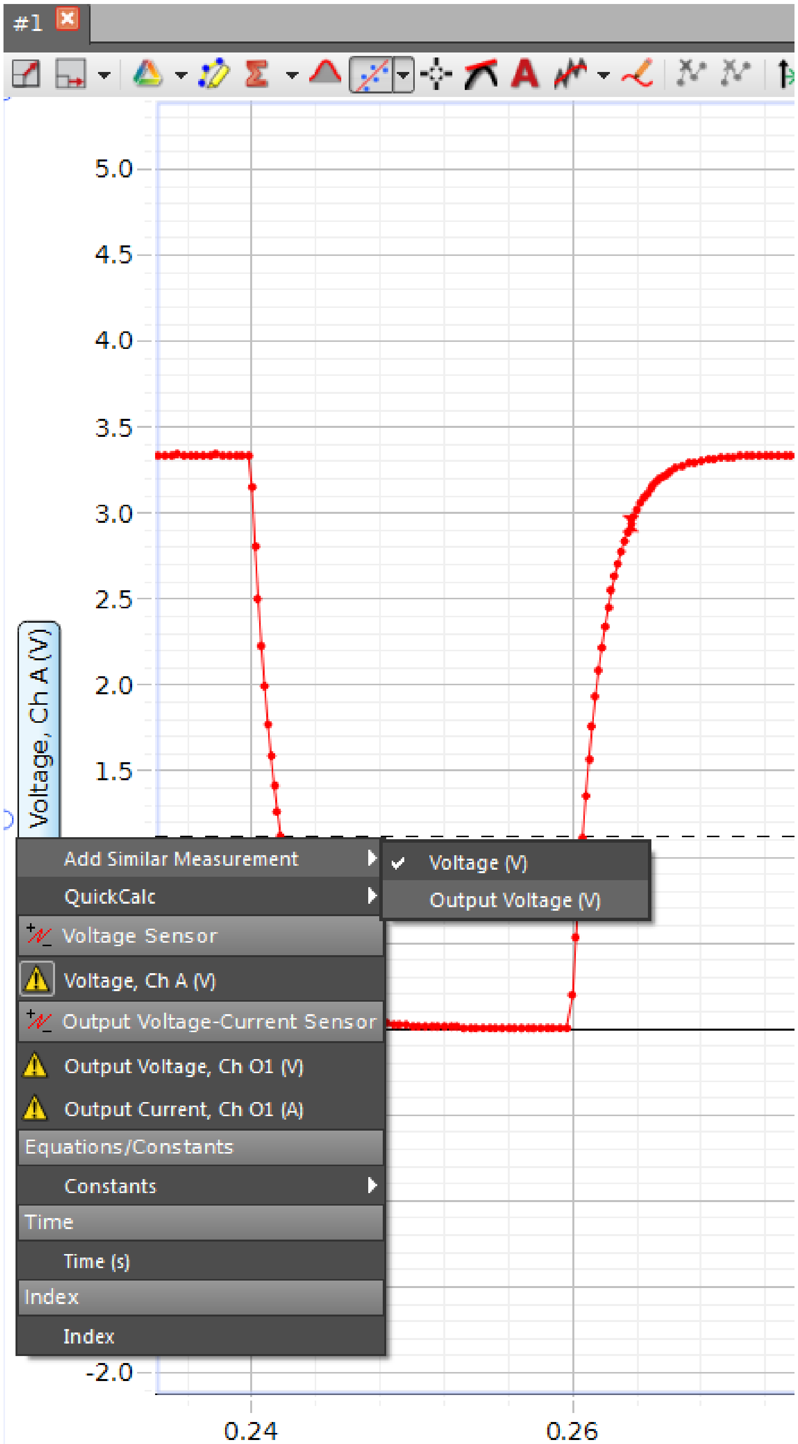
(The screenshot above shows the Output Voltage-Current Sensor and its sample-rate. However, if you click on the down-arrow to the right of this sensor name, you’ll get a dropdown list of the sensors that you have associated with the interface. You can select any sensor that is listed and edit its sample-rate. This is an alternative to using the properties icon ( ) that you get when setting up the hardware using .)

- Drag & drop another graph display onto the Displays area. Rename the x-axis as Time and put the voltage from the recently attached voltage sensor [Voltage Ch A (V)] on the y-axis.
- Record a couple of cycles of data. The graph appears in real-time so you’ll see the charge & discharge that characterize a cycle. **I suggest that you don’t collect more than three or four cycles. A sample rate of 1 MHz gathers enough data that many computers have difficulty keeping up. You may notice your computer slowing down significantly if you try to manipulate a very large set of data.**
- Rescale the axes: . You should get a graph of several cycles of charging and discharging of the capacitor. The cycles may be closely spaced but after you rescale the Time axis with , you should be able to get;

