重庆大学-辛辛那提大学联合学院

学生实验报告

CQU-UC Joint Co-op Institute (JCI)

Student Experiment Report

实验课程名称 Experiment Course Name Circuit and Sensor Experiment

开课实验室（学院）Laboratory (School) College of Mechanical Engineering

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学生姓名 Student Name Yi, Hongrui 学号 Student Number 20186103

学生姓名 Student Name Zhuang, Yan 学号 Student Number 20186105

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成绩 Grade		
教师签名 Signature of Instructor		

批改说明 Marking instructions:

指导老师请用红色水笔批改，在扣分处标明所扣分数并给出相应理由，在封面的平时成绩处注明成绩。

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University of Cincinnati
College of Engineering and Applied Science
School of Dynamic Systems

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	: **Zhuang, Yan**
Instructor	: **Hu, Xiaoping**

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ABSTRACT

The purpose of this exercise is to introduce the student to the circuits and sensing laboratory, and help to become familiar with the basic instrumentation. A brief overview of electric circuit theory will also be provided. Finally, the student will also have the opportunity to better understand the terms used to describe periodic signals.

There are two basic sets of laboratory equipment which will be introduced. The first is a set of traditional measurement hardware instrumentation. The second is a set of virtual instruments which mimic the historical instruments. The virtual instruments consist of a computer and a data acquisition card which have been programmed to simulate the instrumentation. Both traditional hardware instruments and virtual instruments will be used in this laboratory.

In this experiment, we explore how to calculate the DC Voltage, Current and Power of a Voltage Divider Circuit, DC Voltage, Current and Power of a Current Divider Circuit, the Traditional Hardware and Virtual Oscilloscopes, RMS and Peak-to-Peak Parameters of Periodic Signals, Impedance and Output Impedance of Instrumentation Equipment, Loading of a Measurement Device, and Phase Difference between Two Signals of the Same Frequency.

Table of Contents

1. Objectives

At the end of this experiment, the students are expected to:

- Get familiarized with basic instrumentation.
- Overview electric circuit theory.
- Better understanding of term of periodic signals.

2. Theoretical Background

2.1 DC Voltage, Current and Power of a Voltage Divider Circuit

The current in the whole circuit is same since this circuit is in series. Then, from ohm law $V = IR$, there is $\frac{V_1}{V_S} = \frac{I_1 R_1}{I_s R_{total}} = \frac{I R_1}{I R_{T-x}} = \frac{R_1}{R_{T-x}}$. In the same way, there is $\frac{V_2}{V_S} = \frac{R_{2-x}}{R_{T-x}}$.

$$\%ERROR = \frac{|\textbf{Predicted}-\textbf{Measure}|}{\textbf{Predicte}} \times \mathbf{100}$$

$$\%DIFF == \frac{\text{Nominal}-\text{Measure}}{\text{Nominal}} \times \mathbf{100}$$

2.2 DC Voltage, Current and Power of a Current Divider Circuit

The voltage of R_1 and R_2 is same since this circuit is in parallel. Then, from ohm law $V = IR$, there is $\frac{I_1}{I_T} = \frac{\frac{V_1}{R_1}}{\frac{V_T}{R_T}} = \frac{\frac{V}{R_1}}{\frac{V}{R_T}} = \frac{R_{2-x}}{R_1 + R_{2-x}}$. In the same way, there is $\frac{I_2}{I_T} = \frac{R_1}{R_1 + R_{2-x}}$.

2.3 Using the Analog and Virtual Oscilloscopes

The way oscilloscopes work is different than the way DMMs work. A multimeter can measure voltage, resistance, and current by selecting the proper setting on the multimeter. If we are trying to measure the voltage drop across a resistor using a multimeter by connecting the two multimeter leads/probes across the resistor, we will directly measure the voltage drop across that resistor. But the procedure to measure voltage is different with the oscilloscope. One purpose of using an oscilloscope is to have a better signal-to-noise ratio. To achieve this, one end of the scope is always connected to the ground. Therefore, to measure the voltage drop across a resistor we will have to measure the output voltage at A and subtract it from the output voltage at B to get the drop across the resistor, where A and B are points at each end of the resistor.

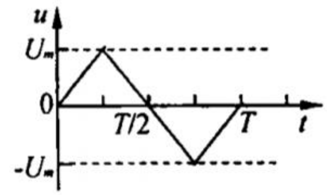
2.4 RMS and Peak-to-Peak Parameters of Periodic Signals

Derivation for rms:

There are those known parameters: the period T, the upper peak voltage U_m

a) For the triangular wave, in $\frac{1}{4}$T, the voltage u = $\frac{U_m}{\frac{T}{4}}\mathbf{t}$, the total heat energy produced in $\frac{1}{4}$T is:

$$Q_1 = \int_0^{T/4} \frac{u^2}{R} dt = \int_0^{T/4} \frac{(\frac{4U_m}{T}t)^2}{R} dt = \frac{16U_m^2}{R} \cdot \frac{T^3}{3} \Big|_0^{T/4}$$
$$= \frac{U_m^2 T}{12R};$$



Then the total energy produced in a period is:

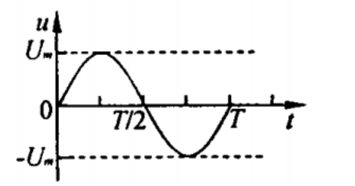
$$Q_a = 4Q_1 = \frac{U_m^2 T}{3R}$$

For the rms, $Q_d = \frac{U^2 T}{R} = Q_a$, there is

$$U = \frac{U_m}{\sqrt{3}} = \frac{\sqrt{3}U_m}{3}$$

b) For the sinusoidal wave, in $\frac{1}{4}$T, the voltage u = $\frac{U_m}{\frac{T}{4}}$ **t**, the total heat energy produced in $\frac{1}{4}$T is:

$$Q_1 = \int_0^{T/4} \frac{(U_m \sin\omega t)^2}{R} dt = \frac{U_m^2}{R}\int_0^{T/4} \sin^2\omega t dt$$
$$= \frac{U_m^2}{R}\int_0^{T/4} \frac{1-\cos2\omega t}{2} dt = \frac{U_m^2}{R\omega}(\frac{\omega t}{2} - \frac{1}{4}\sin2\omega t) \Big|_0^{T/4},$$



i.e. $$Q_1 = \frac{U_m^2 T}{8R}.$$

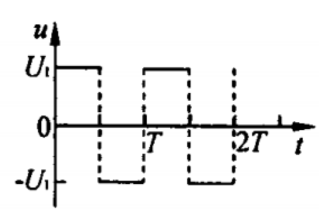
Then the total energy produced in a period is:

$$Q_a = 4Q_1 = \frac{U_m^2 T}{2R}$$

And solve for $Q_d = Q_a$, there is

$$U = \frac{U_m}{\sqrt{2}}.$$

c) For the square wave,



$$Q_a = \frac{U_1^2}{R} \cdot \frac{T}{2} + \frac{U_2^2}{R} \cdot \frac{T}{2}$$

For a pure resistance R in period T, there is $Q_d = Q_a$, and

$$U = \sqrt{\frac{U_1^2 + U_2^2}{2}}$$

If $U_1 = U_2$, there is $U = U_m$.

