Report
As a partial requirement
For
The course on

Engineering Experimentation
ME 3901, D07

Laboratory Experiment 1:
EXPERIMENTS WITH A DIGITAL OHMMETER

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Lab score:

ORGANIZATION AND PRESENTATION:	________
LABORATORY DESCRIPTION AND OBJECTIVES:	________
METHODOLOGY:	________
RESULTS:	________
INTERPRETATION OF RESULTS (DISCUSSION)	________
CONCLUSIONS AND RECOMMENDATIONS:	________
TOTAL:	________

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Abstract

This series of experiments used a digital ohmmeter to collect descriptive statistics on a batch of 10 carbon 1 kΩ-rated resistors. The device's ability to work with 2.2Ω, 120Ω and $47k\Omega$ was also checked. Each measurement in the experiment was repeated 10 times to minimize imprecision due to noise and due to the low resolution of the ohmmeter used. The batch mean was computed to be $971 \pm 2\Omega$, measured with the resolution of 4.9 Ω. Then 10 random pairs from the batch were measured in series and in parallel. The mean of in-series measurements was $1965 \pm 0.31\%\Omega$. The mean of in-parallel measurements was $491.2 \pm 0.28\%\Omega$. This agreement is approximately in-line with the theoretical error propagation for this type of measurement. Resolution of the system was measured, and found to be exactly linear with the higher limit of the expected range of measurements. Also, the resistance of a 2.2 Ω resistor was found to slightly increase when heated with a soldering iron, thus confirming the theoretical relation.

Introduction

This series of short experiments with the digital ohmmeter served to inspect the technicalities of analog to digital conversion, as well as analyze what the limiting factors to the accuracy and precision of the measured value are when making this kind of measurements. Population statistics were collected and computed for a batch of 10 1 kΩ-rated resistors. Also, the uncertainty propagation and the effect of temperature on the resistance of a carbon resistor were analyzed.

The limitations of the device were determined by measuring a mix of 2.2 Ω, 120 Ω and 47 kΩ. The resolution of the device was measured by a series of 100 measurements of a 1 kΩ resistor with expected higher value of the range varying between 1 kΩ, 2 kΩ, 5 kΩ and 10 kΩ.

Ref. [1] contains the general procedure followed during this series of experiments, for more details see Methodology. The digital ohmmeter used was controlled using LabVIEW 8 visual instrument (see Appendix C for screenshot); 4-wire type of measurements with fixed current and varying voltage were used. This ohmmeter worked by running a fixed value of current ($1.0 \pm 0.5mA$) through the resistor, and measuring the resulting voltage across the resistor.

The following equations were used for predicting the uncertainties:

R - resistance being measured
δR - uncertainty in resistance being measured
I - current put through the resistor (fixed at $1.0 \pm 0.5mA$)
V - voltage created by the current sent through the resistor

$R = \frac{V}{I}$, thus $\delta R = R \cdot \sqrt{\left(\frac{\delta V}{V}\right)^2 + \left(-\frac{\delta I}{I}\right)^2}$ (Ref. [4]).

The A/D converter used in this experiment was 12-bit, and therefore the resolution of the digital ohmmeter can be theoretically predicted by: $res = \frac{R_{max} - R_{min}}{2^{12}}$. This equation holds true until $R_{max} - R_{min}$ does not become too small, and the A/D converter's maximum resolution (4.9 mV) does not come into play. As such, we can predict seeing the resolution max out at a given interval for each resistor.

Methodology

A LabVIEW 8 Visual Instrument was created to allow 4-wire resistance measurements (see Appendix C for screenshot, Ref [1] for instructions on creating the VI). Signal conditioning chassis and screw terminal from National Instruments were used (see Appendix A for complete list of instrumentation used). The VI was configured to record the data automatically in a Microsoft Excel spreadsheet.

The program read the current and voltage running through a resistor and displayed values of resistance for each resistor. It was set to take ten readings for each resistor, display the readings on a digital display as well as a dial, and save the data to a Microsoft Excel spreadsheet.

0. Several test readings were taken to make sure the digital ohmmeter was functioning (although not necessarily calibrated); that data was then discarded.

Any measurement in this experiment from this point on was repeated 10 times, to account for fluctuations in current, temperature, and other sources of noise.