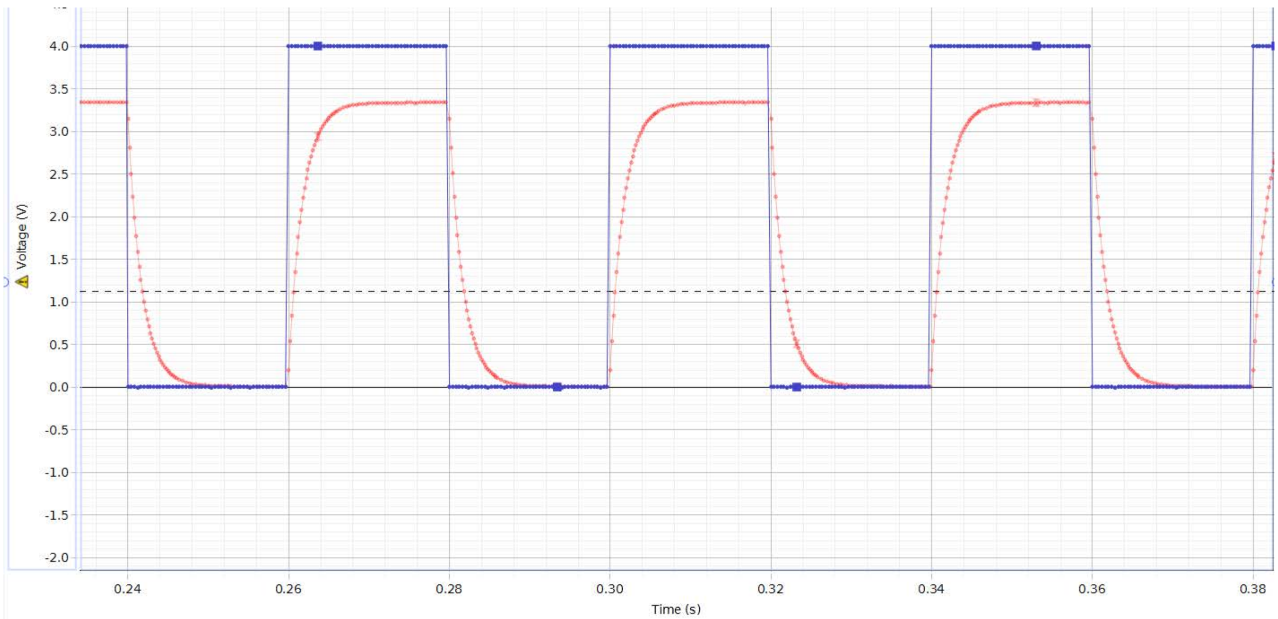


Remember that the graph is of the voltage across the capacitor.

- It is useful to see what the signal generator is doing while the capacitor is responding as in the graph above. Click the Voltage axis. From the dropdown (picture below) hover over "Add Similar Measurement" and you can select to put the output voltage from the signal generator on the y-axis too.

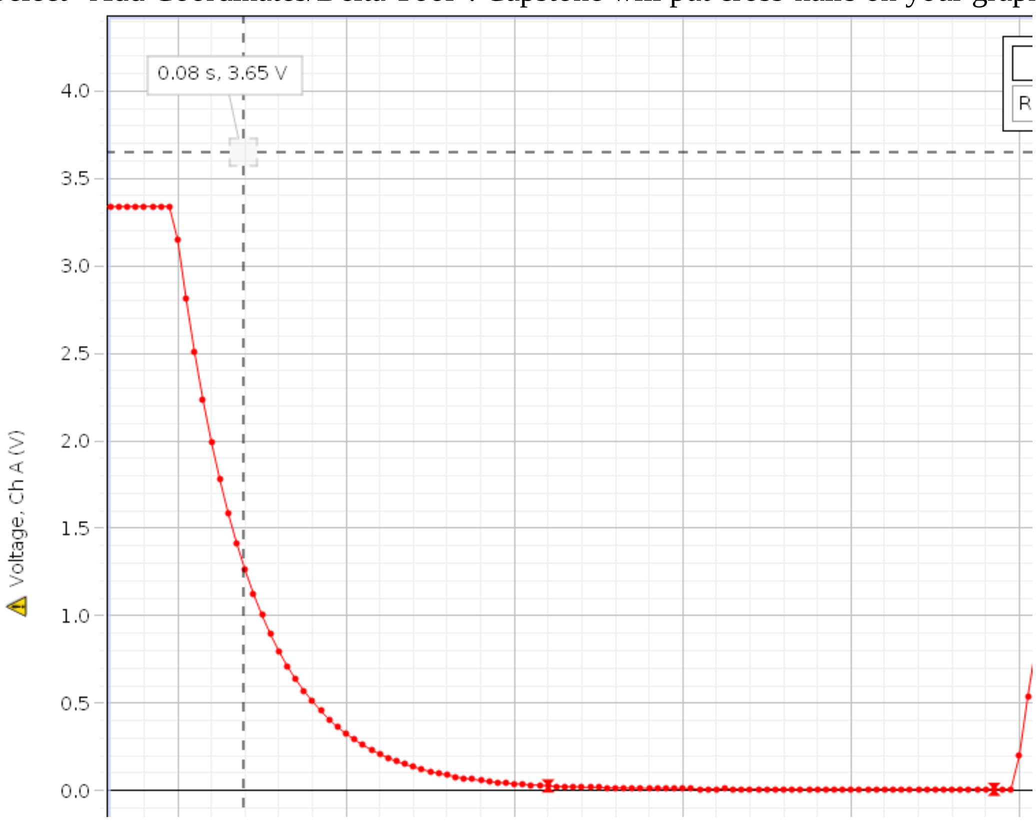


After adding the voltage supplied by the signal generator, you'll get something like;



