Lab Report:

Verification of Ohm's Law and the Voltage-Divider Rule

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10 November 2005

Abstract

This lab shows the results of a comparison predictions of circuit currents using Ohm's law to values obtained experimentally. Ohm's Law states that $V = IR$, so the ratio $V/(IR)$ should equal 1. Our results achieve this ratio within an average of 2%, leading to this question: why is the result not exactly 1? Our conclusions offer several possible explanations of the unexpected result.

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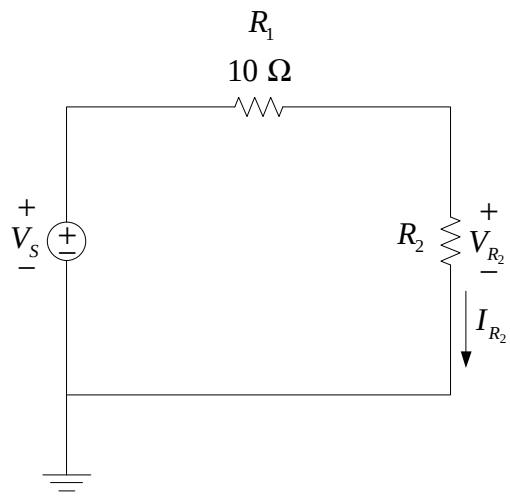

Figure 1: Schematic drawing of the experimental circuit. Resistor R_1 is fixed at $10\,\Omega$. Resistor R_2 is selected from one of these values: $1\,\Omega$, $10\,\Omega$, $100\,\Omega$, $1\,\mathrm{k}\Omega$, $10\,\mathrm{k}\Omega$, $100\,\mathrm{k}\Omega$, $1\,\mathrm{M}\Omega$.

1 Purpose of the Experiment

The purpose of the experiment was to obtain measured values of current through a pair of resistors connected in series and of voltage across one of them. These values were then compared with those that would be predicted by using Ohm's law and the voltage-divider rule

2 Equipment Used

- Hewlett Packard HP34401A Multimeter
- Global Specialties Proto-Board PB-503
- Resistors:
  - 1 $10\,\Omega$ resistor (R_1 in the schematic drawing of Figure 1)
  - 1 of each of the following: $1\,\Omega$, $10\,\Omega$, $100\,\Omega$, $1\,\mathrm{k}\Omega$, $10\,\mathrm{k}\Omega$, $100\,\mathrm{k}\Omega$, $1\,\mathrm{M}\Omega$ (R_2 in the schematic drawing of Figure 1)

3 Experimental Setup

The experimental setup is shown in the schematic drawing of Figure 1. Resistor R_1 was fixed at $10\,\Omega$. Resistor R_2 was selected from one of these values: $1\,\Omega$, $10\,\Omega$, $100\,\Omega$, $1\,\mathrm{k}\Omega$, $10\,\mathrm{k}\Omega$, $100\,\mathrm{k}\Omega$, $1\,\mathrm{M}\Omega$. For a given value of input voltage V_S,

we measured the value of the voltage V_{R_2} across resistor R_2 and the current I_{R_2} through it.

4 Observations

Measurements of V_{R_2} and I_{R_2} are shown in Table 1 on page 8. No measurements were taken in the case of $V_S = 10\,\mathrm{V}$ for $R_2 \in \{1\,\Omega, 10\,\Omega, 100\,\Omega\}$ because the currents through the resistors would have been so large that their power ratings would have been exceeded, possibly damaging the resistors. The power dissipated by resistor R_2 is given by

$$P_{R_2} = I_{R_2}^2 R_2. \tag{1}$$

With $V_S = 10\,\mathrm{V}$ and $R_2 = 10\,\Omega$, for example, we can predict

$$\begin{aligned} P_{R_2} &= (500\,\mathrm{mA})^2 (10\,\Omega) \\ &= 2.5\,\mathrm{W}, \end{aligned}$$

well over the 250 mW power rating of the resistor.

