**MEMORANDUM**

|  |  |
| --- | --- |
| Date: | Thursday, February 25, 2021 |
| To: | Dr. Brianna Kurtz, Ph.D. – Piedmont Virginia Community College |
| From: | Mr. Thomas Lever – Piedmont Virginia Community College |
| CC: | ––––– |
| Subject: | Derivation of Equation for DUT Effective Resistance in terms of WBC Resistances for Galvanometer Current Zero |

Dear Dr. Kurtz,

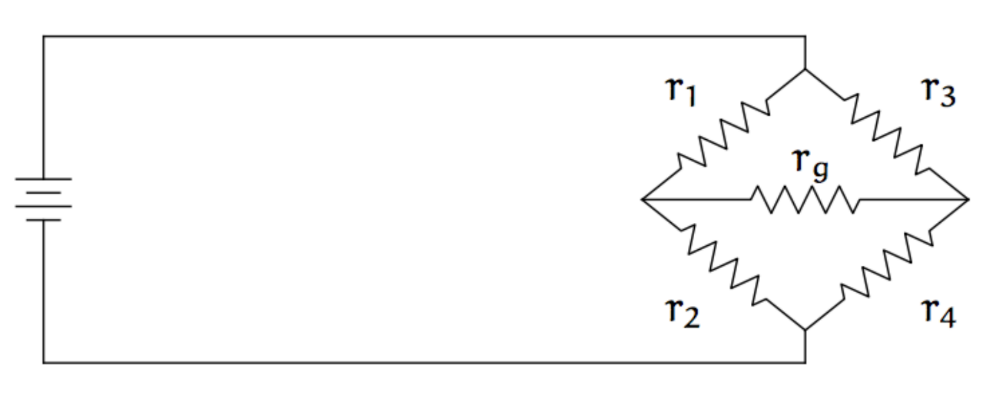
In my last memorandum (attached), I provided a preliminary design of a low-power, high-accuracy, high-precision ohmmeter that has discrete components, two powered circuits, no error due to current through the measuring circuit, and the ability to measure resistances lower than the smallest measurable resistance of our laboratory’s ohmmeter. I proposed that our laboratory launch a research project into developing a version of this ohmmeter that is self-calibrating, has a digital display, is durable, and is enjoyable to use.

In response, you requested my derivation of the equation that I used for Device-Under-Test (DUT) effective resistance in terms of Wheatstone Bridge Circuit (WBC) resistances for a galvanometer current of zero. This memorandum presents this derivation.

*Context*

The Wheatstone Bridge Circuit has a voltage source , resistors with fixed resistances and , a potentiometer with variable resistance , and a galvanometer with resistance . The operator of the ohmmeter varies the resistance of the potentiometer until the current through the galvanometer is zero and the galvanometer reads zero. When the current through the galvanometer is zero, the effective resistance of the DUT

**Figure 3: Wheatstone Bridge Circuit**



*Proof*

Per Kirchhoff’s First Law, the rate of electron flow into a junction is equal to the rate of electron flow out of the junction. Current is directed oppositely to electron flow. Given that the current through the galvanometer is zero, the direction of current may be chosen arbitrarily. In math,

|  |  |
| --- | --- |
|  |  |
|  |  |

where is the junction closest to the components with resistances , , and ; is the source current; and is the current through the component with resistance . Simplifying,

|  |  |
| --- | --- |
|  |  |
|  |  |

Per Kirchhoff’s Second Law, the total voltage across supplies of electrons in a closed loop is equal to the total voltage drop across non-supplying components. In math,

|  |  |
| --- | --- |
|  |  |
|  |  |

where is the closed loop involving components with resistances , , and and is the voltage drop across component with resistance . Simplifying,

|  |  |
| --- | --- |
|  |  |
|  |  |

Scaling the equation by the reciprocal of the scalar ,

Rearranging,

Applying Ohm’s Law,

Because and ,

Best regards,

Tom Lever

Researcher

Piedmont Virginia Community College

**MEMORANDUM**

|  |  |
| --- | --- |
| Date: | Thursday, February 11, 2021 |
| To: | Dr. Brianna Kurtz, Ph.D. – Piedmont Virginia Community College |
| From: | Mr. Thomas Lever – Piedmont Virginia Community College |
| CC: | ––––– |
| Subject: | Preliminary Design for a Low-Power, High-Accuracy, High-Precision Ohmmeter |

Dear Dr. Kurtz,

*Intention*

In this memorandum, I provide a preliminary design of a low-power, high-accuracy, high-precision ohmmeter that has discrete components, two powered circuits, no error due to current through the measuring circuit, and the ability to measure resistances lower than the smallest measurable resistance of our laboratory’s ohmmeter. I propose that our laboratory launch a research project into developing a version of this ohmmeter that is self-calibrating, has a digital display, is durable, and is enjoyable to use.