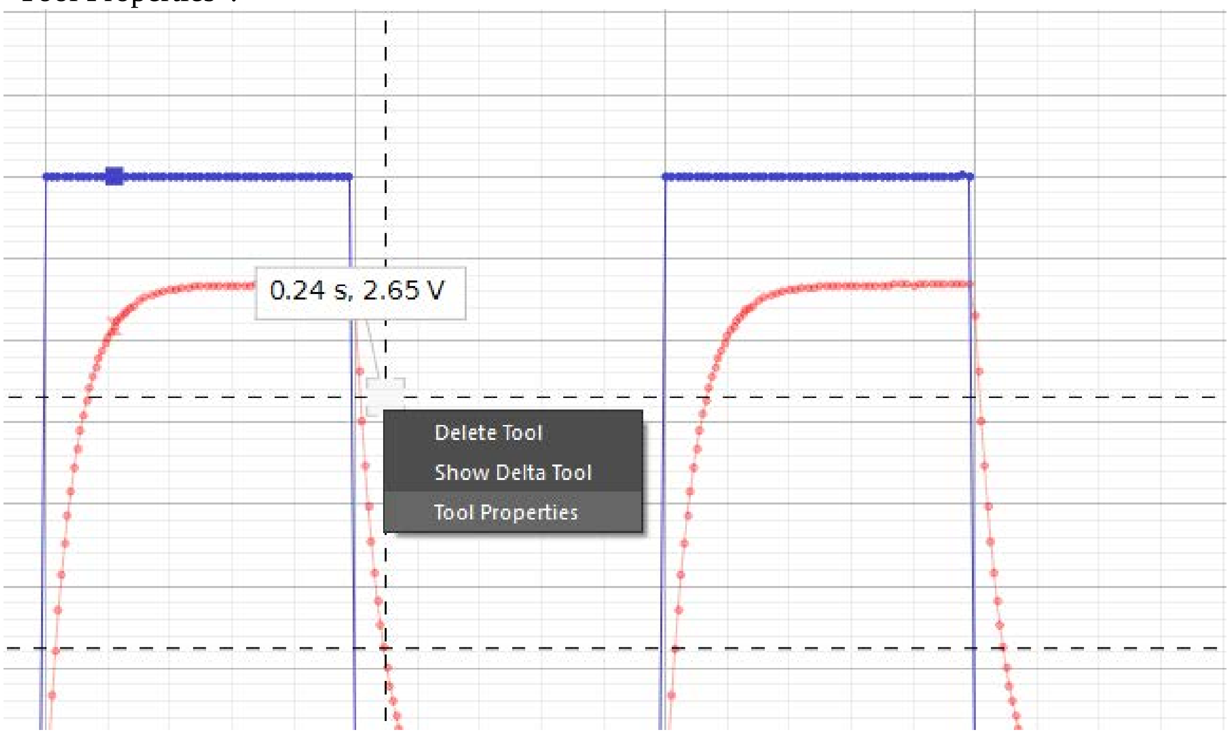
From this graph, the voltage across the capacitor (red) begins to increase as soon as the signal from the signal generator changes from 0 V to 4 V. Consider a single ½ - cycle during which the voltage across the capacitor decays.

The software has got a Coordinates Tool to help you read values accurately from a graph. The icon for the Coordinates Tool is . (It is on the toolbar above your graph.) Click on it. Select "Add Coordinates/Delta Tool". Capstone will put cross-hairs on your graph.

