Basic DC Meter Design
ECE 2100 Circuit Analysis Laboratory
7 October 2020

Equipment and Supplies

<table>
<thead>
<tr>
<th>Item</th>
<th>In kit?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meter Movement (0-100μA)</td>
<td></td>
</tr>
<tr>
<td>DC Voltage Source, 0 to 10V</td>
<td></td>
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<tr>
<td>Digital Multimeter (DMM)</td>
<td>✓</td>
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<tr>
<td>Breadboard</td>
<td>✓</td>
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<tr>
<td>Hookup Wire (if needed)</td>
<td></td>
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<tr>
<td>(2) 1kΩ ¼W resistor</td>
<td>✓</td>
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<tr>
<td>(2) 100kΩ ¼W resistor</td>
<td>✓</td>
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<tr>
<td>1MΩ ¼W resistor</td>
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</tr>
<tr>
<td>Banana-to-Banana Plug Cables w/ Grabbers</td>
<td>✓</td>
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Learning Outcomes

Students will:
1. Design and validate a meter-movement based voltmeter and ammeter, including characterization of the error between the designed meters and a DMM.
2. Prepare a calibration curve.
3. Explore limitations of the designed voltmeter.

Pre-Laboratory Assignment (STEPS 1-6)

COVID-19 Safety

1. Complete the COVID screening questionnaire here PRIOR to coming to campus. If you are not able to come to campus as a result of this screening process, a makeup lab will be arranged.
2. Review the Bronco Student Pledge here.
3. You will be required to wipe down your keyboard, monitor, mouse, work area, meter movement, equipment buttons and knobs, and any contacted surfaces using a disinfecting wipe at the start and end of lab.
4. WASH YOUR HANDS immediately after lab.

DC Meter Design

5. Design a voltmeter with a full-scale voltage $V_{FS}$ equal to 10 V using a meter movement rated at 100μA with a full-scale voltage of 250mV.
6. Design an ammeter with full-scale current $I_{FS}$ equal to 5 mA using the meter movement of pre-lab step 5.
Procedures

1. Maintain social distancing during lab.

2. **BE SURE ALL EQUIPMENT IS OFF.**

   Wipe down your keyboard, monitor, mouse, work area, meter movement, and power supply buttons and knobs, with the provided disinfecting wipe.

*Meter Movement Characterization*

3. *The meter movement is a delicate instrument and can be easily damaged. Use care.*

4. Turn on and set DC power supply to 1V. Set the current limit to as near 120μA as possible. Turn off supply.

5. Connect your DMM to measure the supply voltage.
   Practice varying the supply voltage one-tenth of a voltage at a time.
   Return the power supply to 1V.
   Turn off power supply.

6. Connect the circuit of Figure 1, Connect your DMM across the meter movement to measure $V_{mm}$ as shown. Ask your lab instructor to check your circuit before applying power.

7. Apply power. **SLOWLY adjust the power supply voltage until the meter movement reads 100μA.** Record $V_{mm}=V_{FS}$. Turn off the power supply.

8. Compute $r_{mm}=V_{FS}/100\mu A$.

![Figure 1. Circuit to find $V_{mm}=V_{FS}$.]
Ammeter Design and Validation

9. Redesign your 5mA full-scale ammeter using the measured $V_{FS}$ and computed $r_{mm}$.

10. Construct the circuit of Figure 2. Before connecting the power supply, be sure it is set to 1V. Set the 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.

11. Apply power. SLOWLY vary the power supply to measure and record at least ten cases of $V_s$ (from your power supply), the current $I$ as measured by your DMM and your designed ammeter, spaced equally over the 0-5mA range. Use the format of Table 1.

12. Turn off power supply.

13. Compute the average error for your ammeter design by assuming that the standard ammeter (your DMM) provides perfect measurements. DO NOT PROCEED UNTIL YOUR AMMETER IS WORKING.

![Figure 2. Ammeter test circuit](image)

<table>
<thead>
<tr>
<th>$V_s$</th>
<th>standard ammeter current</th>
<th>designed ammeter current</th>
<th>% error</th>
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<td>average % error:</td>
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Table 1. Table for ammeter test circuit data
14. Redesign your 10V full-scale voltmeter using the measured $V_{FS}$ and computed $r_{mm}$.

15. Construct the circuit of Figure 3. Before connecting the power supply, be sure it is set to 1V. Set the current limit to as near 120μA 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.

16. Apply power. SLOWLY vary the power supply to measure and record at least ten cases of $V_s$ (from your power supply), the voltage $V$ as measured by your DMM and your designed voltmeter, spaced equally over the 0-10V range. Use the format of Table 2.

17. Turn off power supply.

18. Compute the average error for your voltmeter design by assuming that the standard voltmeter (your DMM) provides perfect measurements. DO NOT PROCEED UNTIL YOUR VOLTMETER IS WORKING.

Figure 3. Voltmeter test circuit

<table>
<thead>
<tr>
<th>$V_s$</th>
<th>standard voltmeter voltage</th>
<th>designed voltmeter</th>
<th>% error</th>
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Table 2. Table for voltmeter test circuit data
**Voltmeter Design Limitations**

19. For the circuit of Figure 4 calculate the voltage \( V \) in terms of \( V_S, R_1 \) and \( R_2 \).
   Find the voltage \( V \) for \( R_1=R_2=1k \).

20. Before connecting the power set its voltage to 10V.
    Set the current limit to as near 6mA as possible. Turn the power supply off.

21. Construct the circuit of Figure 4 for \( R_1=R_2=1k \).

22.
   a. Connect your DMM to measure \( V \). Turn on power. Measure and record \( V \).
      Turn off power.
   
   b. Connect your designed voltmeter to measure \( V \). Turn on power. Measure and record \( V \). Turn off power.

   c. Compare your results. Explain any discrepancies.

23. Find the voltage \( V \) for \( R_1=R_2=100k \).

24. Before connecting the power set its voltage to 10V.
    Set the current limit to as near 100μA as possible. Turn the power supply off.

25. Construct the circuit of Figure 4 for \( R_1=R_2=100k \).

26.
   a. Connect your DMM to measure \( V \). Turn on power. Measure and record \( V \).
      Turn off power.
   
   b. Connect your designed voltmeter to measure \( V \). Turn on power. Measure and record \( V \). Turn off power.

   c. Compare your results. Explain any discrepancies.
Clean-Up

1. **Wipe down your keyboard, monitor, mouse, work area, meter movement, equipment knobs and dials, and any other contacted surfaces with the provided disinfecting wipe.**

2. **Wash your hands after lab.**

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 45 degree 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_S ≤ 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. Using a circuit model, verify the voltage values measured by the designed voltmeter in laboratory procedures 22 and 26 (hint: add a resistor to model the effect of the designed voltmeter on the measured voltages).

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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