

LABORATORY 1 WRITEUP - PHYSICS 517/617

Prof. L. S. Durkin

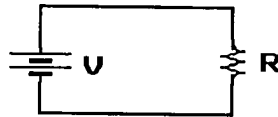
July 5, 1992

DISCLAIMER: There are many ways to write up a lab report, none of them superior to any other. Below is an example of an acceptable report. It is not necessary to generate typewritten text or computer plots. Computer plots are easier to generate and fit than hand plots, but feel free to plot things by hand. Information is what counts, not style.

I.1 Purpose

The purpose of this measurement is to verify Ohm's law ($V=IR$) for constant voltages and constant currents. Two resistors will be used with resistances varying by nearly three orders of magnitude.

I.2 Procedure



The current and voltages will be measured using a Fluke meter. I have chosen resistors:

1. $R=1100 \pm 5\% \Omega$ (1088 Ω measured with meter), and 2. $R=1.20 \pm 5\% \text{ M}\Omega$ (1.21 $\text{M}\Omega$ measured with meter).

I.3 Data

Table 1 – $R = 1100 \Omega$

Voltage Resistor (V)	Current Resistor (mA)
0.0	0.00
16.0	15.5
4.0	3.70
13.0	12.5
5.6	5.03
11.5	10.12

My measurements were taken alternately between high and low values to reduce any effects due to equipment drift (Resistor heating ...).

Note: My voltage supply started smoking half way through the data taking. I replaced it and don't expect this to have any effect.

Table 2 – R = 1.2 MΩ

Voltage Resistor (V)	Current Resistor (mA)
0.00	0.00
30.5	0.028
5.5	0.005
29.9	0.025
10.67	0.010
18.00	0.014

Note: I had a faulty wire which made these measurements difficult. I was forced to rewire several times.

I.4 Data Analysis

The data plots for the two resistors are shown in figures 1 and 2 below.

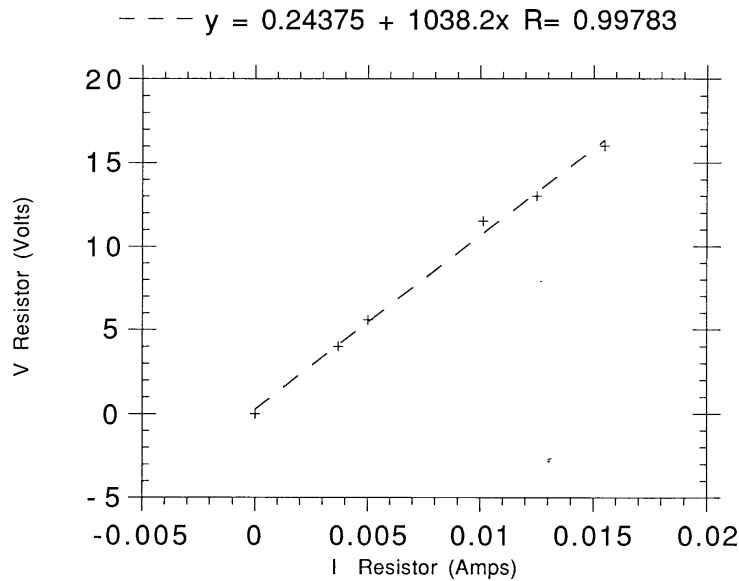


FIGURE 1 – DC Voltage-Current R = 1100 Ω

For the R=1100 Ω resistor, the line is seen to be a very good fit. The values agree with the line within the measurement errors listed below (≈ 2 %). The slope of the line is not in very good agreement with the resistance measured by the meter. I went back and check this resistance and

could find no problem. I don't understand this 4 % discrepancy given this result is a fit to many points (Error should reduce by $\approx 1/\sqrt{N}$).