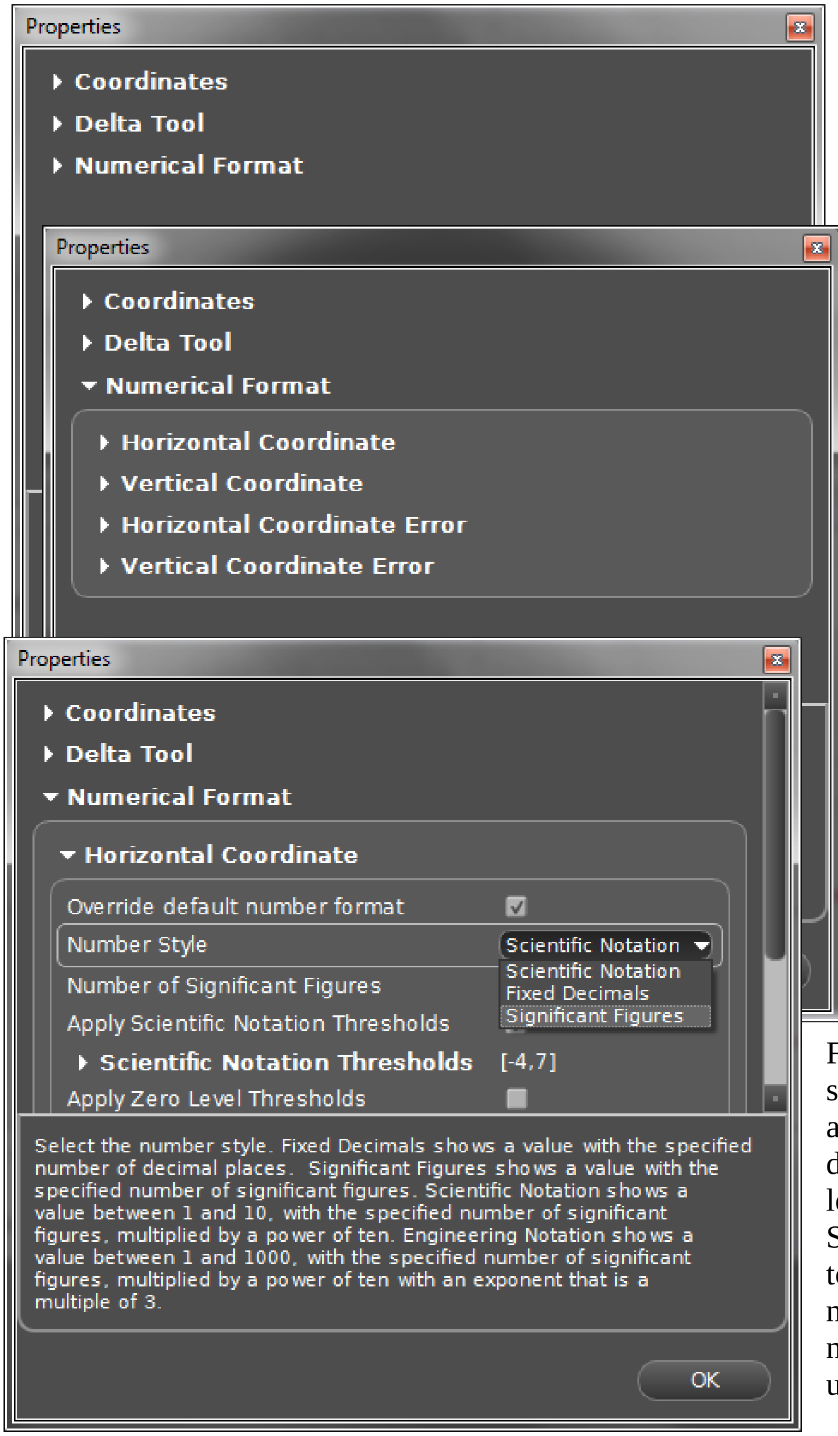


If the tool is not on any point of measured data then it is gray. If it is on a data-point then it adopts the color of the data point. (If the Coordinates Tool is not on the data, move the cursor to the intersection of the cross hairs, hold down the left mouse button and drag the coordinate tool to the data). Notice that you can use the left and right arrow keys to move the Coordinates Tool through the data.

The tool may not give enough decimal places when Capstone first puts the tool on your graph. To change this, click on the Coordinates Tool (either on the boxed coordinates or the intersection of the cross hairs). A drop-down menu will appear from which you can select "Tool Properties".



This will give you:



Click on the arrow to the left of “Numerical Format” to give;
.

Select “Horizontal Coordinate” and you’ll get;