5 Analysis of the Results

Using the measured values of V_{R_2} and I_{R_2} given in Table 1 on page 8 and taking their ratio V_{R_2}/I_{R_2} yields the results in Table 2 on page 9.

A comparison of the measured value of R_2 to the ratio of V_{R_2}/I_{R_2} is instructive and is given in the same table. Ideally, the ratio would be exactly 1 because, according to Ohm's law, $V_{R_2} = I_{R_2} R_2$. Several of these ratios are more than 20% away from unity and have been discarded in calculating the average ratio in the rightmost column of the table. These values appear to have been due to blunders in the lab, although it is unclear exactly what error might have caused them. Also, no current was measurable in the 1 MΩ with $V_S = 10\,\mathrm{mV}$, so the ratio V_{R_2}/I_{R_2} could not be calculated.

The ratios are plotted as a function of the nominal values of R_2 in Figure 2 on the following page. The graph makes it clear that Ohm's law is approximately obeyed, at least as far as the experimental data suggest, although had the suspect data not been discarded, the values in the plot would have been even further from unity than they are. If the ratio values of Table 2 on page 9 all are averaged, the average ratio 1.02 is obtained, suggesting that the experimental method used verifies Ohm's law (approximately) to within 2%.

6 Conclusions

The data are a little surprising, given the heavy reliance on Ohm's law given in an elementary course in circuits—indeed, in any course in electrical engineering. Several possible hypotheses come to mind in considering why there is so much deviation from our expectation that $V/(IR) = 1$.

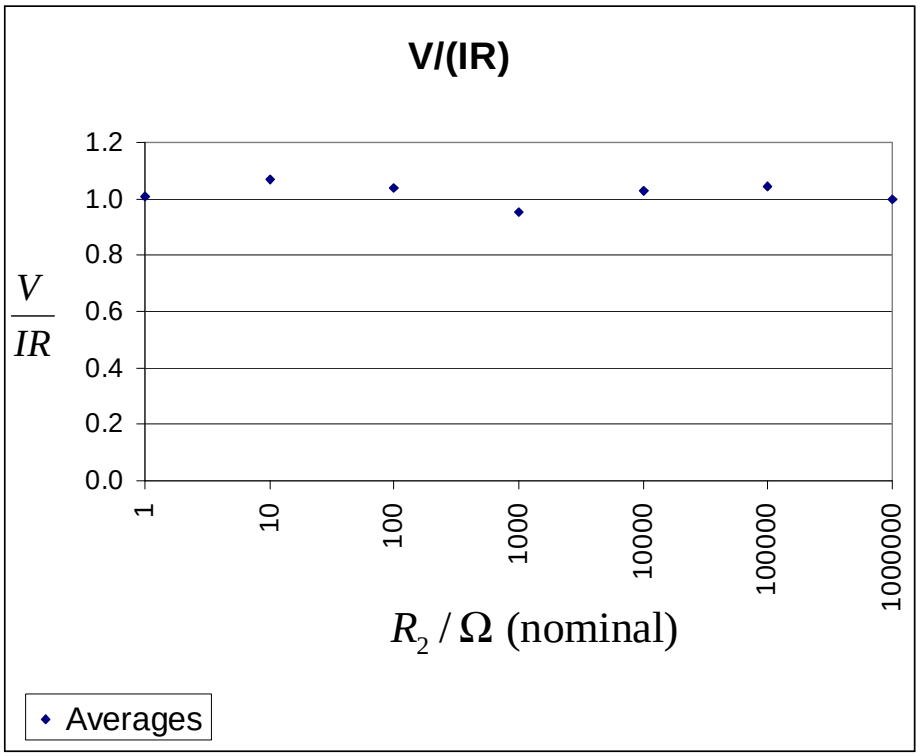

Figure 2: Graph of the ratio $V_{R_2}/(I_{R_2}R_2)$

- When the measurements were taken, they were still changing. Possibly this was due to changing temperature of the resistors, which would lead to varying resistances. Furthermore, the data were recorded in this sequence: V_S, V_{R_2}, and finally I_{R_2}. Because V_S was not stable, this sequence may have led to a systematic error in the measured values of V_{R_2} and I_{R_2}. In a more careful experiment, a longer wait might have countered this effect. Alternatively, a series of readings could be taken and averaged.