*Motivation*

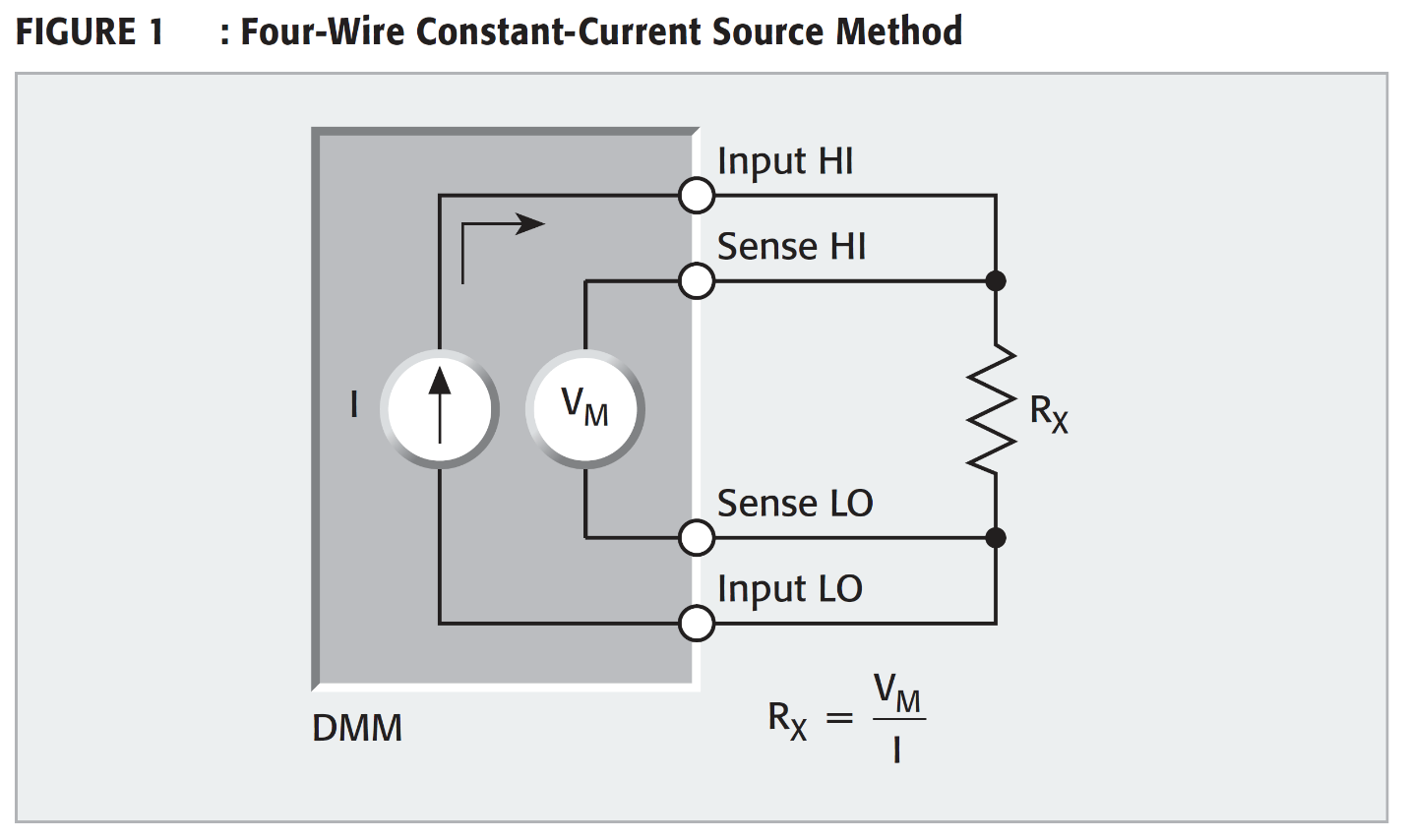
Our laboratory’s ohmmeter uses a four-wire constant-current source method (as shown in Figure 1). Using this method, the ohmmeter sources a known constant current to the Device Under Test (DUT) with the effective resistance and measures the voltage . Resistance is calculated by a divider circuit using the known current and measured voltage. A meter circuit displays the calculated resistance. The test current sourced to the DUT depends on the selected measurement range. For example, when our ohmmeter is set to a 100-ohm range, our ohmmeter has a test current of 1 milliampere.

