California State University, Northridge

College of Engineering & Computer Science

Department of Electrical and Computer Engineering

ECE 240L Electrical Engineering Fundamentals

Laboratory Report

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Fall 2020

Instructor: Sequare Daniel-Berhe, Ph.D.

California State University, Northridge
College of Engineering and Computer Science
Electrical and Computer Engineering Department

ECE 240L Electrical Engineering Fundamentals Laboratory Reports Title

{Design Electrical Engineering Fundamentals circuit to meet a desired specification!}

No	Main Lab Topics	Design Specifications are given in Lab Manual/ it will be given during lab sessions
1	Laboratory Instruments and Reports	Combine Lab # 1 and #2 Being Familiar with DC Power Supply, AC Function Generator, Oscilloscope and all other Laboratory Instruments as well as Lab Report Writing
2	Oscilloscopes,	
3	DC Circuits Design, Experimental Test and Analysis	
4	Computer Simulations Design on DC & AC Circuits, Simulation and Experimental Test as well as Analysis	
5	Design Experiment – Circuit I - Implementing Mesh Analysis – Design, Simulation and Experimental Test as well as Analysis	
6	Application of Network Theorems (Thevenin's, Norton's & Superposition Theorems) Circuit Design, Simulation and Experimental Test as well as Analysis	
7	Design Experiment – Circuit II - Implementing Maximum Power Transfer – Design, Simulation and Experimental Test as well as Analysis	
8	Operational Amplifiers Design, Simulation and Experimental Test as well as Analysis	
9	First Order Circuits Design, Simulation and Experimental Test as well as Analysis	
10	Design Experiment – Circuit III - Implementing RC Circuits, Simulation and Experimental Test as well as Analysis	
11	Second Order Circuits Design, Simulation and Experimental Test as well as Analysis	
12	Impedance and Admittance Circuits Design, Simulation and Experimental Test as well as Analysis	
13	Frequency Response AC Circuits Design, Simulation and Experimental Test as well as Analysis	
14	Passive Filters Design, Simulation and Experimental Test as well as Analysis	

Practical Application - Final Lab Project Titles:

Cristian Robles

[1] Soil Moisture Sensor

[2] PowerDrill

[3] Motion Sensor Faucet

Elvis Chino-Islas

[4] TxDAC

[5] Guitar Amplifier

[6] AC to DC Adapter

ECE 240L Electrical Engineering Fundamentals Laboratory

Lab Course Description

The ECE 240 course deals with introduction to the theory and analysis of electrical circuits; basic circuit elements including the operational amplifier; circuit theorems; DC circuits; forced and natural responses of simple circuits; sinusoidal steady state analysis and the use of a standard computer-aided circuit analysis program. The course also focuses on power, energy, impedance, phasors, frequency response calculations and their use in circuit design. The corresponding ECE 240L lab includes laboratory instruments and reports, oscilloscopes, DC circuits, computer simulations, design experiments – circuit I, network theorems, design experiments – circuit II, operational amplifiers, first order circuits, design experiments – circuit III, second order circuits, impedance and admittance, frequency response and passive filters. This lab will pursue extensive simulation exercises and practical experiments with the help of discrete components and/or IC's circuits by applying Computer Aided Design (CAD) simulation programs/software like PSpice. In addition, analytical and graphical tools will be used to examine and explain the basic design and analysis of fundamental electrical engineering circuits. The main focus is on design and analysis of Electrical Engineering and Computer Science problems and solutions.

Preparations for this Lab are:

- Revision of basic physics (Electricity and Magnetism) and mathematics.
- Be familiar with PSpice & MATLAB. Introduce yourself also to other industrial simulation programs like Spice, Micro-CAP 9, MultiSim, Quartus II, Altera Max Plus II whenever you have time.

Texts and Materials

- ECE240 Lab Manual and
- Introduction to Electric Circuits, 8th ed., by Svoboda JA, DORF RC, John Wiley & Sons, Inc., 2010.
- PSPICE, by Cadence Corporation: http://www.cadence.com/
- PSPICE by OrCAD MicroSim Corporation http://www.microsim.com/
- In addition to the textbook, main lecture notes and supplemental lecture materials will be offered to provide additional materials for the class.

Main Labs Outline

In this lab the students will learn how to design, analyze & experimentally test the following main labs.

- **Laboratory Instruments and Reports,**
- **Oscilloscopes,**
- **DC Circuits,**
- **Computer Simulations,**
- **Design Experiments – Circuit I,**
- **Network Theorems,**
- **Design Experiments – Circuit II,**
- **Operational Amplifiers,**
- **First Order Circuits,**
- **Design Experiments – Circuit III,**

- **Second Order Circuits,**
- **Impedance and Admittance,**
- **Frequency Response and**
- **Passive Filters.**

<u>Student Learning Outcomes and Lab Course Learning Objectives</u>

<u>Student Learning Outcomes</u>

After completing this laboratory course the students should have an:

- **Ability to apply laboratory equipment relating to basic circuit analysis and design.**
- **Ability to design, analyze and experimentally test DC circuits.**
- **Ability to design, analyze and experimentally test various types of circuits based on given specification designs (Design Experiments – Circuit I, II & III).**
- **Ability to design, analyze and experimentally test network theorems.**
- **Ability to design, analyze and experimentally test operational amplifiers.**
- **Ability to design, analyze and experimentally test first order circuits.**
- **Ability to design, analyze and experimentally test second order circuits.**
- **Ability to design, analyze & experimentally test any circuits related to impedance & admittance.**
- **Ability to design, analyze and experimentally test circuits with frequency responses and**
- **Ability to design, analyze and experimentally test Passive filters.**

<u>Lab Course Learning Objectives</u>

- The objective of Electrical Engineering Fundamentals lab is to have the student design, analyze and build basic circuits using discrete components and/or IC's.
- **The lab will help students to how to solve D.C. circuit problems with independent and dependent sources, op-amps and resistors using nodal analysis, mesh analysis, superposition, source transformations and Thevenin/Norton equivalent circuits.**
- **The lab will help students to how to find the complete response for first and second-order circuits to input signals modeled by waveforms that are DC, step, window, ramp, decaying exponential and sinusoidal.**
- **The lab will help students to how to apply phasors and the concept of impedance to analyze circuits with sinusoidal input under steady-state conditions and to find the frequency response of linear, time-invariant circuits.**

- **The lab will help students to how to design 1st & 2nd-order filters given specifications in terms of 3-db bandwidth & center freq.**
- **The lab will help students to how to use PSpice for the design & analysis of aforementioned fundamental electrical ct.'s simulations.**
- **To accomplish this, the student will:**
    - **Learn how to analyze basic circuits using concepts learned in Electrical Engineering Fundamentals course**
    - **Learn basic circuits and network theorems.**
    - **Learn basics of operational amplifiers, first order circuits and second order circuits.**
    - **Learn how to design basic circuit to meet a desired specification**
- **More emphasis will be given on their applications, and extensive hardware experimental designs and simulation exercises will be examined with the help of discrete components and/or IC designs as well as using simulation programs.**

- **Hardware experimental circuit designs, Computer Aided Design (CAD) simulation programs/software, analytical, graphical, and instrumentation tools will be used to examine and explain the basic building blocks of advanced electronics circuit design, analysis and test.**
- **The objective of this lab is also to introduce and be familiar with current industrial and educational simulation programs/software like PSpice/Spice, Micro-CAP, MultiSim, Quartus, Altera Max Plus, and MATLAB.**
- **Students will learn applications and troubleshooting of basic circuits and systems. They will be exposed to hands on practice and/or computer simulation and analysis of fundamental circuits & systems.**
- **The main focus is on design, analysis and test of Engineering and Computer Science problems and solutions.**
- **This basic circuit design, analysis and test lab provides the student with the basic knowledge necessary to understand the operation and application of fundamental circuits using discrete components and/or IC's.**
- **Following the completion of this lab the student should be well versed in electronics circuit design, analysis, and test and should be able to continue with advanced courses.**

Contribution of Lab Course to Meeting the Professional Component

- This advanced lab contributes primarily to the students' knowledge of Electrical, Electronics and Computer Engineering topics, and does provide fundamental design experience.
- The following statement indicates which of the following considerations are included in this lab primarily: economic, environmental, ethical, political, societal, health and safety, manufacturability, sustainability.
    - Solution: Issues of manufacturability, economics, environmental, and health and safety are primarily relevant in the context of electronic design.
- Thus, the contribution of ECE 240L course and lab to meeting the professional component becomes
    - Engineering Design 2.5 (with the Laboratory)
    - Engineering Science 1.5 (with the course)

Relationship of Lab Course to Undergraduate Degree Program Objectives and Outcomes

This course supports the achievement of the following program objectives and outcomes:

- ***An ability to apply knowledge of mathematics, science, and engineering to the analysis of electrical and electronic engineering problems.***
- ***An ability to identify, formulate and solve electrical engineering problems. An ability to design and conduct scientific and engineering experiments, as well as to analyze and interpret data.***
- ***An ability to design systems that include hardware and/or software components within realistic constraints such as cost, manufacturability, safety and environmental concerns.***
- ***An ability to communicate effectively through written reports and oral presentations.***
- ***An ability to use modern engineering techniques for analysis and design***
- ***An ability to analyze & design complex devices and/or systems containing hardware and/or software components. This leads to recognition of the need for & an ability to engage in life-long learning.***
- ***An ability to apply knowledge of mathematics including differential equations, linear algebra, complex variables and discrete math to the analysis of electrical engineering problems.***
- ***An ability to be competitive in the engineering job market and/or to continue their studies at the graduate level.***

In addition, the following information describes how the lab course contributes to the undergraduate program objectives and supports the achievements of the following expected lab outcomes.

- This lab provides a basic understanding of the methods in the analysis and design of basic circuits using IC's and/or discrete components. It gives each student a solid knowledge based in the fundamentals of electrical and computer engineering.
- This lab develops in each student the basic skills of problem solving and critical thinking.
- Project works, labs and examinations require students to think critically based on engineering and science concepts, and at the same time, let students practice and develop problem solving techniques.
- This lab provides extensive hardware experimental designs and simulation exercises that require students to put methods learned in lectures into practice. This lab develops in each student the team-working skills necessary to perform effectively as an engineer. The project work allows students to discuss in groups at least in pairs but each student will do his/her own work.
- This lab develops in each student good writing skills so that they are able to communicate technical material effectively and clearly. The lab project works have formal reports that require student to document theory, experimental outputs and simulated results as well as their interpretations in an organized manner. These reports are graded based on writing skill (Clarity, Format, Completeness, Mechanics, Appearance, etc.), Technical Presentations/Descriptions, Procedures, Data and Figures, as well as Discussions and Conclusions.
- This lab imparts to each student a sense of ethical and professional responsibility. An understanding or professional and ethical responsibility is obtained through the strict enforcement of the Academic Honesty Policy of the University, which applies to all labs and projects.
- This lab develops basic skill in methods of design and analysis across a broad range of electrical and computer engineering areas. This lab provides knowledge and abilities to apply various techniques and theories to the operation and design of fundamental circuits.

Assessment of Student Progress Toward Lab Course Objectives

- **Design oriented lab project works will be provided including extensive use of computer aided simulation and design techniques especially using PSPICE.**
- **Students' progress is measured in weekly based lab project work activities, demonstrations and presentations that exercise the analysis and design skills developed throughout the semester, and based on the overall final project work reports.**

Lab Grading Standards:

A final letter grade is to be awarded to each enrolled student based on the grading system shown below.

Letter Grade	***Percent of Total Points***	***Grade Points***
A	90% to 100%	4.00
A-	85% to 89%	3.70
B+	80% to 84%	3.30
B	75% to 79%	3.00
B-	70% to 74%	2.70

Letter Grade	***Percent of Total Points***	***Grade Points***
C+	66% to 69%	2.00
C	60% to 64%	2.00
C-	55% to 59%	1.75
D	50% to 54%	1.00
F	49% & below	0.00

Note: *100% can be achieved by doing extra credit hardware experimental designs and/or simulation exercises, etc.*

Grading Weights: The final grade will be determined by the below percentages.

Professionalism/Participation

10%

Weekly Lab Work Progress & Activities

35%

- **Based on Hardware Experimental Designs Preparation**
- **Based on Simulation Program Exercises Preparation (if necessary)**

Final Lab Project Work Demonstration & Presentation

15%

Design & Analysis of any Practical Application of this Lab Course

- **Based on Hardware Experimental Design Outcome**
- **Based on Simulation Program Exercise Outcome (if necessary)**

Overall Lab Project Work Reports

40%

- **Based on Simulation & Hardware Experimental Designs Outcome**
- **Based on Technical Writing Skill (Clarity, Format, Completeness, Mechanics, Appearance, Technical Presentations/Descriptions, etc.)**
- **Based on Procedures, Data & Figures, Discussions & Conclusions**

==

Total ***100%***

- **Extra Credit (10%)** If you design & analyze any of the extra credit lab works you can get extra credits.

- **Professionalism/Participation** – is based on:
  - **Reliability** - *Attended lab; brought required texts and materials to lab; reading textbook, handouts/ assigned materials; met deadlines for graded assignments, kept instructor informed of future absences.*
  - **Punctuality** – *Came to lab on time & returned from break(s) on time.* **Please do not miss lab sessions.**
  - **Positive Attitude** – *Showed intent to learn, staying focused on task; participated actively in lab, discussions and group activities;*
  - **Respect for others** – *Turned off audible signal of cell phone, pager while in lab room; remained for duration of each lab session; etc.*
  - **Teamwork** – *Encouraged responsible behavior by group members; attended & contributed to group meetings; completed own group assignment(s) on time; worked to keep group focused on project goals; helped group members understand & complete their assigned tasks;*
  - **Trustworthiness** – *Avoided all dishonest acts including plagiarism; refrained from injuring others…*

To be successful –

- **You need to work hard - show an effort to study;**
- **You need to work smart – follow guidelines, methods, theorems, order of operations, etc.;**
- **You need to have positive attitude – think positively or open your mind to learn new methods;**
- **You need to study for two hours for every one hour lecture before you come to the next session;**
- **You need to study 70% of your study time alone and 30% in a group of three or five on weekly bases at a library.**

Required Reading Sources

- Introduction to Electric Circuits, 8th ed., by Svoboda JA, DORF RC, John Wiley & Sons, Inc., 2010.
- PSPICE, by Cadence Corporation: http://www.cadence.com/
- PSPICE, by OrCAD Corporation (www.orcad.com) or refer to www.microsim.com/
- Main Lecture Notes, and Handouts

Supplemental Reading Sources/References

- Electric Circuits Analysis, 3rd ed., David E. Johnson and et al, John Wiley & Sons, Inc., 1999.
- Fundamentals of Electric Circuits, 3 ed. Charles Alexander et al.
- Electric Circuits, 3rd Ed., by Alexander and Sadiku, 2007.

Software and Demos

- PSpice Simulation Program – that provides fully interactive mixed analog and digital simulations.
- MATLAB is also required to study frequency response of analog circuits.
- For downloading PSpice refer to
  - PSPICE, by Cadence Corporation: http://www.cadence.com/
  - PSPICE by OrCAD MicroSim Corporation http://www.microsim.com/
- Introduce yourself to other industrial simulation programs like Spice, Micro-CAP, MultiSim, Quartus, Altera Max Plus whenever you have time.

BEING FAMILIAR WITH DC POWER SUPPLY, AC FUNCTION GENERATOR, OSCILLOSCOPE AND ALL OTHER LABORATORY INSTRUMENTS AS WELL AS LAB REPORT WRITING

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Abstract: The objective of this lab is primarily to learn how to set up circuits with different components and power supplies as well as an introduction to proper lab report writing that will be useful later. The circuit in part 1 of the lab consisted of 2 resistors with R1 being 1kΩ and R2 being 2kΩ connected in series. Part 2 of the lab required a second circuit containing a 10kΩ R1 and 4.7kΩ R2 resistors.

Keywords: Direct Current (DC), Alternating Current (AC), Ground, Resistor, Resistance (R) Function Generator, Frequency, Voltage (V), Current(I)

1-2.1 Simulation Setups Lab 1:

1-2.1.1 DC Input
The first step for the DC input circuit was to input 6V/12V into the circuit and measure its waveform.

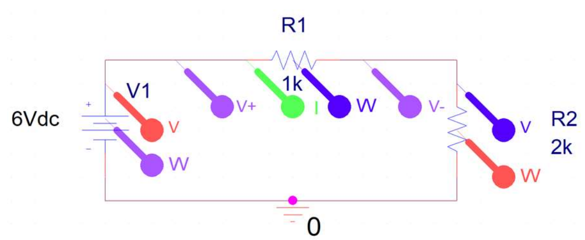

Figure 1-2.1 – Author 1 6V DC Input

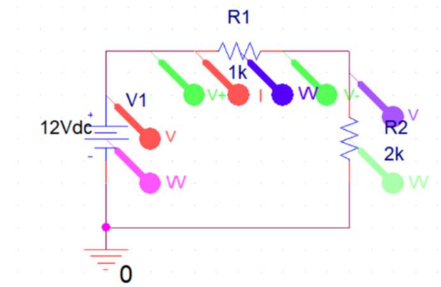

Figure 1-2.2 – Author 2 12V DC Input

1-2.1.2 Sinusoidal Wave Input
This input required the sine wave to have a frequency of 1kHz/2kHz along with an amplitude of 3V/6V making the wave 6V/12V peek-to-peek.

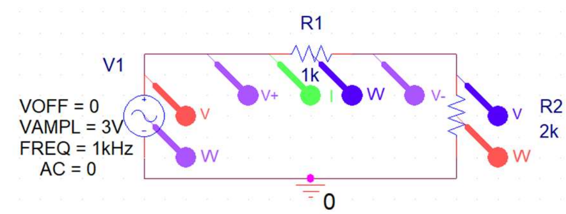

Figure 1-2.3 – Author 1 3V Sin Wave Input, f = 1kHz

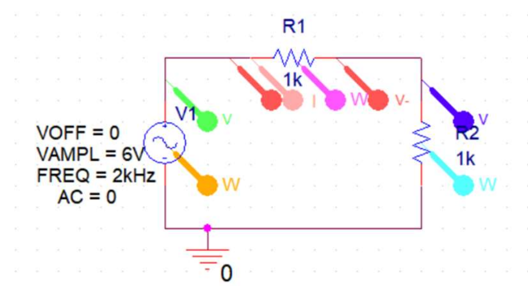

Figure 1-2.4 – Author 2 6V Sin Wave Input, f = 2kHz

1-2.1.3 Square Wave Input

Inputting a square wave into the circuit required a 3V/6V input making it 6V/12V peek-to-peek like the previous wave. Its frequency also had to be 1kHz/2kHz.