- Possibly the power supply was not stable. The protoboard's internal power supply was used. Because it could not achieve voltages below around 1.5 V, we used a voltage divider. It may be that this contributed to the surprising observations.

- The ambient temperature in the lab may have fluctuated, contributing to the observed effect. Recording the temperature would be useful, although self-heating of the resistors would likely be a more significant effect.

- Ohms' law is an idealization. Possibly there is an unknown effect contributing to the deviation of our data from Ohm's law. This seems unlikely in view of the fact that it has been used so successfully for more than a century. On the other hand, Newtonian physics also was used for a long time before anyone imagined it might be based on an invalid premise about the nature of space.

A Appendix

V_S		R_1/Ω		R_2/Ω		V_{R_2}			I_{R_2}		
Nominal	Measured	Nominal	Measured	Nominal	Measured	Prediction 1	Prediction 2	Measured	Prediction 1	Prediction 2	Measured
10 mV	10.30 mV	10	9.909	1	1.091	909 µV	1.02 mV	982 µV	909 µA	936 µA	880 µA
	10.1 mV			10	9.964	5 mV	5.06 mV	5.10 mV	500 µA	508 µA	459 µA
	9.61 mV			100	105.72	9.09 mV	8.79 mV	8.82 mV	90.9 µA	83.1 µA	80.0 µA
	9.786 mV			1 k	1.058 k	9.9 mV	9.70 mV	9.68 mV	9.90 µA	9.16 µA	9.8 µA
	10.168 mV			10 k	9.831 k	9.99 mV	10.2 mV	10.174 mV	999 nA	1.03 µA	1.0 µA
	10.51 mV			100 k	99.33 k	10.0 mV	10.5 mV	10.88 mV	100 nA	106 nA	100 nA
	10.27 mV			1 M	1.035 M	10.0 mV	10.3 mV	10.28 mV	10.0 nA	9.92 nA	0 nA
100 mV	105.3 mV			1		9.09 mV	10.4 mV	10.11 mV	9.09 mA	9.57 mA	9.30 mA
	98.90 mV			10		50.0 mV	49.6 mV	49.73 mV	5.00 mA	4.98 mA	4.89 mA
	100.9 mV			100		90.9 mV	92.3 mV	92.5 mV	909 µA	873 µA	859 µA
	100.1 mV			1 k		99.0 mV	99.2 mV	99.16 mV	99.0 µA	93.7 µA	100.7 µA
	99.54 mV			10 k		99.9 mV	99.4 mV	99.52 mV	9.99 µA	10.1 µA	10.1 µA
	100.7 mV			100 k		100 mV	101 mV	100.9 mV	1.00 µA	1.01 µA	1.0 µA
	101.6 mV			1 M		100 mV	102 mV	101.6 mV	100 nA	98.2 nA	100 nA
1 V	1.014 V			1		90.9 mV	101 mV	96.9 mV	90.9 mA	92.2 mA	68.9 mA
	1.069 V			10		500 mV	536 mV	538 mV	50.0 mA	53.8 mA	43.8 mA
	1.021 V			100		909 mV	977 mV	935 mV	9.09 mA	9.25 mA	8.51 mA
	1.037 V			1 k		990 mV	1.02 V	1.027 V	990 µA	962 µA	1.043 mA
	1.039 V			10 k		999 mV	1.04 V	1.038 V	99.9 µA	106 µA	105.6 µA
	1.055 V			100 k		1.00 V	1.05 V	1.055 V	10.0 µA	10.6 µA	10.6 µA
	1.06 V			1 M		1.00 V	1.96 V	1.056 V	1.00 µA	1.02 µA	1.0 µA
10 V				1		909 mV	—	—	909 mA	—	—
				10		5.00 V	—	—	500 mA	—	—
				100		9.09 V	—	—	90.9 mA	—	—
	10.00 V			1 k		10.0 V	9.91 V	9.86 V	9.90 mA	9.36 mA	9.97 mA
	9.90 V			10 k		10.0 V	9.89 V	9.90 V	999 µA	1.01 mA	1.02 mA
	10.0 V			100 k		10.0 V	10.0 V	9.97 V	100 µA	101 µA	102 µA
	10.1 V			1 M		10.0 V	10.1 V	10.0 V	10.0 µA	9.76 µA	9.8 µA