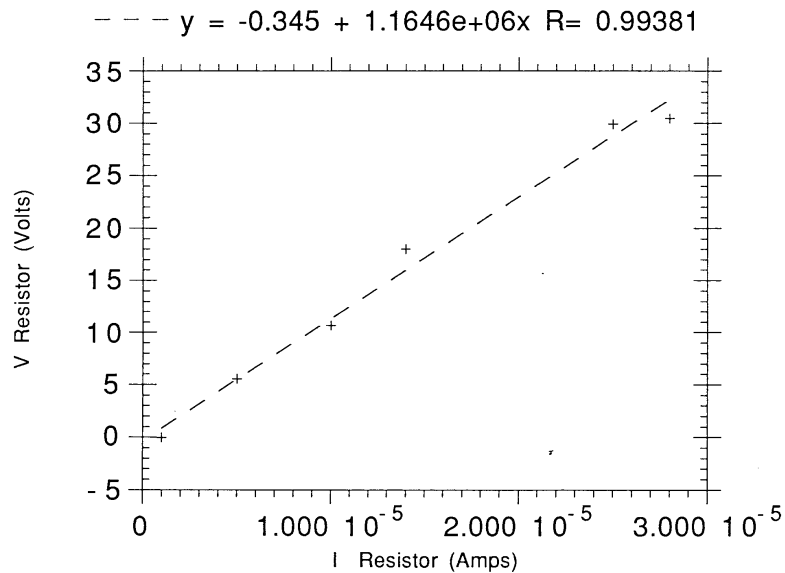


FIGURE 2 – DC Voltage-Current R = 1.2 MΩ

For the 1.2 MΩ resistor once again the line seems to be a good fit to the data. The values agree with the line within measurement errors (see below). The slope once again is 4 % lower than the value I measured with the voltmeter. In this case I think I have an explanation. Since the internal resistance of the meter is 10 MΩ (see later in lab book), and I am using a 1.0 MΩ resistor, I might expect to be low by nearly 10 %.

Possible sources of measurement error are simple here:

- The current measurement in the FLUKE manual has an error of 1 %.
- The voltage measurement is good to the digital display accuracy (about 1 %).
- The resistance measurement is good to the digital display accuracy (about 1 %).

Possible sources of systematic error are:

- The resistor could heat up changing the resistance. Since my currents are low this effect should be negligible. I also staggered my measurements to protect against this problem.

II.1 Purpose

The purpose of this measurement is to verify Ohm's law ($V=IR$) for sinusoidal voltages and currents. One resistor will be used at two varying frequencies: 100 Hz and 50 KHz.

II.2 Procedure



The current and voltages will be measured using a Fluke digital volt meter (D.V.M) (Thus R.M.S. measurements). I have chosen a resistor: $R=560 \pm 5\% \Omega$ (563 Ω measured with meter).

II.3 Data

Table 3 – $R = 560 \Omega$, $f = 100 \text{ Hz}$

Voltage Resistor (rms V)	Current Resistor (rms mA)
0.042	0.08
0.144	0.26
4.07	7.250
0.414	0.74
3.120	5.550
1.312	2.34
3.56	6.33
1.881	3.35
2.586	4.60

Table 4 - $R = 560 \Omega$, $f = 50 \text{ KHz}$

Voltage Resistor (rms V)	Current Resistor (rms mA)
0.000	0.02
0.035	0.06
0.12	3.23
0.077	1.78
0.106	2.79

Note: The current measurements when taking this data were very unstable. The meter would suddenly fall to zero and I would have to turn off the meter to get a reading. A quick ratio with the calculator shows the effective resistance is way off. I had better take some data to investigate.

Try keeping the voltage constant, I change the frequency measuring the current.

Table 5 - R = 560 Ω , V = .120 V

frequency	Current Resistor (rms mA)
100	0.21
1000	0.22
2000	0.23
3000	0.23
4000	0.23
5000	0.28
8000	0.37
10000	0.46
20000	unstable
30000	1.6

Note: Once again the current meter is very unstable. At 20KHz it was impossible even to obtain a reading. The DVM varied from .0-.7 mA rms.

II.4 Data Analysis

In figure 3 is shown the Ohms law data for 100 Hz. The straight line agrees with the fit line well within measurement errors (see below). The resistance from the slope also agrees well, within the expected errors of $\approx 2\%$, with the resistance measured from the meter.