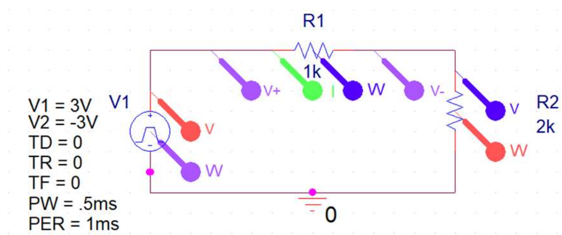

Figure 1-2.5 – Author 1 3V Square Wave Input, f = 1kHz

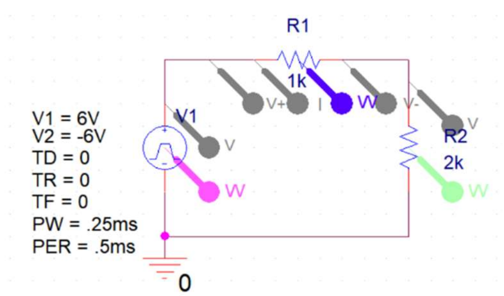

Figure 1-2.6 – Author 2 6V Square Wave Input, f = 2kHz

1-2.1.4 Triangular Wave Input

The triangular input had the same requirements as the sinusoidal and square wave, that being a 3V/6V input. Along with a frequency of 1kHz/2kHz

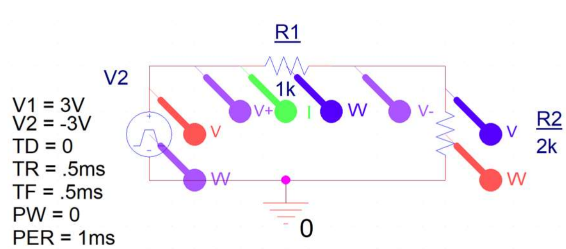

Figure 1-2.7 – Author 1 3V Triangular Wave Input, f = 1kHz

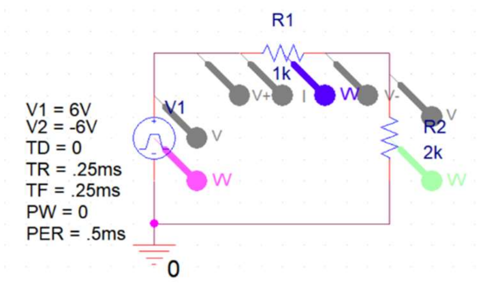

Figure 1-2.8 – Author 2 6V Triangular Wave Input, f = 2kHz

1-2.1.5 Ramp Wave Input

The requirements for this input were the same as all other inputs. It needed to be 6V/12V peek-to-peek with a 1kHz/2kHz frequency

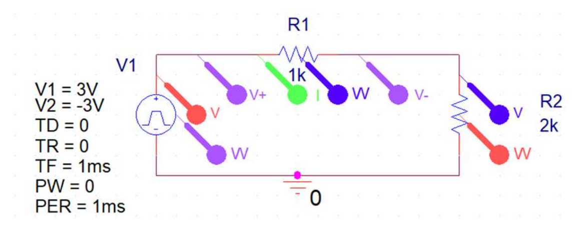

Figure 1-2.9 -Author 1 3V Ramp Wave Input, f = 1kHz

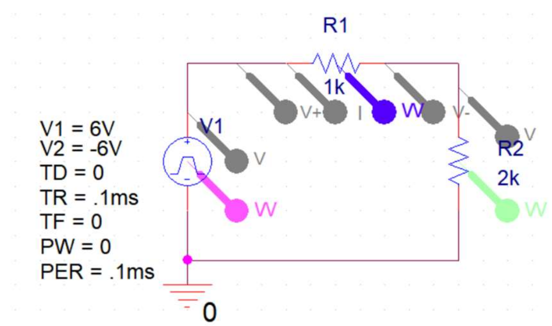

Figure 1-2.10 -Author 2 6V Ramp Wave Input, f = 2kHz

1-2.2 Simulation Setup Lab 2:

1-2.2.1 Sine Wave Input on Circuit 2

This input required the waves amplitude to be 2V/4V giving it 4V/8V peek-to-peek. Requiring a 1kHz/2kHz frequency.

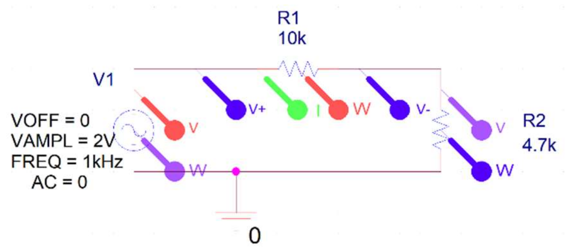

Figure 1-2.11 – Author 1 2V Sin Wave Input, f = 1kHz

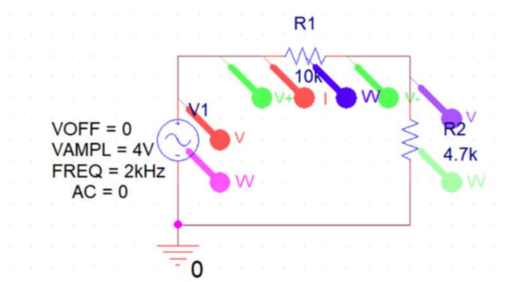

Figure 1-2.12 – Author 2 4V Sin Wave Input, f = 2kHz

1-2.2.7 Sine Wave Input on Circuit 2

This waveform has the same requirements are the previous input

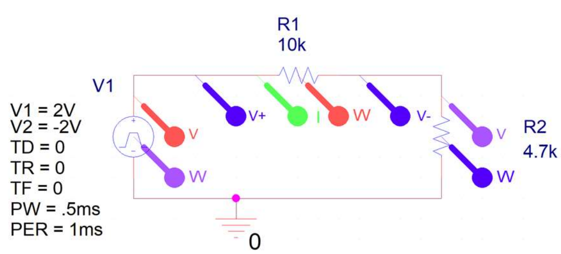

Figure 1-2.13 – Author 1 2V Square Wave Input, f = 1kHz

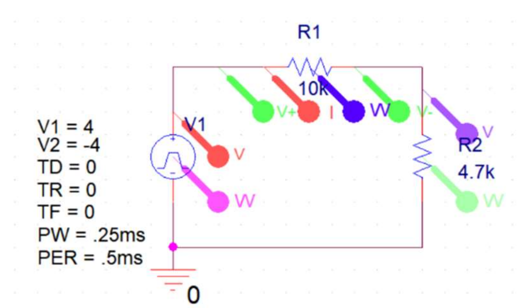

Figure 1-2.14 – Author 1 4V Square Wave Input, f = 2kHz

1-2.3 EXPERIMENTAL & SIMULATION DATA & RESULTS

1-2.3.1 DC Input Results

Figure 1-2.15 - Waveform for 6V DC Input

TABLE 1-2.1
DIFFERENT VOLTAGE INPUT USING DC

V_{IN}	V_{R1}	V_{R2}	I_{IN}
5 V	1.67 V	3.33 V	1.67 mA
3 V	1 V	2 V	1 mA
1 V	0.33 V	0.67 V	0.33 mA

The results showed that the simulation was able to achieve the correct expected measurements from the circuits. The following step was to change the input voltage, V_{IN}, three times

1-2.3.2 Sine Wave Results

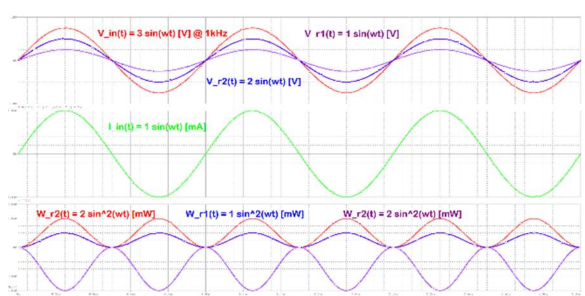

Figure 1-2.16 - Waveform for Author 1 Sine Wave Input, f = 1kHz

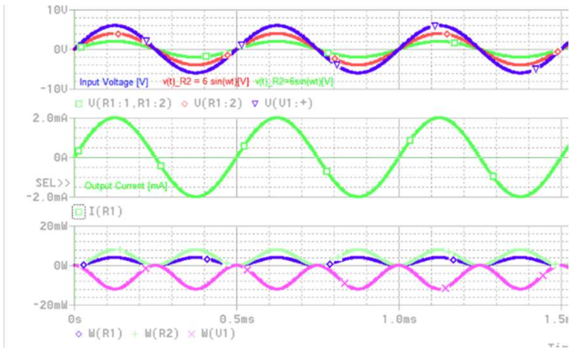

Figure 1-2.17 - Waveform for Author 2 Sine Wave Input, f = 2kHz

The results showed four sinusoidal waves which were expected. It also showed three semi-sinusoidal waves for power dissipation. After further inspection it was determined that these waves where not sinusoidal because power dissipation is calculated by multiplying voltage by current which causes their sines to square.

1-2.3.3 Square Wave Results

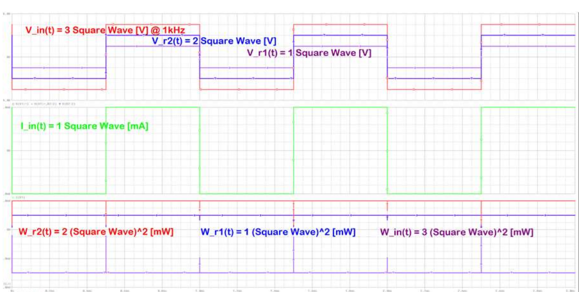

Figure 1-2.18 - Waveform for Author 1 Square Wave Input, f = 1kHz

Figure 1-2.19 - Waveform for Author 2 Square Wave Input, f = 2kHz

For the square wave's frequency to be 1kHz, it was needed that the period (PER) of the input voltage to be 1ms since and its pulse width (PW) 0.5ms. For the frequency to be 2kHz it was needed for the PER to be .5 and the PW to be .25.

1-2.3.4 Triangular Wave Results

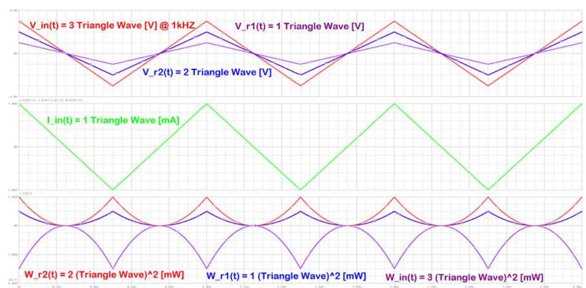

Figure 1-2.20 - Waveform for Author 1 Triangular Wave Input, f = 1kHz

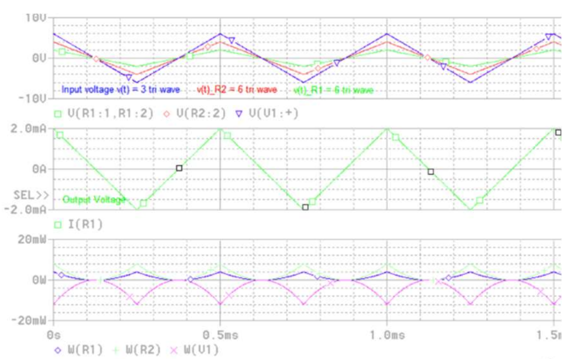

Figure 1-2.21 - Waveform for Author 2 Triangular Wave Input, f = 2kHz

For the triangular wave to be created the pulse wave's rise time (TR) and fall time (TF) needed to be equal while the PW needed to be zero. This created a triangular wave to form. Making this waves period 1ms allowed the frequency to be 1kHz and making it .5ms allowed it to be 2kHz for author 2.

1-2.3.5 Ramp Wave Results

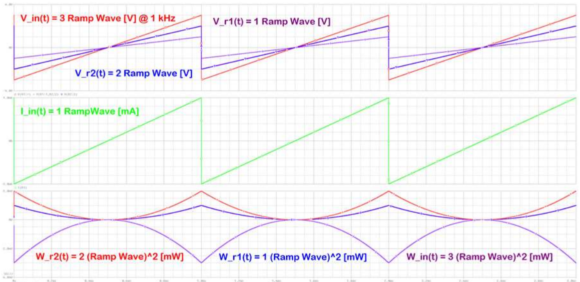

Figure 1-2.22 - Waveform for Author 1 Ramp Wave Input, f = 1kHz

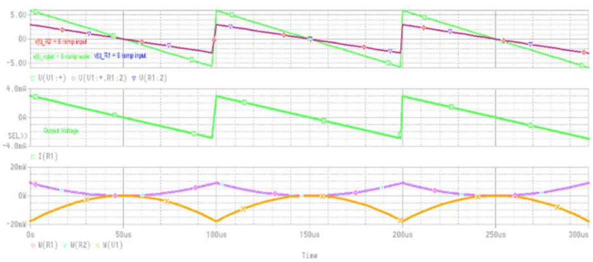

Figure 1-2.23 - Waveform for Author 2 Ramp Wave Input, f = 2kHz

Achieving the ramp wave shape required the pulse to have TR of zero and a TF of 1ms.

1-2.3.6 Sine Wave on Circuit 2 Results

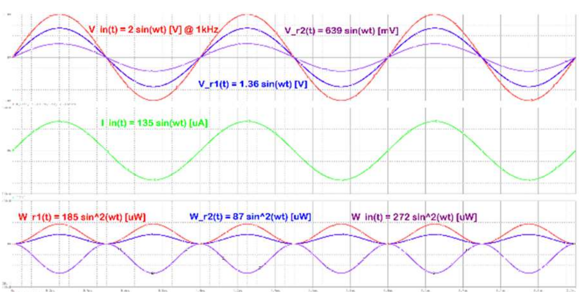

Figure 1-2.24 - Waveform for Author 1 Sine Wave Input, f = 1kHz

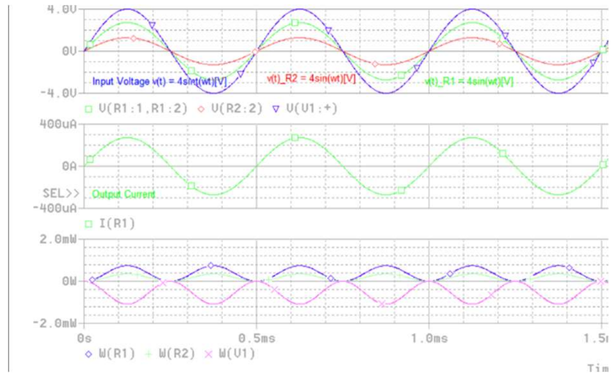

Figure 1-2.25 - Waveform for Author 2 Sine Wave Input, f = 2kHz

In this circuit R1 is greater than R2 causing the waveforms for the voltages across each resistor to switch location. Along with the corresponding waveforms for power dissipation

1-2.3.7 Square Wave on Circuit 2 Results

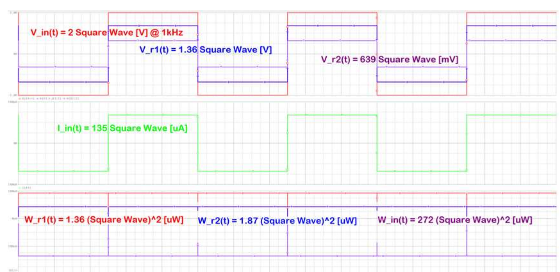

Figure 1-2.26 - Waveform for Author 1 Square Wave Input, f = 1kHz

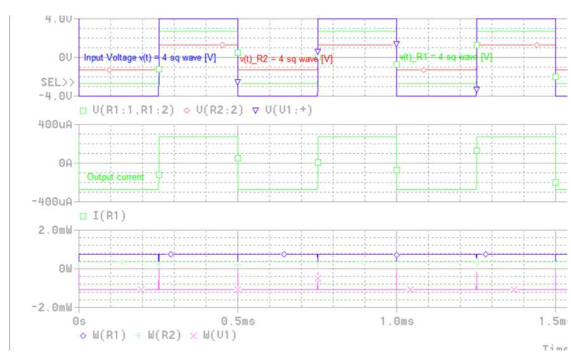

Figure 1-2.27 - Waveform for Author 2 Square Wave Input, f = 2kHz

The results match those of the sinusoidal wave, the only difference is the function that is multiplied to the coefficient to achieve the desired waveform.

1-2.4 DISCUSSION & CONCLUSION

The purpose of this lab was to get us introduced to different types of components in the PSpice simulation software and I think it did a good job at accomplishing that. We learned how to build circuits and input different types of sources. This lab also allowed us to learn to write reports in a proper format.

DC CIRCUITS DESIGN, EXPERIMENTAL TEST & ANALYSIS

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ABSTRACT: The objective of this lab is to calculate theoretical voltage values across various resistors wired either in parallel or series as well as currents and to compare the calculations with the measured result as well as the percentage error. This was done by using a DC power supply, ohmmeter, breadboard and resistors. The theoretical values were calculated using various techniques including Ohm's law, Kirchhoff's voltage law (KVL), Kirchhoff's current law (KCL), voltage division, current division. Lastly, we had to find the error percentage in each resistor, voltage, current.

KEYWORDS: DC Power Supply, Resistors, DMM, Kirchhoff's Current Law, Kirchhoff's Voltage Law, Series Circuits, Parallel Circuits and Ohmmeter

3.1 INTRODUCTION

Six circuit where used to test the validity of KVL and KCL. Equations such as voltage divider and current divider will be used in conjunction with KVL and KCL to see is these two laws hold up. These results will then be compared to the measured simulated results.

