Electric Circuits I

Laboratory 3 – Dependent Sources and Meter Impact on Measurements

Objective:

- To analyze measurement errors introduced by the internal resistance of voltmeters and ammeters.
- To design a current divider and a voltage divider that meet given specifications.
- To use voltage-dependent and current-dependent sources to improve meter performance (e.g., reduce the impact of meter on measurement).

I. Equipment:

- DC Power Supply (Keysight EDU36311A)
- Digital Multimeter (Keysight EDU34450A)
- Breadboard for connecting resistors.
- Resistors:

1 resistor and label it as R_{vm} =10kΩ, 1 resistor and label it as R_{am} =100Ω. 1 resistor and label it as R_s =10kΩ.	2 resistors, R_1 and R_2, between 1kΩ to 10kΩ. 2 resistors, R_3 and R_4, between 50Ω to 200Ω. 1 resistor R_{test}, between 200Ω to 1kΩ

- Operational Amplifier Demo Box

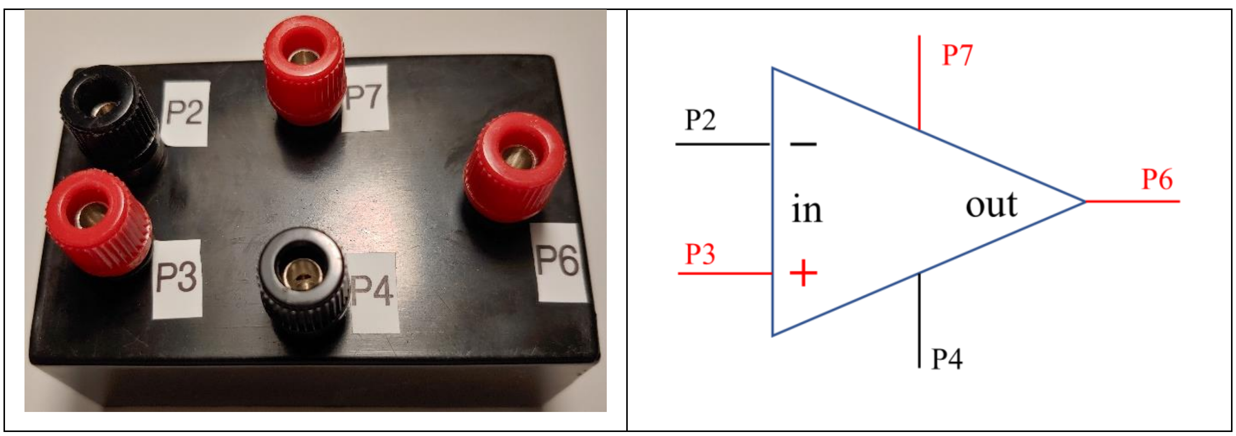
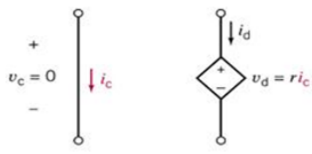
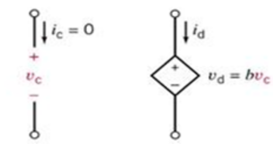
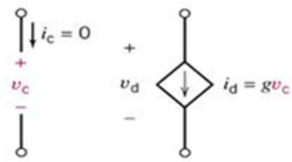
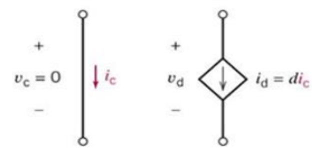


Figure 1 – Operational Amplifier Demo Box

II. Background and Theory:

A. Dependent Sources

Current-controlled Voltage Source (CCVS)	Voltage-controlled Voltage Source (VCVS)	Voltage-controlled Current Source (VCCS)	Current-controlled Current Source (CCCS)
			
r is the gain, and its unit is volt/ampere	b is the gain, and its unit is volt/volt	g is the gain, and its unit is ampere/volt	d is the gain, and its unit is ampere/ampere

