Lab Objectives
- Develop proficiency with two new pieces of laboratory equipment:
  - The function generator;
  - The oscilloscope.
- Understand resistance matching.

Equipment
- Breadboard;
- Decade resistance box;
- Assorted resistors;
- Multi-meters;
- Waveform Function Generator (new);
- Oscilloscope (new).
References
- Pre-lab #4 assignment;
- Circuits text book;
- Descriptions of instruments hand-out;
- Resistor color-code chart.

Procedure
The first step in this lab exercise is to model the function generator as a non-ideal voltage source and compute its Thévenin equivalent circuit as shown at the right. The resistance $R_S$ is called the output impedance of the function generator. This part of the lab requires finding the optimum values for $V_S$ and $R_S$ by connecting a decade resistance box between the + and – terminals at the output of the Source and measuring the output voltage ($V_O$) as a function of load resistance.

1) Place the oscilloscope probe directly across the output of the function generator and adjust $V_S$ to 6 volts peak-to-peak at a frequency of 1000Hz. Note that $R_S$ shown in the circuit at the right is internal to the function generator and not part of your external circuit.

2) Using an $R_S$ value of 50Ω, use the voltage-divider law to calculate the expected value of $V_O$ from the circuit above and place your calculated values in the table below.

<table>
<thead>
<tr>
<th>$R_L$ (Ω)</th>
<th>1000</th>
<th>500</th>
<th>200</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{O\text{calc}}$ (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{O\text{meas}}$ (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3) Connect the decade resistance box across $V_O$ to provide a load resistance and fill in the measured values in the table above for the indicated values of $R_L$. Measure peak-to-peak voltage using the oscilloscope.

4) Download the Excel Solver Spreadsheet from the Lab4 section of the course web page. The spreadsheet has adjacent columns with $R_L$, $V_{O\text{meas}}$, $V_{O\text{calc}}$, and the square of the difference between $V_{O\text{meas}}$ and $V_{O\text{calc}}$. Replace the $V_{O\text{meas}}$ data with your own data but leave the other columns alone. Add the Solver function in Excel using the following steps:
   - Choose File ⇒ Options ⇒ Add-ins
   - Select the Go… button near the bottom of the screen.
   - Check the Solver add-in box.
   - Find the Solver tab on the far right in the Data menu.

5) Using Solver, find the values of $V_S$ and $R_S$ that minimize the sum-squared error in $(V_{O\text{meas}} - V_{O\text{calc}})$ while it fits the data to the following equation:

$$V_O = V_S \frac{R_L}{R_L + R_S}$$
6) Using the $V_s$ and $R_s$ values optimized by Solver in step 5, recalculate $V_o$ using the equation in step 5 for the $R_L$ values in step 2 and enter the results into the table below. Then calculate % difference.

<table>
<thead>
<tr>
<th>$R_L$</th>
<th>1000</th>
<th>500</th>
<th>200</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_o$(calc) step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_o$(calc) step 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% difference</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$$V_S = \underline{\text{_________ V}} \quad R_S = \underline{\text{_________ \Omega}}$$

7) Assemble the $\pi$-attenuator circuit shown above on your breadboard. These values are chosen to create a 20 decibel (factor of 10) attenuation between the input and output voltages. Calculate (or copy from your pre-lab) and measure, using a Fluke meter, the input resistance to the attenuator stage (the resistance seen to the right of $R_s$) for loads of $R_L = 0 \ \Omega$, $R_L = 50 \ \Omega$ and $R_L = \infty \ \Omega$. You may draw your circuits on the right and below to aid your computations.

For $R_L = 0 \ \Omega$

$R_{in, \text{calculated}} = \underline{\text{_________ \Omega}}$

$R_{in, \text{measured}} = \underline{\text{_________ \Omega}}$

For $R_L = 50 \ \Omega$

$R_{in, \text{calculated}} = \underline{\text{_________ \Omega}}$

$R_{in, \text{measured}} = \underline{\text{_________ \Omega}}$

For $R_L = \infty \ \Omega$

$R_{in, \text{calculated}} = \underline{\text{_________ \Omega}}$

$R_{in, \text{measured}} = \underline{\text{_________ \Omega}}$
8) Set the function generator output to $6.00v_{pp}$ and assemble the source, attenuator, and load (the decade resistance box) to measure $V_o$ like you did in step 2.

<table>
<thead>
<tr>
<th>$R_L$ (Ω)</th>
<th>1000</th>
<th>500</th>
<th>200</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_o$ (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9) Please write your observations and conclusions concerning this lab exercise.