3.2 EXPERIMENTAL & SIMULATION SETUP & PROCEDURES

Equations

$$Ohm's\ Law: V = IR \quad (3.1)$$

$$Series\ Resistors: R_E = R_1 + R_2 + \cdots + R_t \quad (3.2)$$

$$Parallel\ Resistors: R_E = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}} \quad (3.3)$$

$$Voltage\ Divider:\ V_{out} = \frac{R_2 * V_{in}}{R_1 + R_2} \quad (3.4)$$

$$Current\ Divider:\ I_{R2} = \frac{R_1||R_2}{R_2} * I_{in} \quad (3.5)$$

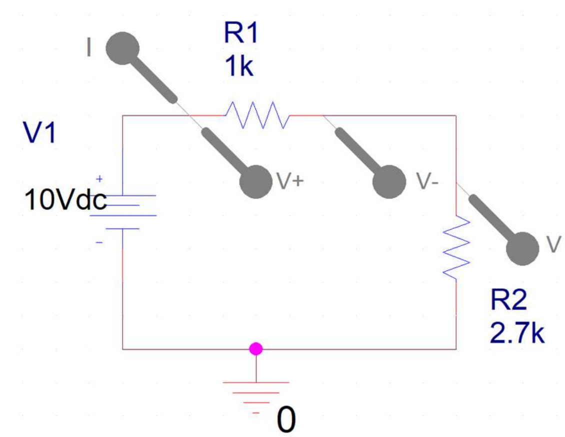

Figure 3.1 – Simple Series Circuit I

The circuit on Figure 3.1 two resistors max and min resistance where calculated and where but into Table 3.1. With that data, those values where used to calculate the current and voltage across each resistor using every possible combination of max, min, and nominal resistor values, this data is stored in Table 3.2. The circuit was then simulated and its results where store in Table 3.4

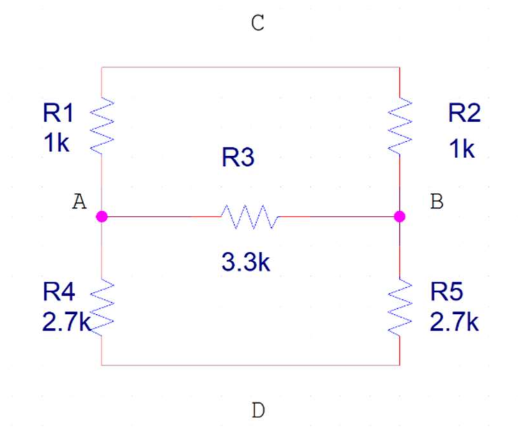

Figure 3.2 – Delta Configuration Circuit II

The procedure for the circuit on Figure 3.2 was to find the equivaled resistance between modes AB, AC, and CD. This was accomplished using the equations in Figure 3.3.

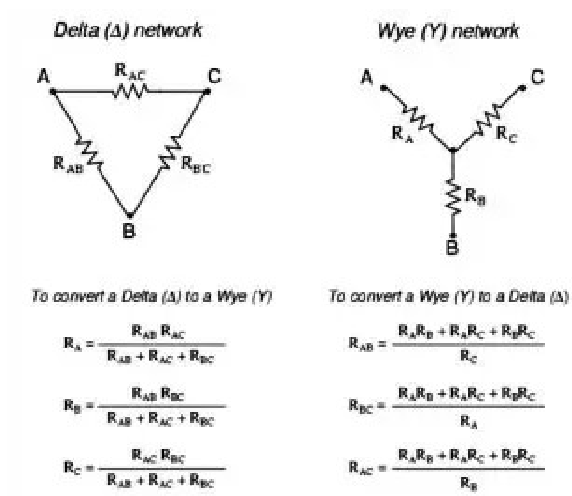

Figure 3.3 – Delta to Wye Conversion Formulas

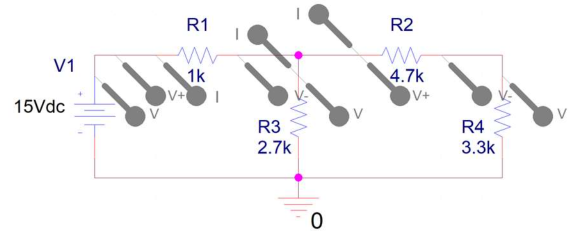

Figure 3.4 – Voltage Divider Circuit III

The circuit on Figure 3.4 required the voltage of R3 and R4 to be calculated and measured using voltage divider, then storing results in Table 3.7. The circuit was also simulated, and those measurements are stored in Table 3.6.

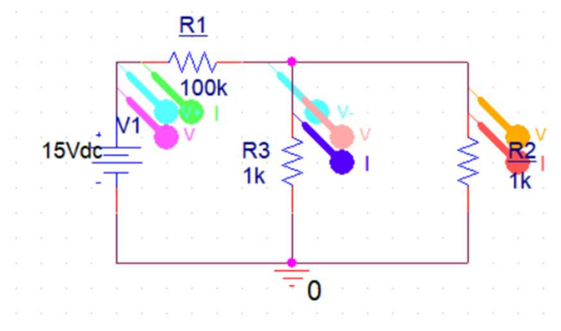

Figure 3.5.1 – Current Divider Circuit IV with 1 kΩ resistor for R2

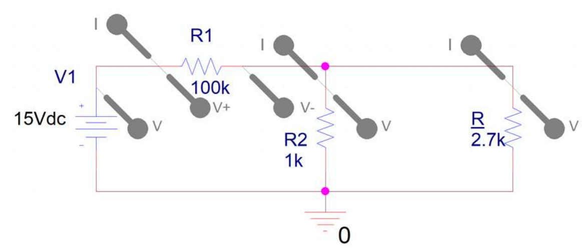

Figure 3.5.2 – Current Divider Circuit IV with 2.7 kΩ resistor for R

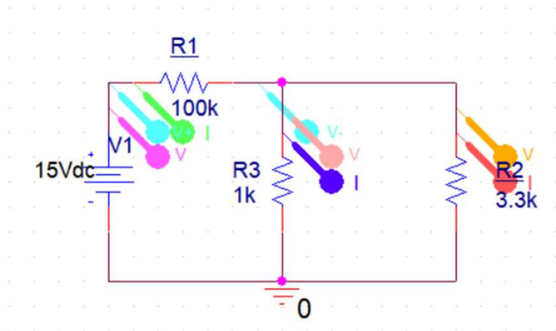

Figure 3.5.3 – Current Divider Circuit IV with 3.3 kΩ resistor for R2

The circuits on Figures 3.5.1-3 require the use of current divider (3.4) to calculate the current passing through the resistors in parallel. The results are in Table 3.9. Figure 3.5.1 was simulated, and its results stored in Table 3.8

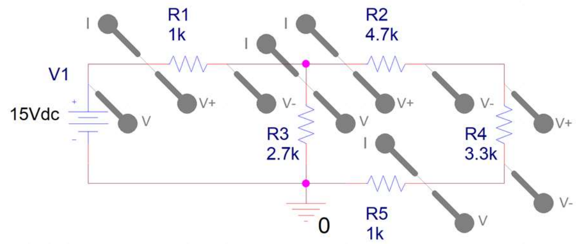

Figure 3.6 – Circuit V

The circuit on Figure 3.6 required the voltage across each resistor and the currents going through each resistor to be calculated. This was accomplished using Equations 3.1-5. The results are stored in Table 3.12. This circuit was also simulated, and measurements stored in Table 3.11.

3.3 EXPERIMENTAL & SIMULATION DATA & RESULTS

Rnominal	Rmin (kΩ)	Rmax (kΩ)
1 kΩ	0.950	1.05
2.7 kΩ	2.565	2.835

Table 3.1 - Max, Min, Nominal and Measured Values of 2 Resistors Based on Fig 3.1

Rmeasured (kΩ)	Percent Error (%)

Table 3.1 – Continued

	R_1, min R_2, min	R_1, max R_2, min
I (mA)	2.845	2.766
V_1 (V)	2.703	2.905
V_2 (V)	7.297	7.095

Table 3.2 – Max, Min of 2 Resistors Based on Fig 3.1

R_1, min R_2, max	R_1, max R_2, max
2.642	2.574
2.510	2.703
7.490	7.297

Table 3.2 – Continued

	max	min	nom
V_1 (V)	2.574	2.703	2.703
V_2 (V)	7.297	7.297	7.297
I (mA)	2.574	2.845	2.703

Table 3.3 – Max and Min values of I and V(i) for Figure 3.1

max % error	meas	% error
4.77%		
0%		
4.77%		

Table 3.3 – Continued

	Calculated	Meas.	%Err.
V1 V2	2.7 V 7.2973 V		

Table 3.4 – 15 V DC Input on Fig 3.1

Resistance	Calculated
R_{ab} R_{ac} R_{cd}	1.012 kΩ 0.811kΩ 1.85 kΩ

Table 3.5 – Resistance between points of Figure 3.2

Measured	% error

Table 3.5 – Continued

The resistance between A and B was achieved by using simple resistor combination. This is done through the use of Equations 3.2 and 3.3. Similarly, the resistance between A and C also only required Equations 3.2 and 3.3. The resistance between C and D was not possible through just combination of resistors. R1 and R2, and R3, which are in a delta configuration, need to be configured into a wye configuration using the equations in Figure 3.3. After that, the resistance between C and D was achieved with Equations 3.2 and 3.3 between the new Wye network, R4 and R5.

Parameters	Measurements
V_1 V_{R1} V_{R2} V_{R3} V_{R4} I_1 I_{R3} I_{R2}	15 V 4.969 V 5.8932 V 10.031 V 4.1378 V 4.969 mA 3.7152 mA 1.2539 mA

Table 3.6 – Simulation Measurements from Figure 3.4

	Calc	Meas	% error
V_1 V_2	10.031 V 4.138 V		

Table 3.7 – Voltages in Figure 3.4

The voltages for the circuit shown in Figure 3.4 where calculated by using Equation 3.2, 3.3, and 3.4. First equations 3.2 was used to find R_{24}, then equation 3.3 was used to find R_{234}. Equation 3.4 was used to find V_{R3}. Then Equation 3.4 was used again to find V_{R4}. The simulations results, Figure 3.4, confirms that the process of getting these results are correct.

Parameters	Measurements
V_1 V_{R1} V_{R2} V_R I_1 I_{R2} I_{R3}	15 V 14.891 V 108.667 mV 108.667 mV 148.913 μA 108.667 μA 40.247 μA

Table 3.8 – Simulation Measurements from Figure 3.5.1

R	I, calc (μA)	I_r, calc (μA)
1 kΩ 2.7 kΩ 3.3 kΩ	149.254 108.667 148.858	74.627 40.247 34.618

Table 3.9 – Results from Figure 3.5.1-3

I, meas	I_r, meas

Table 3.9 – Continued

The currents for the circuits show in Figures 3.5.1-3 where calculated by first calculating the equivalent resistance, R_E, in order to find the source current. Then Equation 3.4 was used to find I_R. Then I_R was subtracted from the source current to find the remain current. This is justified through KCL. Circuit shown in Figure 3.5.1 was then simulated and the measurements taken confirm that the process of obtaining the I and I_R was indeed correct.

Parameters	Measurements
V_1	10 V
V_{R1}	3.525 V
V_{R2}	2.525 V
V_{R3}	6.75 V
V_{R4}	2.475 V
V_{R5}	750 mV
I_{R1}	3.25 mA
I_{R2}	750 µA
I_{R3}	2.5 mA

Table 3.10 – Simulation Measurements from Figure 3.6

PARA	CALC	MEAS	%ERR
V_1	3.25 V		
V_2	3.525 V		
V_3	6.75 V		
V_4	2.475 V		
V_5	750 mV		
I_1	3.25mA		
I_2	750 µA		
I_3	2.5 mA		
I_4	750 µA		
I_5	750 µA		

Table 3.11 – Results from Circuit V from Figure 3.6

The calculations for the circuit shown in Figure 3.6 where done by fist calculating the equivalent resistance in order to the find the source current. After the source current, I_1, is found, currents I_2, I_4, and I_5 can be found using Equation 3.5 since resistors R2, R4, and R5 are in series. Now that I_{245} is known it can be subtracted from I_1 to find I_3 because of KCL. Since the current going through all resistors is known the Voltage through each resistor can now be calculated using Equation 3.1. The circuit in Figure 3.6 was also simulated and the measurements records confirm our results from theoretical calculation.

3.4 DISCUSSION & CONCLUSION

The purpose of the lab was to explore the validity of KVL and KCL. The theoretical values calculated through this lab where calculated assuming these laws where indeed valued. This was pair with a computer simulation of the circuit who's theoretical was where calculated. When compared these values indeed match the theoretical value or were off by 0.0001. With further inspection it was also seen that when a current went into a junction the output currents did indeed add up to the input current. This was also observed with KVL where all the voltages around a loop added up to zero. To conclude, the objective of this lab to explore KVL and KCL was successful and those law are indeed valid.

REFERENCES

[1] Mallard, Bejamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

[2] Svoboda, James A., and Richard C. Dorf. *Introduction to Electric Circuits*. John Wiley & Sons, 2014.

[3] Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.html

Computer Simulations Design on DC & AC Circuits, Simulation and Experimental Test as well as Analysis

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ABSTRACT: The objective of this lab is to setup and analyze a Wheatstone bridge circuit with a direct current input by using PSpice to find the theoretical values of the node voltages and currents I1 and I2 using a multimeter. In this lab we also did a transient analysis of a circuit where we plotted the first 2 cycles and later the 10th and 11th cycles of a circuit with 2 resistors in series with 2 types of alternating current input.

KEYWORDS: Direct Current (DC), Alternating Current (AC), Resistors, Bridge Circuit, Current, Node Voltage, Simulation.

4.1 INTRODUCTION

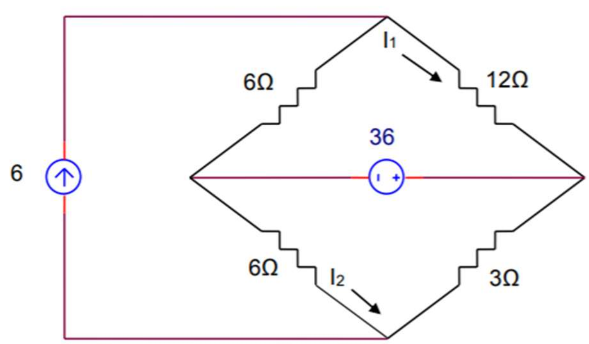

Figure 4.1- Wheatstone Bridge Circuit Fig. 4.1 in Lab Manual

This is 1st circuit required for this lab where we were found the node voltage as well as I1, and I2 using PSpice.

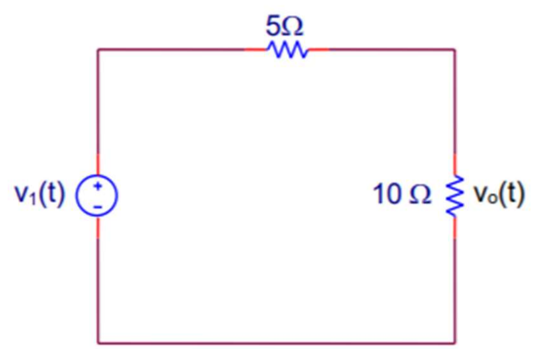

Figure 4.2- Series Resistor Circuit Fig. 4.2 in Lab Manual

This circuit was the 2nd where we plotted cycles at different times for sine and square wave inputs.

4.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

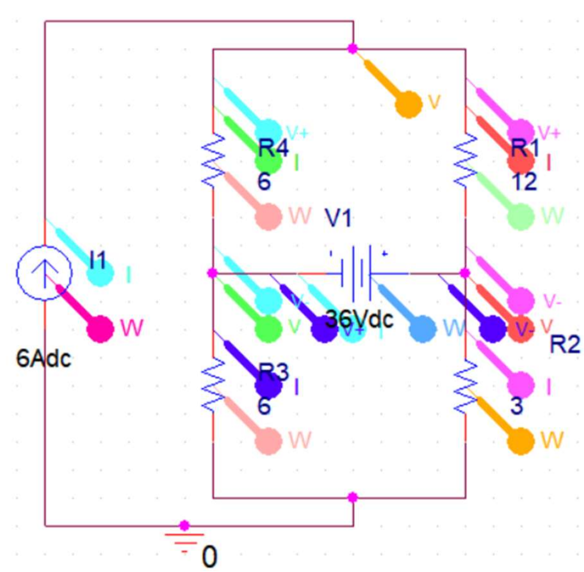

Figure 4.3- Schematic for Fig 4.1 in PSpice

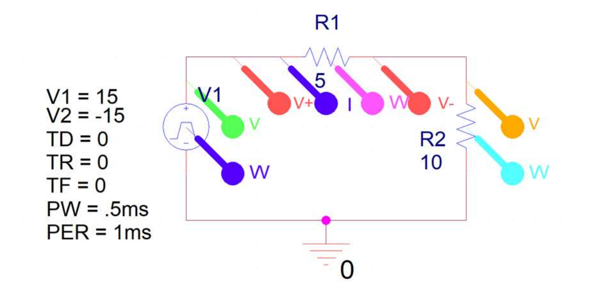

Figure 4.4- Schematic for Figure 4.2 with square wave input

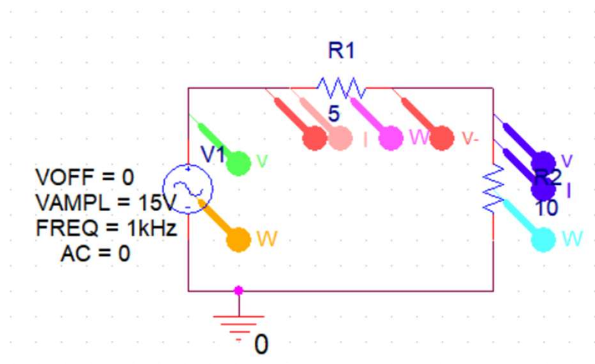

Figure 4.5- Schematic for Figure 4.2 with sin wave input

4.3 EXPERIMENTAL & SIMULATION DATA & RESULTS

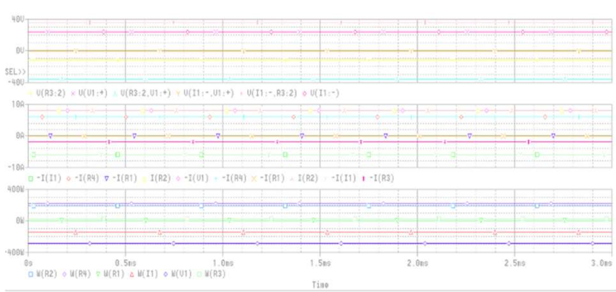

Figure 4.6- Circuit 1 Waveform

	Simulated	Measured
Node 1	24V	
Node 2	-12V	
Node 3	36V	
I1	-7.99pA	
I2	-2A	

Table 4.1- Values of fig 4.1

Figure 4.7 – Circuit 2 Square Waveform, Cycles 1-2

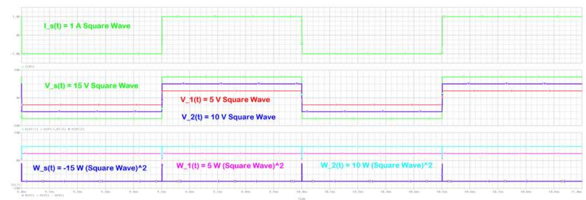

Figure 4.8 – Circuit 2 Square Waveform, Cycles 10-11

	Simulated	Measured
Vs	15V	
VR1	4V	
VR2	8mV	
Is	800mA	

Table 4.2 – Values of fig 4.2 with square wave input

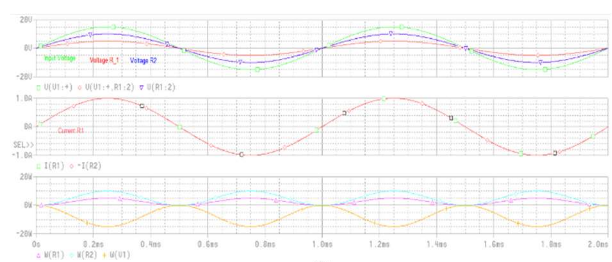

Figure 4.9- Circuit 2 Sine Waveform, Cycles 1-2

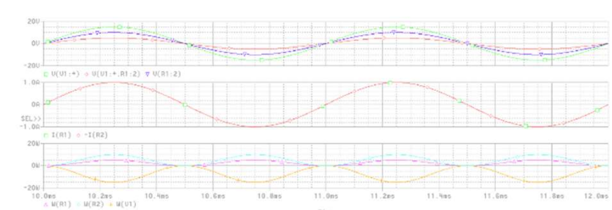

Figure 4.10 – Circuit 2 Sine Waveform, Cycles 10-11

	Simulated	Measured
Vs	3.393nV	
VR1	3.142mV	
VR2	6.283mV	
Is	628.33 uA	

Table 4.3 – Values of fig 4.2 with sine wave input

4.4 DISCUSSION & CONCLUSION

The purpose of this lab was to simulate and analyze as well as measure values in the given circuits. We were able to find all the values we needed from the simulation but do not yet have the data to compare them to experimental tests without the lab kits. The simulation portion of this lab though is a success and we were able to find everything that was needed.