1. A batch of 10 1 kΩ-rated resistors was measured, and both the batch and individual resistor statistics calculated and recorded. For these measurements DAQ limits (set in the VI) of [1Ω, 10 kΩ] were used. These measurements were made to analyze the variance in a batch of similar resistors. One of these resistors was also measured with a multimeter; that data was used for offset in calibration of the ohmmeter.
2. 100 consecutive readings were run on a batch resistor with a varying top limit. This was done to identify the dependence of resolution on top limit.

3. Then the ohmmeter was tested on a mix of three resistors with ratings of 2.2 Ω, 120 Ω and 47 kΩ; limits were varied on these measurements to analyze how high the ohmmeter's resolution can go on each scale.

4. 10 random pairs from the batch (picked as a simple random sample) were then measured in series and in parallel, in order to analyze how the population variance will propagate into these measurements. Limits were also adjusted in this measurement, to remove resolution as a source of uncertainty.

5. Finally, the 2.2 Ω-rated resistor was measured with high resolution, and then heated with a soldering iron (see Appendix A for details on the instrumentation) and remeasured. This was for qualitatively verifying the variation of resistance as a function of temperature.

Results and Discussion

1. A batch of 10 1 kΩ-rated resistors was measured and both the batch and individual resistor statistics calculated and recorded. Limits of [1Ω, 10 kΩ] were used; these limits provided resolution of 2.441Ω, both theoretically (see Introduction) and experimentally (see Fig. 2 for resolution measurements). Fig. 1 contains the data collected during this step.