Similar to independent sources, independent sources will provide a constant voltage or current to circuits. However, the magnitude of independent sources is controlled by a voltage (v_c) or current (i_c) within a circuit. The electric symbol of a dependent source is a diamond shape. There are four types of dependent sources:

- Current-controlled voltage source (CCVS) is a voltage source whose value is controlled by a current.
- Voltage-controlled voltage source (VCVS) is a voltage source whose value is controlled by a voltage.
- Voltage-controlled current source (VCCS) is a current source whose value is controlled by a voltage.
- Current-controlled current source (CCCS) is a current source whose value is controlled by a current.

In this lab, we will use to OpAmp Demo box to implement a voltage-controlled voltage source (VCVS) and a current-controlled current source (CCCS).

Figure 2 shows an implementation of a voltage-controlled voltage source (VCVS) using the OpAmp demo box. In this implementation, the OpAmp (triangle shape) functions as a dependent voltage source whose magnitude depends on the value of voltage V_x.

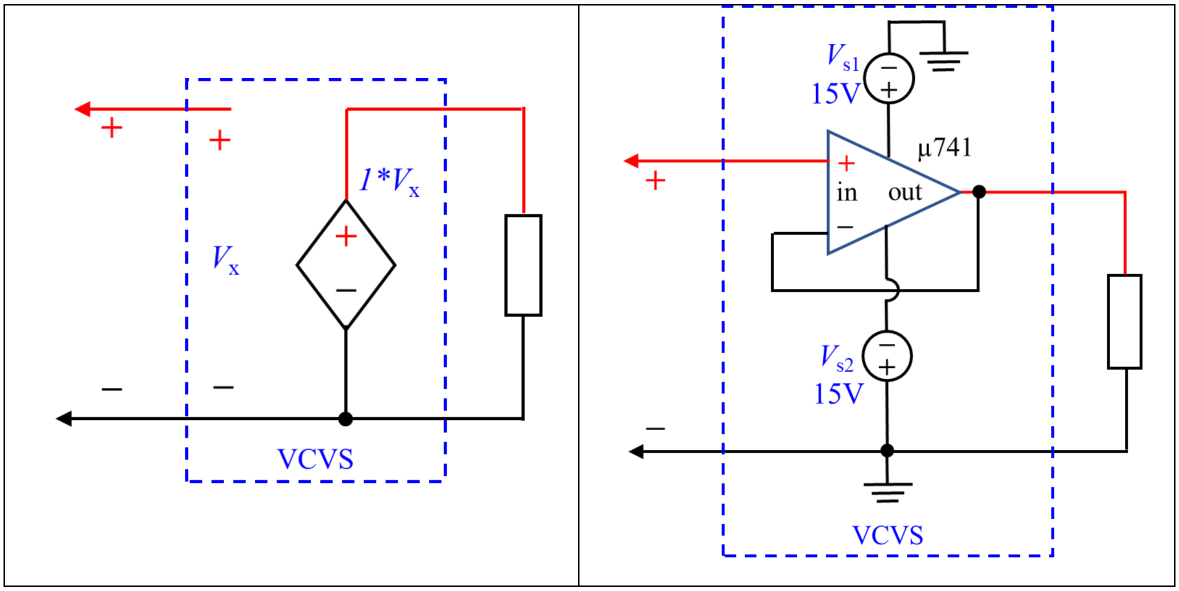


Figure 2 – Implementation of Voltage-controlled Voltage Source (VCVS) Using OpAmp Demo Box

In **Figure 3**, the OpAmp circuit implements a current-controlled current source (CCCS) whose magnitude depends on the value of current I_x.

