Basic DC Meter Design  
ECE 2100 Circuit Analysis Laboratory  
version 8 January 2022

**Equipment and Supplies**

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meter Movement (0-100μA)</td>
</tr>
<tr>
<td>DC Voltage Source, 0 to 10V</td>
</tr>
<tr>
<td>Digital Multimeter (DMM)</td>
</tr>
<tr>
<td>Breadboard</td>
</tr>
<tr>
<td>Hookup wires</td>
</tr>
<tr>
<td>Resistor Substitution Box</td>
</tr>
<tr>
<td>1kΩ 1/4W resistor (2)</td>
</tr>
<tr>
<td>100kΩ 1/4W resistor (2)</td>
</tr>
<tr>
<td>Banana-to-Banana Plug Cables</td>
</tr>
<tr>
<td>SAFETY GLASSES</td>
</tr>
</tbody>
</table>

**Learning Outcomes**

Students will:
1. Design and validate a meter-movement based ammeter and voltmeter, including characterization of the error between the designed meters and a DMM.
2. Prepare a calibration curve.
3. Explore limitations of the designed voltmeter.
4. Determine if the designed ammeter and voltmeter meet a desired accuracy specification using experimental data.

**Pre-Laboratory Assignment (STEPS 1-2)**

1. Design an ammeter with full-scale current $I_{FS}=5mA$ using a $100μA$ meter movement with resistance $r_{mm}=2.4kΩ$. Be sure to show the design schematic.

2. Design a voltmeter with full-scale voltage $V_{FS}=10V$ using the meter movement of pre-lab step 1. Be sure to show the design schematic.

**Procedures**

**Ammeter Design and Validation**

1. Construct the circuit of Figure 1 using your designed ammeter.

   Before connecting the power supply, DISABLE its output using the OUTPUT button (not illuminated). Set the power supply voltage to 0V and current limit to as near 6mA as possible.

   Your DMM, configured as an ammeter, is the ‘standard,” and your designed ammeter is the “design.”

   Ask your lab instructor to check your circuit before applying power.
2. Enable power supply output via the OUTPUT button. Starting at 0V, \textbf{SLOWLY} vary the power supply voltage so that current $I_s$ varies from 0 to 5mA.

3. Measure and record at least ten cases of $V_s$ (from your internal power supply voltmeter), the current $I_s$ as measured by your DMM and designed ammeter, so $I_s$ is spaced about equally over the 0-5mA range. Use the format of Table 1.

4. Set power supply to 0V and turn it off.

5. Compute the average error for your ammeter design assuming that the “standard” ammeter (your DMM) provides perfect measurements.

DO NOT PROCEED unless your “standard” and “design” current values closely match.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{ammeter_test_circuit.png}
\caption{Ammeter test circuit}
\end{figure}

\begin{tabular}{|c|c|c|c|}
\hline
$V_s$ (V) & standard ammeter current (mA) & designed ammeter current (mA) & \% error \\
\hline
0V & . & . & . \\
\hline
average \% error: & . & . & . \\
\hline
\end{tabular}

Table 1. Table for ammeter test circuit data

\textbf{Voltmeter Design and Validation}

6. Construct the circuit of Figure 2 using your designed voltmeter.

Before connecting the power supply, DISABLE its output using the OUTPUT button (not illuminated). Set the power supply voltage to 0V and current limit to as near 120\mu A as possible.
Your DMM, configured as a voltmeter, is the ‘standard” and your designed voltmeter is the “design.”

Ask your lab instructor to check your circuit before applying power.

7. Enable power supply output via the OUTPUT button. Starting from 0V, SLOWLY vary the supply voltage so Vs varies from 0 to 10V.

8. Measure and record at least ten cases of Vs as measured by your DMM and designed voltmeter, spaced about equally over the 0-10V range. Use the format of Table 2.

9. Set power supply to 0V and turn it off.

10. Compute the average error for your voltmeter design by assuming that the “standard” voltmeter (your DMM) provides perfect measurements.