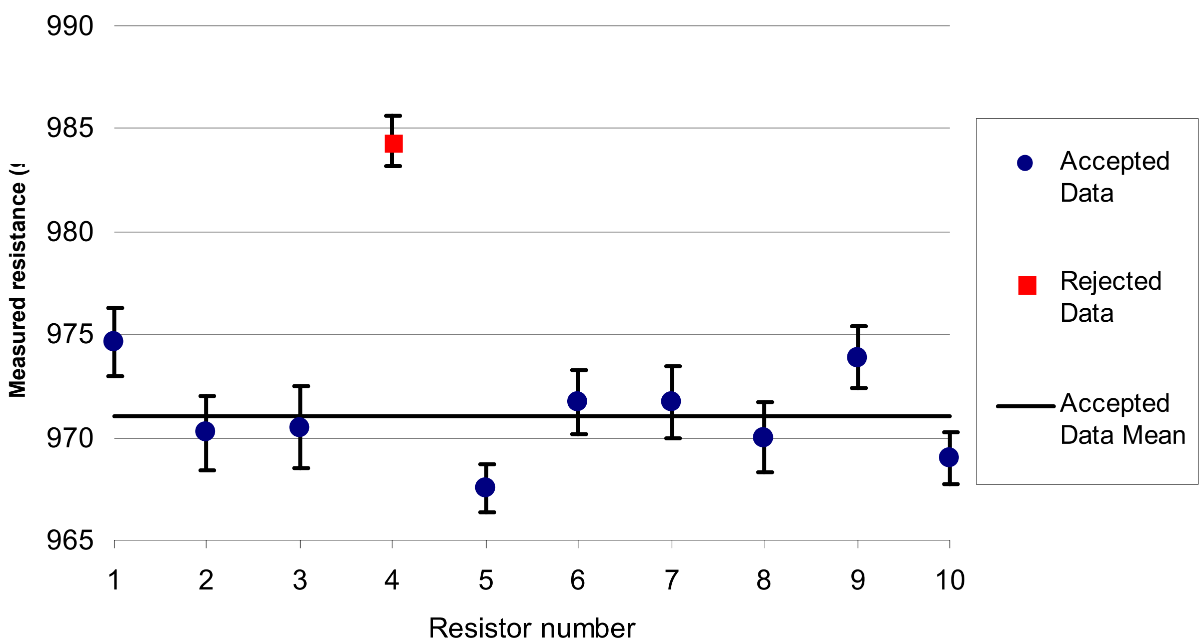

Fig. 1 Calibrated batch readings

Resistor 10 in the batch was measured (with the digital ohmmeter) to be $979.9 \pm 1.7\Omega$. When measured with a calibrated multimeter (see Appendix A for instrumentation used), it was measured to be 969 Ω. Therefore, all batch data was offset by -10.9 Ω, Fig. 1 contains calibrated measurements. No slope calibrations were conducted, so only batch data is calibrated in this experiment. Also, Chauvenet's criterion was used to reject Resistor #4 from the batch. The final batch statistics are $971 \pm 2\Omega$. Thus the probability of a batch resistor falling outside the specified limits (being outside the [950, 1050] Ω limit) is 0 to at least 15 decimal places. From Figure 1 we can clearly see that the variance in the batch is primarily due to the differences between the individual resistors, and not the variances of the individual resistors themselves. The variances of the individual resistors themselves are mostly due to the relatively low resolution during these measurements.

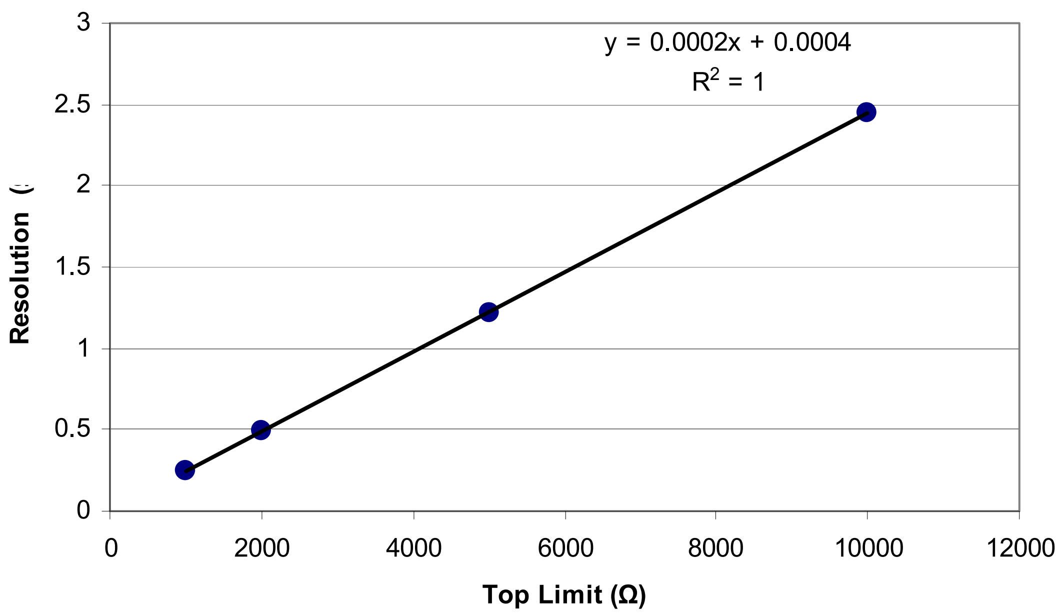

Fig. 2 Resolution in measurements of a batch 1 kΩ resistor as a function of top limit

2. 100 consecutive readings were run on a batch resistor with a varying top limit. This was done to identify the dependence of resolution on top limit. See Figure 2 for the outcome.

We can see that the resolution exhibited a perfectly linear variation as a function of top limit. However, the lower limit remained 1 during this measurement, and thus the number of bits in the signal conditioner never became the issue. It does become the limiting factor when the entire interval is adjusted, as is seen in measuring non-batch resistors.

3. The ohmmeter was tested on a mix of three resistors with ratings of 2.2 Ω, 120 Ω and 47 kΩ; limits were varied on these measurements to analyze how high the ohmmeter's resolution can go on each scale. See Table 1 for the summarizing statistics of this data.

Table 1 Summarizing statistics of the measurements of mix of resistors

Resistor (Ω)	Bottom Limit (Ω)	Top Limit (Ω)	$\bar{x}$ (Ω)	σ (Ω)	Resolution (Ω)
120	1	10000	119.0	1.2	2.441
	110	130	118.11	0.03	0.049
	115	125	118.09	0.03	0.049
2.2	1	10000	3.1	1.9	2.441
	0.1	5	2.2348	0.0016	0.002
	2	2.5	2.236	0.002	0.003
47000	43000	50000	8162.0	1.5	2.441

We can see that with the 2.2 Ω and 120 Ω resistors, the resolution increases up to a point, and then the number of bits in the signal conditioner becomes the limiting factor. We can also see that the variance of the samples depends largely on the resolution.