2.5 Impedance and Output Impedance of Instrumentation Equipment

To calculate the output resistance, use:

$$R_O = R_1 \left(\frac{v_S}{v_1} - 1 \right)$$

To calculate the input resistance, use:

$$R_i = R_2 \left(\frac{v_2}{v_S - v_2} \right) - R_O$$

2.6 Impedance and Output Impedance of Instrumentation Equipment

$$R_{23} = \frac{X}{L} \times R_T$$

$$V_0 = \frac{R_{23}}{R_T} \times V_s$$

We get that:

$$V_0 = \frac{X}{L} \times V_s$$

Thus

$$K_p = \frac{V_s}{L}$$

2.7 Phase Difference between Two Signals of the Same Frequency

For a circuit as the Figure 5, the frequency of the battery is $\omega = 2\pi f$

The resistance of the capacity in series is:

$$-\frac{1}{\omega_c} j = -1X_c$$

The total resistance is:

$$Z_c = R + X_c$$

The currency is:

$$\mathrm{I} = \frac{V_{rms}}{Z_c}$$

3. Experimentation

3.1 DC Voltage, Current and Power of a Voltage Divider Circuit

3.1.1 Summary of Procedure

The equipment used in this part are a DC voltage source, 5 resistors and a Fluke DMM. This part of experiment has 3 purpose. First, compare the nominal resistance and actual resistance. Second, compare the nominal voltage and power with actual voltage and power. Third, compare the resistance ratio and voltage radio after changing different R2

(a) Use Fluke DMM to acquire the actual resistance inside 5 resistors and record the values in table 1. Use Equation 1 to determine the percentage difference between the nominal and measured resistance values.

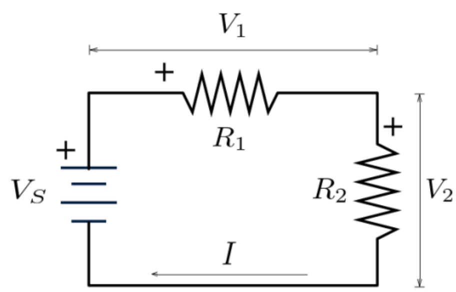


Figure 1. Voltage divider circuit

$$\%\boldsymbol{Difference} = \frac{|\boldsymbol{R}_{\mathbf{Nominal}} - \boldsymbol{R}_{\mathbf{Measured}}|}{\boldsymbol{R}_{\mathbf{Nominal}}} \times \mathbf{100}\% \qquad (1)$$

Table 1. Resistance Values

PARAMETER	NOMINAL (Ω)	MEASURED (Ω)	% DIFFERENCE
R_1			
$R_{2\text{-}x}$			

(b) Using theoretical Vs to calculate the theoretical voltage divided to R1 and R2 with R2's nominal resistance = 470Ω. Use Fluke DMM to measure the actual voltage, use equation 2 to calculate %Error and record it in table 2.

(c) Calculate the nominal power dissipated by resistor R1, and by resistor R2 and the actual power respectively. Then, use the equation 2 to calculate the error and record them in the table 2 as well.

(d) Calculate the total nominal power and actual one. Calculate the error and record them in table 2.

$$\%Error = \frac{|Theoretical - Measured|}{Theoretical} \times 100\% \quad (2)$$

Table 2. Voltage, Current and Power in the Circuit with R_2 = 470 Ω

PARAMETER	THEORETICAL	MEASURED	%ERROR
V_S			
V_1			
V_2			
I			
Power at R_1			
Power at R_2			
Total Power			

Table 3. Voltage Readings, Voltage and Resistance Ratios with Varying R_2

$R_{2\text{-}x}$	V_1 (V)	$\frac{V_1}{V_S} \times 100\%$	$\frac{R_1}{R_{T-x}} \times 100\%$	V_2 (V)	$\frac{V_2}{V_S} \times 100\%$	$\frac{R_{2-x}}{R_{T-x}} \times 100\%$
$R_{2\text{-}1}$ ~ 470Ω						
$R_{2\text{-}2}$ ~ 1 kΩ						
$R_{2\text{-}3}$ ~ 2.2 kΩ						
$R_{2\text{-}4}$ ~ 10 kΩ						

(e) Change R2 with resistors owning different difference. Measure V1 in each circuit. Calculate the quotient between V1/Vs and compare it with the quotient between $R_1$and R_{T-x}.

(f) Change R2 with resistors owning different difference. Measure V2 in each circuit. Calculate the quotient between V2/Vs and compare it with the quotient between $R_2$and R_{T-x}.

3.1.2 Results

Table 4. Resistance Values

PARAMETER	NOMINAL (Ω)	MEASURED (Ω)	% DIFFERENCE
R_1	1000	982	1.8
$R_{2\text{-}x}$	470	461	1.9

	1000	974	2.6
	2200	2167	1.5
	10000	10140	1.4

Table 5. Voltage, Current and Power in the Circuit with R_2 = 470 Ω

PARAMETER	THEORETICAL	MEASURED	%ERROR
V_S	4V	3.97V	0.75
V_1	2.72V	2.68V	1.47
V_2	1.28V	1.26V	1.56
I	$2.72 \times 10^{-3} A$	$2.69 \times 10^{-3} A$	1.10
Power at R_1	$7.40 \times 10^{-3} W$	$7.21 \times 10^{-3} W$	2.56
Power at R_2	$3.48 \times 10^{-3} W$	$3.39 \times 10^{-3} W$	2.60
Total Power	$10.88 \times 10^{-3} W$	$10.68 \times 10^{-3} W$	1.80

Table 6. Voltage Readings, Voltage and Resistance Ratios with Varying R_2

$R_{2\text{-}x}$	V_1 (V)	$\frac{V_1}{V_S} \times 100\%$	$\frac{R_1}{R_{T-x}} \times 100\%$	V_2 (V)	$\frac{V_2}{V_S} \times 100\%$	$\frac{R_{2-x}}{R_{T-x}} \times 100\%$
$R_{2\text{-}1}$ ~ 470 Ω	2.68	67.5%	68.0%	1.26	31.7%	31.9%
$R_{2\text{-}2}$ ~ 1 kΩ	1.98	49.9%	50.2%	1.98	49.9%	49.8%
$R_{2\text{-}3}$ ~ 2.2 kΩ	1.24	31.2%	31.2%	2.73	68.8%	68.8%
$R_{2\text{-}4}$ ~ 10 kΩ	0.36	9.07%	8.82%	3.60	90.7%	91.2%

Simple calculations:

In table 1:

According to the equation 1: $\%Difference = \frac{|R_{\text{Nominal}} - R_{\text{Measured}}|}{R_{\text{Nominal}}} \times 100\%$

For R_1:

$$\%Difference = \frac{|982 - 1000|}{1000} = 1.8\%$$

In table 2:

According to equation 2: $\%Error = \frac{|Theoretical - Measured|}{Theoretical} \times 100\%$

For V_S

$$\%Error = \frac{|4 - 3.97|}{4} \times 100\% = 0.75\%$$

For power at R_1: $P = VI = 2.68\,V \times 2.69 \times 10^{-3} A = 7.21 \times 10^{-3} W$

In table 3:

For $R_{2\text{-}1}$ ~ 470 Ω:

$$\frac{V_1}{V_S} \times 100\% = \frac{2.68V}{3.97V} = 67.5\%$$

$$\frac{R_1}{R_{T-x}} \times 100\% = \frac{982\Omega}{982\Omega + 461\Omega} = 68.0\%$$

$$\frac{V_2}{V_S} \times 100\% = \frac{1.26V}{3.97V} = 31.7\%$$

$$\frac{R_2}{R_{T-x}} \times 100\% = \frac{461\Omega}{982\Omega + 461\Omega} = 31.9\%$$

3.1.3 Analysis & Discussion

From table 1, though there's some difference between nominal values and the actual values, all of them are smaller than 5%.

From table 2, we find that the sum of voltages of $R_1$and R_2 is almost equal to the total voltage and the sum of two power is almost equal to the total power. This verifies the Kirchhoff's laws.

$$\sum_{k=1}^{m} V_m = 0$$

From table 3, we can observe that value of $\frac{V_1}{V_S}$ is quite close to that of $\frac{R_1}{R_{T-x}}$, and so do the $\frac{V_1}{V_S}$ and $\frac{R_1}{R_{T-x}}$ even though $\frac{V_1}{V_S}$ and $\frac{V_1}{V_S}$ are quite different. Reason behind this similarity is that $R_1$is in series with R_2.If two resistors are in series with each other, the larger the resistance is, the more voltage it will gain.

