Electronic Measurement Devices & Elementary Circuit Theory

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(2nd Week Pre-Experiment Lab Report)

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I. EXPERIMENT DATA & ANALYSIS

A. Function Generators and Oscilloscopes

After turning on the *NI ELVIS*, the function generator was used to create a sine wave with a frequency 100 Hz and a peak-to-peak voltage of 5 V. This signal was measured using the oscilloscope, which calculated an internal value of V_{PP} and V_{RMS}.

$$V_{\mathrm{RMS}} = \frac{V_{\mathrm{PP}}}{2\sqrt{2}} \tag{1}$$

A separate calculation for the V_{RMS} was additionally made using this V_{PP} using the equation (1) of above.

sine wave (5 V, 100 Hz)			square wave (5 V, 1 Hz)			triangle wave (5 V, 10 kHz)		
V_{PP}	V_1	V_2	V_{PP}	V_1	V_2	V_{PP}	V_1	V_2
5.12	1.81	1.83	2.58	0.91	1.29	2.08	0.74	0.60

TABLE I. Comparison of the values of the peak-to-peak value (V_{PP}), root-mean-square value according to equation (1) (V_1), and the root-mean-square value according to the oscilloscope (V_2) for different waveforms in volts (V).

The three different voltage values are listed above I, showing a side-to-side comparison. The differences between the root-mean-square values according to the equation and the root-mean-square value according to the oscilloscope increase as the waveforms vary from a sine wave, to triangle wave, and to a square wave. The increasing difference can be seen more quantitatively in the following table II.

sine wave (5 V, 100 Hz)			square wave (5 V, 1 Hz)			triangle wave (5 V, 10 kHz)		
V1	V2	% diff.	V1	V2	% diff.	V1	V2	% diff.
1.81	1.83	1.09	0.91	1.29	29.5	0.74	0.60	23.3

TABLE II. Percentage differences between V_1 and V_2 for different wave forms with voltages in volts (V).

After the investigation of different RMS (root-mean-square) values for different waveforms, the RMS values for the square wave (1 kHz) with different duty cycles were sought. The results can be seen in the table below III.

square waves (duty cycle 20%)			square waves (duty cycle 80%)		
V_{PP}	V_1	V_2	V_{PP}	V_1	V_2
5.12	1.81	2.49	5.36	1.90	1.20

TABLE III. Comparison of the values of the peak-to-peak value (V_{PP}), root-mean-square value according to equation (1) (V_1), and the root-mean-square value according to the oscilloscope (V_2) for different duty cycles of the square wave in volts (V).

As the duty cycle increases, a clear increase of discrepancy between the two voltage values can be seen, further emphasized in the following table IV.

square waves (duty cycle 20%)			square waves (duty cycle 80%)		
V_1	V_2	% diff.	V_1	V_2	% diff.
1.81	2.49	27.3	1.90	1.20	58.3

TABLE IV.

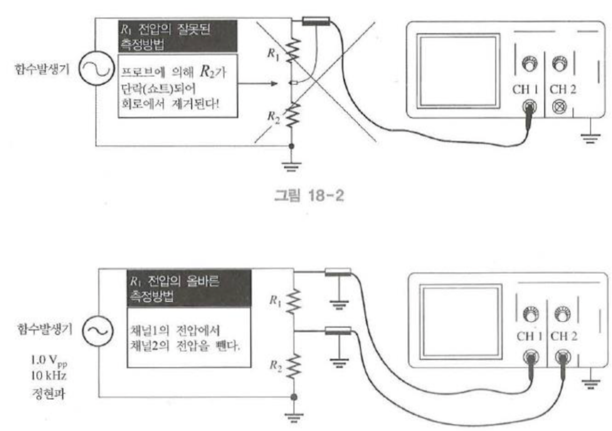

FIG. 1. Signal measurement circuit involving the oscilloscope.

The overall results clearly display an error in the theoretical values of the RMS voltage, hinting in the fact that the theoretical values must be adjusted. This will be further discussed in the second part of this lab report.

R_1 (1 kΩ)				R_2 (2 kΩ)				R_3 (0.51 kΩ)			
voltage (V)		current (mV)		voltage (V)		current (mV)		voltage (V)		current (mV)	
exp.	the.	exp.	the.	exp.	the.	exp.	the.	exp.	the.	exp.	the.
4.360	4.273	4.412	4.273	8.612	8.546	4.412	4.273	2.614	2.179	4.311	4.273

TABLE V. Experimental and theoretical values for the voltage and current for each resistor.