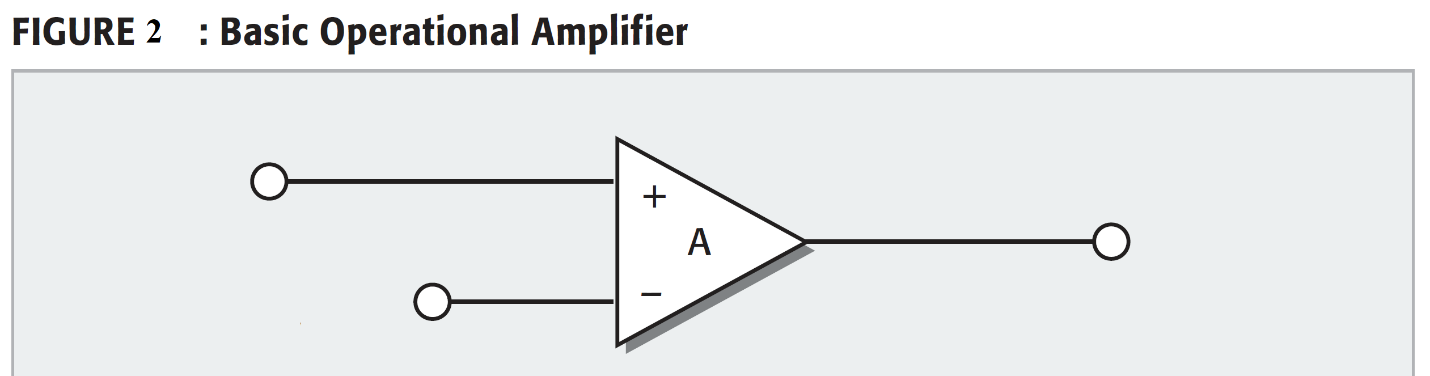
The voltage-measuring circuit in our ohmmeter contains an operational amplifier (as shown in Figure 2) with output voltage

,

where is the gain of the op amp, is the voltage source-side of the DUT, and is the voltage ground-side of the DUT. The op amp is a sophisticated integrated circuit. The op amp requires a power supply. Current through the op amp inputs is ideally but not perfectly zero, drawing current away from the DUT and thus changing the voltage drop across the DUT.

The divider circuit is a complex circuit that requires a power supply. The meter circuit is an elaborate analog-to-digital converter with display that requires a power supply.





Source: Keithley: A Tektronix Company (2014). “Section 1.5: Circuit Design Basics”. Low Level Measurements Handbook: 7th Edition. Tektronix. Accessed 02/11/21 at <http://download.tek.com/document/LowLevelHandbook_7Ed.pdf>.