In this part, %error are all less than 5% which means we perform our experiment in an appropriate way.

3.2 DC Voltage, Current and Power of a Current Divider Circuit

3.2.1 Summary of Procedure

Equipment used in this procedure are a DC voltage source, 5 different resistors and a Fluke DMM. Purpose of this procedure is to verify the KCL, which is that the sum of the current flowing into a node is equal to the sum of the current flowing out the node.

First, use Fluke DMM to measure the actual resistance inside these five resistors and record them into the table 4. Use equation 1 to calculate the difference rate between nominal one and actual one.

Second, following the Figure 2, build up the circuit, where Vs = 4V and R_1 = 1 kΩ, R_2 = 470 Ω. Later, R_2 will be changed to the other three resistors whose resistances are 1 kΩ, 2.2 kΩ, 10 kΩ respectively.

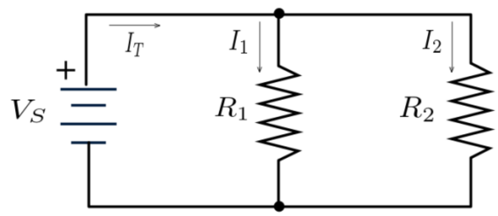


Figure 2. Current Divider Circuit

Third, calculate the theoretical current and power inside the circuit and measure the current flowing through R_1 R_2 and the total current. Compare these two kinds of value, and calculate the error rate by using the equation 2.

Forth, change R_2 with resistors owning different difference. Measure I_1 in each circuit. Calculate the quotient between I_1/ I_T and compare it with the quotient between $R_1$and R_{T-x}.

Fifth, change R_2 with resistors owning different difference. Measure I_2 in each circuit. Calculate the quotient between I_2/ I_T and compare it with the quotient between $R_2$and R_{T-x}.

3.2.2 Results

Table 4. Resistance Values

PARAMETER	NOMINAL (Ω)	MEASURED (Ω)	% DIFFERENCE
R_1	1000	982	1.8
R_{2-x}	470	461	1.9
	1000	974	2.6
	2200	2167	1.5
	10000	10140	1.4

Table 5. Voltage, Current and Power in the Circuit with R_2 = 470 Ω

PARAMETER	PREDICTED USING THEORY	MEASURED VALUE	% ERROR
V_S	4.00V	3.95V	1.25
I_1	$4.00 \times 10^{-3}A$	$3.97 \times 10^{-3}A$	0.75
I_2	$8.51 \times 10^{-3}A$	$8.42 \times 10^{-3}A$	1.06
I_T	$1.25 \times 10^{-2}A$	$1.24 \times 10^{-2}A$	0.80
Power by R_1	$1.60 \times 10^{-2}W$	$1.57 \times 10^{-2}W$	1.87
Power by R_2	$3.40 \times 10^{-2}W$	$3.32 \times 10^{-2}W$	2.35
Total Power	$5.00 \times 10^{-2}W$	$4.89 \times 10^{-2}W$	2.20

Table 6. Current Readings, Current and Resistance Ratios with Varying R_2

R_{2-x}		I_T (mA)		I_1 (mA)	$\frac{I_1}{I_T} \times 100\%$	$\frac{R_{2-x}}{R_1 + R_{2-x}} \times 100\%$		I_2 (mA)	$\frac{I_2}{I_T} \times 100\%$	$\frac{R_1}{R_1 + R_{2-x}} \times 100\%$
R_{2-1} ~ 470 Ω		12.4		3.97	32.00%	31.9%		8.42	67.90%	68.0%
R_{2-2} ~ 1 kΩ		8.02		4.02	50.12%	49.8%		4.01	50.00%	50.2%

$R_{2\text{-}3}$ ~ 2.2 kΩ	[redacted]	5.73	[redacted]	3.92	68.41%	68.8%	[redacted]	1.82	31.76%	31.2%
$R_{2\text{-}4}$ ~ 10 kΩ	[redacted]	4.42	[redacted]	4.01	90.72%	91.2%	[redacted]	0.40	9.05%	8.82%

Simple calculations:

In table 4:

According to the equation 1: $\%Difference = \frac{|R_{\text{Nominal}} - R_{\text{Measured}}|}{R_{\text{Nominal}}} \times 100\%$

For R_1:

$$\%Difference = \frac{|982 - 1000|}{1000} = 1.8\%$$

In table 5:

According to equation 2: $\%Error = \frac{|Theoretical - Measured|}{Theoretical} \times 100\%$

For V_S

$$\%Error = \frac{|4 - 3.95|}{4} \times 100\% = 1.25\%$$

For power at R_1: $P = VI = 3.95\text{V} \times 3.97 \times 10^{-3} A = 1.57 \times 10^{-2} W$

In table 6:

For $R_{2\text{-}1}$ ~ 470 Ω:

$$\frac{\mathrm{I}_1}{\mathrm{I}_\mathrm{T}} \times 100\% = \frac{3.97mA}{12.4mA} = 32.0\%$$

$$\frac{\mathrm{R}_{2-\mathrm{x}}}{\mathrm{R}_1 + \mathrm{R}_{2-\mathrm{x}}} \times 100\% = \frac{461\Omega}{982\Omega + 461\Omega} = 31.9\%$$

$$\frac{\mathrm{I}_2}{\mathrm{I}_\mathrm{T}} \times 100\% = \frac{8.42mA}{12.4mA} = 67.9\%$$

$$\frac{\mathrm{R}_1}{\mathrm{R}_1 + \mathrm{R}_{2-\mathrm{x}}} \times 100\% = \frac{982\Omega}{982\Omega + 461\Omega} = 68.0\%$$

3.2.3 Analysis & Discussion

From table 4, though there’s some difference between nominal values and the actual values, all of them are smaller than 5%.

From table 5, we find that the sum of currents of $\mathrm{R}_1$and R_2 is almost equal to the total current and the sum of two power is almost equal to the total power. This verifies the Kirchhoff’s laws.

$$\sum_{k=1}^{m} I_{in} = \sum_{k=1}^{m} I_{out}$$

From table 6, we can observe that value of $\frac{I_1}{I_T}$ is quite close to that of $\frac{R_{2-x}}{R_1+R_{2-x}}$, and so do the $\frac{I_2}{I_T}$ and $\frac{R_1}{R_1+R_{2-x}}$even though $\frac{I_1}{I_T}$ and $\frac{I_2}{I_T}$ are quite different. Reason behind this similarity is that $R_1$is in parallel with R_2.If two resistors are in parallel with each other, the larger the resistance is, the less current will flow through it.

In this part, %error are all less than 5% which means we perform our experiment in an appropriate way.

3.3 Using the Traditional Hardware and Virtual Oscilloscopes

3.3.1 Summary of Procedure

Equipment used in this procedure containing a function generator, a GDS-2072A Digital Storage Oscilloscope and several wires. Purpose of this procedure is to get familiar with Oscilloscope and observe the phenomenon of AC voltage.

Procedures are followed:

a) Your instructor will set up the function generator to produce a signal for you. Connect the output of the function generator to the channel 1 input of the oscilloscope using a co-axial cable with Experiment 1 – Basic Instruments Page 5 BNC connectors.

b) Identify the waveform produced by the function generator. Measure and record the peak-to peak amplitude, Vp-p, of the waveform.

c) Measure and record the actual period T of the waveform. Calculate and record the actual frequency f (in Hz) and ω (in rad/s) of the waveform.