R_1 (1 kΩ)		R_2 (2 kΩ)		R_3 (0.51 kΩ)	
voltage (V)	current (mV)	voltage (V)	current (mV)	voltage (V)	current (mV)
2.036 %	3.253 %	0.772 %	3.253 %	19.96 %	0.889 %

TABLE VI. Percentage differences for the experimental and theoretical values for the voltage and current for each resistor.

The last measurement set for the first experiment was the measurement of the voltage across a resistor (R_1) using the oscilloscope's difference function. A diagram of the circuit and the connections can be seen above 1.

V_{PP}	freqency	R_1	R_2	V_1	V_2
1.0	10 kHz	51 Ω	100 Ω	119 mV	99 mV

TABLE VII. Experimental RMS voltage (on the oscillator) across R_1 (V_1) and theoretical RMS voltage across R_1 (V_2).

The total percentage difference can be seen in the table below.

V_{RMS} theoretical	V_{RMS} experimental	% diff.
119 mV	99 mV	20.2

TABLE VIII. Percentage difference between RMS values.

for reference, throughout the calculations, the percentage difference was always sought using the following formula. For tables II and IV, V_2 was used for the theoretical value of the voltage and V_1 was used for the experimental value of the voltage.

$$V \text{ \% error} = \frac{|V_{\text{theoretical}} - V_{\text{actual}}|}{V_{\text{theoretical}}} \qquad (2)$$

In finding the theoretical RMS voltage, the following formula is used, using elementary circuit theory.

$$\frac{R_1}{R_1 + R_2} \frac{V_{\text{PP}}}{2\sqrt{2}} = 119 \text{ mV} \qquad (3)$$

Something noticeable throughout the experiments was that the theoretical values throughout the experiments were all higher than the experimental values. This consistent pattern gives hints to reasons why the errors throughout the experiments happened. These will further be analyzed in the second part of this report.

B. The *NI ELVIS* and Multimeters

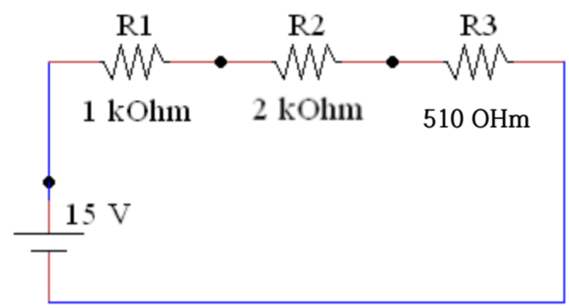

FIG. 2. Circuit diagram of the *NI ELVIS* circuit used for the first measurement set of the second experiment.

In the first measurement set of the second experiment was on creating in the circuit shown in the figure above 2, and measuring the voltage and current across each each resistor. These experimental values of the voltage and current for each resistor was to be compared to the theoretical values calculated separately. The results can be seen above V. The theoretical values of the current and voltage each were found using the equations (4) and (5) shown below.

$$V_i = \frac{15 \; R_i}{\sum_{k \neq i} R_k}, \qquad i, k \in \{1, 2, 3\} \qquad (4)$$

$$I_i = \frac{V_i}{R_i} \qquad (5)$$

The error between the experimental values of the voltages and currents were also sought for each physical quantity, as seen in the table above VI.

The second measurement set of the second experiment was on resistance in particular, and measuring the cumulative resistance across R_1 and R_3. This was done in two

R_1 (1 kΩ)				R_2 (2 kΩ)				R_3 (0.51 kΩ)			
V_{RMS} (V)		I_{RMS} (mV)		V_{RMS} (V)		I_{RMS} (mV)		V_{RMS} (V)		I_{RMS} (mV)	
exp.	the.	exp.	the.	exp.	the.	exp.	the.	exp.	the.	exp.	the.
1.211	1.218	1.195	1.257	0.455	0.499	0.236	0.236	0.455	0.499	0.959	0.962

TABLE IX. Experimental and theoretical values for the voltage and current for each resistor.