Also, we can see that the 47 kΩ resistor could not be measured properly with this apparatus. That is because the ohmmeter used in this laboratory is fixed to 1 mA of current, and that produces voltage of 47 V across the resistor. The apparatus is limited to [-10, 10] V, and there is no attenuation available in this setup. So the highest resistance that can be measured with this apparatus is one in which no signal attenuation is necessary, which theoretically is: $R_{\max} = \frac{10V}{1mA} = 10k\Omega$, assuming absolutely no noise or variations in current. However, we can see that the actual measurement peaked at $8162.0 \pm 1.5\Omega$ - likely due to variations in current.

4. 10 random pairs from the batch (picked as a simple random sample) were then measured in series and in parallel, in order to analyze how the population variance will propagate into these measurements. Limits of [1900, 2100] were used on the in-series measurements, and [400, 600] on the parallel measurements. That was to maximize the variance in the batch as the leading cause of uncertainty and minimize uncertainty due to the resolution of the ohmmeter. Again, the batch statistic was measured in part 1 of the experiment to be $971 \pm 2\Omega$. Notice, that this number is calibrated by an offset, and the in-parallel and in-series measurements are not calibrated by an offset. That, however, is not a problem for this experiment, because the variance is not affected by a bias shift. The final in-parallel descriptive statistic was $491.2 \pm 1.4\Omega$, and in-series was $1965 \pm 6\Omega$. Theoretically, if a random resistor from the batch has mean resistance R and uncertainty δR, then the error in the mean of a simple random sample of in-parallel pair measurements will be $\frac{\delta R}{2}$, and for in-series pairs it will be $2\delta R$ (Ref. [4]). That is the approximately the behavior we are observing here: the error approximately doubled from the batch to the in-series measurements (from 2 Ω to 6 Ω) and halved for the in-parallel measurements (from 2 Ω to 1.4 Ω). If more simple random pairs were measured, the errors in the sample means would further approach their theoretical values (which in this case are 4 Ω for the in-series measurements and 1.0 Ω for the in-parallel measurements).

5. Finally, the 2.2 Ω-rated resistor was measured with high resolution, and then heated with a soldering iron (see Appendix A for details on the instrumentation) and remeasured. This was for qualitatively verifying the variation of resistance as a function of temperature. The 2.2 Ω resistor was used because it should have the least material in it, so it is easier to heat up; also the variation in the measurements of this resistor are the least, and the variation due to temperature is thus easier to identify. See Figure 3 for observed variation.