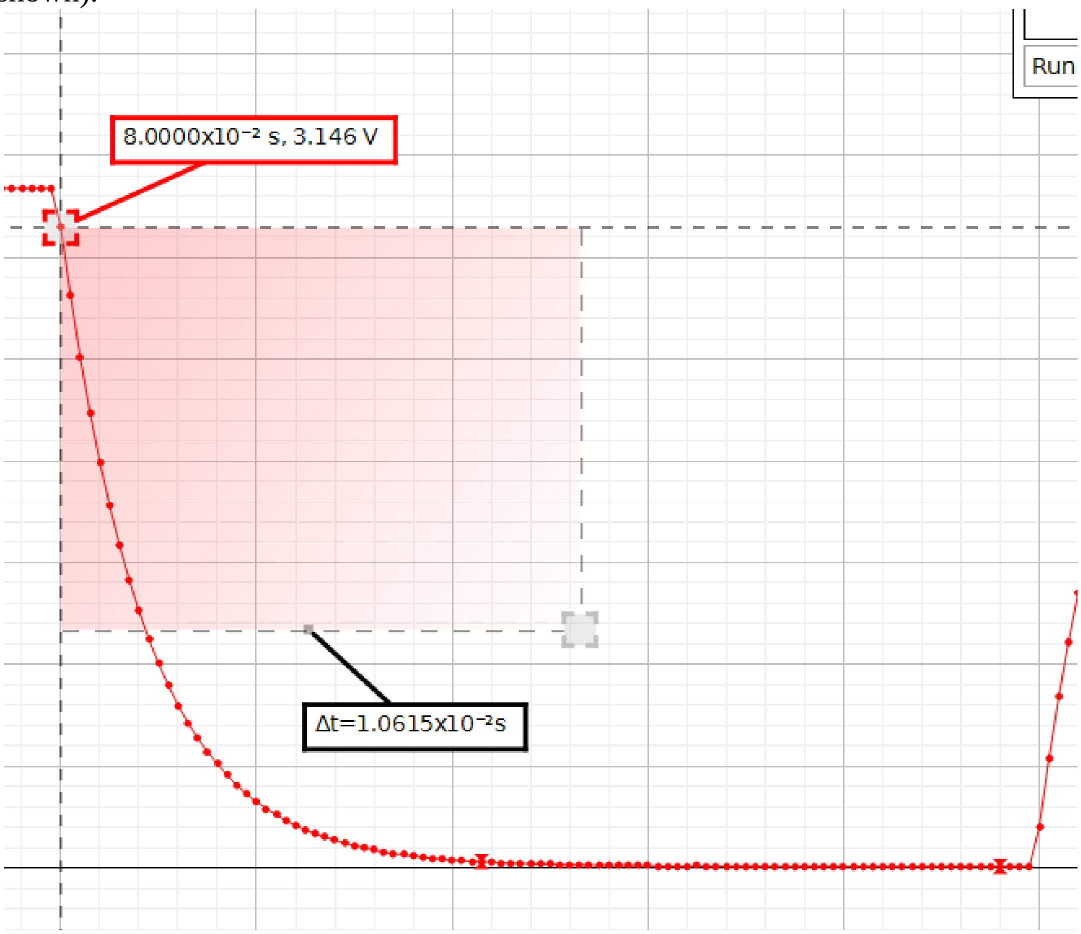
Check the box “Override default number format” & change the numerical format as you wish. Five significant figures in scientific notation will be adequate. (The ‘5’ is under the drop-down in the picture to the left!) I usually check “Apply Scientific Notation Thresholds” too. This means that scientific notation won’t be used if the number is easier to read without using it.

Repeat for the Vertical Coordinate.

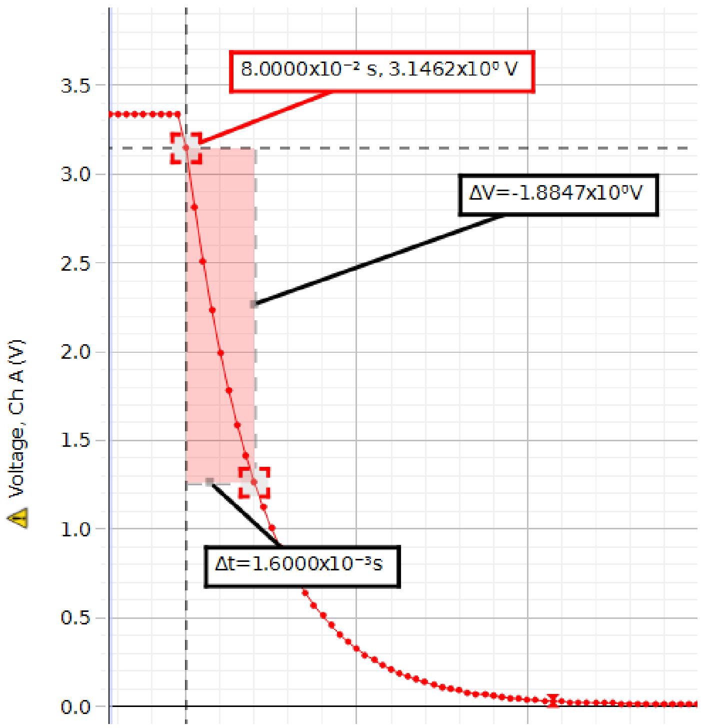
At this point you have two choices. The objective is to measure the time constant and you can use either choice described below.

One choice is to add another "Coordinates Tool" to your graph. This Tool will have its own set of boxed coordinates. Since this Tool includes a coordinate that is the voltage, having calculated 0.36788 of the voltage of the first point on your graph, you'll be able to move the second Coordinates Tool to a suitable data point with which to calculate the time constant. (The calculation of $t_{1/2}$ and of τ in the introduction were all done this way and don't need further comment.)

The other choice is to use the Delta Tool rather than add another Coordinates Tool. Right click the boxed coordinate again and check "Show Delta Tool". Another set of cross hairs will appear but they are not as long (and unfortunately the coordinates of their intersection are not shown).



The two points on the corners of the shaded rectangle are associated with each other. The interval on the graph marked $\Delta t = \cdots$ is the time between the two points that are marked. Drag the grey box to the data.