R_1 (1 kΩ)		R_2 (2 kΩ)		R_3 (0.51 kΩ)	
V_{RMS} (V)	I_{RMS} (mV)	V_{RMS} (V)	I_{RMS} (mV)	V_{RMS} (V)	I_{RMS} (mV)
0.575 %	4.932 %	8.818 %	0 %	8.818 %	0.312 %

TABLE X. Percentage differences for the experimental and theoretical values for the voltage and current for each resistor.

cases, where in one case, a 15 V was applied across the resistors using constant power source, and in the other case, no voltage was applied whatsoever. The experimental (measured) values and the theoretical values for the total resistance (R_{T}) along with the percentage error can be seen in the table below XI.

voltage (V)	experimental R_{T} (kΩ)	theoretical R_{T} (kΩ)	percentage difference
0	3.495	3.510	0.427 %
15	over	3.510	null

TABLE XI. Experimental (measured) values and the theoretical values for the total resistance (R_{T}).

When 15 V was applied, the multimeter returned a value of "over" clearly indicating that when measuring resistance, no voltage is suppose to be sent across the resistors.

In the third measurement set, a different circuit was used, where the resisters were connected in parallel rather than in series. The circuit alignment can be seen in the figure below.

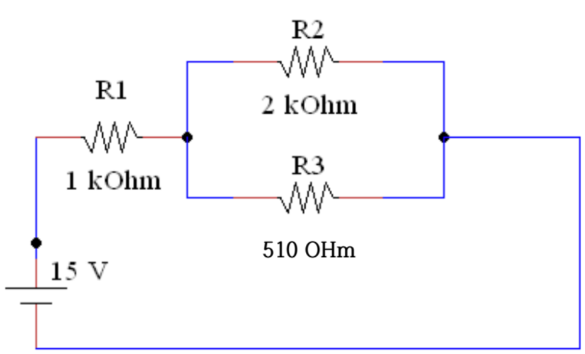

FIG. 3. Circuit diagram of the *NI ELVIS* circuit used for the third measurement set of the second experiment.

This time, an AC current (in a sine-wave form) with a peak-to-peak value of 5 V was sent throughout the circuit through the function generator. The AC voltage and current was measured across each circuit, shown in the table above IX. The percentage differences were again sought, again shown above. The RMS voltage and current was obtained using the same theory used above, with equations (4) and (5) but with appropriate RMS calibration as seen in equation (1).

C. The Superposition Theorem

In the third experiment, the following circuit 4 was used to verify the superposition theorem. In electrical circuits, the *superposition theorem* is a theorem derived from the superposition principle in physics, stating that in a linear system, the response of the constituents (most commonly the current or voltage) having more than one independent source is the superposition of the individual responses of the sources and hence the name.

The first measurement set involved calculating and verifying the total resistance (R_{T}). The verification of the total resistance was done through the multimeter when no voltage was sent across the multimeter. The organized table can be seen below. The percentage difference was not sought, as the main focus on collecting this data was in seeing if the values were roughly accurate, which could be done qualitatively by comparing the data putting them side to side.

voltage (V)	experimental R_{T} (kΩ)	theoretical R_{T} (kΩ)	experimental I_{T} (mA)	theoretical I_{T} (mA)
5	6.367	6.360	0.785	0.786

TABLE XII. Experimental and theoretical total resistance R_{T} and current I_{T} with respect to the 5 V power source.

Again, the percentage differences were not sought for purposes mentioned above. From these values, the current across each resistor can be found, as seen in the calculations below.

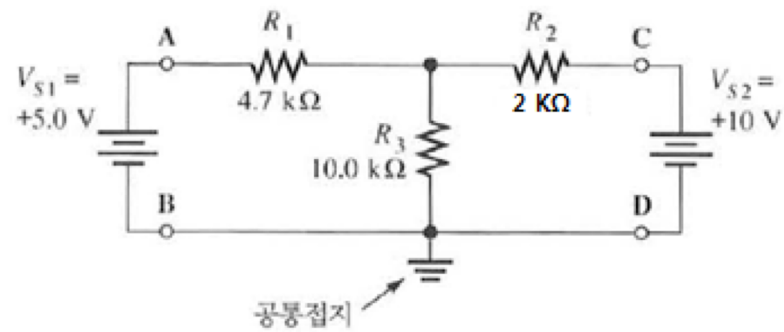

FIG. 4. Circuit diagram of the *NI ELVIS* circuit used for the third experiment.

$$I_2 = I_T \left(\frac{R_3}{R_2 + R_3} \right), \quad I_3 = I_T \left(\frac{R_2}{R_2 + R_3} \right) \tag{6}$$

Using these values of current, the theoretical voltages were found using Ohm's law, and the actual measured voltages (experimental) voltages were recorded using the DMM (digital multimeter). A organisation of this data can be seen below.