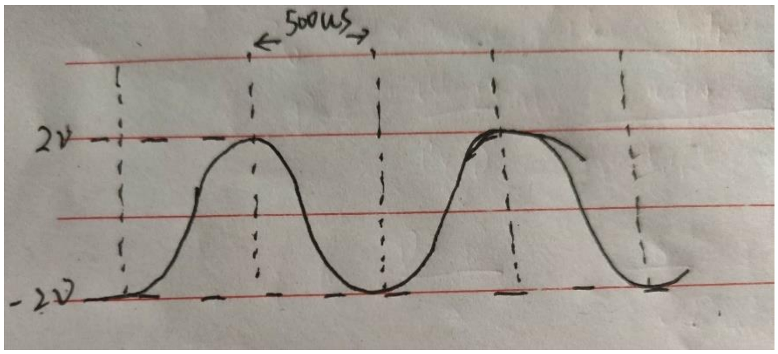
d) Adjust with the trigger controls (trigger source, the trigger slope, and the trigger level) until you are familiar with all of them. In particular, observe what happens when the trigger level is above the waveform's positive peak value or below the waveform's minimum value.

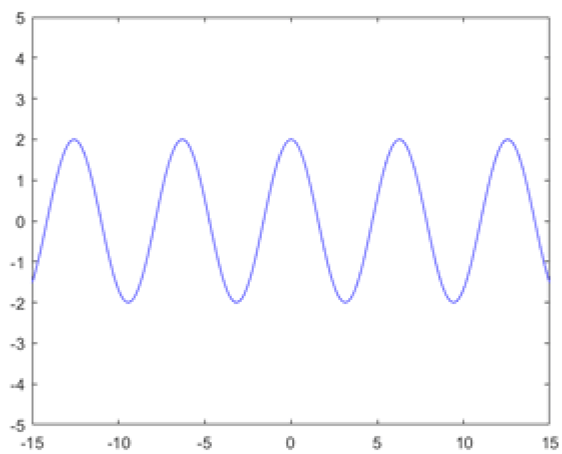
e) Adjust the DC offset of the waveform produced by the function generator. Record your observation as the DC offset voltage is adjusted. Also, note the effect on the oscilloscope display when AC coupling and when DC coupling is used. (TIP: It is quite important to understand the difference between DC and AC coupling. Ask the teaching assistants if you have any questions about this).

f) Adjust with the vertical mode controls until you are familiar with all of them. g) Repeat the above steps with the virtual oscilloscope (TIP: Note that the virtual oscilloscope does not have all the controls and tools that the analog oscilloscope has. You can slightly modify the procedure for the virtual oscilloscope training as needed.).

3.3.2 Results

Illustration of the Signal Waveform: (Indicate amplitude levels):





VOLTS/DIV Setting: 1V

TIME/DIV Setting: $\underline{500\mu s}$

Type of Waveform: sine

Peak-to-Peak Voltage (Vpp) = 4V

Actual Period (T) = $\underline{1.00 \times 10^{-3} s}$

Calculated Frequency (f) = 1000Hz

Calculated Angular Frequency (w) = 6283rad/s

a) Change the dc offset from the function generator. What happens to the waveform as the dc offset if adjusted:

i) positively When DC offset is +1V, the graph of waveform will arise up 1 V

ii) negatively When DC offset is -1V, the graph of waveform will drop down 1 V

b) While changing the dc offset, change the coupling mode. Comment on the effect of:

i) dc coupling: The graph of the waveform will move up or down which depends on the DC offset

ii) ac coupling: The graph of the waveform will not change.

3.3.3 Analysis & Discussion

When we put DC offset into the circuit, if we use dc coupling, the graph will change immediately. However, if we change it to ac coupling, the graph will undergo no change. The reason why dc coupling has influence is that all the DC and AC components can flow into the circuit. However, if Oscilloscope is in ac coupling, input components will be in series with a capacitor which means the DC signals will be filtered. Thus, only AC signals displays on the screen.

3.4 RMS and Peak-to-Peak Parameters of Periodic Signals

3.4.1 Summary of Procedure

Equipment used in this procedure containing a function generator, a GDS-2072A Digital Storage Oscilloscope, several wires and a Fluke DMM. Purpose of this experiment is to observe different kinds of waveforms.

3.4.2 Results

Derivation for rms:

Table 7. Calculated and measured voltages for various waveforms

Waveform	Measured v_{pp} Tektronix	Calculated v_{rms}	Measured v_{rms} FLUKE
Sinusoid	4.00V	1.43V	1.382V
Triangular	3.92V	1.13V	1.087V
Square	3.92V	1.96V	2.055V

Sample calculations:

In the table 7:

sinusoid: Vrms = $\frac{\text{Vpp}}{2\sqrt{2}} = \frac{4}{2\sqrt{2}}$ = 1.41 V

Triangular: Vrms = $\frac{\text{Vpp}}{2\sqrt{3}} = \frac{3.92}{2\sqrt{3}}$ = 1.143V

Square: Vrms = $\frac{\text{Vpp}}{2} = \frac{3.92}{2}$ = 1.96V

3.4.3 Analysis & Discussion

Though three Vpp are all around 4.00V, their Vrms values are quite different. Moreover, their effect values are quite different either which means Vpp value doesn't determine the actual output.

3.5 Impedance and Output Impedance of Instrumentation Equipment

3.5.1 Summary of Procedure

Equipment used in this procedure containing a resistor whose resistance is 1 MΩ, a function generator, a GDS-2072A Digital Storage Oscilloscope, a Fluke DMM and several wires. The purpose of this experiment is to calculate the internal resistance of the function generator and that of the oscilloscope.

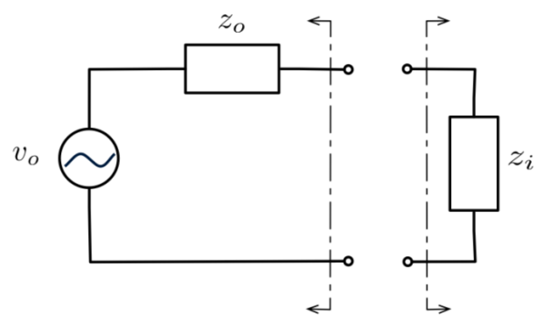


Figure 3. Measurement Setup

a) Set up the function generator to produce a 1 kHz, 4 Vpp sinusoid.

b) The output impedance of the function generator is expected to be purely resistive (z0 = R0) for the frequencies we consider, and equal to about 50 Ω or 150 Ω. To determine v0 simply measure it using a high impedance measurement device which will produce negligible voltage drop across R0. To determine R0 connect a 100 Ω resistor R1 across the output terminals of the function generator, and measure the new output voltage vl. Sketch the circuit diagram for this setup, and show that $R_0 = R_1[\left(\frac{v_0}{v_1}\right) - 1]$. Calculate and record the output impedance (resistance) of the function generator. Remove the resistor Rl when you are finished with this step.

c) The input impedance of the oscilloscope with DC coupling is expected to be purely resistive (zi = Ri) for the frequencies we consider, and equal to about 1 MΩ. To determine Ri, first recheck the value of v0. Then, connect a resistor R2 = 1 MΩ between the positive terminal of the function generator and the positive terminal of the oscilloscope. The new measured voltage is v2. Sketch the circuit diagram for this setup, and show that $R_i = R_2\left(\frac{v_2}{v_o - v_2}\right) - R_0$. Calculate and record the input impedance (resistance) of the oscilloscope. Compare this value to the specified value in the operator manual.

d) Repeat step 2.5c but replace the device-under-test with the Fluke DMM, and with the ELVIS DMM.

e) Compare your results with the nominal resistance values to be provided by the TA.