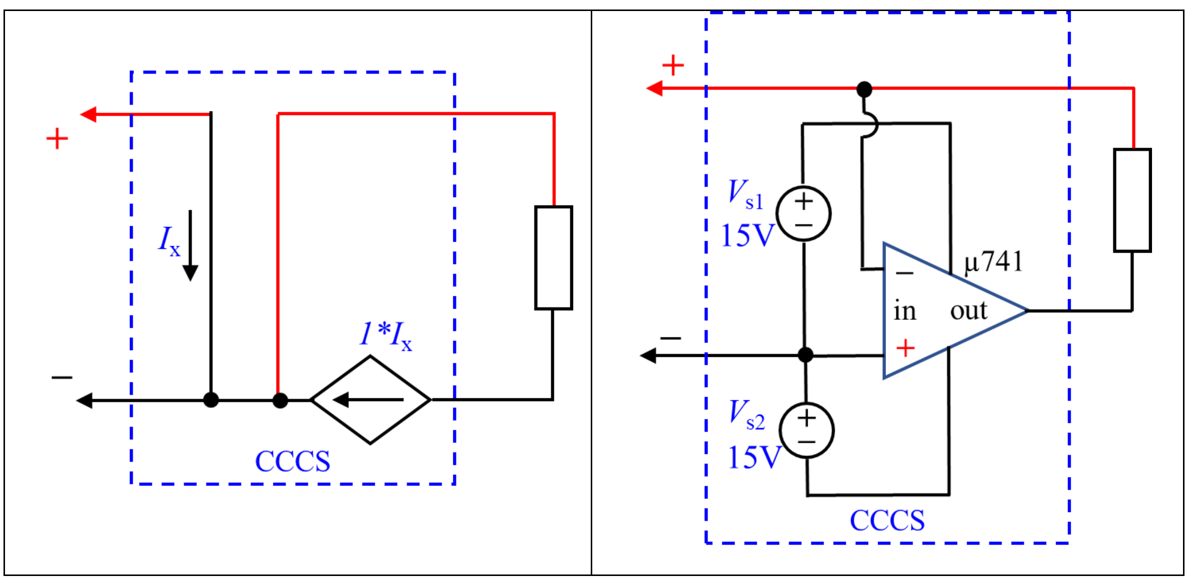


Figure 3 – Implementation of Current-controlled Current Source (CCCS) Using OpAmp Demo Box

B. Meter Impact on Measurements

Multimeters can contribute to measurement error due to their internal resistance in voltage or current mode, particularly low-quality meters. For low-quality meters, the internal resistance can be as low as 100kΩ for voltage-measurement mode and as high as 100Ω for current measurement. Ideally, we want the internal resistance of a multimeter to be ∞ Ω (or open-circuit) for voltage measurement and 0Ω (or short-circuit) for current measurement. Even the internal resistance of high-quality meters is not close to that of the ideal multimeter. Understanding the effect of the internal resistance on measures will allow us to infer the correct measurements or utilize dependent sources to correct the meter deficiency when we cannot afford a very high-end multimeter.

III. Prelab Assignment:

The prelab assignments should be completed and submitted to Camino before the lab.

A. Part 1 – Impact of Voltmeter with a Low Internal Resistance

An ideal voltmeter behaves as an open circuit. An accurate voltmeter can be modeled as an ideal voltmeter in parallel with a resistor equal in value to its internal resistance. In **Figure 4**, the circuit shows how the performance of a voltmeter can be degraded when it has a low internal resistance of R_{vm}, such as 10kΩ.

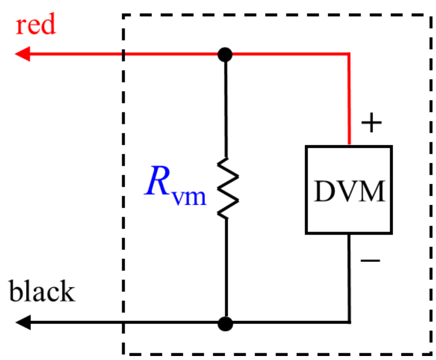


Figure 4 – Circuit of Voltmeter with R_{vm} internal resistance (inexpensive voltmeter)