REFRENCES

1. Mallard, Benjamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

2. PSPICE Guide for ECE 240L Lab Prepared by: Pamela Norva, ECE Lab Assistant, Spring 2018

DESIGN EXPERIMENT – CIRCUIT I - IMPLEMENTING MESH ANALYSIS – DESIGN, SIMULATION AND EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ASTRACT: The purpose of this lab is to learn to design a resistive circuit to achieve desired voltages. Kirchhoff's voltage and current laws along with Ohm's law will be used to calculate the resistors values needed to achieve the desired voltages. These theoretical values calculated by these laws will then be simulated and proven.

KEYWORDS: Oscilloscope, Function Generator, DMM, Resistors, Circuit Design, Kirchhoff Current Law, Kirchhoff Voltage Law, Ohm's Law

5.1 INTRODUCTION

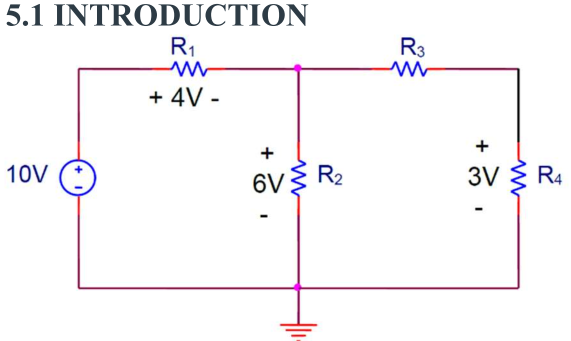

Figure 5.1 – Circuit I

Figure 5.1 is a resistive circuit in which correct resistor values must be chosen in order to achieve the desired voltage drops across each individual resistor. Ohm's law, KCL, and KVL were used to calculate the needed resistors values.

Equations		
Ohm's Law	$V = I * R$	(1)
KCL	$I_i = I_{o1} + I_{o2} + \cdots + I_{oN}$	(2)
KVL	$V_1 \pm V_2 \pm \cdots \pm V_N = 0$	(3)

5.2 EXPERIMENT & SIMULATION SETUP & PROCEDURES

Equations Calculated for Figure 5.1

$$i_2R_3 = i_2R_4 = 3\text{V} \rightarrow R_3 = R_4 \quad (4)$$

$$i_2R_4 = 3\text{V} \rightarrow i_2 = \frac{3\text{V}}{R_4} \quad (5)$$

$$i_2(R_3 + R_4) = (i_1 - i_2)R_2 = 6\text{V} \quad (6)$$

$$i_2 = (i_1 - i_2) \therefore R_3 + R_4 = R_2 \quad (7)$$

$$i_1R_1 = 4\text{V} \quad (8)$$

$$i_1 = 2 * i_2 \quad (9)$$

$$R_1 = \frac{4\text{V}}{i_1} \quad (10)$$

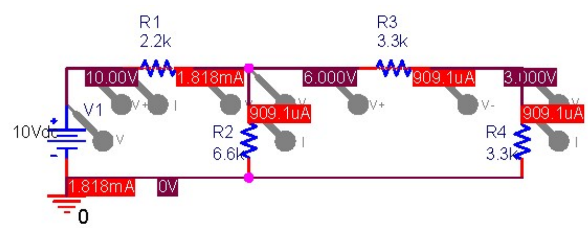

Figure 5.2 – Designed Resistive Circuit with 2.2 kΩ, 6.6 kΩ, and two 3.3kΩ resistors

For Figure 5.2 the resistor value where calculated using equations (4-10). Since in equation (4) it was seen that R_3 and R_4 are equal, a resistor value of 3.3kΩ was assigned to theses two resistors. R_2 was then calculated, equation (6 – 7), through the use of Ohm's Law, equation (1), its value was 6.6kΩ. R_1 was then calculated through the use of KCL, equation (2), and Ohm's law, equation (1). Its resistance value was 2.2kΩ.

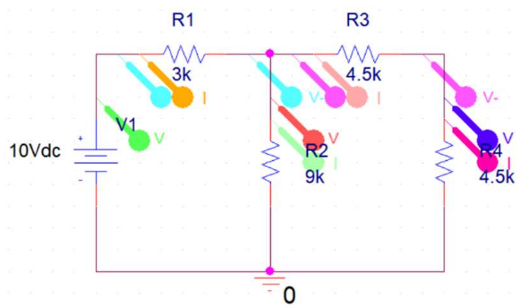

Figure 5.3 – Designed Resistive Circuit with 3kΩ, 9kΩ, and two 4.5kΩ resistors

For the circuit in Figure 5.3 the same procedure of find the resistors values was used as in Figure 5.2. Equation (4) was used to find R_3 and R_4. Then, equation (7) was used to calculated R_2. Finally, R_1 was calculated using equation (10).

5.3 EXPERIMENT & SIMULATION DATA & RESULTS

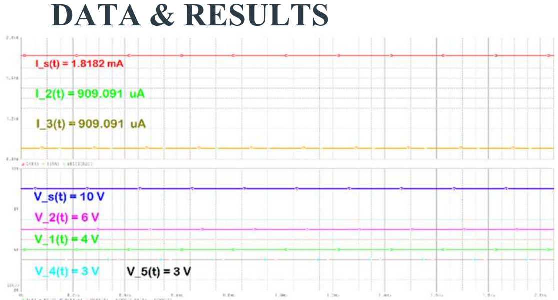

Figure 5.4 – Waveform for Circuit Shown in Figure 5.1

When Figure 5.1 was simulated, and the desired voltages where achieved. It showed that the use of Ohm's law, KCL, and KVL was done correctly. The waveform output by the simulation of Figure 5.2 is seen at Figure 5.4 along with the simulation data on Figure 5.5.

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	0.000	0.000	0.000		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(V1:+,R1:2)	4.0000	4.0000	0.000		0.000	0.000	4.0000	4.0000	4.0000
	V(V1:+)	10.000	10.000	0.000		6.0000	6.0000	10.000	10.000	10.000
	V(R3:2)	6.0000	6.0000	0.000		2.0000	2.0000	6.0000	6.0000	6.0000
	V(R3:1)	3.0000	3.0000	0.000		-1.0000	-1.0000	3.0000	3.0000	3.0000
	V(R2:2,R3:1)	3.0000	3.0000	0.000		-1.0000	-1.0000	3.0000	3.0000	3.0000
	I(R1)	1.8182m	1.8182m	0.000		-3.9982	-3.9982	1.8182m	1.8182m	1.8182m
	I(R4)	909.091u	909.091u	0.000		-3.9991	-3.9991	909.091u	909.091u	909.091u
	ABS(I(R2))	909.091u	909.091u	0.000		-3.9991	-3.9991	909.091u	909.091u	909.091u

Figure 5.5 – Simulation Data for Circuit Shown in Figure 5.1

Figure 5.6 – Waveform for Circuit Shown in Figure 5.2

Figure 5.3 was also simulated, and the desired voltages where achieved. The waveform output by the simulation of Figure 5.3 is seen at Figure 5.6 along with the simulation data on Figure 5.7.

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	0.000	0.000	0.000		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	I(R1)	1.3333m	1.3333m	0.000		0.000	0.000	1.3333m	1.3333m	1.3333m
	I(R3)	666.667u	666.667u	0.000		-666.667u	-666.667u	666.667u	666.667u	666.667u
	-I(R2)	666.667u	666.667u	0.000		-666.667u	-666.667u	666.667u	666.667u	666.667u
	-I(R4)	666.667u	666.667u	0.000		-666.667u	-666.667u	666.667u	666.667u	666.667u
	V(R1:1)	10.000	10.000	0.000		9.999	9.999	10.000	10.000	10.000
	V(R2:2)	6.0000	6.0000	0.000		5.9987	5.9987	6.0000	6.0000	6.0000
	V(R4:2)	3.0000	3.0000	0.000		2.9987	2.9987	3.0000	3.0000	3.0000
	V(R1:1,R2:2)	4.0000	4.0000	0.000		3.9987	3.9987	4.0000	4.0000	4.0000
	V(R2:2,R4:2)	3.0000	3.0000	0.000		2.9987	2.9987	3.0000	3.0000	3.0000

Figure 5.7 – Simulation Data for Circuit Shown in Figure 5.2

5.4 DISCUSSION & CONLUSION

Using Ohm's Law along with Kirchhoff's voltage and current law allowed us to calculate the needed resistors values in order to get the desired resistors values. When simulated, it showed how these laws indeed work when used to design a resistive circuit instead of using it for only analyzing a circuit. When analyzing the simulated circuit is can be seen that our calculations are correct due to KVL and KCL holding up when analyzing the circuit post-simulation. Along with matching our theoretical calculations.

To conclude, the purpose of this lab was to further explore the use of Ohm's Law, KVL, and KCL. In context of this lab to use those fundamental electrical law to design a circuit instead of using it for strictly analysis of a circuit.

REFERENCES

[1] Mallard, Bejamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

[2] Svoboda, James A., and Richard C. Dorf. Introduction to Electric Circuits. John Wiley & Sons, 2014.

[3] Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm

APPLICATION OF NETWORK THEOREMS (THEVENIN'S, NORTON'S & SUPERPOSITION THEOREMS) CIRCUIT DESIGN, SIMULATION & EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ABSTRACT:

The objective of this lab is to calculate simulate and experimentally test network theorems including Thevenin, Norton, and Superposition Theorems. To accomplish this, we need three different circuits where we will need to calculate theoretical values and later test experimentally.

KEYWORDS: Thevenin, Norton, Superposition, Maximum Power Theorem

6.1 INTRODUCTION

General Equations:

Ohm's Law	$V = I * R$	(1)
KCL	$I_i = I_{o1} + I_{o2} + \cdots + I_{oN}$	(2)
KVL	$V_1 \pm V_2 \pm \cdots \pm V_N = 0$	(3)

Theorems:

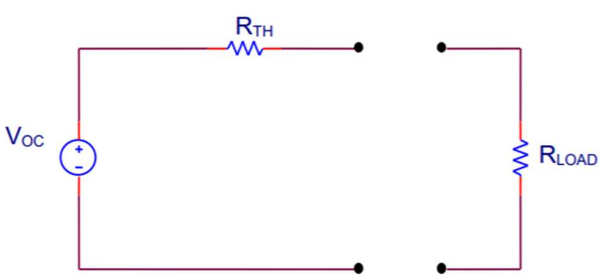

Figure 6.1-Thevenin's Theorem Circuit

Any two-terminal linear resistive circuit can be replaced by an equivalent circuit with a voltage source and a series resistor.

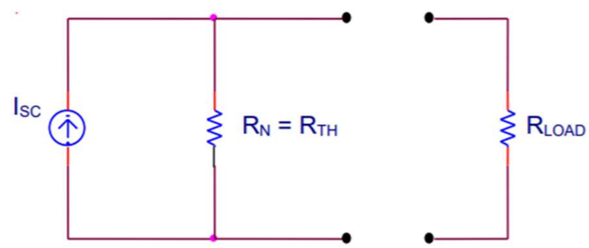

Figure 6.2-Norton's Theorem Circuit

Any two-terminal linear resistive circuit can be replaced by an equivalent circuit with a current source and a parallel resistor.

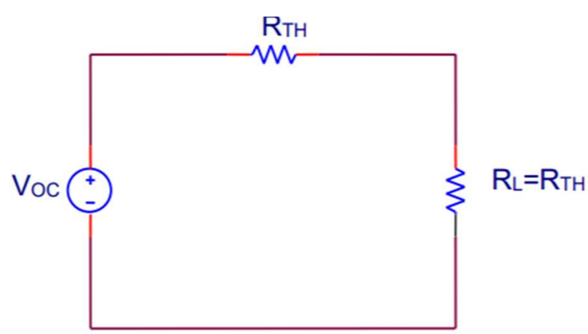

Figure 6.3 – Super Position Circuit

The maximum power theorem states that for the load resistor RL to dissipate the maximum power, its value must be equal to the Thevenin resistance

6.2 EXPERIMENT & SIMULATION SETUP & PROCEDURES

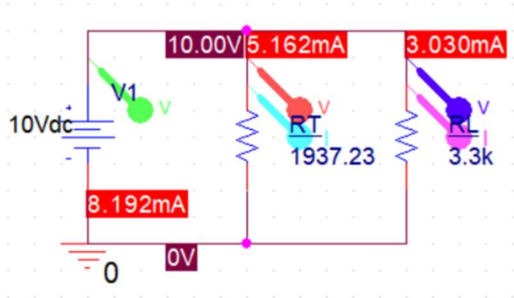

Figure 6.4 – Thevenin Equivalent Circuit I

Equations Calculated, Thevenin Circuit Author 1

$$R_{th} = 1k + 2.7k$$

$$R_{th} = 3.7k||1k$$

$$R_{th} = 787.23 + 680 + 470$$

$$R_{th} = 1937.23\,\Omega$$

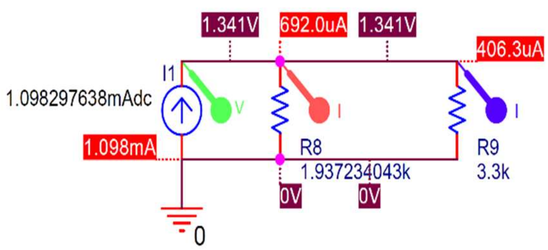

Figure 6.5 – Norton Equivalent Circuit I

Equations Calculated, Norton Circuit Author 2

$$R_{th} = ((R1 + R7)||R6) + R2 + R5$$

$$R_n = R_{th} = 1.937234043\ k\Omega$$

$$I_s = \frac{10\ V}{(R1 + R6 + R7)}$$

$$I_s = 2.127659574\ mA$$

$$V_a = -I_s R_2 + 10$$

$$V_a = 7.872340426\ V$$

$$V_b = V_a - I_s R_6$$
$$V_b = 5.744680852\ V$$

$$V_{oc} = V_a - V_b = 2.127659574\ V$$

$$I_{sc} = \frac{V_{oc}}{R_{th}} = 1.098297638\ mA$$

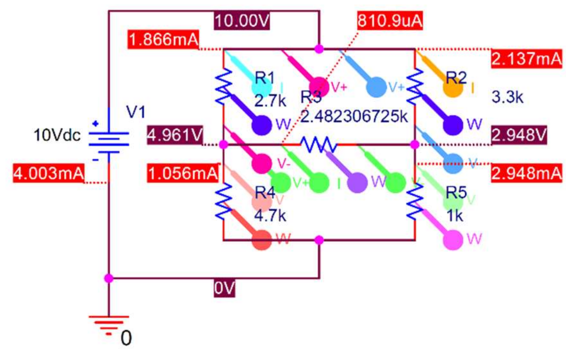

Figure 6.6 – Resistive Circuit II

Equations Calculated, Max Power

$$R_{th} = (R_1 \mid\mid R_4) + (R_2 \mid\mid R_5)$$

$$R_{th} = 2.482306725\ k\Omega$$

$$V_a = \frac{R_1 * 10V}{R_1 + R_4} = 6.\overline{351}\ V$$

$$V_b = \frac{R_2 * 10V}{R_2 + R_5} = 3.325581395\ V$$

$$V_{oc} = V_a - V_b = 4.02576656\ V$$

$$P_{max} = \frac{V_{oc}^2}{4 * R_{th}} = 1.6322342\ mW$$

$$R_{th} = R_L \rightarrow P_{max}$$

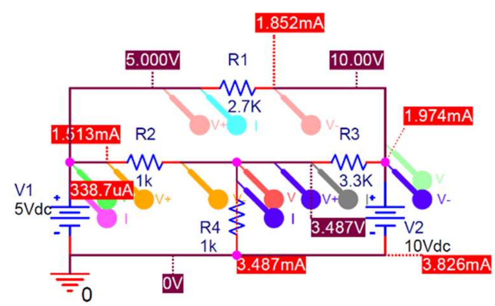

Figure 6.7 – Resistive Circuit III

	VR4	VR3
5 V	2.171052632	2.171052632
10 V	-8.684210526	1.315789474
Both	-6.513157894	3.486842106

Figure 6.8 – Circuit III Theoretical Values

6.3 EXPERIMENTAL & SIMULATION DATA & RESULTS

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	0.000	0.000	0.000		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(V1:+)	10.000	10.000	0.000		0.000	0.000	10.000	10.000	10.000
	V(V1:+,R1:2)	2.2141	2.2141	0.000		-7.7859	-7.7859	2.2141	2.2141	2.2141
	V(R2:1,R2:2)	276.254m	276.254m	0.000		-9.724	-9.724	276.254m	276.254m	276.254m
	V(R4:2,R4:1)	1.3407	1.3407	0.000		-8.6594	-8.6594	1.3407	1.3407	1.3407
	V(R5:1,R5:2)	190.941m	190.941m	0.000		-9.809	-9.809	190.941m	190.941m	190.941m
	V(R7:2,R7:1)	5.9781	5.9781	0.000		-4.0219	-4.0219	5.9781	5.9781	5.9781
	V(R2:1,R6:2)	1.8078	1.8078	0.000		-8.1922	-8.1922	1.8078	1.8078	1.8078
	I(R1)	2.2141m	2.2141m	0.000		-9.998	-9.998	2.2141m	2.2141m	2.2141m
	I(R6)	1.8078m	1.8078m	0.000		-9.998	-9.998	1.8078m	1.8078m	1.8078m
	I(R2)	406.256u	406.256u	0.000		-10.000	-10.000	406.256u	406.256u	406.256u