3.5.2 Results

a) Set up the ELVIS function generator to produce a 1-kHz, 4 Vpp sine wave signal (Vs). Measure the actual resistance of a 100-Ω (Brn, Blk, Brn) resistor, R1.

Vs (actual peak-to-peak) = 4V, R1 = 100.7Ω Vrms = 1.43V

b) Connect the 100-Ω resistor, R1, across the ELVIS function generator. Then, connect the Tektronix oscilloscope across R1. Sketch the circuit diagram for this setup.

$$\boldsymbol{v_0 = 1.382V}$$

Record the peak-to-peak voltage measured from the Tektronix oscilloscope, V_1 = 0.908V

Calculate the output resistance (RO) of the ELVIS function generator. R_0 = 52.2Ω

$$\boldsymbol{R_0 = R_1\left(\frac{V_0}{V_1} - 1\right)}$$

c) Measure and record the actual resistance of a 1-MΩ resistor, R2 = 1.014MΩ

Connect the ELVIS function generator, R2 and Tektronix oscilloscope in series. Sketch the circuit diagram for this setup.

$$v_0 = \mathbf{1}.382\boldsymbol{V}$$

Record the peak-to-peak voltage measured from the Tektronix oscilloscope, v2 = 0.68V

Calculate the input resistance (Ri) of the Tektronix oscilloscope. Ri = 0.98 MΩ

$$R_i = R_2\left(\frac{v_2}{v_o - v_2}\right) - R_0$$

Using the last circuit setup, replace the Tektronix oscilloscope with the Fluke digital multimeter. Record the rms voltage as read from the Fluke multimeter, v2 = <u>1.184V</u>

Using the equation provided in the last step, calculate the input resistance of the Fluke MM. Ri = <u>6.06MΩ</u> (CAVEAT: Use rms vS.)

Sample calculations:

$$\boldsymbol{R_0} = \boldsymbol{R_1}\left(\frac{V_0}{V_1} - \mathbf{1}\right) = 100.8 \times (\frac{1.382}{0.908} - 1) = 52.2\Omega$$

$$R_i = R_2\left(\frac{v_2}{v_o - v_2}\right) - R_0 = 1.014M\Omega \times \left(\frac{0.68V}{1.382V - 0.68V}\right) - 1.014M\Omega = 0.98M\Omega$$

<u>3.5.3 Analysis & Discussion</u>

The internal resistance of the function generator and oscilloscope are very close to the nominal value. However, the resistance, we measured, inside the Fluke DMM is quite different from the nominal value. It is because the internal resistance is way larger than $\boldsymbol{R_1}$. When we get them in parallel, the combination resistance will change a lot and so the error will become very big.

3.6 Loading of a Measurement Device

<u>3.6.1 Summary of Procedure</u>

Equipment used for this procedure are a DC voltage source, a swing resistance, a Fluke DMM and several wires. The purpose of this step is to see the effect of "loading" by a measuring device.

a) Measure the potentiometer total swing resistance (RT), generate a 4 VDC voltage using the ELVIS VPS and measure the actual voltage using a DMM and record the voltage as VS-actual. Determine the effective length L of the resistive portion of the slide potentiometer. Record your data in Table 8. Set up the circuit shown in Figure 4.

Table 8. Voltage Measurements

	Different Slide Potentiometer Settings (*x*)					
	0	0.2L	0.4L	0.6L	0.8L	L
Calculated R_{23}						
V_0 w/o load						
V_0 w/ 2.2 kΩ load						

b) Use the DMM to measure V0 for x = 0, 0.2L, 0.4L, 0.6L, 0.8L, and L. (NB: x is measured with reference to terminal 3.) If you plot V0 as a function of the potentiometer length, L, what relationship can you observe? Is it linear or nonlinear? At which length setting is the voltage V0 maximum? Minimum? Explain what happens to the resistance across terminals 2 and 3 as you move from zero to maximum length.

c) Connect a 2.2 kΩ resistor across the terminals of the DMM (or across terminals 2 and 3 of the potentiometer) to simulate a low input impedance measuring device and repeat the measurements of part (b). Record the data for parts (b) and (c) in Table 8. Plot V0 as a function of L, do you have similar observations as in step 2.6b? Is it linear or nonlinear? Explain what happens to the resistance across terminals 2 and 3 with the added 2.2 kΩ resistor as you move from zero to maximum length of the potentiometer.

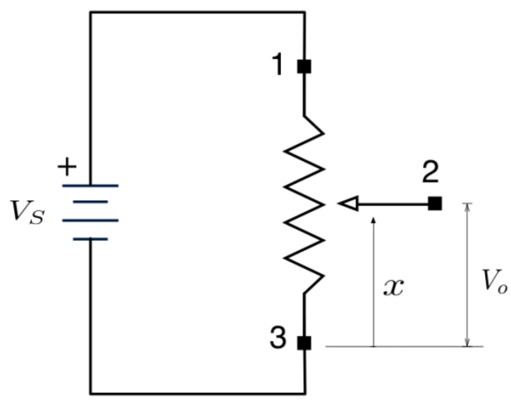


Figure 4. Voltage Divider Circuit using a Slide Potentiometer

3.6.2 Results

L = 15.1cm

R_T = 512Ω

$V_{S\text{-act}}$ = 3.966V

Table 8. Voltage Measurements

	Different Slide Potentiometer Settings (x)					
	0	0.2L	0.4L	0.6L	0.8L	L
Calculated R_{23}	0.00	102	204	306	408	510
V_0 w/o load	0.00	0.78	1.60	2.46	3.25	4.00
V_0 w/ 2.2 kΩ load	0.00	0.72	1.55	2.32	3.14	3.96

Sample calculations:

In the table 8:

From equation below:

$$R_{23} = \frac{X}{L} \times R_T$$

$$V_0 = \frac{R_{23}}{R_T} \times V_s$$

We get that:

$$V_0 = \frac{X}{L} \times V_s$$

Thus

$$K_p = \frac{V_s}{L}$$

3.6.3 Analysis & Discussion

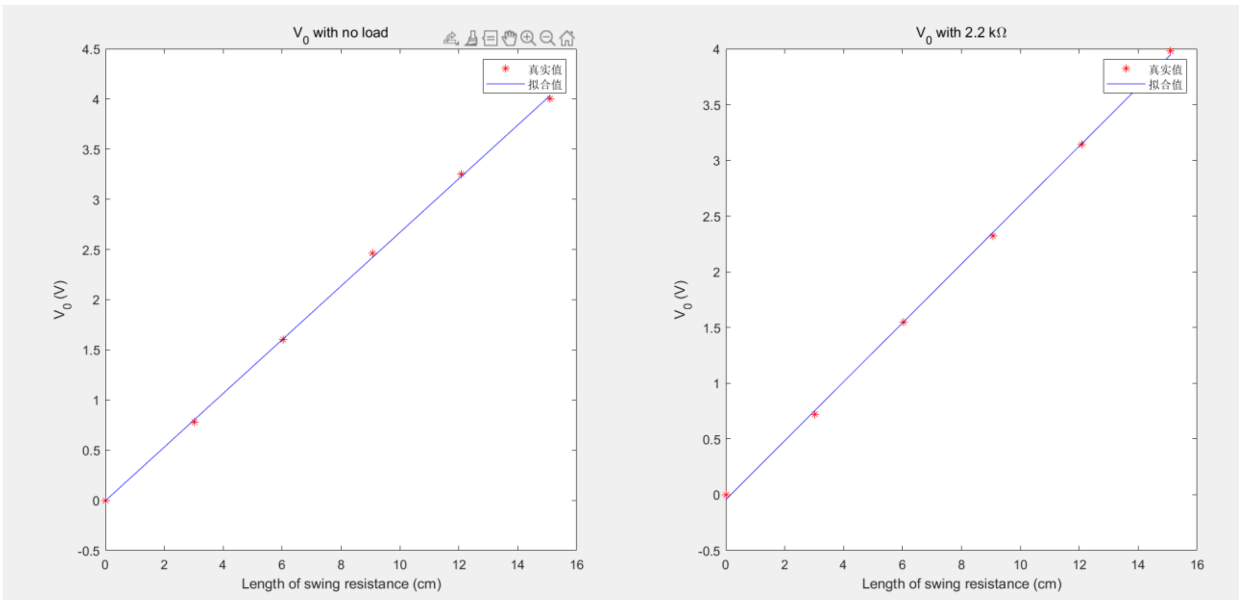


Figure 5. Fitting plot of V0 and the length of swing resistance

From the experiment, we can find that with increasement of x, the resistance of R_{23} increases correspondently, so do the voltage across it. V_0 reaches the maximum value when the x is equal to the total length L. With the usage of MATLAB to plot the V_0 and length, in Figure 5, we find that the relationship between V_0 and x is linear, which means V_0 is proportional to x.