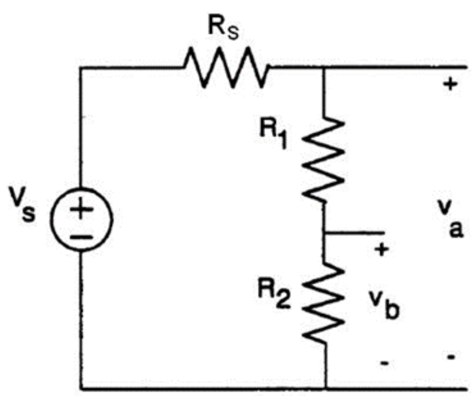


Figure 5 – Voltage Divider Circuit

1. With V_s = 5V in **Figure 5**, create a MATLAB script with chosen values of resistors to calculate:
   a. The expected values of V_a and V_b.
   b. The expected values of V_{aL} and V_{bL} with the impact of the inexpensive voltmeter (or having R_{vm} in parallel).

V_a	V_b	V_{aL}	V_{bL}

B. Part 2 – Impact of Ammeter with a High Internal Resistance

An ideal ammeter behaves as a short circuit. A real ammeter can be modeled as an ideal ammeter in series with a resistor $\boldsymbol{R_{am}}$. High-end ammeters have a very low internal resistance (about 0.01Ω), whereas, in low-end (or inexpensive) ammeters, the internal resistance can be a few hundred ohms. **Figure 6** shows an example of an inexpensive ammeter with high internal resistance.

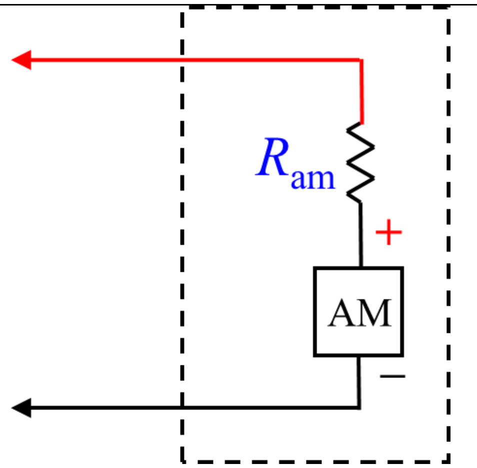


Figure 6 – Circuit of ammeter with $\boldsymbol{R_{am}}$ internal resistance (inexpensive ammeter)

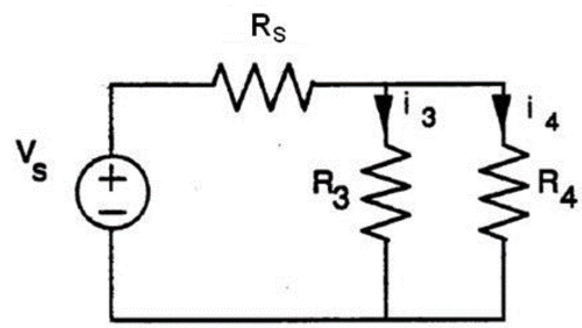


Figure 7 – Current Divider Circuit

1. With V_s = 5V in **Figure 7**, create a MATLAB script to calculate:
   a. The expected values of $\boldsymbol{I_3}$ and $\boldsymbol{I_4}$.
   b. The expected values of $\boldsymbol{I_{3L}}$ and $\boldsymbol{I_{4L}}$ with the impact of the inexpensive ammeter (or having $\boldsymbol{R_{am}}$ in series).

I_3	I_4	I_{3L}	I_{4L}	
				mA

IV. Laboratory Part 1 – Impact of Voltmeter

Verify the results of MATLAB scripts of your prelab assignment with the TA before working on the lab procedure.

A. Impact of Voltmeter with a Low Internal Resistance

1. Use the digital multimeter to measure resistors in the prelab assignments. Record their measured values in **Table 1**.