Once the grey box is on the data then you can use the left and right arrow keys to move the Coordinates Tool through the data. Use ΔV to choose a 'suitable' point for the lower corner: $3.1462 \times 0.36788 = 1.1574$. Thus, we move to a point so that ΔV is as close to $3.1462 - 1.1574 = 1.9888$ V as is in the data. The corresponding Δt is the time constant so that this data gave $\tau = 1.6000 \times 10^{-3}$s.

Whichever method you adopt, **choose two points with which to calculate the time constant. (Give their coordinates in your report.) Find the time constant for circuit 1 using the two points that you have chosen**. **Print the graph that shows these two points**. (Annotate the graph if you think that this helps.)

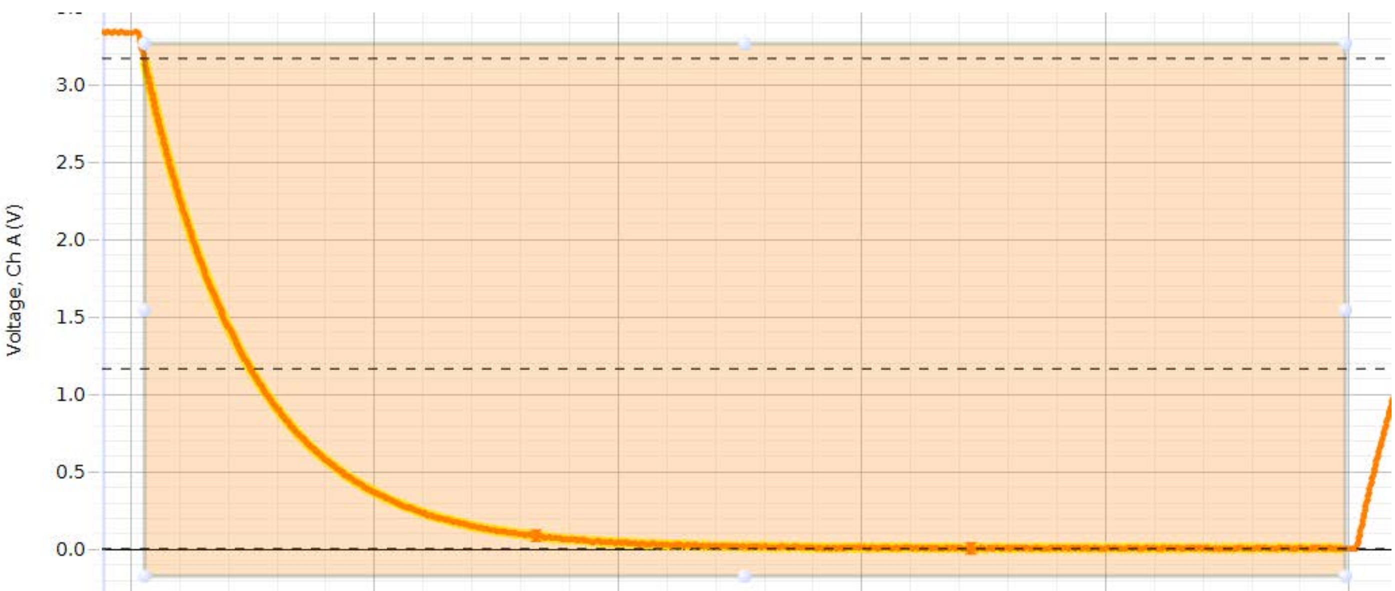
By what percentage does this time constant differ from that given by $\tau = RC$? Should you use nominal or measured values to calculate $\tau = RC$? (Use the expression;
$\text{error} \equiv \dfrac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}}$ to calculate error).

Curve fit:

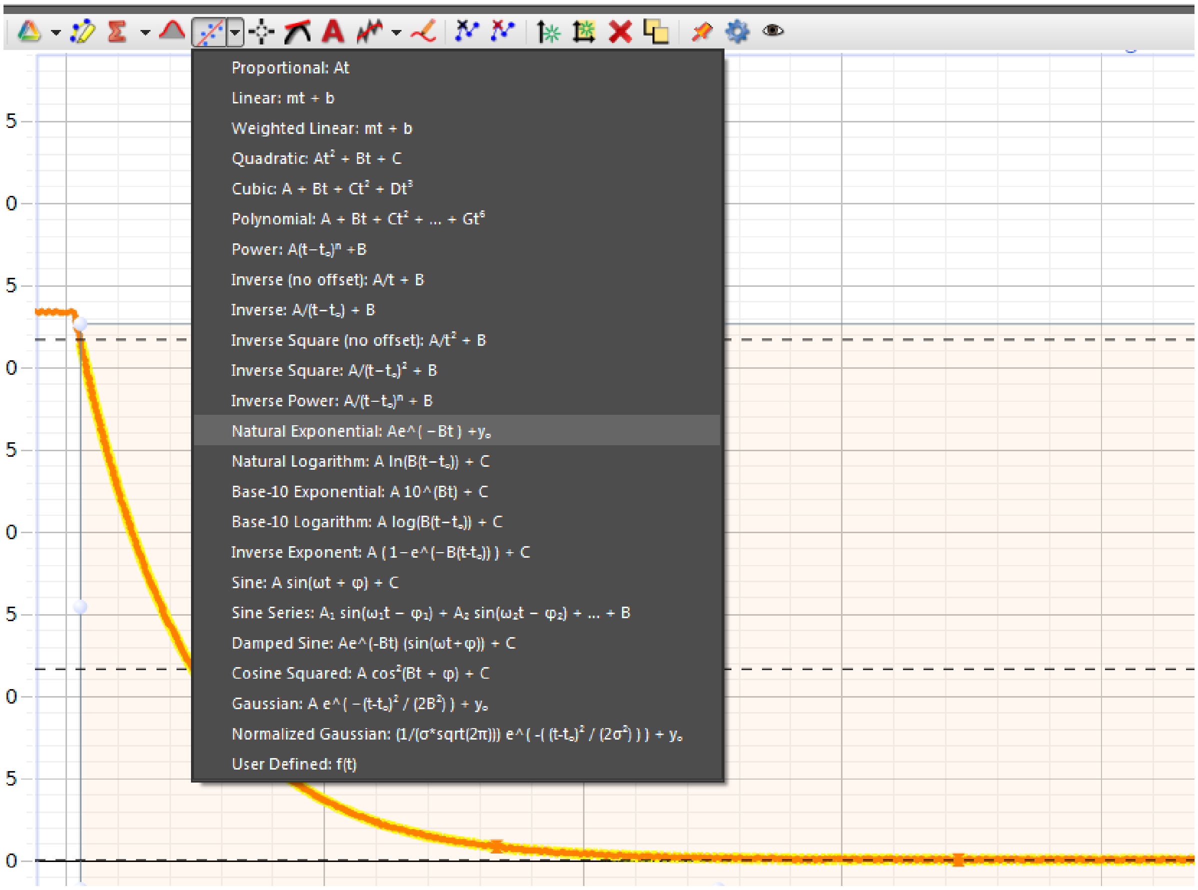
Calculating the time constant this way, uses much more of your data (and is fairly easy!).

Click "Select Data" . At first, this just puts a rectangle on your graph;

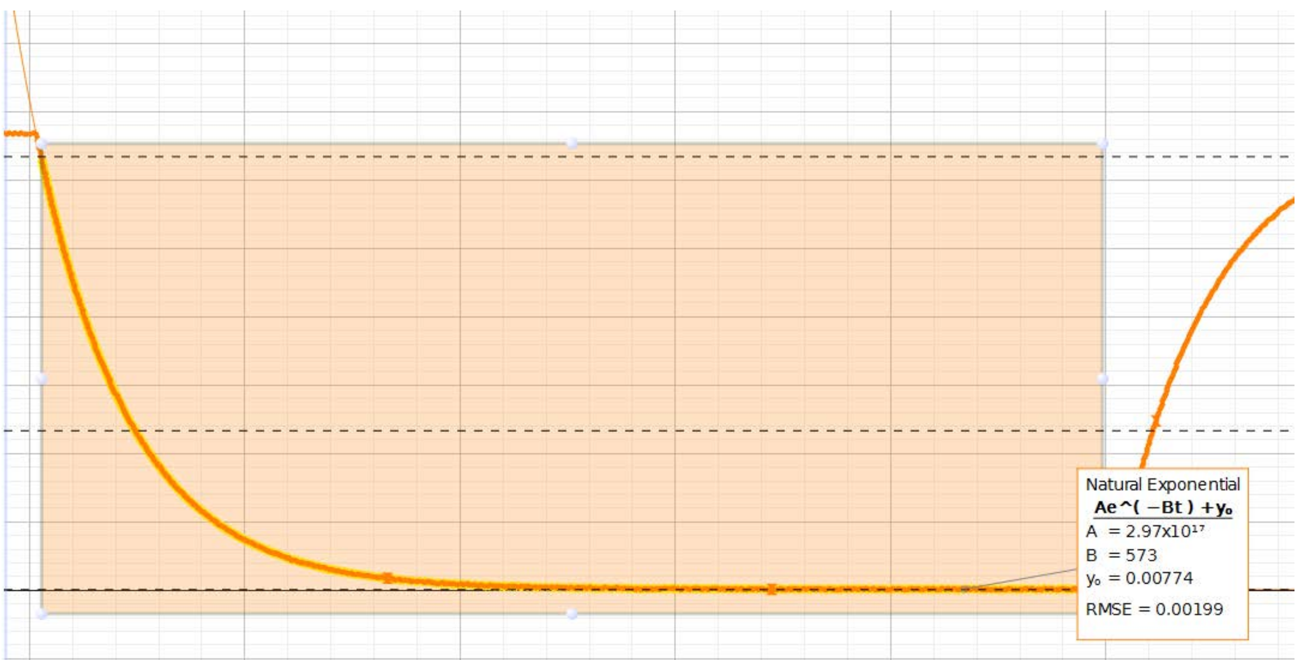
Move cursor to the rectangle. Hold & drag it to data. Notice where I put the top-left corner of the rectangle: I excluded data that wasn't part of the voltage-decay. (Any data that is selected will be highlighted in yellow). Resize the rectangle to select most of the data for a single decay:



Click the down-arrow beside the curve-fits button  to get a drop-down menu (below). Select "Natural exponential".