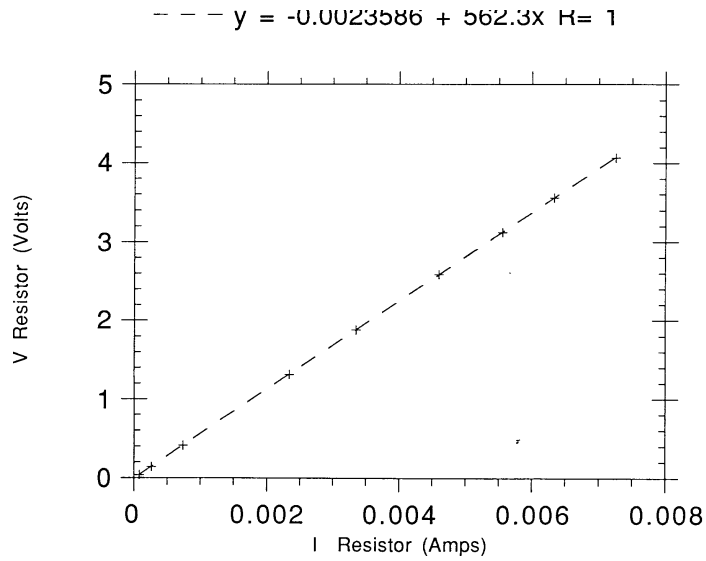


FIGURE 3 – 50 Hz, $R = 560 \Omega$, Values are R.M.S.

In figure 4 is shown the Ohms law data for 50 KHz. There are immediate problems seen in this data. It doesn't pass through zero. The best fit slope doesn't agree with the resistor used at all. Looking at the FLUKE manual it only gives a meter accuracy below 1 KHz. I suspect this means it doesn't work above 1 KHz. To investigate this I took the data in figure 5. It is seen the FLUKE meter works well up to about 5 KHz and then the measurement takes off. I had better believe the FLUKE book and only use the DVM below 1 KHz in the future.

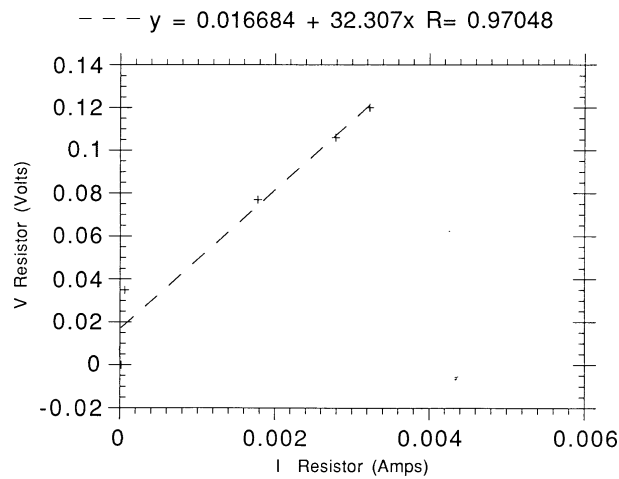


FIGURE 4 – 50 KHz, $R = 560 \Omega$, Values are R.M.S.

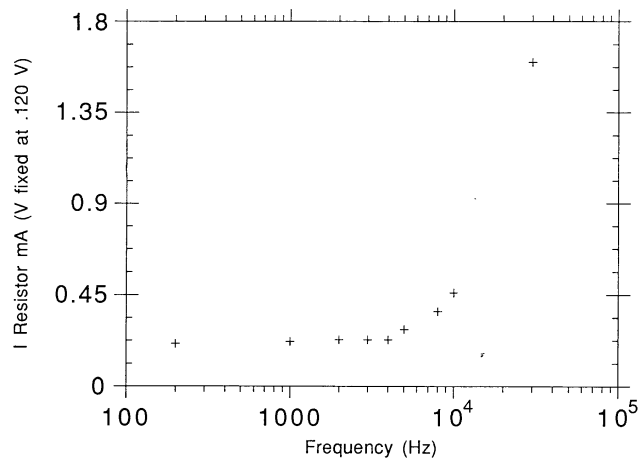


FIGURE 5 – Current through a 560 Ω resistor as a function of the frequency with the voltage across the resistor fixed at .120v. Values plotted are R.M.S.

Possible sources of measurement error (Below 1 KHz) are simple here:

- The current measurement in the FLUKE manual has an error of 1 %.
- The voltage measurement is good to the digital display accuracy (about 1 %).
- The resistance measurement is good to the digital display accuracy (about 1 %).

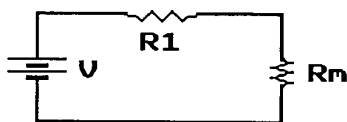
Possible sources of systematic error are:

- The resistor could heat up. Since my currents are low this effect should be negligible. I also staggered my measurements to protect against this problem.
- Clearly the meter does not operate much above 1 KHz.