Table 1 – Resistance Values

	R_{vm}	R_{am}	R_s	R_1	R_2	R_3	R_4
Nominal Values							
Measured Values							

2. Build the voltage divider circuit in **Figure 5** with $V_s = 5$V. Use the MATLAB script in the prelab assignment to recalculate the expected values of $\boldsymbol{V_a}$ and $\boldsymbol{V_b}$ with the measured values of resistors. Measure $\boldsymbol{V_a}$ and $\boldsymbol{V_b}$ and record all values in **Table 2**.

Table 2 – Voltage Values

Voltages	Expected Value (V)	Measured Value (V)
$\boldsymbol{V_a}$		
$\boldsymbol{V_b}$		

3. Set the digital multimeter to DCV mode and build the circuit of the voltmeter with $\boldsymbol{R_{vm}}$ internal resistance in **Figure 4**. This circuit of the voltmeter with $\boldsymbol{R_{vm}}$ internal resistance is called an ***inexpensive voltmeter*** (IEVM).
4. Use IEVM to measure $\boldsymbol{V_{aL}}$ and $\boldsymbol{V_{bL}}$ in **Figure 5**. Use the MATLAB script in the prelab assignment to recalculate the expected values of $\boldsymbol{V_{aL}}$ and $\boldsymbol{V_{bL}}$ with the measured values of resistors and $\boldsymbol{R_{vm}}$ in parallel. Record all values in **Table 3**.

Table 3 – Voltage Values

Voltages	Expected Value (V)	Measured value with $\boldsymbol{R_{vm}}$ in parallel (V)
$\boldsymbol{V_{aL}}$		
$\boldsymbol{V_{bL}}$		

5. Explain why the internal resistance of the voltmeter creates an impact on the measurements. *Do not disassemble the circuit*.
6. If the internal resistance $\boldsymbol{R_{vm}}$ of the voltmeter is known, for example, $\boldsymbol{R_{vm}} = 10\text{k}\Omega$, propose a way to calculate the value of voltages $\boldsymbol{V_a}$ and $\boldsymbol{V_b}$ based on the readings of $\boldsymbol{V_{aL}}$ and $\boldsymbol{V_{bL}}$.

B. Isolation of Voltmeter Internal Resistance

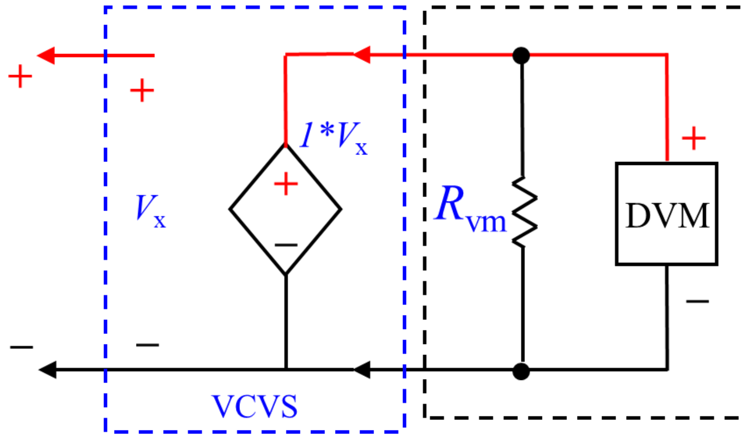


Figure 8 – Technique used for isolating a voltmeter from the circuit being measured

A voltage-controlled voltage source (VCVS) can be used to buffer (isolate) the current needs of the voltmeter from the measured circuit. **Figure 8** shows a circuit model that can be used to achieve this purpose. One common technique to implement VCVS is to use an Operational Amplifier. The connections are shown in **Figure 9**.