Figure 6.9 – Circuit I Simulation Results

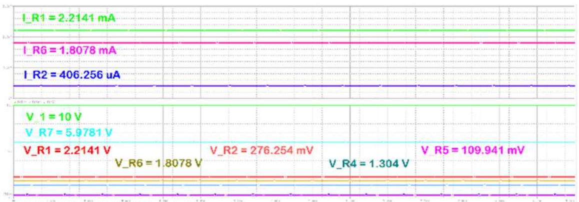

Figure 6.10 – Circuit I Waveform

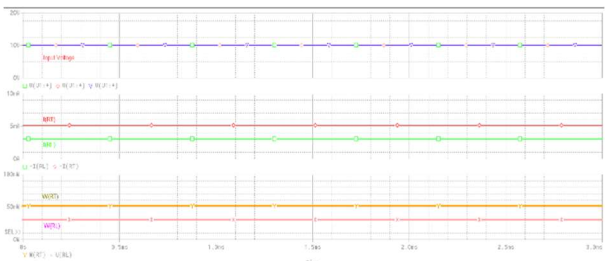

Figure 6.11 – Circuit I Thevenin Equivalent Circuit Waveform

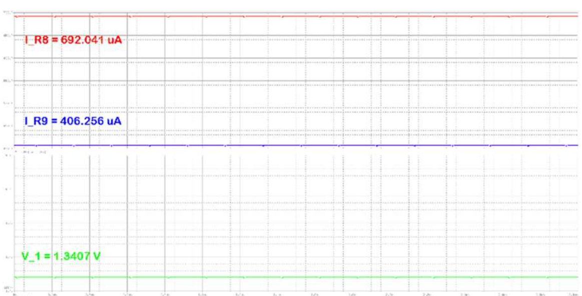

Figure 6.12 - Circuit I Norton Equivalent Circuit Waveform

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	0.000	0.000	0.000		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(R4:2,R3:1)	2.0129	2.0129	0.000		0.000	0.000	2.0129	2.0129	2.0129
	W(R4)	5.2360m	5.2360m	0.000		-2.0077	-2.0077	5.2360m	5.2360m	5.2360m
	W(R1)	9.4051m	9.4051m	0.000		-2.0035	-2.0035	9.4051m	9.4051m	9.4051m
	W(R5)	8.6901m	8.6901m	0.000		-2.0042	-2.0042	8.6901m	8.6901m	8.6901m
	-I(R1)	1.8664m	1.8664m	0.000		-2.0110	-2.0110	1.8664m	1.8664m	1.8664m
	-I(R2)	2.1370m	2.1370m	0.000		-2.0108	-2.0108	2.1370m	2.1370m	2.1370m
	V(R4:2)	4.9608	4.9608	0.000		2.9479	2.9479	4.9608	4.9608	4.9608
	V(R5:2)	2.9479	2.9479	0.000		935.010m	935.010m	2.9479	2.9479	2.9479
	V(V1:+,R1:1)	5.0392	5.0392	0.000		3.0263	3.0263	5.0392	5.0392	5.0392
	V(V1:+,R2:1)	7.0521	7.0521	0.000		5.0392	5.0392	7.0521	7.0521	7.0521
	W(R3)	1.6322m	1.6322m	0.000		-2.0113	-2.0113	1.6322m	1.6322m	1.6322m
	-I(R3)	810.893u	810.893u	0.000		-2.0121	-2.0121	810.893u	810.893u	810.893u
	W(R2)	15.070m	15.070m	0.000		-1.9978	-1.9978	15.070m	15.070m	15.070m

Figure 6.13 – Circuit II Simulation Results

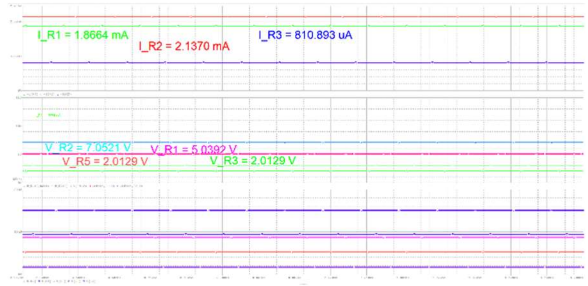

Figure 6.14 – Circuit II Waveform

Resistor (kΩ)	Power (mW)
1	1.337
1.5	1.533
2	1.613
2.48	1.632
3	1.629
3.5	1.599
4	1.476

Figure 6.15 – Circuit II
Table of Resistance vs Power

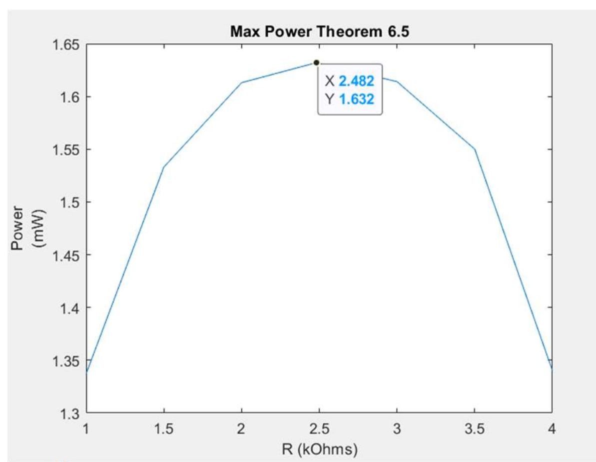

Figure 6.16 – Circuit II
Plot of Resistance vs Power

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	0.000	0.000	0.000		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	V(R2:1,R2:2)	1.5132	1.5132	0.000		1.5128	1.5128	1.5132	1.5132	1.5132
	V(R2:1,R1:2)	-5.0000	-5.0000	0.000		-5.0003	-5.0003	-5.0000	-5.0000	-5.0000
	V(R2:1)	5.0000	5.0000	0.000		4.9997	4.9997	5.0000	5.0000	5.0000
	V(R2:2)	3.4868	3.4868	0.000		3.4865	3.4865	3.4868	3.4868	3.4868
	V(R2:2,R3:2)	-6.5132	-6.5132	0.000		-6.5135	-6.5135	-6.5132	-6.5132	-6.5132
	V(V2:+)	10.000	10.000	0.000		10.000	10.000	10.000	10.000	10.000
CURSOR 1,2	I(V1)	338.694u	338.694u	0.000		0.000	0.000	338.694u	338.694u	338.694u
	-I(R4)	3.4868m	3.4868m	0.000		3.1482m	3.1482m	3.4868m	3.4868m	3.4868m
	I(R1)	-1.8519m	-1.8519m	0.000		-2.1906m	-2.1906m	-1.8519m	-1.8519m	-1.8519m
	ABS(I(R3))	1.9737m	1.9737m	0.000		1.6350m	1.6350m	1.9737m	1.9737m	1.9737m

Figure 6.17 – Circuit III Simulation Results

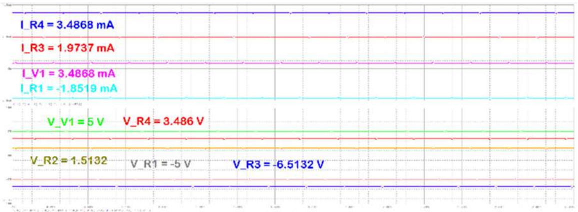

Figure 6.18 – Circuit III Waveform

6.4 DISCUSSION & CONCLUSION

The purpose of this lab was to first, find the Thevenin and Norton equivalents of circuit I, second to find to apply the max power theorem onto circuit II to find the max power output, and finally to use superposition and find to find the voltages across resistors R3 and R4 in circuit III. We have not yet completed the experimental part of the lab, but it is a success since our calculated values matched with simulated values validating the theorems we used.

REFRENCES

1. Mallard, Bejamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

2. Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm

DESIGN EXPERIMENT – CIRCUIT II - IMPLEMENTING MAXIMUM POWER TRANSFER – DESIGN, SIMULATION AND EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ABSTRACT: The purpose of this lab is to learn to design a resistive circuit to achieve the desired max power transfer. Thevenin equivalent theory was used to create a 1-to-1 circuit in order to simplify an otherwise complex resistive circuit. Then through the use of Maximum power transfer theorem, the maximum power through the load resistor, R_L, would be found.

KEYWORDS: Ohm's Law, KCL, KVL, Power, Resistive, Design, MATLAB, Simulation, PSpice, Max Power Transfer

7.1 INTRODUCTION

Equations		
Ohm's Law	$V = I * R$	(1)
Voltage Divider	$V_{out} = V_{in} * \left(\frac{R_2}{R_1 + R_2}\right)$	(2)
Parallel Resistors	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$	(3)
Series Resistors	$R_{eq} = R_1 + R_2 + \cdots + R_n$	(4)
Maximum Power Transfer	$P_{MAX} = \frac{V_{oc}^2}{4R_{th}}$	(5)

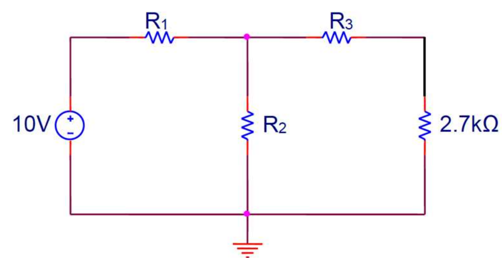

Figure 7.1 – Designed Resistive Circuit Canvas

Figure 7.1 is a resistive circuit in which correct resistor values must be chosen in order to achieve the desired Thevenin resistance in order to adhere to the Maximum Power Transfer Theorem. In other word, R_{th}, must equal R_L to calculate the maximum power possible in this circuit.

7.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

Equations Calculated for Figure 7.2

$$R_{th} = (R_1||R_2) + R_3$$
$$2.7k\Omega = \frac{R_1R_2}{R_1 + R_2} + R_3$$
$$R_1, R_2 = 1k\Omega, \quad R_3 = 2.2k\Omega$$
$$V_{OC} = \frac{R_2 * 10V}{R_2 + R_1}$$
$$V_{OC} = 5V$$
$$R_L = 2.7k\Omega$$
$$P_{MAX} = \frac{V_{oc}^2}{4R_{th}}$$
$$P_{MAX} = 2.314814815\ mW$$

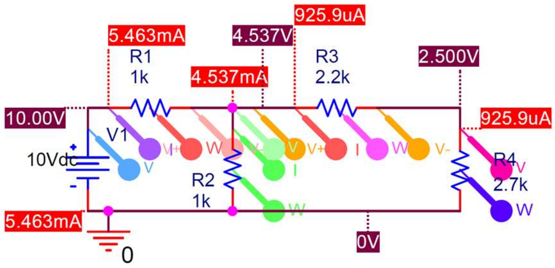

Figure 7.2 – Designed Resistive Circuit I

In order to create a Thevenin equivalent circuit of Figure 7.2, the Thevenin resistance and the Voltage of the open circuit need to be calculated. The Thevenin resistance was calculated by removing the load resistor, 2.7kΩ, and shorting the voltage source. Since we need to design the circuit, resistor value for R_1 and R_2 were set to 1kΩ. This resulted in R_3 being 2.2kΩ. V_{oc} was calculated by using voltage divider (2) of R_1 and R_2 which was 5 V. These are then plugged in into the maximum power transfer theorem (5) and our maximum power transfer is ~2.315.

Equations Calculated for Figure 7.3

$$R_{th} = (R_1||R_2) + R_3$$

$$2.7k\Omega = \frac{R_1 R_2}{R_1 + R_2} + R_3$$

$$R_1, R_3 = 1.5k\Omega, \qquad R_2 = 1.95k\Omega$$

$$V_{OC} = \frac{R_2 * 10V}{R_2 + R_1}$$

$$V_{OC} = 5.652173913 \text{ V}$$

$$R_L = 2.7k\Omega$$

$$P_{MAX} = \frac{V_{oc}^2}{4R_{th}}$$

$$P_{MAX} = 2.314814815\ mW$$

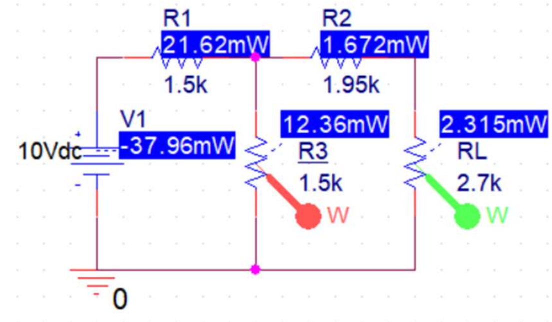

Figure 7.3 – Designed Resistive Circuit II

The steps taken to calculated theoretical values of Figure 7.2 were repeated for Figure 7.4.

7.3 EXPERIMENTAL & SIMULATION DATA & RESULTS

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	0.000	0.000	0.000		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	W(R4)	2.3148m	2.3148m	0.000		-2.2222m	-2.2222m	2.3148m	2.3148m	2.3148m
	W(R3)	1.8862m	1.8862m	0.000		-2.6509m	-2.6509m	1.8862m	1.8862m	1.8862m
	W(R2)	20.585m	20.585m	0.000		16.048m	16.048m	20.585m	20.585m	20.585m
	W(R1)	29.844m	29.844m	0.000		25.307m	25.307m	29.844m	29.844m	29.844m
	V(R3:1,R3:2)	2.0370	2.0370	0.000		2.0325	2.0325	2.0370	2.0370	2.0370
	V(R3:1)	4.5370	4.5370	0.000		4.5325	4.5325	4.5370	4.5370	4.5370
	V(R4:1)	2.5000	2.5000	0.000		2.4955	2.4955	2.5000	2.5000	2.5000
	V(V1:+)	10.000	10.000	0.000		9.996	9.996	10.000	10.000	10.000
	V(R1:1,R1:2)	5.4630	5.4630	0.000		5.4584	5.4584	5.4630	5.4630	5.4630
CURSOR 1,2	-I(R2)	4.5370m	4.5370m	0.000		0.000	0.000	4.5370m	4.5370m	4.5370m
	I(R3)	925.926u	925.926u	0.000		-3.6111m	-3.6111m	925.926u	925.926u	925.926u
	I(R1)	5.4630m	5.4630m	0.000		925.926u	925.926u	5.4630m	5.4630m	5.4630m

Figure 7. 4 – Circuit I Simulation Results

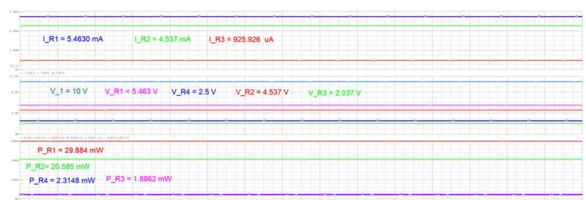

Figure 7.5 – Circuit I Waveform

The theoretical calculations done for Figure 7.2 are aligned with the simulation results. Since only R_L = 2.7kΩ was simulated this only shows us the power at this point, to see if this resistor value does indeed achieve maximum power transfer, we need to plot it along with other resistor values greater and lesser than.

Resistor (kΩ)	Power (mW)
1	1.82615
1.5	2.12585
2	2.26346
2.7	2.31481
3.5	2.27627
4	2.22766
5	2.10828

Table 7.6 – Circuit I with Variable R_L Resistor and Power

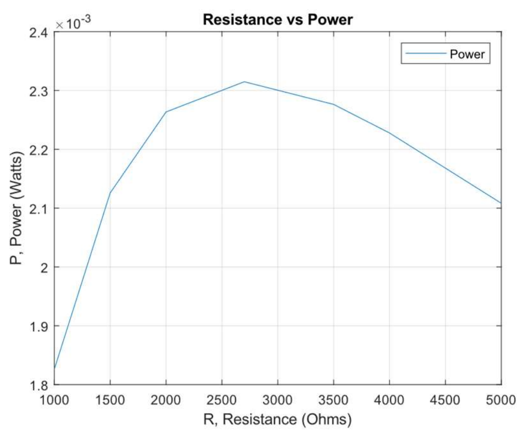

Figure 7.7 – Circuit I with Variable R_L Resistor vs Power Plot

Figure 7.7 indeed proves that the max power transfer was achieved in the simulated and calculated circuit since resistors greater and less than have a lower power level then if R_L was 2.7kΩ.

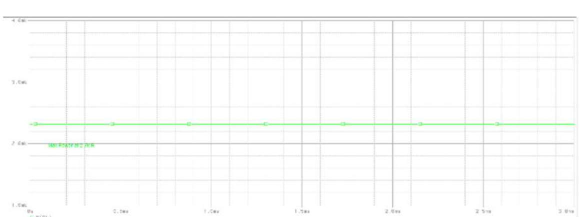

Figure 7.8 – Circuit II Simulation Waveform

The simulation waveform for Figure 7.3 also shows that the selected resistor values did indeed cause R_L to have the desired maximum power transfer.

Resistor (kΩ)	Power (mW)
1	1.826
1.5	2.126
2	2.263
2.7	2.315
3	2.293
3.5	2.276
4	2.228

Figure 7.9 – Circuit II with Variable R_L Resistor and Power

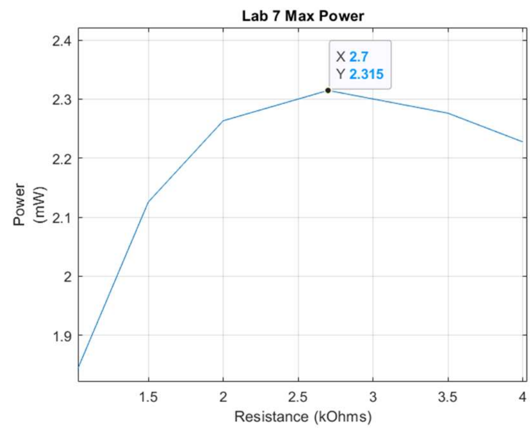

Figure 7.10 – Circuit II with Variable R_L Resistor vs Power Plot

Figure 7.10 shows the circuit response to a varying R_L and its effect on its power.

7.4 DISCUSSION & CONCLUSION

By creating a Thevenin equivalent circuit we are able to design a circuit in order to achieve a desired max power transfer. When simulated we see that these theorems do indeed work as seen in the theoretical calculations. The lab main objective was accomplished since the desired power was calculated and simulated correctly. It was also further proved by plotting different resistor values in order to see is 2.7kΩ truly achieved.

To conclude, the purpose of this lab was to further explore the use of the maximum power transfer theorem in a design implementation. In context of this lab to use fundamental electrical laws to design a circuit to achieve desired results.

REFERENCES

[1] Mallard, Bejamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

[2] Svoboda, James A., and Richard C. Dorf. Introduction to Electric Circuits. John Wiley & Sons, 2014.