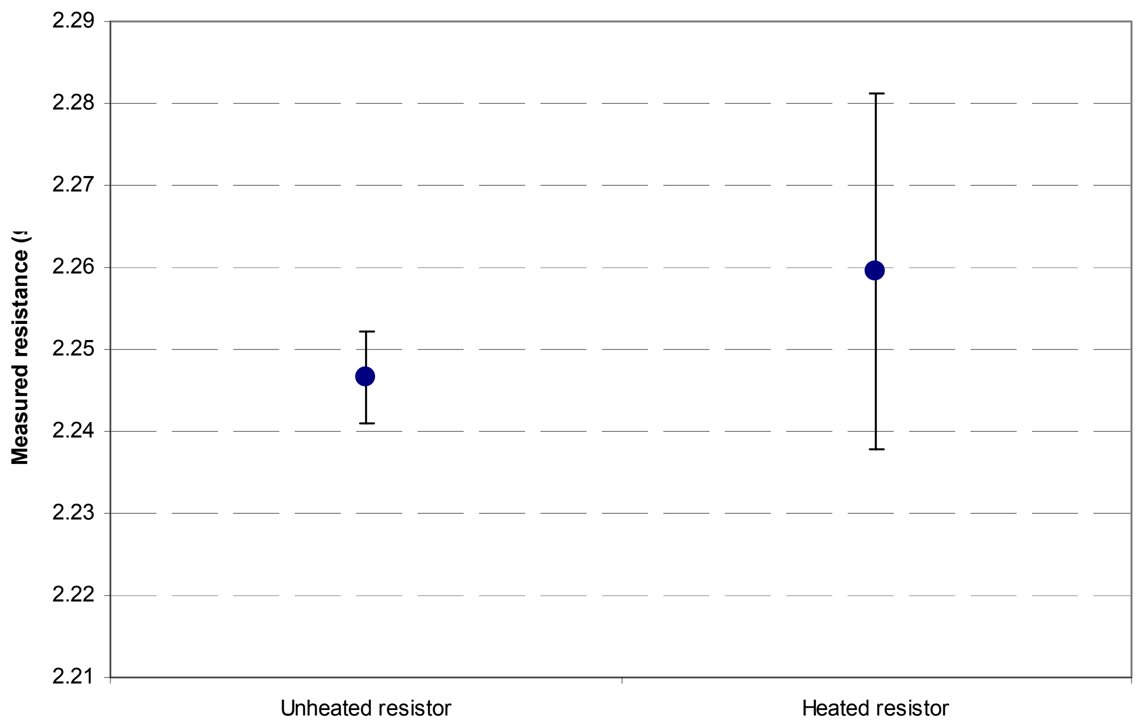

Fig. 3 Variations of resistor readings with temperature

We can see that there is a small observed increase in resistance with temperature. However, there is a large observed increase in variance as well – possibly due to temperature fluctuations due to air flow.

Conclusions and Recommendations

The batch was calculated to have descriptive statistics of $971 \pm 2\Omega$. It is less than the rated 1 kΩ, but still very well within the specified tolerances. Thus while a linear offset of 29 Ω may be recommended to the manufacturer, it is not necessary. The probability of a resistor being outside the specified tolerance is 0 to at least 15 decimal places.

Resolution (minimum difference between two nearby values) increases linearly with increase in the higher limit, and decreases linearly with decrease in the higher limit. This behavior is true as long as the number of bits in the A/D converter of the signal conditioner does not become the limiting factor.

Linear offset was used for calibration. However, it is recommended to also calculate a slope offset to fully calibrate this ohmmeter. To do so, several additional measurements of resistors other than 1 kΩ must be taken, and a linear least squares regression conducted to calculate the β.

The ohmmeter cannot accurately measure resistances above about 8 kΩ, because the produced voltage across the resistor becomes too high, and the signal conditioner cannot attenuate the signal.

Error was observed to propagate from batch to in-parallel and in-series readings exactly as expected from the theory of error propagation. If the number of simple random pairs measured in-series and in-parallel was increased, the variance in the in-series and in-parallel means is expected to even further approach the expected values.

Small increase in resistance was observed when a resistor was heated with soldering iron. It is recommended that more controlled conditions are used to further verify this behavior – i.e., a non-conducting bath or thermal chamber used to heat the resistor. Also, the variation observed was very small, so it is likely that the resistors are intentionally manufactured for their resistance to vary as little as possible with the temperature, since they are not thermistors.

Appendix A: Instrumentation Used

Table 2 Instrumentation used

Device	Model Number	Manufacturer	Serial Number	Calibration due date
Multimeter	22-809	RadioShack	06A01	Unknown/Not Calibrated
Signal Conditioner Chassis	SCXI-1000	National Instruments	N/A	Unknown/Not Calibrated
Signal Conditioner	SCXI-1122	National Instruments	N/A	Unknown/Not Calibrated
Screw Terminal Strip	SCXI-1322 Rev. A	National Instruments	ASSY182385-01	Unknown/Not Calibrated
Soldering Iron	25W, 120V, 60Hz	Weller	336B	N/A
LabVIEW 8 Software Package	Student Edition	National Instruments	Uknown	N/A
Microsoft Office 2003	N/A	Microsoft	N/A	N/A

Appendix B: References

[1]. Documents posted on http://users.wpi.edu/~cfurlong/me3901.html:

Lab1: Description, Procedure: Part 1, Procedure: Part 2, Resistors: Color codes.