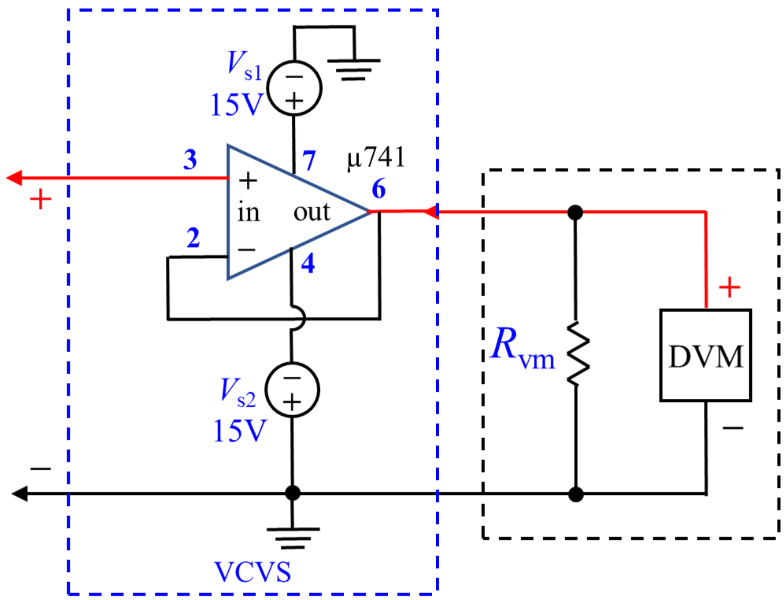


Figure 9 – Voltmeter using OpAmp to Implement Voltage Control Voltage Source (OpAmpVM). Note that the numbers in the figure are the pin numbers of the Operational Amplifier chip (µ741). The symbol ⏚ is the ground connection symbol.

1. Turn off the power supply. Build the isolated VM circuit in **Figure 9**. *DO NOT turn on the power until TA checks the circuit*.
2. Measure V_a and V_b again in **Figure 5** with the isolated VM and record all values in **Table 4**

Table 4 – Voltage Values

Voltages	Expected (V)	Measured with R_{vm} in parallel (V)	Measured with OpAmpVM (V)
V_a			
V_b			

3. Replace R_{vm} with R_{test} and measure V_a and V_b again in **Figure 5** to see if these voltages change. What is the conclusion?

V. Laboratory Part 2 – Impact of Ammeter

A. Impact of Ammeter with a High Internal Resistance

1. Build the voltage divider circuit in **Figure 7** with $V_s = 5V$. Use the MATLAB script in the prelab assignment to recalculate the expected values of I_3 and I_4 with the measured values of resistors. Measure I_3 and I_4 and record all values in **Table 5**.

Table 5 – Current Values

Currents	Expected Value (mA)	Measured Value (mA)
I_3		
I_4		

2. Set the digital multimeter to amp mode and build the circuit of the ammeter with R_{am} internal resistance in **Figure 6**. This voltmeter circuit with R_{am} internal resistance is called an ***inexpensive ammeter*** (IEAM).
3. Use IEAM to measure I_{3L} and I_{4L} in **Figure 7**. Use the MATLAB script in the prelab assignment to recalculate the expected values of I_{3L} and I_{4L} with the measured values of resistors and R_{am} in series. Record all values in **Table 6**.

Table 6 – Current Values

Currents	Expected Value (mA)	Measured value with R_{am} in series (mA)
I_{3L}		
I_{4L}		

4. Explain why the internal resistance of the ammeter creates an impact on the measurements. *Do not disassemble the circuit*.

5. Suppose that the internal resistance R_{am} of the ammeter is known, such as $R_{am} = 50\Omega$, find a way to calculate the value of voltages I_3 and I_4 based on the readings of I_{3L} and I_{4L}.