This selection will fit the selected data to the curve $V = Ae^{-Bt} + y_0$.



(Notice that an extrapolation appears on your graph. The curve-fit routine doesn't have any information about data that is outside the rectangular selection. This means that the extrapolation is of a single exponential that is the best fit of the data that has been selected.)

Since we expect $V = V_0 e^{-\frac{\Delta t}{\tau}}$, we expect $y_0 = 0$ and the curve-fit-constant B to be $\frac{1}{\tau}$. This 'measurement' of the time constant is actually better than a calculation that uses just two points because this measurement uses all the selected points to calculate $\frac{1}{\tau}$. The results on the graph give

$$\tau = \frac{1}{573} = .00175s$$

Now do the same with the data that you used to calculate τ by choosing two points. Curve-fit your data. **Print the graph along with the curve-fit statistics (as above). Comment on the quality of the curve-fit. Explain how you know that the fit is good or bad. Calculate the time constant using the curve-fit statistics. By what percentage does this time constant differ from that given by $\tau = RC$?**

(Use the expression; $\text{error} \equiv \frac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}}$ to calculate error).

Remember leave the apparatus as it was when you arrived.
Ask your TA to check your apparatus before you turn in your reports
Shut-down the computer. Turn off meters and power-supplies.

The prelab for Helmholtz Coils is not usually found easy. Please begin it soon so that you can ask questions about it long before that prelab is due.

PRE-LAB

NAME:___________________________ Course & Section _________________________

Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

How can you change the time constant if the capacitance of the circuit is fixed?

____**[1]**

Initially, how large is $\frac{\Delta V(t)}{\Delta V(0)}$? After an infinitely long time, what is the value of $\frac{\Delta V(t)}{\Delta V(0)}$?

____

____**[2]**

Find $t_{1/20}$ in terms of τ. Will $t_{1/20}$ be changed if the time constant for the circuit is increased? If it changes, explain how.

____

____

____**[2]**

Now use $\frac{\Delta V(t)}{\Delta V(0)} = e^{-\frac{t}{\tau}}$ to show that $t_{1/2} = \tau \ln 2$.

____

____**[2]**

What is the ratio of the voltage after $t = 20\tau$ to the initial voltage across the capacitor?

____

____**[2]**

Find the <u>approximate</u> time constant for circuit one.

____**[1]**

…what <u>approximate</u> frequency corresponds to $T = 20\tau$?

____

____**[1]**

Will this decay still be an exponential function of time? Will the time constant have changed? Explain.

____

____

____**[2]**

Identify the component of circuit 1 across which the voltage must appear.

____

____**[1]**

Identify the parts of the cycle at which the current is smallest.

____**[1]**

Use the points selected to find the time constant;

____**[1]**

Here is another decay: calculate the time constant using the points selected.

____**[1]**

Do the time constant and half-life given by the graphs agree with the relation you found previously? Show your answer using the data above.

____**[2]**

About how many data points were collected during the decay?

____**[1]**

If we expect $\boldsymbol{\Delta V(t) = \Delta V(0) e^{-\frac{t}{\tau}}}$ then what do we expect the fitting procedure to give for $\boldsymbol{y_0}$?

____**[1]**

Given that $\boldsymbol{t}$ is time [in seconds], what do we expect to get for $\boldsymbol{B}$? What units do you expect for $\boldsymbol{B}$?

____

____**[2]**

What was the time constant for the curve-fit data above?

____**[1]**

REPORT

NAME:____________________________ Course & Section: ___________________

Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

Nominal Values	Measured Values
100 kΩ	
0.02 μF	

[2]

	$\tau_{\text{approx}} = RC$ (s)
Circuit 1	

[1]

Finding Time Constant by Choosing Two Points

… choose two points with which to calculate the time constant. **[2]**

Point one:

Point two:

Find the time constant for circuit 1 using the two points that you have chosen.

____**[1]**

Print the graph that shows these two point. (Annotate the graph if you think that this helps.) Include your graph with this report.

[6]

By what percentage does this time constant differ from that given by $\tau = RC$? Should you use nominal or measured values to calculate $\tau = RC$?
(Use the expression; $\text{error} \equiv \frac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}}$ to calculate error).

____

____**[2]**

Finding Time Constant by Fitting a Curve

Print the graph along with the curve-fit statistics. (Include it with this report.) **[2]**

Comment on the quality of the curve-fit. Explain how you know that the fit is good or bad.

____**[2]**

Calculate the time constant using the curve-fit statistics

____**[1]**

By what percentage does this time constant differ from that given by $\tau = RC$? (Use the expression; $\text{error} \equiv \frac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}}$ to calculate error).

____**[1]**