V_1 exp. (V)	V_1 the. (V)	V_2 exp. (V)	V_2 the. (V)	V_3 exp. (V)	V_3 the. (V)
3.699	3.690	1.288	1.308	1.300	1.308

TABLE XIII. Experimental and theoretical voltage across each resistor.

In the second measurement set of the third experiment, the 5 V from the power source was taken away, and a 10 V power source was connected. Identical measurements were made like the first measurement set. However, this time, there were voltage values with a negative sign, given their direction relative to the direction that they had in the experiment above.

voltage (V)	experimental R_T (kΩ)	theoretical R_T (kΩ)	experimental I_T (mA)	theoretical I_T (mA)
5	5.129	5.197	0.975	0.962

TABLE XIV. Experimental and theoretical total resistance R_T and current I_T with respect to the 5 V power source.

Again, the percentage differences were not sought for purposes mentioned above. From these values, the current across each resistor can be found, as seen in equations shown in (6). Using these values of current, the theoretical voltages were found using Ohm's law, and the actual measured voltages (experimental) voltages were recorded using the DMM (digital multimeter). A organisation of this data can be seen below.

V_1 exp. (V)	V_1 the. (V)	V_2 exp. (V)	V_2 the. (V)	V_3 exp. (V)	V_3 the. (V)
-6.000	-6.152	-3.512	-3.848	5.938	6.151

TABLE XV. Experimental and theoretical voltage across each resistor.

After the two measurement sets were calculated, the last step involved finding the algebraic sum of the experimental results of the two experiments, and finding the actual value of this by connecting both the 5 V and 10 V power sources at the same time. The results can summarized in the table below.

V_1 exp. (V)	V_1 the. (V)	V_2 exp. (V)	V_2 the. (V)	V_3 exp. (V)	V_3 the. (V)
-2.301	-2.498	-2.224	-2.511	7.238	7.484

TABLE XVI. Experimental and theoretical voltage across each resistor.

The table shows surprising accuracy between the theoretical and actual values, quantitatively compared via percentages in the table below.

V_1 % diff. (V)	V_2 % diff. (V)	V_3 (V) % diff.
7.886	11.43	3.287

TABLE XVII. Percentage difference of the experimental and theoretical voltage across each resistor.

II. DISCUSSION

A. Goals and Recapitulation of Experiments

For the whole experiment, there were three sub-experiments, aimed at obtaining a total of two goals. The two goals were:

a. Understanding basic electronic measurement devices and understanding how elementary devices work.

b. Using *NI ELVIS* in a basic experiment (*NI ELVIS* being a prototyping board used in testing circuits and thus being able to understand elementary circuit theory and relevant concepts.

Consequently, in total, there were 3 different sets of measurements made for the first experiment, 3 different sets of measurements made for the second experiment, and 5 different sets of measurements made for the last third experiment. The 11 total number of experiments can be seen in the list below.

1. The first measurement (set) of the first experiment was on measuring the measuring the peak-to-peak value and RMS value of differently shaped waves (sine, triangle, and square). A separate calculation of the RMS value was made through the peak-to-peak value, and this was compared with the value that showed up in the oscillator. The results can be seen in I and II.

2. The first sceond (set) of the first experiment was on measuring the measuring the peak-to-peak value and RMS value of differently shaped waves (square with different duty cycles). A separate calculation of the RMS value was made through the peak-to-peak value, and this was compared with the value that showed up in the oscillator. The results can be seen in III and IV.

3. The third measurement (set) of the first experiment was on using the oscilloscope's difference function to measure the resistance across a certain resistor R_1. The results can be seen in VII and VIII.

4. The first measurement (set) of the second experiment was on creating a three-resistor series circuit, and theoretically and experimentally finding the voltage and current across each resistor using the *NI ELVIS* board and the *Multimeter*. Results can be seen in V and VI.

5. The second measurement (set) of the second experiment was on using the same three-resistor series circuit above, but measuring the total resistance across the three resistors. The Results can be seen in XI.

6. The third measurement (set) of the second experiment was on creating a three-resistor series circuit, but this time a AC current, and theoretically and experimentally finding the voltage and current across each resistor using the *NI ELVIS* board and the *Multimeter*. Results can be seen in IX and X.