Table 1: Predicted and Measured Values of $V_{R_2} = \frac{R_2}{R_1+R_2} V_S$ and $I_{R_2} = \frac{V_S}{R_1+R_2}$. Prediction 1 is based on the use of nominal values of voltage and resistance; prediction 2 is based on the use of measured values. The measured values of the resistors are only shown once because the same resistors were used repeatedly. Three rows of the table for $V_S = 10\,\mathrm{V}$ were not used to avoid exceeding the rated power for the resistors.

R_2 nominal	R_2 measured	V_{R_2}	I_{R_2}	$\frac{V_{R_2}}{I_{R_2}}$	Ratio $\frac{V_{R_2}}{I_{R_2}R_2}$	Average
1 Ω	1.091 Ω	982 mV	880 μA	1.12 Ω	1.02	
		10.11 mV	9.30 mA	1.09 Ω	1.00	
		96.9 mV	68.9 mA	1.41 Ω	*1.29*	1.01
10 Ω	9.964 Ω	5.10 mV	459 μA	11.1 Ω	1.12	
		49.73 mV	4.89 mA	10.2 Ω	1.02	
		538 mV	43.8 mA	12.3 Ω	*1.23*	1.07
100 Ω	105.72 Ω	8.82 mV	80.0 μA	110.3 Ω	1.04	
		92.5 mV	859 μA	57.9 Ω	*0.55*	
		935 mV	8.51 mA	109.9 Ω	1.04	1.04
1 kΩ	1.058 kΩ	9.68 mV	9.8 μA	988 Ω	0.93	
		99.16 mV	100.7 μA	1.002 kΩ	0.95	
		1.027 V	1.043 mA	1.037 kΩ	0.98	
		9.86 V	9.97 mA	996 Ω	0.94	0.95
10 kΩ	9.831 kΩ	10.174 mV	1.0 μA	10.2 kΩ	1.04	
		99.52 mV	10.1 μA	9.96 kΩ	1.01	
		1.038 V	105.6 μA	10.4 kΩ	1.06	
		9.90 V	1.02 mA	9.91 kΩ	1.01	1.03
100 kΩ	99.33 kΩ	10.88 mV	100 nA	109 kΩ	1.10	
		100.9 mV	1.0 μA	101 kΩ	1.02	
		1.055 V	10.6 μA	106 kΩ	1.06	
		9.97 V	102 μA	99.7 kΩ	1.00	1.04
1 MΩ	1.035 MΩ	10.28 mV	0 nA	—	—	
		101.6 mV	100 nA	1.02 MΩ	0.98	
		1.056 V	1.0 μA	1.06 MΩ	1.02	
		10.0 V	9.8 μA	1.02 MΩ	0.99	1.00

Table 2: Calculation of V_{R_2}/I_{R_2}. Some of the ratios are shown in *italics*. These values are more than 20% away from the value 1 and so have been discarded in computing the average ratio in the last column on the footing that they may have resulted from blunders in the lab. The first row of the table dealing with the 1 MΩ resistor cannot be used to calculate a ratio because no measurable current could be detected.