Experiment 3: Basic Electronic Circuits II  
(tbc 1/7/2007)

**Objective:**  
a) To study the first-order dynamics of a capacitive circuits with the application of Kirchoff’s law, Ohm’s law and Capacitance formula.  
b) To learn how to do data-logging using Labview 8 and the USB-6009 device.

I. Capacitors  

**A. Definitions and Units**

Capacitance \( C \) = ratio of electrical charge \( Q \) to voltage \( V \)  
Units: 1 farad (F) = 1 coulomb/volt

Capacitors are electrical components with constant capacitance:  
\[
C = \frac{Q}{V} = \frac{dQ}{dV} = \frac{dV}{dt} \Rightarrow I = C \frac{dV}{dt}
\]

Caution: some capacitors (specially electrolytic types) are polarized.

**B. Symbols**

![Symbols for capacitors](image)

Figure 1. Symbols for capacitors.
II. Experimental Setup

![Circuit Diagram](image)

Figure 1. $C = 10\mu F$, $R = 1 \, M\Omega$

II. Labview Setup

![Labview Interface](image)

Figure 2. Front Panel Configuration
Procedure to include the “Read Capacitor” block shown in Figure 3:

1. In the “Block Diagram” window, access the Functions palette and expand the [Express]->[Input] icon subdirectory. Select the [DAQ Assistant] block and drop into the “While loop” box.
2. A configuration window should pop out. [Click] the [Analog Input] item to expand the menu choices, then select [Voltage]. (see Figure 4)
3. A menu of available channels and devices should appear. (Make sure the “USB-6009” device is connected to the computer). Select the item “ai0” then [Click] the [Finish] button to move on to the configuration window.

Figure 3. Block Diagram Configuration.

Figure 4. Click this to expand the menu choices.
4. In the configuration window, match the values given in Table 1.

<table>
<thead>
<tr>
<th>Settings – Input Range</th>
<th>Min</th>
<th>-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Scaled Units</td>
<td>Volts</td>
</tr>
<tr>
<td></td>
<td>Terminal Configuration</td>
<td>Differential</td>
</tr>
<tr>
<td>Task Timing</td>
<td>Acquisition Model</td>
<td>Continuous</td>
</tr>
<tr>
<td>Clock Settings</td>
<td>Samples to Read</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Rate (Hz)</td>
<td>100</td>
</tr>
</tbody>
</table>

5. [Click] the [OK] button to finish. (You may need to move the configuration window to the left to show the [OK] button on the lower right corner of the window.)

6. Change to icon view and rename the block as “Read Capacitor”, if desired.

III. Tasks/Procedure

1. Construct both the experimental setup and the Labview VI setup.
2. With the power supply off, run the Labview VI. Make sure that the voltage reading of the capacitor voltage starts at zero. (If not, wait until the voltage settles to zero then stop and repeat the Labview run.)
3. At a chosen elapsed time (e.g. 10 seconds), turn the power supply on.
4. Wait until the voltage settles to a new steady state then stop the Labview run.
5. Load the data into an Excel spreadsheet similar to the one shown in Figure 5. The model for the estimated capacitor voltage will be a first order model:

\[ \tau \frac{dV_c}{dt} + V_c = V_{\text{final}} \quad V_c\big|_{(t=0)} = V_{\text{initial}} \]  

where \( \tau \) is the time constant, and \( \tilde{t} \) is the time elapsed after step change.

Assuming \( V_{\text{cap}} = V_{\text{initial}} \) for \( \tilde{t} < 0 \), the solution is given by:

\[ V_c = \begin{cases} 
V_{\text{initial}} & \text{if } \ t < t_{\text{start}} \\
V_{\text{final}} + (V_{\text{initial}} - V_{\text{final}}) \exp\left(-\frac{t - t_{\text{start}}}{\tau}\right) & \text{if } \ t \geq t_{\text{start}}
\end{cases} \]
6. Use SOLVER to minimize the root mean square (RMS) error, by modifying the values of $t_{\text{start}}$, $V_{\text{initial}}$, $V_{\text{final}}$ and $\tau$. Plot the data together with the estimated voltages to see if the fit is visually acceptable. Fill-in the values in Table 2.

7. Using the voltmeter, measure:
   a) $R_1 =$ the actual resistance of the 1 M$\Omega$ resistor
   b) $R_2 =$ the apparent resistance of the USB-6009 device
   c) $C_1 =$ the actual capacitance of the 10 $\mu$F capacitor
   d) $V_s =$ the voltage of the power supply

   and fill-in the values in Table 3.

8. Compare the value of time constant $\tau$ and $V_{\text{final}}$, obtained from the parameter estimation in step 6, with the calculated values using equation (5) below, which are based on Kirchoff’s law, Ohm’s law and the capacitance formula.

   Let $V_1$, $V_2$ and $V_c$ be the voltages across the 1 M$\Omega$ resistor, the USB-6009 device and the capacitor, respectively. Likewise, let $I_1$, $I_2$ and $I_c$ be the current flowing across the 1 M$\Omega$ resistor, the USB-6009 device and the capacitor, respectively. Thus,

   $\begin{align*}
   I_1 &= I_2 + I_c \\
   \frac{V_1}{R_1} &= \frac{V_2}{R_2} + C_1 \frac{dV_c}{dt}
   \end{align*}$

   Thus, (3)

   Since $V_s = V_1 + V_c$ and $V_2 = V_c$, we have
After comparing the coefficients of (4) with (1),

\[
\tau = \frac{C_1}{\frac{1}{R_1} + \frac{1}{R_2}}
\]

\[
V_{\text{final}} = \left(\frac{1}{\frac{R_1}{R_1} + \frac{1}{R_2}}\right) V_s
\]

Table 2.

<table>
<thead>
<tr>
<th>From Data Fitting</th>
<th>Calculated from Eqn (5)</th>
<th>% Relative Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tau)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{\text{final}})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{\text{initial}})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(t_{\text{start}})</td>
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Table 3.

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>$R_1$</td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td></td>
</tr>
<tr>
<td>$C_1$</td>
<td></td>
</tr>
<tr>
<td>$V_s$</td>
<td></td>
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**Calculation for $\tau$ and $V_{\text{final}}$ using equation (5):**