When we connect a 2.2kΩ resistance in parallel with R_{23}, though the voltage drops slightly, the linear relationship between the length and V_0 doesn't change. The reason why the voltage drops is that when a resistance is in parallel with another resistance, the total resistance will be smaller than any of the resistances. Thus, the voltage across it will decrease.

3.7 Phase Difference between Two Signals of the Same Frequency

3.7.1 Summary of Procedure

Equipment used in this procedure are a function generator, a 10kΩ resistance, a $0.033\mu F$ capacitor , a Fluke DMM and several wires. Purpose of this pat is to observe phase difference between two signals owing same frequency.

a) Set up the circuit shown in Figure 5 with R = 10 kΩ and C = 0.033 μF . (Be sure to measure the actual resistance and capacitance of these devices using the Fluke DMM.) Use the function generator built into the breadboard to generate a 400 Hz sinusoid (any reasonable amplitude will do) for the input signal Vi.

b) Connect Vi to channel 1 of the analog oscilloscope (or virtual oscilloscope) and V_0 to channel 2 of the oscilloscope. Sketch the input and output voltage waveforms in Figure 6 while indicating td, T, V_0, and vi as well as the oscilloscope settings (VOLTS/DIV and TIME/DIV).

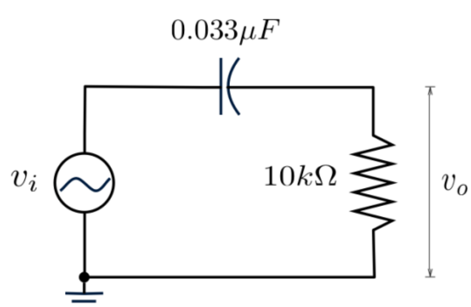


Figure 6. First-order High Pass Filter Circuit

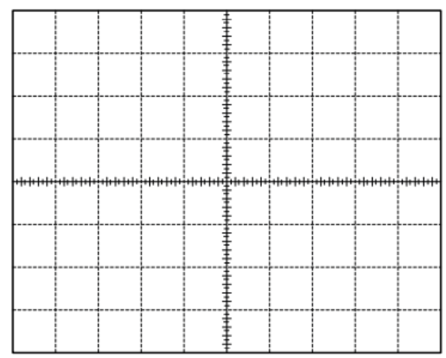
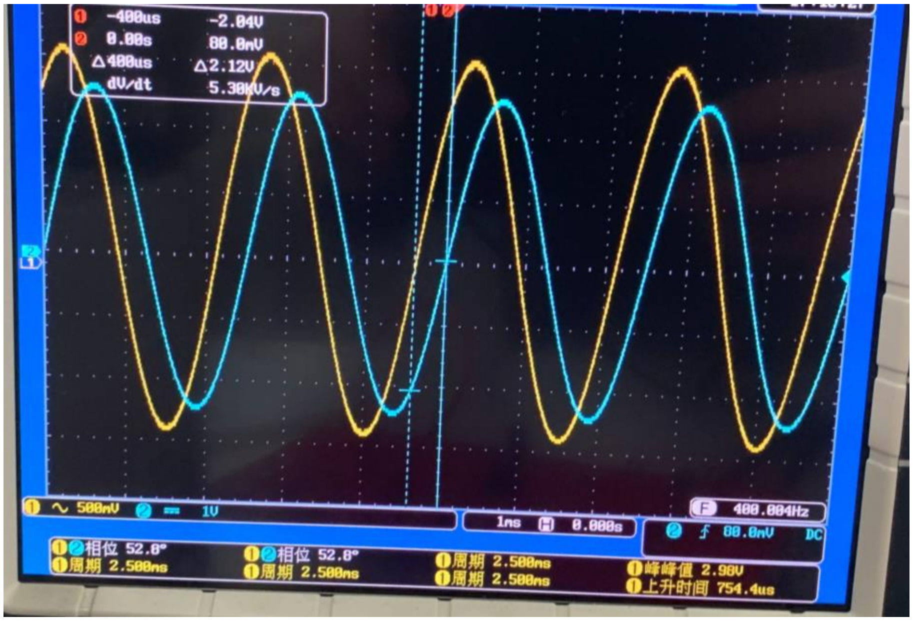


Figure 7. Voltage Waveforms

c) Calculate the phase θ of the output relative to the input and the voltage. Note that for this circuit, the output v0 would be described as leading the input V_i.

3.7.2 Results



Time difference, td = _____0.36 ms__________ Actual period, T = ______2.502 ms_________

Peak voltage of input, vi = ____4.00 V_____

Peak voltage of output, vo = ___3.88 V_____

Calculate the phase difference. θact = ___51.80°___ (Use $\theta_{act} = \frac{360t_d}{T}$)

$$Error = \frac{|52.8 - 51.8^\circ|}{52.8^\circ} = 1.89\%$$

3.7.3 Analysis & Discussion

From the graph of the waveform, we can find that the voltage across the resistor is slightly forward the source voltage.

Error between actual phase difference and the calculated phase difference is 1.22% which is under tolerance.

4. Answers/Solutions to Questions/Problems

i) the true multimeter can measure the wave accurately, but pseudo RMS multimeter will mutiply the result by 1.11 when it measure the wave. For pure sinusoidal wave, both true RMS and average response instruments can accurately measure, but for distorted waveforms, or typical non-sinusoidal waves such as square wave, triangular wave and sawtooth wave, only true RMS instruments can accurately measure.

ii) to show the static sensitivity of the slide pot as Kp=Vs/L

Static sensitivity of a slide pot is defined as the drop in the unit length of the slide L. Also, in other words, the ratio of slide potential to the slide length is known as static sensitivity Kp.

Now consider a circuit where the resistance of the circuit is varied by a slider of length L.

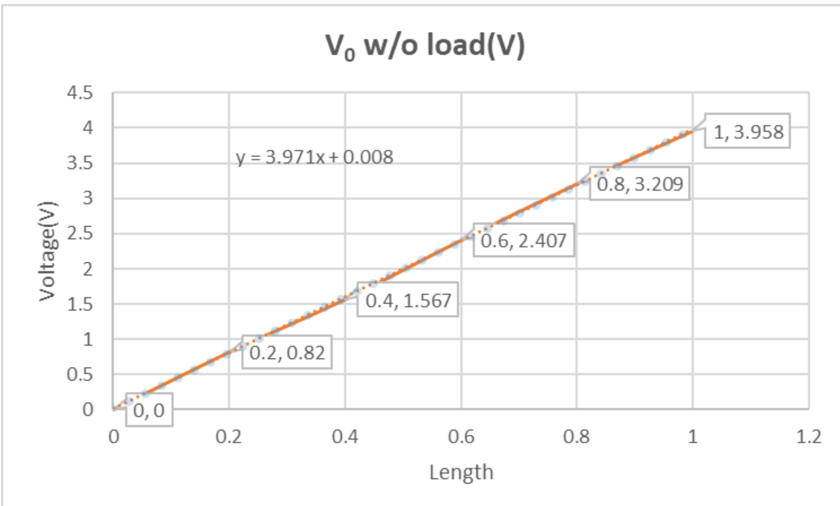
Here, in this circuit the sensitivity of this circuit is dependent on both the potential and the length of the slider. Thus, Static sensitivity is "change in output/ change in input".