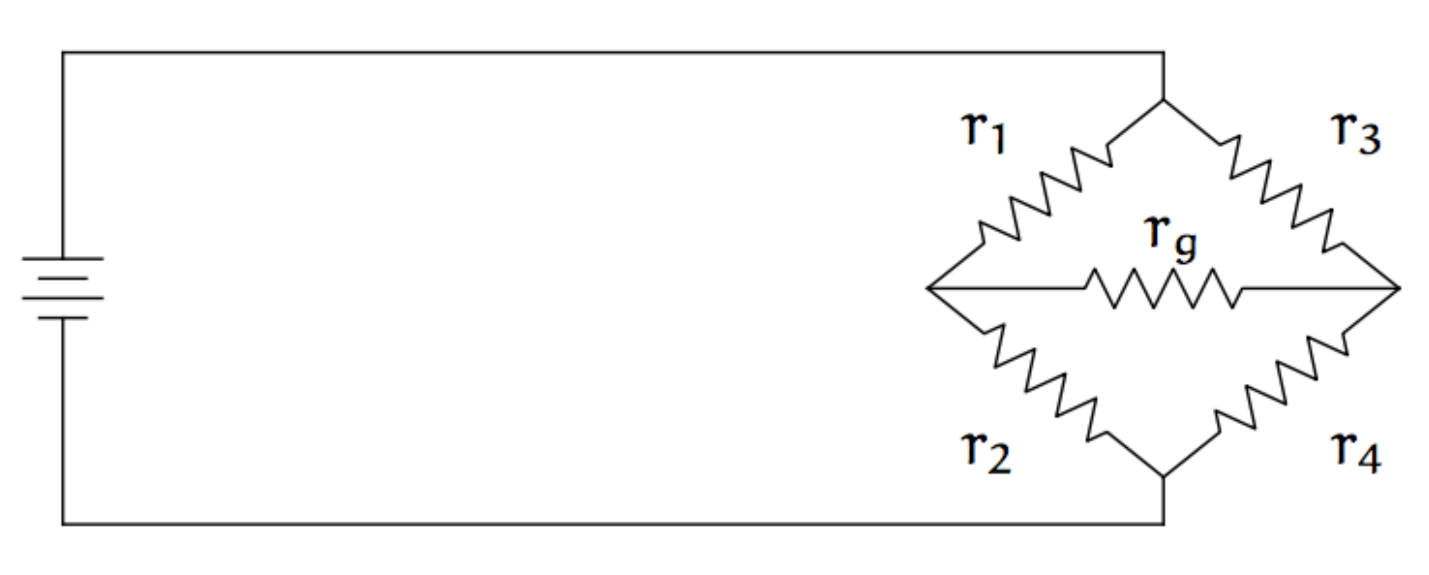
*Preliminary Design for a Low-Power, High-Accuracy, High-Precision Ohmmeter*

My preliminary design of an ohmmeter includes discrete components, two powered circuits, no error due to current through the measuring circuit, and the ability to measure resistances lower than the smallest measurable resistance of our laboratory’s ohmmeter.

1. *Wheatstone Bridge Circuit*

My preliminary design includes a Wheatstone Bridge Circuit (WBC). The resistor with resistance represents the DUT.

**Figure 3: Wheatstone Bridge Circuit**

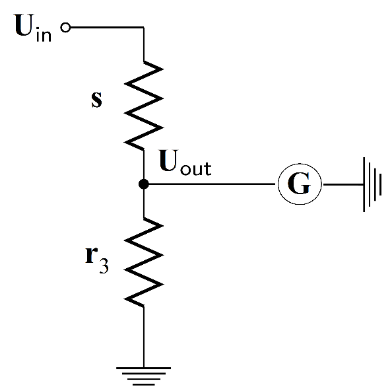


The WBC has a voltage source , resistors with fixed resistances and , a potentiometer with variable resistance , and a galvanometer with resistance . The operator of the ohmmeter varies the resistance of the potentiometer until the current through the galvanometer is zero and the galvanometer reads zero. When the current through the galvanometer is zero, the effective resistance of the DUT

1. *Display Circuit*

My preliminary design includes a Display Circuit consisting of a voltage divider and a galvanometer.

**Figure 4: Display Circuit**



When the operator of the ohmmeter varies the resistance of the potentiometer in the Wheatstone Bridge Circuit, the operator simultaneously varies the resistance of a potentiometer in the Display Circuit. The potentiometer will be the ground-side resistor in a voltage divider with input voltage , fixed source-side resistance , and output voltage

Electrons will flow from ground through the galvanometer with resistance . The galvanometer will deflect according to current and will have a scale with values

*Restatement of Intention*

In this memorandum, I have provided a preliminary design of a low-power, high-accuracy, high-precision ohmmeter that has discrete components, two powered circuits, no error due to current through the measuring circuit, and the ability to measure resistances lower than the smallest measurable resistance of our laboratory’s ohmmeter. I propose that our laboratory launch a research project into developing a version of this ohmmeter that is self-calibrating, has a digital display, is durable, and is enjoyable to use.

Best regards,

Tom Lever

Researcher

Piedmont Virginia Community College

(267) 644-7474

[Thomas.Lever.Business@Gmail.com](mailto:Thomas.Lever.Business@Gmail.com)