[3] Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm

OPERATIONAL AMPLIFIERS DESIGN, SIMULATION AND EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ABSTRACT: The purpose of this lab was to learn how to use inverse and non-inverse operational amplifiers with different Rf values that led to different amplifications of the input waves. In this lab we were tasked to simulate and later experimentally test the circuits in this lab

KEYWORDS: Operational Amplifier (Op Amp), Voltage (V), Resistance (R), Sine Wave, Frequency

8.1 INTRODUCTION

Equations:

Inverse Op-Amp $\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}$

Non-Inverse Op-Amp $\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$

Calculations:

Author 1:

1. Vout = (-10kΩ /10kΩ)*.3sin(t)
   Vout = -.3sin(t)
2. Vout = (-100kΩ /10kΩ)*.3sin(t)
   Vout = -3sin(t)
3. Vout = (1 + (27kΩ /10kΩ))*.3sin(t)
   Vout = 1.11sin(t)
4. Vout = (1 + (0 /10kΩ))*.3sin(t)
   Vout = .3sin(t)

Author 2:

1. Vout = (-27kΩ /10kΩ)*.3sin(t)
   Vout = -0.81sin(t)
2. Vout = (1 + (10kΩ /10kΩ))*.3sin(t)
   Vout = 0.6sin(t)
3. Vout = (1 + (100kΩ /10kΩ))*3sin(t)
   Vout = 3.3sin(t)
4. Vout = (1 + (2kΩ/10kΩ))*.3sin(t)
   Vout = 0.36sin(t)

$$V_{R5} = V_{out} - \left(\frac{6.2k\Omega * V_{out}}{6.2k\Omega + 3.3k\Omega}\right)$$

$$V_{R5} = 0.125\sin(t)\ \mathrm{V}$$

$$V_{R6} = \left(\frac{6.2k\Omega * V_{out}}{6.2k\Omega + 3.3k\Omega}\right)$$

$$V_{R6} = 0.2349\sin(t)\ \mathrm{V}$$

8.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

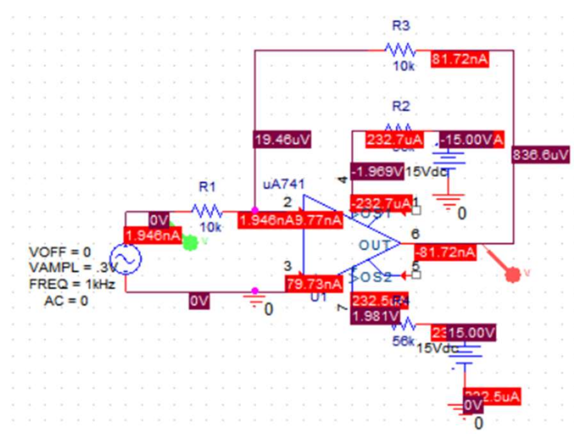

Figure 8.1 – Author 1 Inverting Op-Amp Rf = 10 kOhms

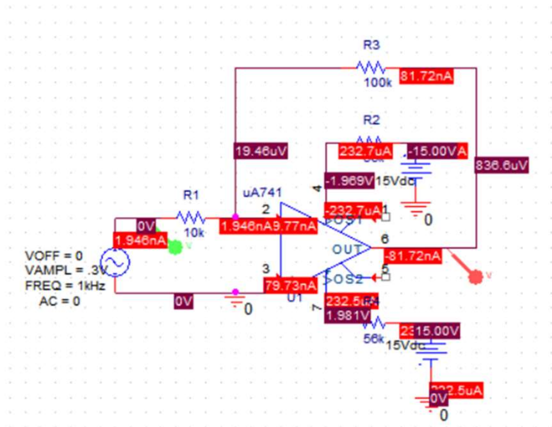

Figure 8.2 – Author 1 Inverting Op-Amp Rf = 100 kOhms

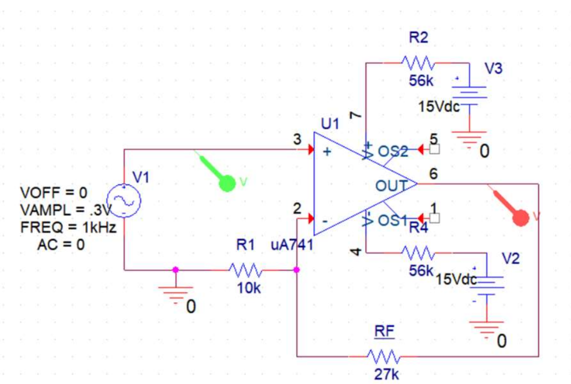

Figure 8.3 – Author 1 Non-Inverting Op-Amp Rf = 27 kOhms

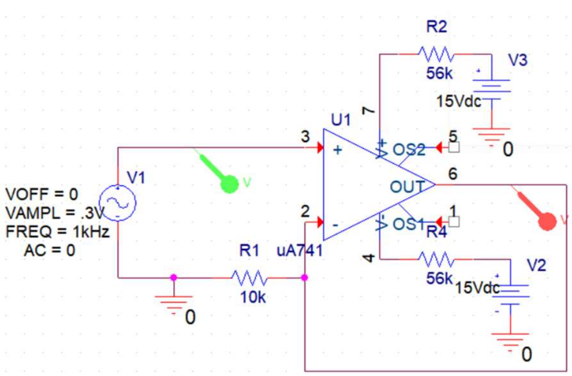

Figure 8.4 – Author 1 Non-Inverting Op-Amp Rf short circuit

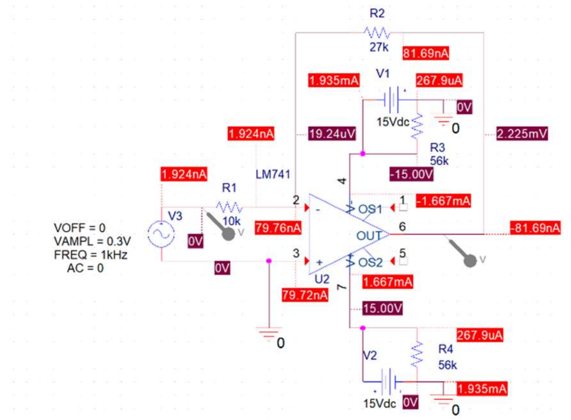

Figure 8.5 – Author 2 Inverting Op-Amp Circuit R_f = 2.7kΩ

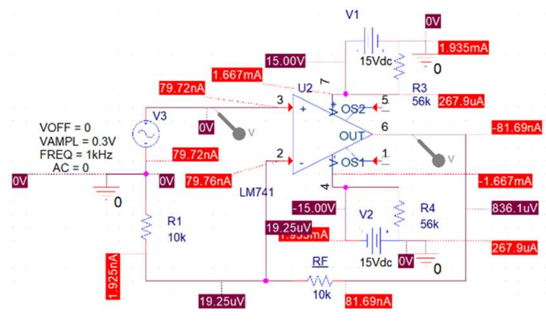

Figure 8.6 – Author 2 Non-Inverting Op-Amp Circuit R_f = 10kΩ

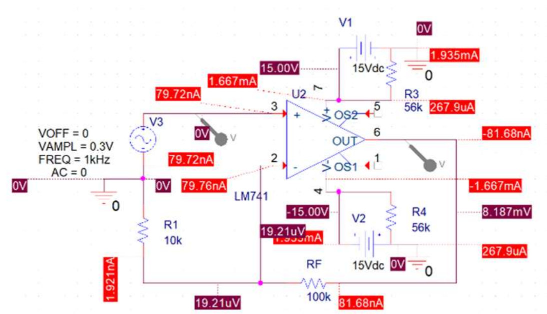

Figure 8.7 – Author 2 Non-Inverting Op-Amp Circuit R_f = 100kΩ

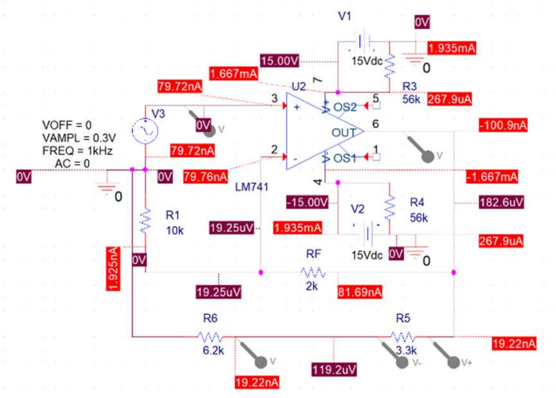

Figure 8.8 – Author 2 Non-Inverting Op-Amp Circuit With Load

8.3 EXPERIMENTAL & SIMULATION DATA & RESULTS

Figure 8.9 – Author 1 Simulated Waveform for Inverting Op-Amp Rf = 10 kΩ

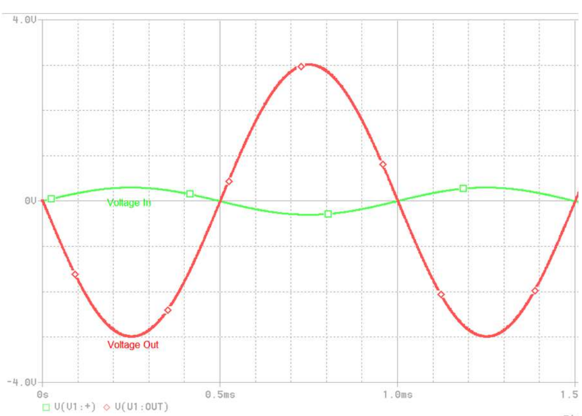

Figure 8.10 – Author 1 Simulated Waveform for Inverting Op-Amp Rf = 100 kΩ

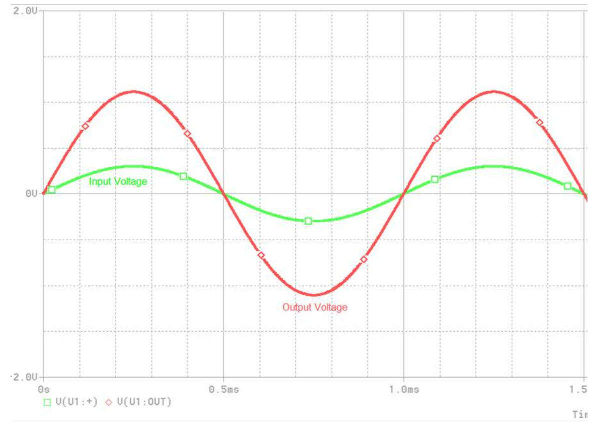

Figure 8.11 – Author 1 Simulated Waveform for Non-Inverting Op-Amp Rf = 27 kΩ

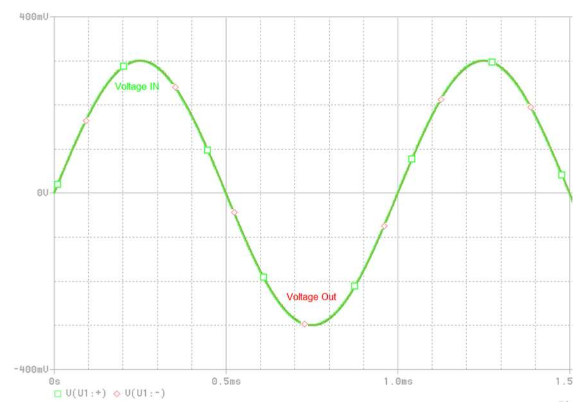

Figure 8.12 – Author 1 Simulated Waveform for Non-Inverting Op-Amp Rf short circuit

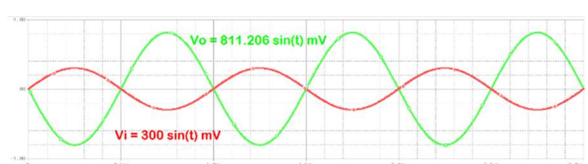

Figure 8.13 – Author 2 Simulated Inverting Op-Amp Circuit Waveform R_f = 27kΩ,

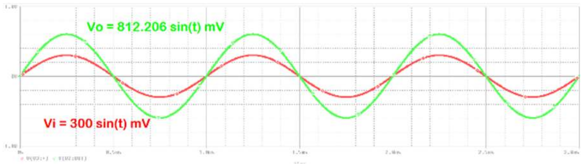

Figure 8.14 – Author 2 Simulated Non-Inverting Op-Amp Circuit Waveform R_f = 10kΩ

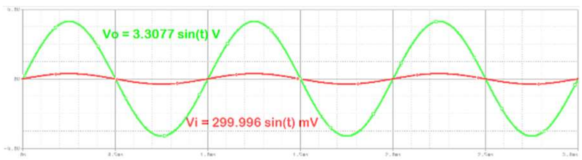

Figure 8.15 – Author 2 Simulated Non-Inverting Op-Amp Circuit Waveform R_f = 100kΩ

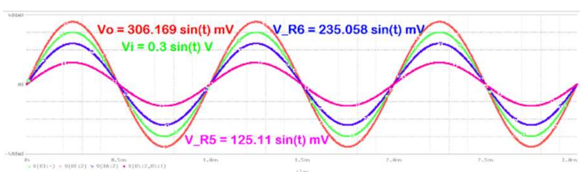

Figure 8.16 – Author 2 Simulated Non-Inverting Op-Amp Circuit With Load Waveform

8.4 DISCUSSION & CONCLUSION

By changing the Rf value we were able to amplify the input voltage and invert it when needed by configuring the op amp as inverting instead of non-inverting. In the simulation everything matched up with theoretically calculated values and for that reason I think that this lab was a success as it gave us an understanding of the theory behind op amps and practice with them.

REFRENCES

1. Mallard, Bejamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

2. Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm

3. PSPICE Guide for ECE 240L Lab Prepared by: Pamela Norva, ECE Lab Assistant, Spring 2018

FIRST ORDER CIRCUITS DESIGN, SIMULATION AND EXPERIMENTAL TEST AS WELL AS ANALYSIS

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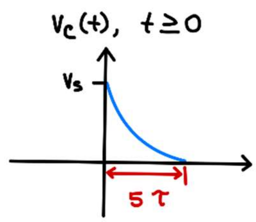
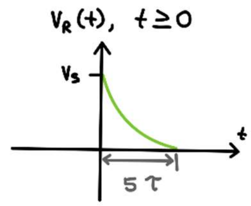
ABSTRACT: The purpose of this lab was to design a RC and RL circuit's input waveform in order to get a desired output signal. These circuit was first theoretically calculated, then simulated and finally experimentally tested.

KEYWORD: RL, RC, Design, Frequency, Discharging, Charging, Capacitor, Inductor

9.1 INTRODUCTION

Preliminary Calculations
(1) $V_s = V_{oc}$ $V_R = V_s\left(\frac{R}{R_{int} + R}\right)$ $V_R = V_{oc}\left(\frac{R}{R_{int} + R}\right)$ $V_R R_{int} + V_R R = V_{OC} R$ $R_{int} = \frac{R(V_{oc} - V_R)}{V_R}$
(2) 
(3) $V_L = 1\text{V} * \frac{R_{dc}}{R + R_{dc}}$ $V_L R + V_L R_{dc} = R_{dc}$ $V_L R = (1 - V_L) R_{dc}$ $R_{dc} = V_L\left(\frac{R}{1 - V_L}\right)$
(4) 

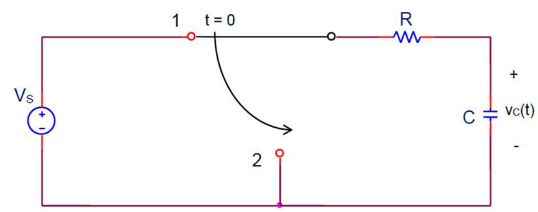


Figure 9.1 – Case 1 & 2 General Circuit

Case I and II consisted of a series RC circuit where the input signal's frequency and period need to be calculated to get a desired output.

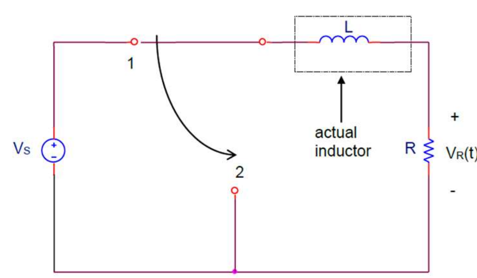


Figure 9.2 – Case 3 & 4 General Circuit

Case III and IV consisted of a series RL circuit and has similar requirements as case I and II.