Here, output is the slider potential Vs, and the input is the slider length L.

Static sensitivity= Vs/L.

Therefore, static sensitivity of the slide pot as Kp = Vs/L.

iii)

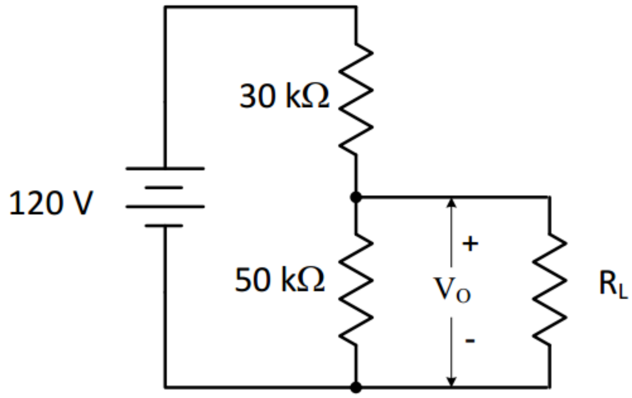


From the section3.6.3, we get a conclusion when the load is much bigger, the curve will tend to be linear. So the curves tend to a linear with the load increasing.

vi)

$$\%Load\ Regulation = 100\% \times \frac{V_{Minimum\ Load} - V_{Full\ Load}}{V_{Nominal\ Load}}$$

v)



a) V_o=(50 kΩ/80 kΩ) ×120V =75V

b) R_t=(450 kΩ×50 kΩ)/(450 kΩ+50 kΩ)=45 kΩ

   V_o=(45 kΩ/75 kΩ) ×120V=72V

c) %Load Regulation=100%×(75V-72V)/72V=4.167%

5. Conclusions

Through the experiment, we could get:

- In the exp1, the voltage divider circuit increases as R_2 is changed to a higher value, and the value measured in V1 decreases though R_1 keeps unchanged. The corresponding reason is that the voltage distributed ratio of R2 is positively related to its resistance ratio.
- In the exp2, the current of the resistor and the power of resistor increase when resistance decrease.
- In the exp3, the waveform will move a distance upwards or downwards if a dc offset had been added
- In the exp4, we get three different equations to calculate the effect voltages. For Sine waveform, $V_{rms}=V_p/\sqrt{2}$. For triangular waveform, Vrms=Vp/$\sqrt{3}$. For square waveform, Vrms=Vp.
- In the exp5, we measured voltage equal to the calculated V_{rms} within normal forecast errors. The measurement of GWINSTEK is the most precise.
- In the exp6, we find the effect of loading by a slide rheostat. When there is no load or the load is big, the relation between the length and voltage is linear. When the load is small, the relation between the length and voltage is nonlinear.
- In the exp7, we calculated the phase difference equals to 51.80 degrees, and compares it to the real result, which has a rational error.

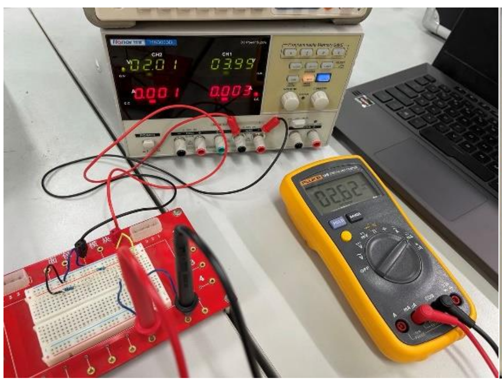
APPENDICES

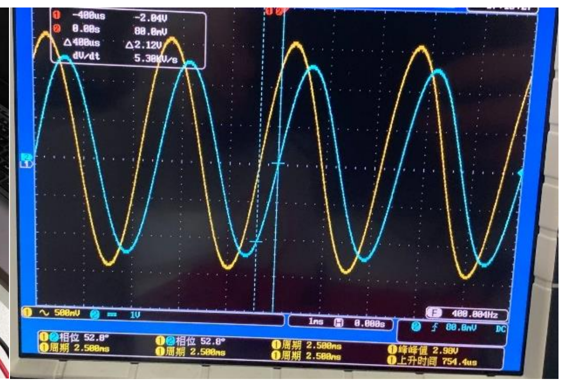
A – EQUIPMENT LIST

Table 9. Equipment List

Equipment Description
GWINSTEK GDS-2072A Digital Storage Oscilloscope (70MHz, 2Gs/s)
Fluke Multimeter
RIGOL DG1022U Function Waveform Generator
Bread Board
DC Power Supply Honor HN3003D

Some Pictures of the Experiment Equipment:





B – Lab Notes

Group Number	2	Names	Yi, Hongrui Zhuang, Yan	Date	2021/3/21
Expt. Number	1	Expt. Title	Basic Instruments		

<u>Part 1: Voltage & Current Measurement and Power Calculation with a dc Voltage Divider Circuit</u>

Table 1. Resistance Values

PARAMETER	NOMINAL (Ω)	MEASURED (Ω)	% DIFFERENCE
R_1	1000	982	1.8
$R_{2\text{-}x}$	470	461	1.9
	1000	974	2.6
	2200	2167	1.5
	10000	10140	1.4

Table 2. Voltage, Current and Power in the dc Voltage Divider Circuit with $R_2 = 470\ \Omega$

PARAMETER	THEORETICAL	MEASURED	%ERROR
V_S	4 V	3.99V	0.25
V_1	2.72V	2.68V	1.47
V_2	1.28V	1.26V	1.56
I	2.72×10^{-3}A	2.69×10^{-3}A	1.10
Power at R_1	7.40×10^{-3}W	7.21×10^{-3}W	2.56
Power at R_2	3.48×10^{-3}W	3.39×10^{-3}W	2.60
Total Power	10.88×10^{-3}W	10.68×10^{-3}W	1.80

Table 3. Voltage Readings, Voltage and Resistance Ratios with Varying R_2

$R_{2\text{-}x}$		V_1 (V)	$\frac{V_1}{V_S}\times 100\%$	$\frac{R_1}{R_{T-x}}\times 100\%$		V_2 (V)	$\frac{V_2}{V_S}\times 100\%$	$\frac{R_{2-x}}{R_{T-x}}\times 100\%$
$R_{2\text{-}1}$ ~ 470 Ω		2.68	67.5%	68.0%		1.26	31.7%	31.9%
$R_{2\text{-}2}$ ~ 1 kΩ		1.98	49.9%	50.2%		1.98	49.9%	49.8%
$R_{2\text{-}3}$ ~ 2.2 kΩ		1.24	31.2%	31.2%		2.73	68.3%	68.8%
$R_{2\text{-}4}$ ~ 10 kΩ		0.36	9.0%	8.82%		3.62	90.7%	91.2%

Expt. Number	1	Expt. Title	**Basic Instruments**

Part 2: Voltage & Current Measurement and Power Calculation with a dc Current Divider Circuit

Table 4. Resistance Values

PARAMETER	NOMINAL (Ω)	MEASURED (Ω)	% DIFFERENCE
R_1	1000	982	1.8
$R_{2\text{-}x}$	470	461	1.9
	1000	974	2.6
	2200	2167	1.5
	10000	10140	1.4