[2]. T.G. Beckwith, R.D. Marangoni, and J.H. Lienhard, *Mechanical Measurements*, 6th ed., Prentice Hall, 2007

[3]. R.H. Bishop, *LabVIEW 8*, Prentice Hall, 2007

[4]. John R. Taylor, *An Introduction to Error Analysis*, 2nd ed., University Science Books, 1997

Appendix C: Visual Instrument Used

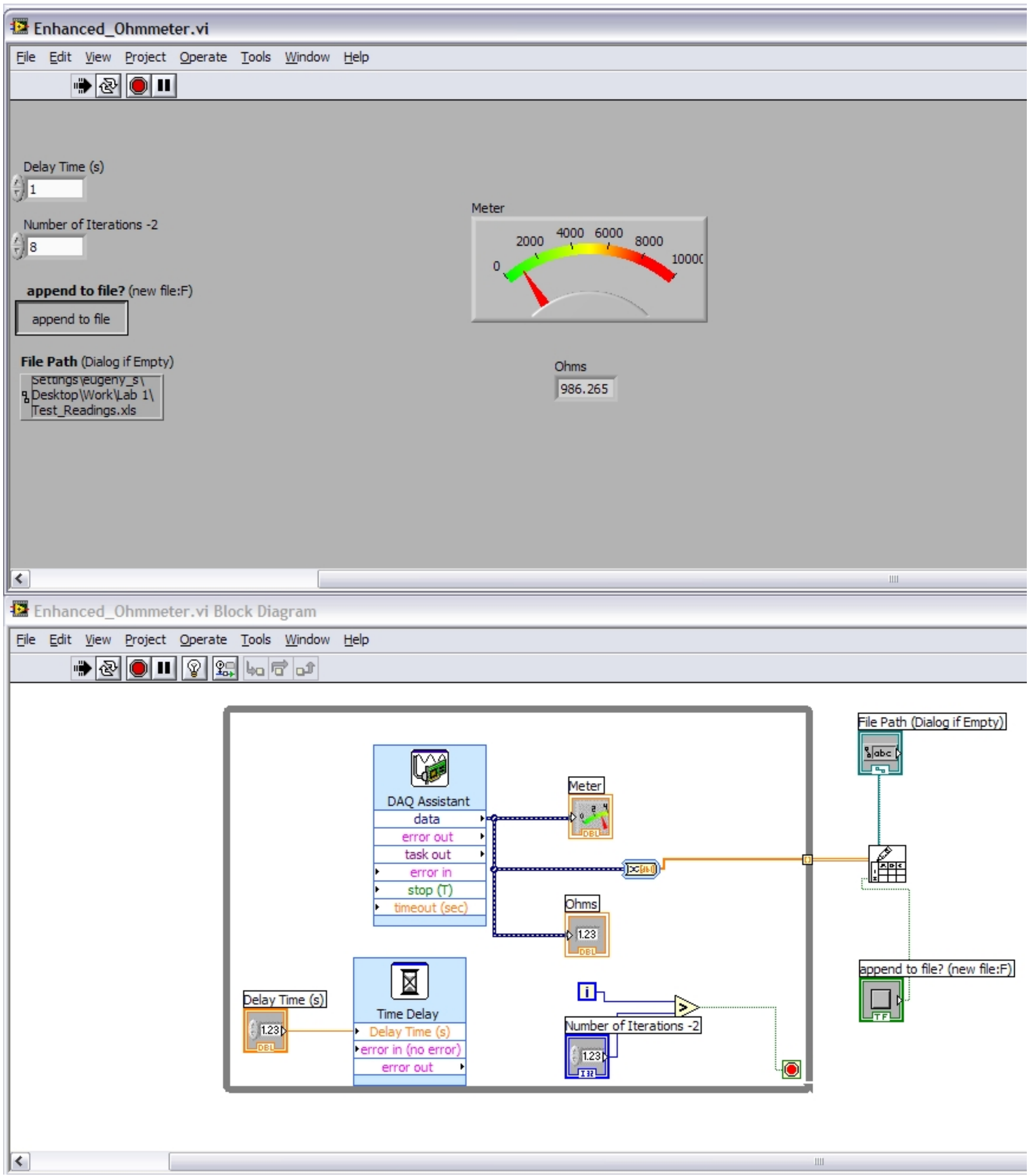

Fig. 4 Screenshot of the VI used