7. The first measurement (set) of the third experiment was on measuring the total resistance and current with respect to a single power source for a particular circuit set up for the verification of the superposition theorem. Results can be seen in XII.

8. The second measurement (set) of the third experiment was on thus obtaining a theoretical voltage across each resistor due according to the values of step 7, and actually measuring them with a DMM and comparing the values from side to side. Results can be seen in XIII.

9. The third measurement (set) of the third experiment was on measuring the total resistance and current with respect to a second power source for a particular circuit set up for the verification of the superposition theorem. Results can be seen in XIV.

10. The fourth measurement (set) of the third experiment was on thus obtaining a theoretical voltage across each resistor due according to the values of step 9, and actually measuring them with a DMM and comparing the values from side to side. Results can be seen in XV.

11. The fifth measurement (set) of the third experiment was on obtaining a algebraic sum of the results of steps 8 and 10, and comparing them with an actual measurement made through activating both power sources. Results can be seen in XVI and XVII.

B. Evaluation and Error Assessment

In the first experiment, a probable reason for high error was faulty theory.

Faulty theory in the first experiment, the V_{P} value, the peak voltage value, was first found using the V_{PP} value, the peak-peak-value of the voltage. The root-mean square value is theoretically the average of the squared values of the current, expressible as the following equation.

$$V_{\mathrm{rms}} = \sqrt{\int \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} [V(t)]^2 \, dt} \tag{7}$$

where the waveform would be defined over the time interval $T_1 \leq t \leq T_2$. In the case that we are seeking the RMS value of the current, the current function $I(t)$ would be substituted instead of the voltage function $V(t)$. For the sine wave, equation (1) was used as the integral was easily calculable as the following.

$$V_{\mathrm{rms}} = \sqrt{\int \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} [V_{\mathrm{P}} \sin(\omega t)]^2 \, dt}$$

$$= V_{\mathrm{P}} \sqrt{\frac{1}{T} \left[\frac{t}{2} - \frac{1}{4} \sin(4\omega t) \right]_0^T} = \frac{V_{\mathrm{P}}}{\sqrt{2}}$$

This formula was ubiquitously used throughout all calculations for the RMS value, approximating the other functions all as the sine-wave form. However, the different functions obviously have a different, more accurate theoretical outcome, as the following. Taking the square wave, with a duty cycle of $p\%$, the function in the integrand becomes

$$V_{\rm rms} = \sqrt{\int \frac{1}{T_2 - T_1}\int_{T_1}^{T_2}\{V(t)\}^2 dt}$$

$$= V_{\rm P}\sqrt{\frac{1}{T}\left(\int_{T_1}^{p\Delta T/100}(V_{\rm P})^2 dt + \int_{p\Delta T/100}^{T_2}(-V_{\rm P})^2 dt\right)}$$

$$= V_{\rm P}$$

strikingly different with the integral with the sine wave above, the integrand converges to the value of the peak-value, hinting to why the results became higher in error when it came to the square function.

In the second and third experiments, probable reasons for the errors would have been faulty wiring of the circuits, voltage drops, and capacitor leakages in the *NI ELVIS* circuit board.

Faulty wiring of the circuits represents a significant potential source of disruption, resulting in erratic signal behavior and fluctuating currents. The voltage and current readings, along with those obtained through the multimeter setup, exhibited considerable variability over time, with measurements having frequent fluctuations. Mitigating such errors would require employing higher voltage and currents while minimizing the frequency of parameter alterations to result in greater stability.

Voltage drops, inherent to electronic systems, introduce disturbances in experimental setups, with their impact very probable in this study. Cable resistance and potential grounding issues during experimentation likely precipitated abrupt and frequent voltage fluctuations, thereby affecting associated measurements. Ways in improving this involve using higher voltages, as written above.

Capacitor leakage constitutes another plausible source of error in circuit-based experiments, potentially leading signal distortion. In the *NI ELVIS* circuit board, and probably in other devices used in the experiment, there were capacitors that might have been old and malfunctioning. The reason why this is probable is because the board often showed irratic behaviour and fluctuations in current, which made the results above hard to obtain. Over time, capacitors may exhibit leakage currents, thereby inducing signal transmission and reception. Such leakage could manifest as fluctuations in voltage and current levels, thereby introducing uncertainty into experimental measurements. Addressing this may require regular monitoring of capacitor performance and, if feasible, using capacitors with lower leakage characteristics to mitigate its impact on experimental outcomes. Exchanging the boards might also help.

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