9.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

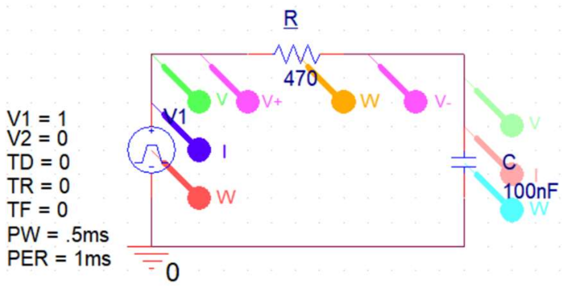


Figure 9.3 – Case 1 Simulated Circuit

Calculations for Figure 9.4	
$\tau = RC = 680\ \mu\text{sec}$	(4)
$T = 2 * 5\tau = 6.8\ msec$	(5)
$f = \dfrac{1}{T} = 147.0588235\ Hz$	(6)

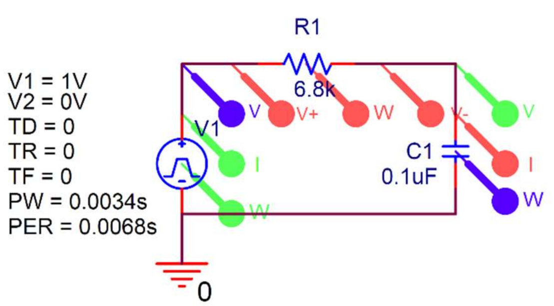


Figure 9.4 – Case 2 Simulated Circuit

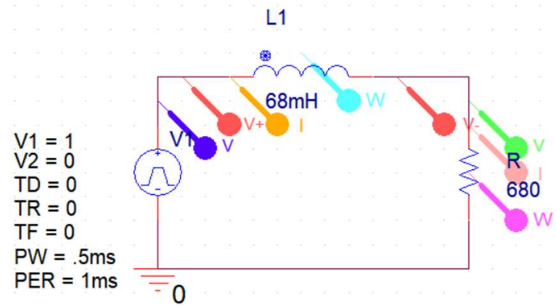


Figure 9.5 – Case 3 Simulated Circuit

Calculations for Figure 9.6	
$\tau = \dfrac{L}{R} = 144.6808511\ \mu\text{sec}$	(7)
$T = 2 * 5\tau = 1.446808511\ msec$	(8)
$f = \dfrac{1}{T} = 691.1764704\ Hz$	(9)

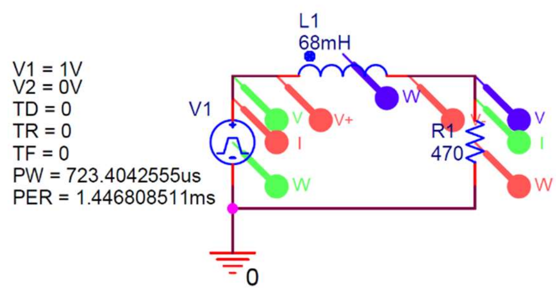


Figure 9.6 – Case 4 Simulated Circuit

9.3 EXPERIMENTAL & SIMULATION DATA & RESULTS

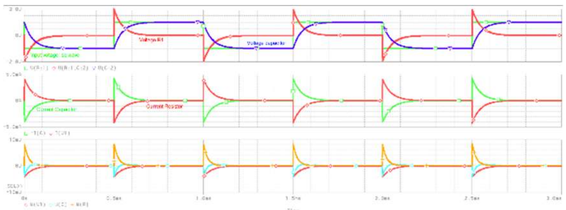


Figure 9.7 – Case 1 Simulated Circuit Waveform

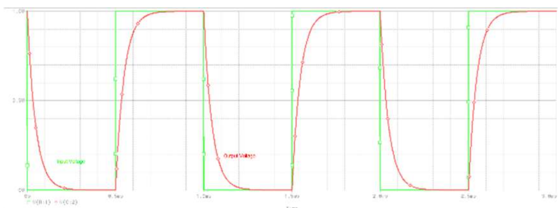


Figure 9.8 – Case 1 Simulated Circuit Waveform, V_{in} & V_{out} only

Probe Cursor

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		146.951u		
	X Values	1.0000u	0.000	1.0000u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	W(V1)	0.000	0.000	0.000		-146.951u	0.000	0.000	0.000	0.000
	W(R1)	14.705n	14.705n	0.000		-146.936u	14.705n	14.705n	14.705n	14.705n
	W(C1)	0.000	0.000	0.000		-146.951u	0.000	0.000	0.000	0.000
CURSOR 1,2	I(V1)	146.951u	0.000	146.951u		0.000	0.000	146.951u	0.000	73.475u
	-I(C1)	0.000	0.000	0.000		-146.951u	0.000	0.000	0.000	0.000
	V(C1:2)	1.0000	1.0000	0.000		0.9999	1.0000	1.0000	1.0000	1.0000
	V(R1:1)	1.0000	1.0000	0.000		0.9999	1.0000	1.0000	1.0000	1.0000
	V(R1:1,R1:2)	111.0E-18	111.0E-18	0.000		-146.951u	111.0E-18	111.0E-18	111.0E-18	111.0E-18

Figure 9.9 – Case 2 Simulated Circuit Tabular Data

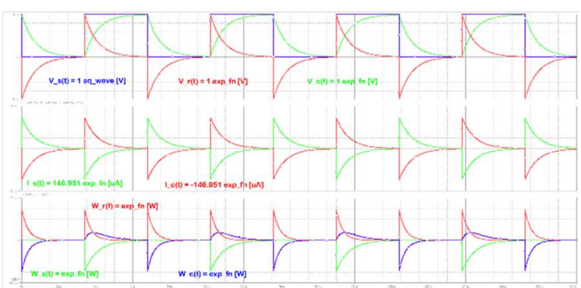


Figure 9.10 – Case 2 Simulated Circuit Waveform

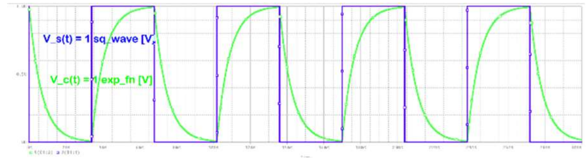


Figure 9.11 – Case 2 Simulated Circuit Waveform, $V_S(t)$ and $V_C(t)$

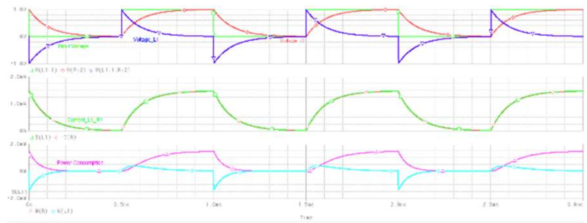


Figure 9.12 – Case 3 Simulated Circuit Waveform

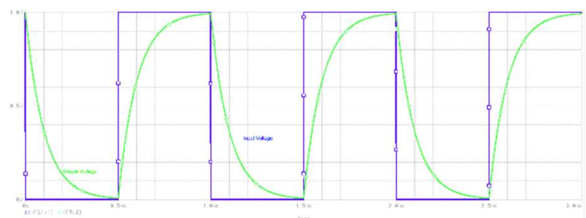


Figure 9.13 – Case 3 Simulated Circuit Waveform, V_{in} & V_{out} only

Probe Cursor

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	0.000	0.000	0.000		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	W(V1)	-2.1312m	-2.1312m	0.000		-1.0021	-1.0021	-2.1312m	-2.1312m	-2.1312m
	W(L1)	10.499u	10.499u	0.000		-1.0000	-1.0000	10.499u	10.499u	10.499u
	W(R1)	2.1277m	2.1277m	0.000		-0.9979	-0.9979	2.1277m	2.1277m	2.1277m
	I(V1)	-2.1277m	-2.1277m	0.000		-1.0021	-1.0021	-2.1277m	-2.1277m	-2.1277m
	-I(R1)	2.1277m	2.1277m	0.000		-0.9979	-0.9979	2.1277m	2.1277m	2.1277m
CURSOR 1,2	V(L1:1)	1.0000	1.0000	0.000		0.000	0.000	1.0000	1.0000	1.0000
	V(L1:1,L1:2)	2.6247m	2.6247m	0.000		-0.9974	-0.9974	2.6247m	2.6247m	2.6247m
	V(R1:2)	1.0000	1.0000	0.000		-691.129n	-691.129n	1.0000	1.0000	1.0000