III.1 Purpose

The purpose of this section is to measure the internal resistance of the DVM when measuring voltage.

III.2 Procedure



In the circuit above the external resistance and external voltage are known. The voltage measured by the voltmeter is known, and thus the only unknown is the internal resistance. Thus the equation for the internal resistance is:

$$R_m = R_1 \frac{V_m}{V - V_m}.$$

For two resistors we measure V and V_m using the DVM.

III.3 Data

All resistors were measured with a DVM.

Table 6 - DVM Internal Resistance

R1 (MΩ)	V (volts)	Vm (volts)	R(internal) (MΩ)
18.29	5.00	2.79	10.2
18.29	10.00	3.55	10.0
18.29	20.00	7.05	10.0
9.40	5.20	5.20	8.8

III.4 Data Analysis

It is seen from the calculated R_{internal} in table 6 that the DVM internal resistance is about 10 MΩ. There seems to be little error associated with voltage measurement as can be seen from the first three measurements in this table. Changing resistors did cause a $\approx 10\%$ change in my measured value. I don't fully understand this change. It is not explained by the measurement errors discussed below.

Possible sources of measurement error are:

- The voltage measurement is good to the digital accuracy (about 1 %).
- The resistance measurement is good to the digital accuracy (about 1 %).

Possible sources of systematic error are:

- There seems to be some unknown effect here. Since I don't have a schematic of the DVM it is impossible for me to guess what the effect is. I could plot the measured resistor as a function of external resistance to see if there is a real effect. Unfortunately I thought of this too late to include it in this lab.

IV.1 Purpose

The purpose of this section is to measure the internal resistance and capacitance of the

oscilloscope.

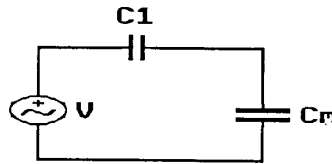
IV.2 Procedure

Capacitors block DC voltage and thus can be ignored in this circuit. My circuit is then identical to the circuit in section III.2. The formulas for resistance is as before:

$$R_m = R_1 \frac{V_m}{V - V_m}$$

Measurements of V and V_m are made using the oscilloscope.

For high enough frequency the impedance of a capacitor becomes very small with respect to the impedance of a resistor. In this limit ($1/\omega c \ll R$), adding an external capacitor, we obtain the following circuit.



In order to satisfy this limit we must have : $\omega \gg 1/RC = 2800$ rad/sec. I therefore choose $f = 100$ KHz. In this limit my equation becomes:

$$C_m = C_1 \frac{V - V_m}{V_m}$$

I once again measure V and V_m using the oscilloscope. I measure C_1 with the capacitance meter in the lab.

IV.3 Data

DC voltage source to measure R internal for scope. R_1 measured with DVM.

Table 7 - Oscilloscope Internal Resistance

R1 (M Ω)	V (volts)	Vm (volts)	R(internal) (M Ω)
1.087	5.00	2.45	1.04
1.087	10.00	4.90	1.04
0.528	5.00	2.61	1.10

Frequency generator ($f = 100$ KHz) was used as the source. The frequency meter was tuned to lower frequencies to check that frequency did not effect the answers. Measured voltages only changed in the vicinity of 1 KHz, which is in good agreement with the calculation above.

The capacitance, C_1 , was measured with the capacitance meter in the lab. V and V_m were measured on the oscilloscope.

Table 8 - Oscilloscope Internal Capacitance

C1 (pF)	V (volts)	Vm (volts)	C internal (pF)
46.9	6.0	1.48	143
46.9	10.00	2.40	149
24.6	6.0	0.80	160
24.6	10.00	1.30	165

IV.4 Data Analysis

The resistance measurements of Table 7 seem quite consistent. The internal resistance of the scope is $1.0\text{ M}\Omega$ with a percentage error of around 5 %. I used my DVM to measure the internal resistance of the scope and obtained $1.01\text{ M}\Omega$ as the internal resistance of the scope.

Possible sources of measurement error are:

- Measuring voltage off the oscilloscope is limited by reading accuracy. If I can't distinguish half a small division my accuracy will be limited to $\approx .5/10$ -50 or 1-5 %.
- Measurement error of resistance from the DVM is negligible.