    DO NOT PROCEED unless your “standard” and “design” voltage values closely match.

\[
\begin{array}{|c|c|c|c|}
\hline
Vs & \text{standard voltmeter voltage (V)} & \text{designed voltmeter voltage (V)} & \% \text{ error} \\
\hline
\hline
\hline
\end{array}
\]

Table 2. Table for voltmeter test circuit data

**Effect of Voltmeter Input Resistance**

11. For the circuit of Figure 3 find an equation for voltage \( V_1 \) in terms of \( V_S, R_1 \) and \( R_2 \). Find the voltage \( V_1 \) for \( R_1=R_2=1k \) and \( V_S=12V \).
12. Construct the circuit of Figure 3 for \( R_1 = R_2 = 1\text{k} \).

Before connecting the power supply DISABLE its output using the OUTPUT button (not illuminated). Set its voltage to 12V and current limit to as near 7mA as possible.

Ask your lab instructor to check your circuit before enabling power via the OUTPUT button.

13.

a. Enable power supply output via OUTPUT button.
   Measure and record \( V_1 \).
   DISABLE power supply output.

b. Connect your designed voltmeter to measure \( V_1 \).
   Ask your lab instructor to check your circuit before enabling power via the OUTPUT button.
   Measure and record \( V_1 \).
   Turn off power supply.

c. Compare measurements of (a) and (b). Explain any discrepancies.

![Figure 3. Voltage divider circuit](image)

14. Find voltage \( V_1 \) for \( R_1 = R_2 = 100\text{k} \).

15. Construct the circuit of Figure 3 for \( R_1 = R_2 = 100\text{k} \).

Before connecting the power supply DISABLE its output using the OUTPUT button (not illuminated). Set its voltage to 12V and current limit to as near 150\(\mu\)A as possible.

Ask your lab instructor to check your circuit before enabling power via the OUTPUT button.

16.

a. Enable power supply output via OUTPUT button.
   Measure and record \( V_1 \).
   DISABLE power supply output.

b. Connect your designed voltmeter to measure \( V_1 \).
   Ask your lab instructor to check your circuit before enabling power via the OUTPUT button.
   Measure and record \( V_1 \).
   Turn off power supply.
c. Compare measurements of (a) and (b). Explain any discrepancies.

**Analysis**

A calibration curve enables correction of measurements by plotting standard measurements (in this case from the assumed perfect digital multimeter) on the y-axis vs. actual measurements (from the designed meter) on the x-axis. To find the true value of an actual measurement, locate the actual measurement on the x-axis, and then locate the corresponding standard measurement on the y-axis. A perfectly calibrated meter would exhibit a straight-line calibration curve passing through the origin at a 45º angle.

1. Draw the calibration curve for your ammeter using the data of Table 1. Be sure to include the full dynamic range (0 mA ≤ I ≤ 5 mA) for which the device was designed. Use a spreadsheet. Be sure that all points, axes, and curves (use a legend) are labeled.

2. Draw the calibration curve for your voltmeter using the data of Table 2. Be sure to include the full dynamic range (0V ≤ V<sub>S</sub> ≤ 10 V) for which the device was designed. Use a spreadsheet. Be sure that all points, axes, and curves (use a legend) are labeled.

3. CRITICAL: Complete the worksheet on the next page. You must attach this as the LAST PAGE of your lab report. REPORTS WITHOUT A COMPLETED AMMETER/VOLTMETER PERFORMANCE EVALUATION will not be accepted.

**Credits and Copyright**

Adapted from material developed by current and former ECE faculty, including Professors Joseph Kelemen and Frank Severance, and input from ECE laboratory instructors. Simin Masihi and Masoud Panahi provided helpful feedback that was incorporated into this lab. Figures drawn using LTspice®

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Recall that *specifications* describe WHAT a device is supposed to do and *parameters* describe HOW the device will be constructed to meet the specifications [1].

Suppose that your meter-movement based meters should meet the following specifications.

1. The meter-movement based ammeter must measure a DC current between 0 and 5mA with at least 5% accuracy.
2. The meter-movement based voltmeter must measure a DC voltage between 0 and 10V with an accuracy of at least 5%.

Determine which of these specifications were met, if any, based on your experimental data. Use the following space to report your evaluation.

1. Is it appropriate to use the *average* error to evaluate the specifications? Explain.

2. Complete the table.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Specification met? (yes or no)</th>
<th>Use this space to <strong>justify</strong> your evaluation using your experimental data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. If either specification was met, under what conditions can you guarantee that the specification will be met?

4. Complete the table.

<table>
<thead>
<tr>
<th>TEAM MEMBER</th>
<th>ENGINEERING MAJOR (Enter N/A if not applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
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