B. Isolation of Ammeter Internal Resistance

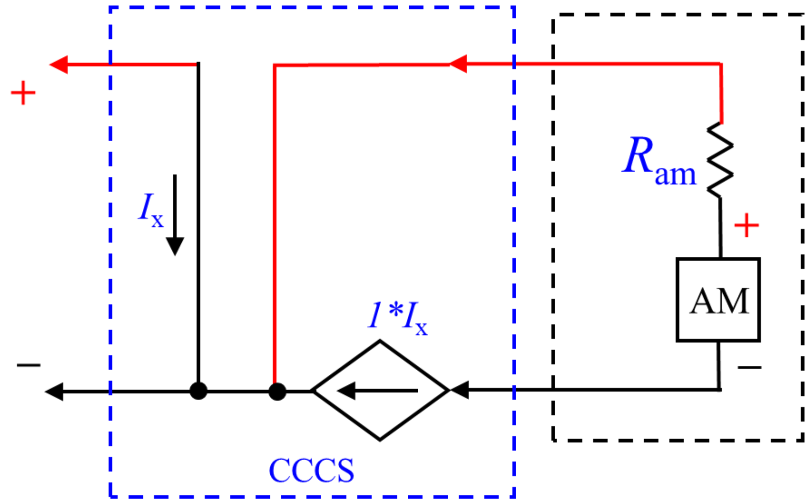


Figure 10 – Technique used for isolating an ammeter from the circuit being measured

A *current-controlled current source* (CCCS) can be used to buffer (isolate) the voltage needs of the ammeter from the measured circuit. The model in **Figure 10** shows how to implement a current control source. One common technique to implement CCCS is to use an Operational Amplifier. The connections are shown in **Figure 11**.

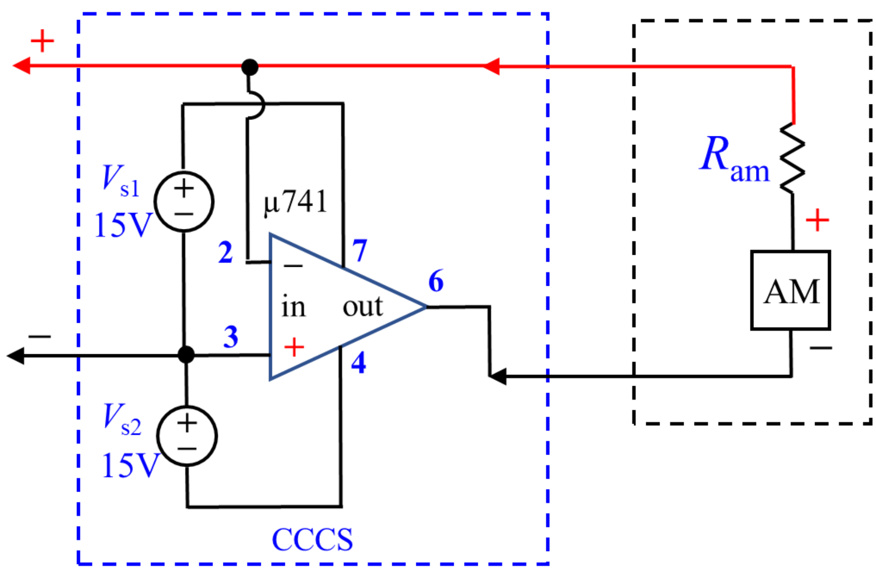


Figure 11 – Using Op Amp to Implement Current Control Current Source (*OpAmpAM*). *Notice that the positions of pins **2** and **3** have changed for (–) and (+) of the Operational Amplifier.*

1. Turn off the power supply. Build the circuit in **Figure 11**. *DO NOT turn on the power until TA checks the circuit*. Measure I_3 and I_4 again in **Figure 7** and record all values in **Table 7**.

Table 7 – Voltage Values

Voltages	Expected (mA)	Measured with R_{am} in series (mA)	Measured with OpAmpAM (mA)
V_a			
V_b			

2. Replace R_{am} with R_{test} and measure I_3 and I_4 again in **Figure 7** to see if these currents change. What is the conclusion?

Make sure to check off with the TA before leaving the lab section.

VI. Laboratory Report:

Include all measurements, computations, tables, and answers to all questions from the laboratory procedure. Clearly label all steps.