Table 5. Voltage, Current and Power in the dc Current Divider Circuit with $R_2 = 470\ \Omega$

PARAMETER	PREDICTED USING THEORY	MEASURED VALUE	% ERROR
V_S	4 V	3.95 V	1.25
I_1	4.00×10^{-3} A	3.97×10^{-3} A	0.75
I_2	8.51×10^{-3} A	8.42×10^{-3} A	1.06
I_T	1.25×10^{-2} A	1.24×10^{-2} W	0.80
Power by R_1	1.60×10^{-2} W	1.57×10^{-2} W	1.87
Power by R_2	3.40×10^{-2} W	3.32×10^{-2} W	2.35
Total Power	5.00×10^{-2} W	4.89×10^{-2} W	2.20

Table 6. Current Readings, Current and Resistance Ratios with Varying R_2

$R_{2\text{-}x}$	I_T (mA)	I_1 (mA)	$\frac{I_1}{I_T} \times 100\%$	$\frac{R_{2-x}}{R_1 + R_{2-x}} \times 100\%$	I_2 (mA)	$\frac{I_2}{I_T} \times 100\%$	$\frac{R_1}{R_1 + R_{2-x}} \times 100\%$
$R_{2\text{-}1} \sim 470\ \Omega$	12.4	3.97	32.00%	31.9%	8.42	67.90%	68.0%
$R_{2\text{-}2} \sim 1\ k\Omega$	8.02	4.02	50.12%	49.8%	4.01	50.00%	50.2%
$R_{2\text{-}3} \sim 2.2\ k\Omega$	5.73	3.92	68.41%	68.8%	1.82	31.76%	31.2%
$R_{2\text{-}4} \sim 10\ k\Omega$	4.42	4.01	90.72%	91.2%	0.40	9.05%	8.81%

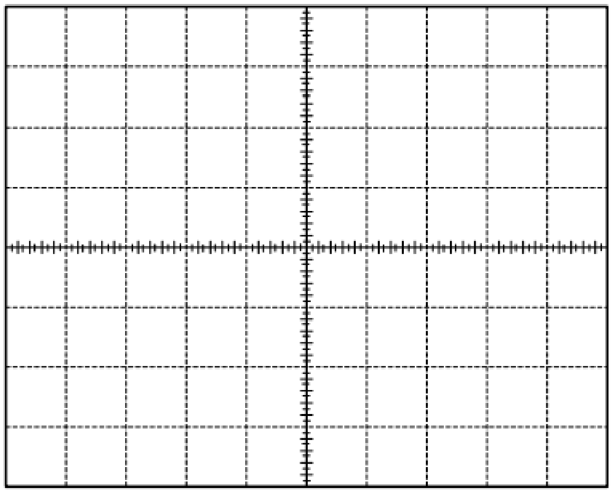
Expt. Number	1	Expt. Title	Basic Instruments

Part 3: Analog (Tektronix) and Virtual (NI-ELVIS) Oscilloscopes

a) After the TA has set up the RSR function generator, connect its output to one of the inputs (ch1 or ch2) of the Tektronix oscilloscope using a coaxial cable with BNC end connectors.

b-c) Draw the waveform, record and measure/calculate the following:

Illustration of the Signal Waveform: (Indicate amplitude levels)



VOLTS/DIV Setting: 1V

TIME/DIV Setting: 500μs

Type of Waveform: Sine

Peak-to-Peak Voltage (Vpp) = 4V

Actual Period (T) = 1.00×10^{-3} s

Calculated Frequency (f) = 1000 Hz

Calculated Angular Frequency (ω) = 6283 rad/s

Table 7. Calculated and Measured Voltage Parameters from Various Waveforms

Waveform	Measured v_{pp} Tektronix (V)	Calculated v_{rms} (V)	Measured v_{rms} FLUKE (V)	Measured v_{rms} ELVIS OSC (V)	Measured v_{rms} ELVIS MM (V)
Sinusoid	4.00V	1.43V	1.382V		
Triangular	3.82V	1.13V	1.087V		
Square	3.82V	1.86V	2.055V		

Expt. Number	1	Expt. Title	Basic Instruments

Part 5: Input and Output Impedance of Laboratory Instruments

a) Set up the ELVIS function generator to produce a 1-kHz, 4 Vpp sine wave signal (v_S). Measure the actual resistance of a 100-Ω (Brn, Blk, Brn) resistor, R_1.
v_S (actual peak-to-peak) = 4V R_1 = 102.7Ω V_{rms} = 1.43V

b) Connect the 100-Ω resistor, R_1, across the ELVIS function generator. Then, connect the Tektronix oscilloscope across R_1. Sketch the circuit diagram for this setup.

Record the peak-to-peak voltage measured from the Tektronix oscilloscope, v_1 = 0.808V
Calculate the output resistance (R_O) of the ELVIS function generator. R_O = 52.2Ω
Use:

$$R_O = R_1\left(\frac{v_S}{v_1} - 1\right)$$

c) Measure and record the actual resistance of a 1-MΩ resistor, R_2 = 1.014MΩ
Connect the ELVIS function generator, R_2 and Tektronix oscilloscope in series. Sketch the circuit diagram for this setup.

Record the peak-to-peak voltage measured from the Tektronix oscilloscope, v_2 = 0.68V
Calculate the input resistance (R_i) of the Tektronix oscilloscope. R_i = 0.88MΩ
Use:

$$R_i = R_2\left(\frac{v_2}{v_S - v_2}\right) - R_O$$

d) Using the last circuit setup, replace the Tektronix oscilloscope with the Fluke digital multimeter. Record the rms voltage as read from the Fluke multimeter, v_2 = 1.184V
Using the equation provided in the last step, calculate the input resistance of the Fluke MM.
R_i = 6.36MΩ   (**CAVEAT**: Use rms v_S.)

Expt. Number	1	Expt. Title	Basic Instruments

Part 6: Loading of a Measurement Device

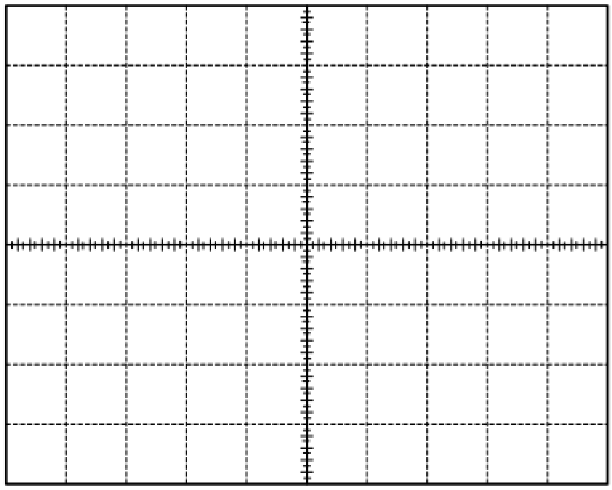
L = 15.1 cm R_T = 512Ω $V_{S\text{-act}}$ = 3.866V

Table 8. Voltage Measurements

	Different Slide Potentiometer Settings (x)					
	0	0.2L	0.4L	0.6L	0.8L	L
Calculated R_{23} (Ω)	0.00	102	204	306	408	510
V_0 w/o load (V)	0.00	0.78	1.60	2.46	3.23	4.00
V_0 w/ 2.2 kΩ load (V)	0.00	0.72	1.55	2.32	3.14	3.86

Part 7: Phase Difference between Two Signals

C = 0.033 μF   R = 10kΩ



Time difference, t_d = 0.36 ms   Actual period, T = 2.502 ms

Peak voltage of input, v_i = 4.00V   Peak voltage of output, v_o = 3.88V

Calculate the phase difference. θ_{act} = 51.80°   (Use $\theta_{act} = \frac{360 t_d}{T}$)