Possible sources of systematic error are:

- There is not much systematic error one can think of except for scope calibration, and that has been cross checked with the DVM.

The capacitance measurements of Table 8 do not seem very consistent. There seems to be greater than a 10 % difference in the answer when I change my C_1 value. Even more shocking is the difference with the manual for the scope which claims an internal capacitance of 35 pF. To check the internal capacitance of the scope I used the capacitance meter in the lab and read the capacitance as 35 pF. After playing with the circuit I found that the leads attaching to the circuit had large capacitances. I measured my leads to have a capacitance of 110 pF using the capacitance meter in the lab. Subtracting this off from the results in Table 8, I get the internal capacitance of the scope to be somewhere around 36-50 pF.

Possible sources of measurement error are:

- Measuring voltage off the oscilloscope is limited by reading accuracy. If I can't distinguish half a small division my accuracy will be limited to $\approx .5/10$ -50 or 1-5 %.
- Measurement error of capacitance from capacitance meter is negligible.

Possible sources of systematic error are:

- The error on this measurement is dominated by stray capacitances. The lead capacitances are bigger than the capacitance of the scope. Even using very short leads one is worried one has not eliminated all stray capacitances.

V.1 Purpose

The purpose of this measurement is cross check the calibration of the frequency meter and the oscilloscope over the full frequency range of the frequency meter.

V.2 Procedure

A frequency is dialed on the frequency meter, and then the frequency of the output sine wave is measured using an oscilloscope.

V.3 Data

Table 9 - Calibration Data

frequency Meter (Hz)	frequency Oscilloscope (Hz)
10	12.6
100	104.7
1000	1047
10000	12500
100000	114000
50	50
500	510
5000	5040
50000	52600
500000	541000

V.4 Data Analysis

Shown in figure 6 is a plot of the meter frequency vs the oscilloscope frequency. The relationship seems to be very linear despite KALIDOGRAPH's idiotic curve. This seems to be a bug in KALIDOGRAPH. It won't plot a straight line on a log-log plot. For a commercial piece of software this is inexcusable. I can't fix it so I ignore it. The linear fit does show an interesting effect. The oscilloscope and the meter reading seem to disagree by over 8 %. It is impossible, without doing something else, to check who is right. I could independently calibrate the oscilloscope by looking at the 60 Hz 120 V signal being put out by the electric company. I am too afraid of being electrocuted so I don't do it. I instead trigger my oscilloscope on the line voltage and dial 60 Hz on the frequency generator. It looks like my oscilloscope is accurate. Thus my frequency generator dial can't be totally trusted. Such is life!

Possible sources of measurement error are:

- Measuring frequency off the frequency meter dial is only accurate to about 5 %.
- Measuring frequency off the oscilloscope is limited by reading accuracy. If I can't distinguish half a small division my accuracy will be limited to $\approx .5/10-50$ or 1-5 %.

Possible sources of systematic error are:

- As I have shown the knob on the frequency generator is somewhat misplaced.

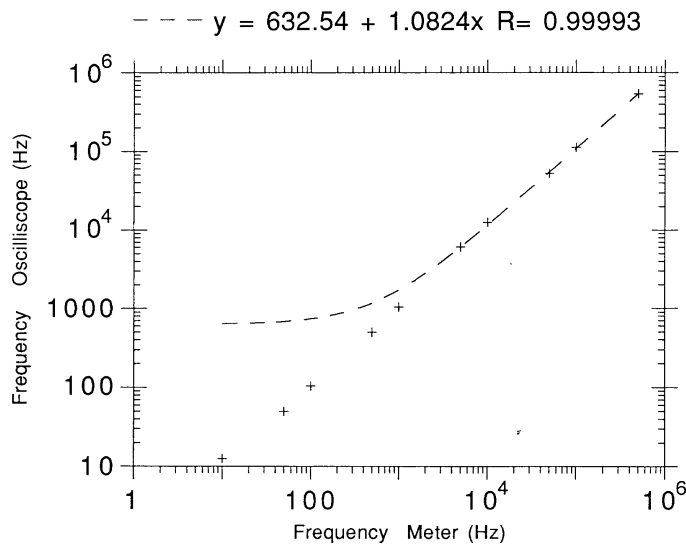


FIGURE 6 – Frequency as measured on the frequency generator vs frequency measured on the oscilloscope. Funny line is an artifact of KALIDOGAPH (see text).