Output Window | Probe Cursor

Figure 9.14 – Case 4 Simulated Circuit Tabular Data

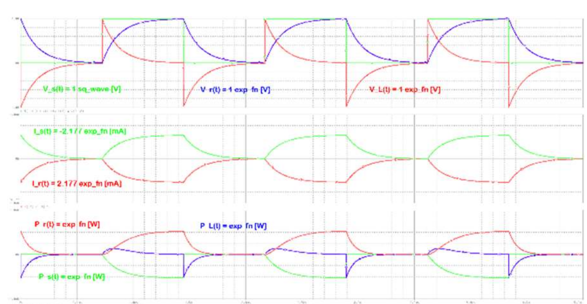


Figure 9.15 – Case 4 Simulated Circuit Waveform

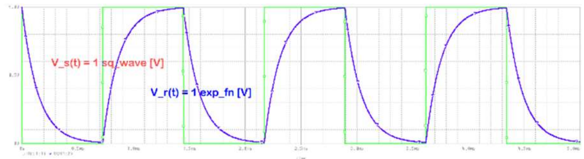


Figure 9.16 – Case 4 Simulated Circuit Waveform, $V_s(t)$ and $V_R(t)$

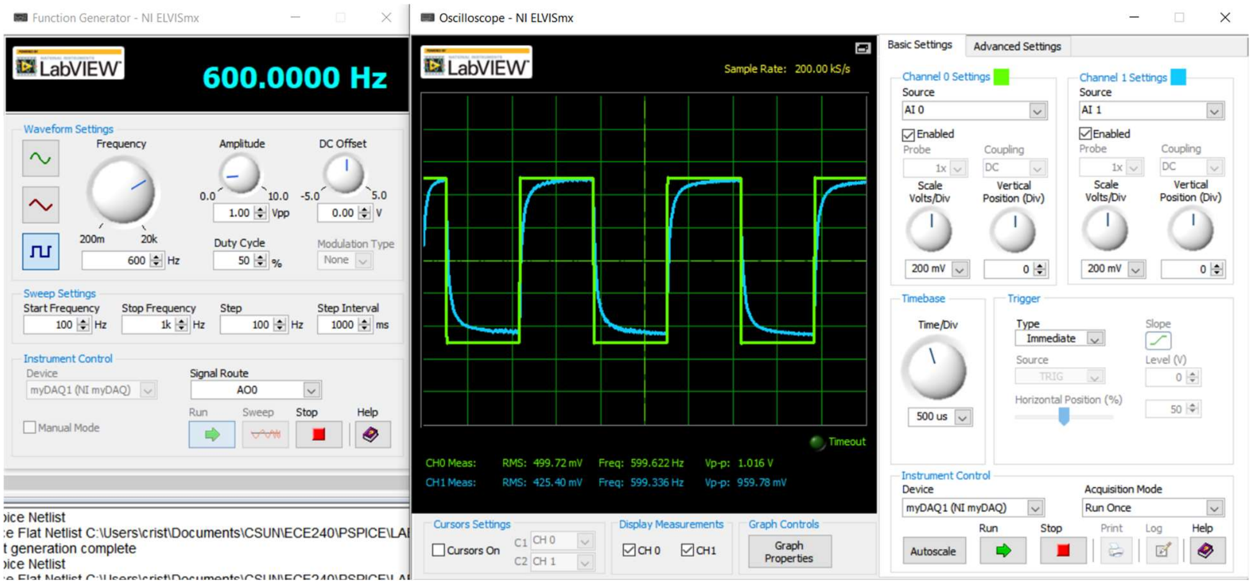


Figure 9.17 – Case 1 Experimental Circuit
Experimental Waveform, V_{in} and V_C

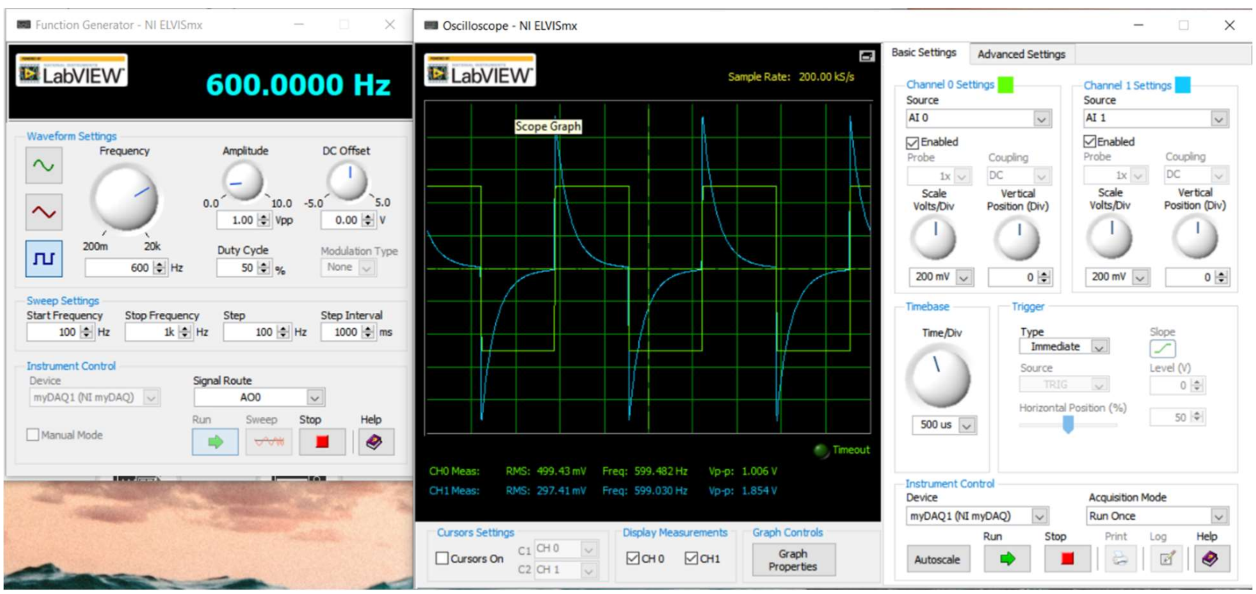


Figure 9.18 – Case 1 Experimental Circuit
Experimental Waveform, V_{in} and V_R

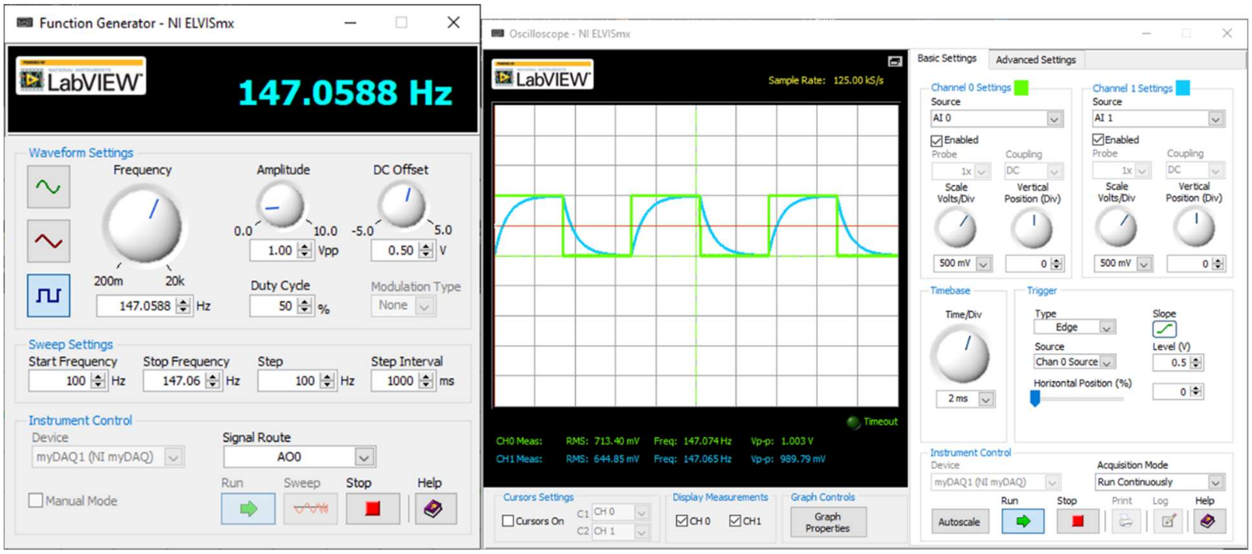


Figure 9.19 – Case 2 Experimental Circuit
Experimental Waveform, V_{in} and V_C

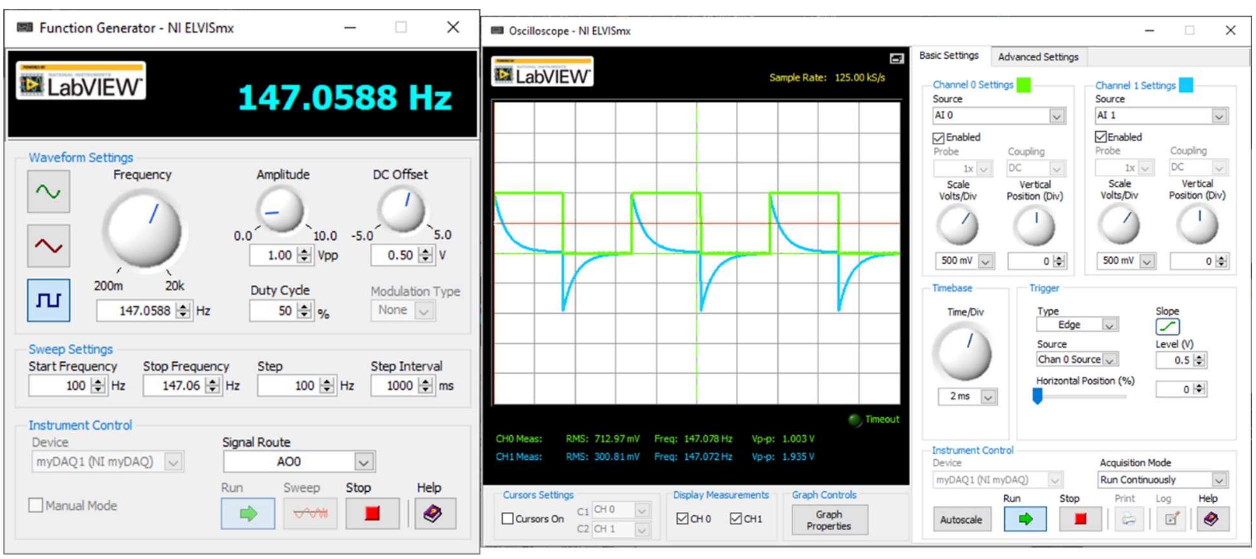


Figure 9.20 – Case 2 Experimental Circuit
Experimental Waveform, V_{in} and V_R

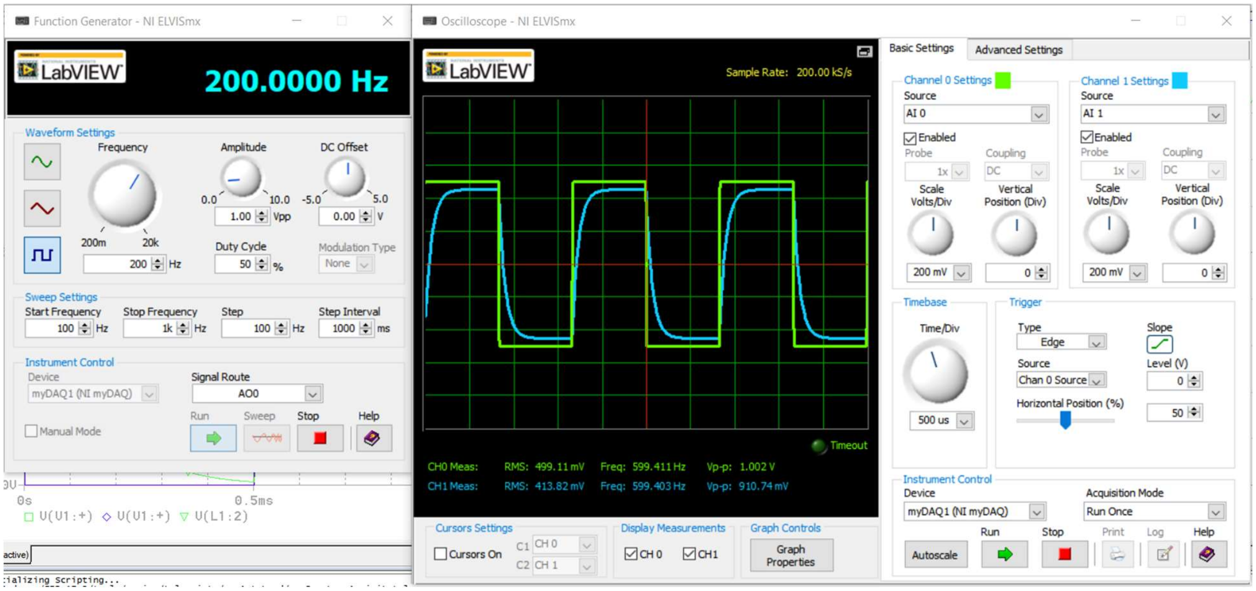


Figure 9.21 – Case 3 Experimental Circuit
Experimental Waveform, V_{in} and V_R

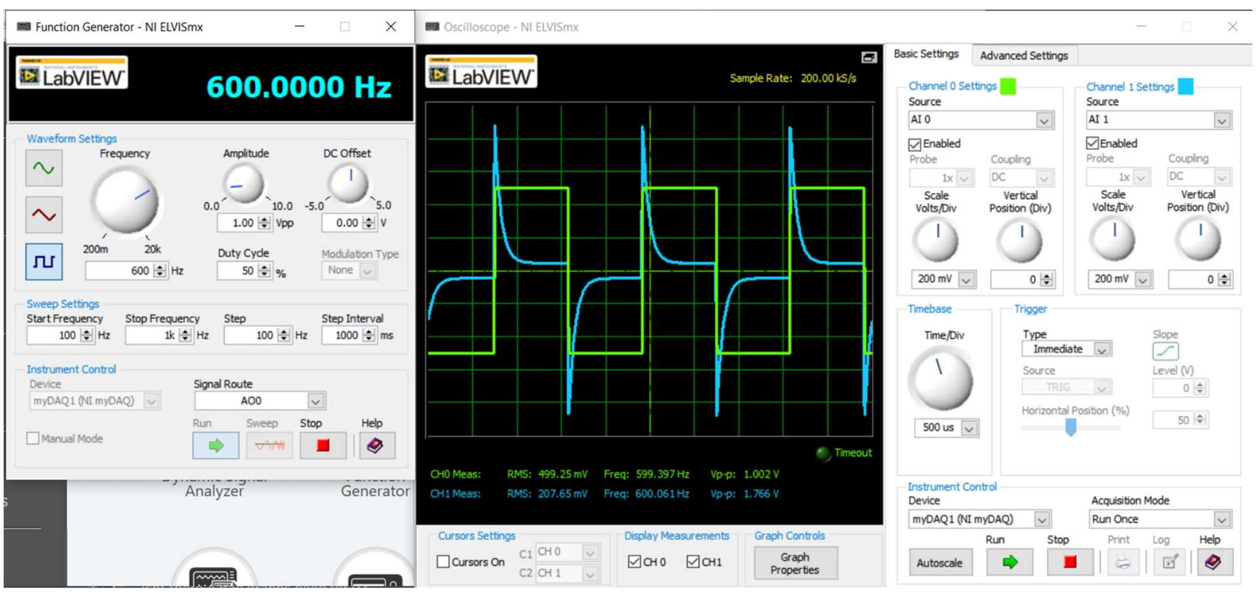


Figure 9.22 – Case 3 Experimental Circuit
Experimental Waveform, V_{in} and V_L

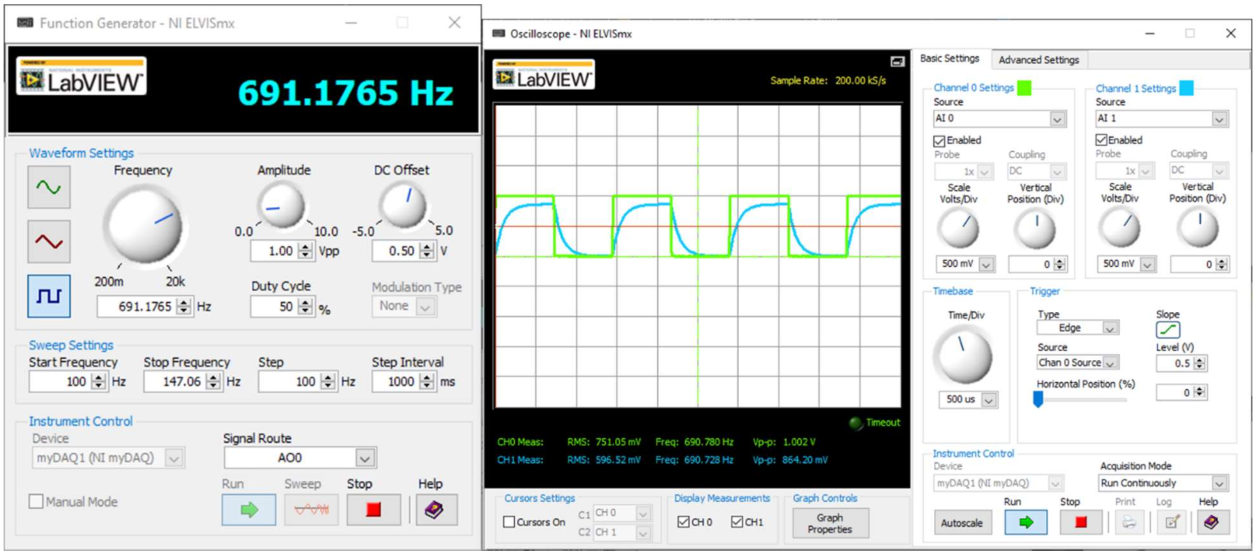


Figure 9.23 – Case 4 Experimental Circuit
Experimental Waveform, V_{in} and V_R

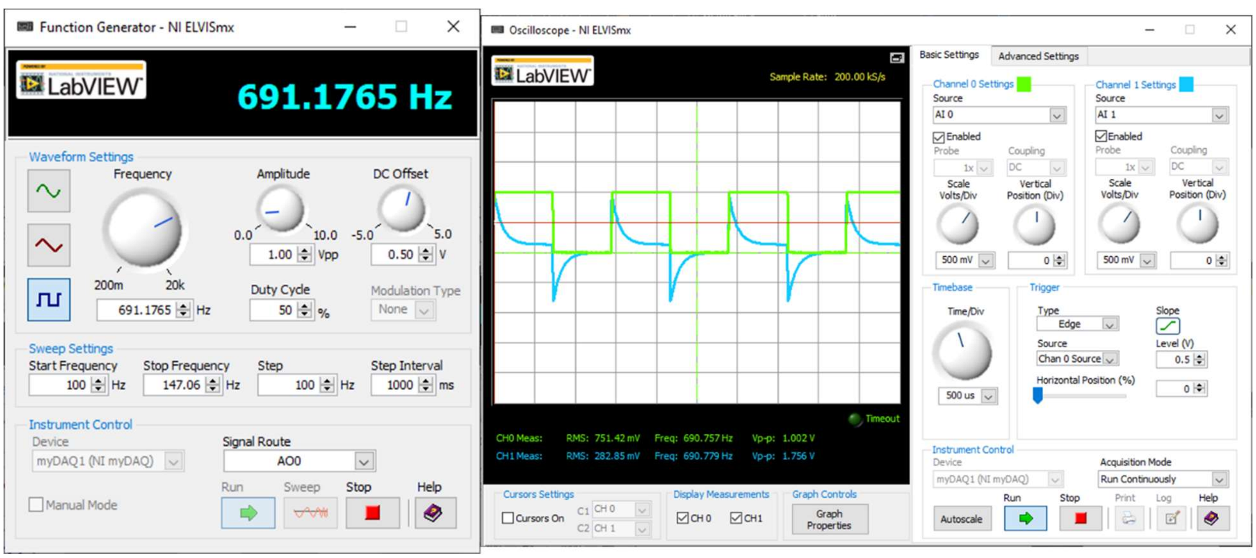


Figure 9.24 – Case 4 Experimental Circuit
Experimental Waveform, V_{in} and V_L

9.4 DISCUSSION & CONCLUSION

Knowing the resistor, capacitor, and inductor values for a specific first order circuit allows us to calculate the frequency and pulse width needed to charge the capacitor or resistor to a desired level. Along with calculated the time need to discharge said component. The experiment conductor were successful due to us being able to precisely calculate the frequency need to output a desired frequency.

REFERENCES

[1] Mallard, Bejamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

[2] Svoboda, James A., and Richard C. Dorf. Introduction to Electric Circuits. John Wiley & Sons, 2014.

[3] Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm

DESIGN EXPERIMENT – CIRCUIT III – IMPLEMENTING RC CIRCUITS, SIMULATION & EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ABSTRACT:

The purpose of this lab was to design a circuit that would charge a capacitor within a certain time using 2 different resistor and capacitor values for author 1 and 2.

10.1 INTRODUCTION

Equations	
$\tau = RC$	(1)
$V_c(t) = Vin * \left(1 - e^{-t/\tau}\right)$	(2)
$5\tau = \frac{T}{2}$	(3)
$f = \frac{1}{T}$	(4)

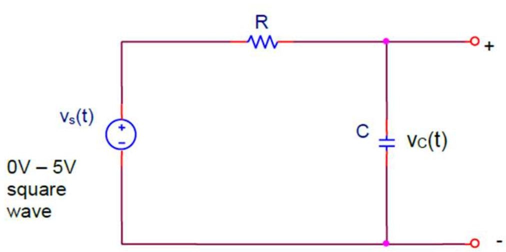

Figure 10.1 – General Circuit III Design

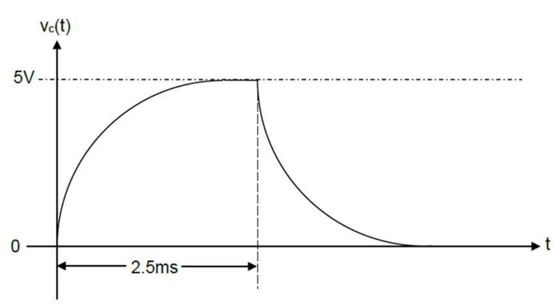

Figure 10.2 – Desired Timing for Circuit III

10.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

Calculations for Figure 10.3	
$\frac{T}{2} = 5\tau = 2.5\ msec$	(5)
$R = 1.5\ k\Omega \rightarrow (5)$ $\therefore C = 333.33\ n\text{F}$	(6)
$T = 2 * \frac{T}{2} = 5\ msec$	(7)
$f = \frac{1}{T} = 200\ \text{Hz}$	(8)

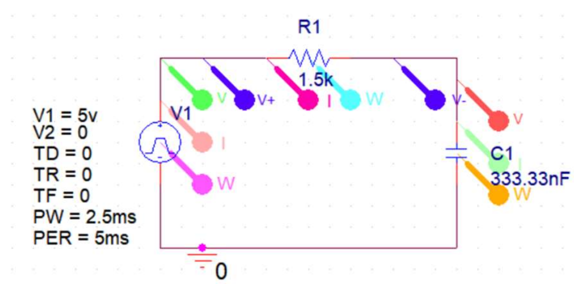

Figure 10.3 - Designed Circuit III Simulated Circuit Author 1

Calculations for Figure 10.4	
$\frac{T}{2} = 5\tau = 2.5\ msec$	(9)
$R = 2.2\ k\Omega \rightarrow (5)$ $\therefore C = 227.\overline{27}\ n\text{F}$	(10)
$T = 2 * \frac{T}{2} = 5\ msec$	(11)
$f = \frac{1}{T} = 200\ \text{Hz}$	(12)

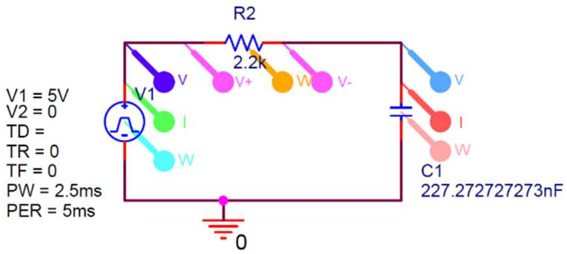

Figure 10.4 – Designed Circuit III Simulated Circuit Author 2

10.3 EXPERIMENTAL & SIMULATION ON DATA & RESULTS

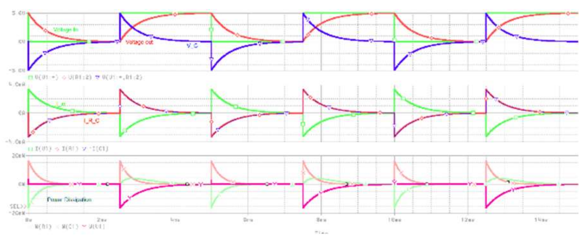

Figure 10.5 – Simulated Circuit Author 1 Waveform

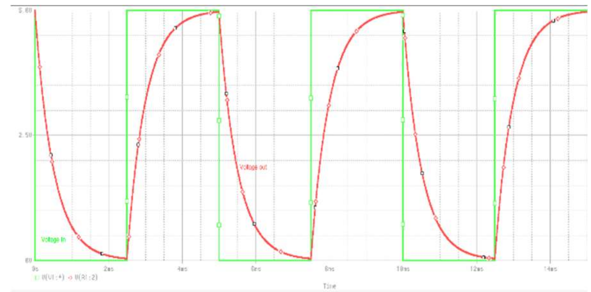

Figure 10.6 – Simulated Author 1 Circuit Waveform, $V_{in}(t)$ and $V_c(t)$

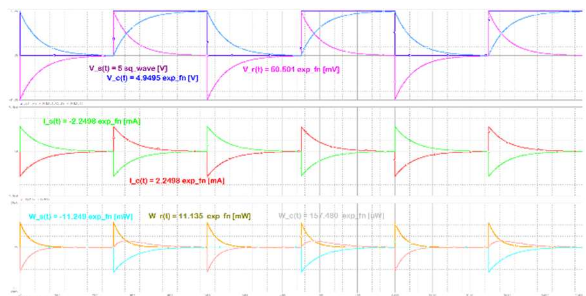

Figure 10.7 – Simulated Circuit Author 2 Waveform

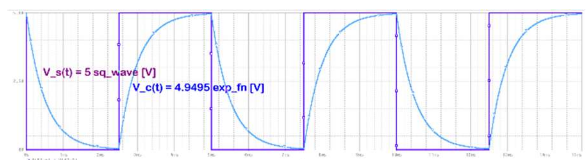

Figure 10.8 – Simulated Author 2 Circuit Waveform, $V_{in}(t)$ and $V_c(t)$

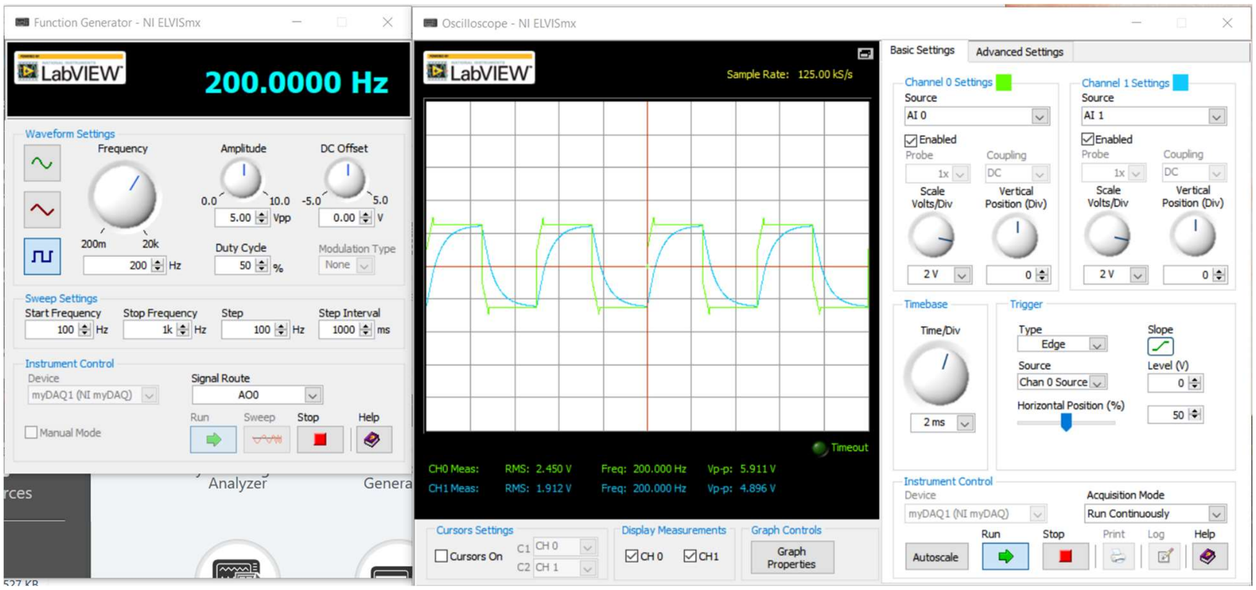

Figure 10.9 – Experimental Circuit Results
Function Generator and Oscilloscope Author 1

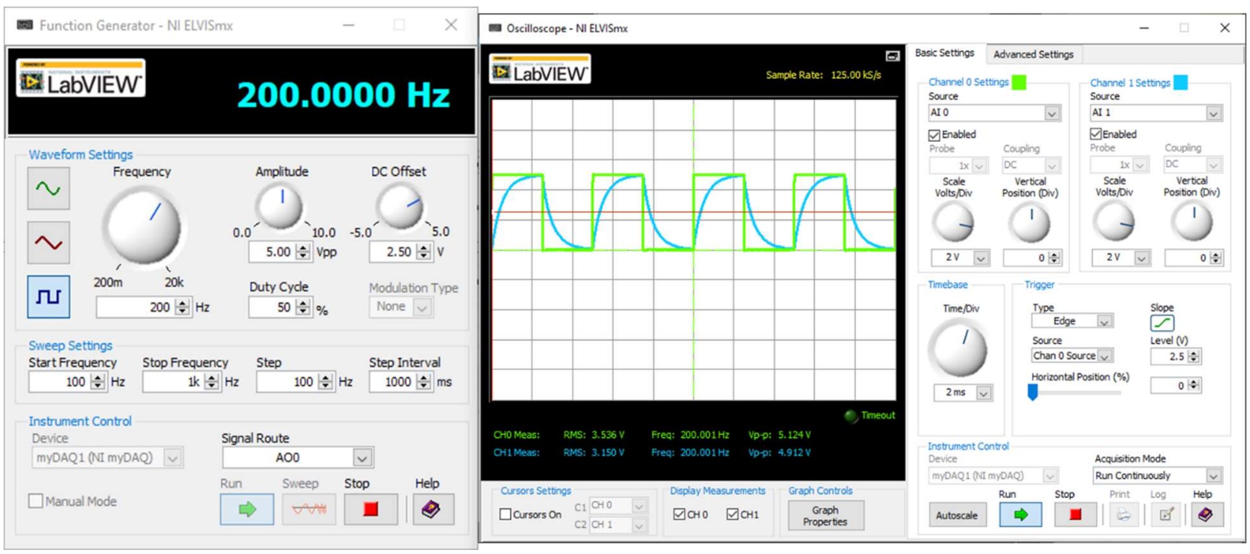

Figure 10.10 – Experimental Circuit Results
Function Generator and Oscilloscope Author 2

10.4 DISCUSSION & CONCLUSION

The purpose of this lab was to find 2 different sets of resistor and capacitor values for the same circuit in order to get the capacitor to charge in a certain amount of time. This was done successfully both theoretically and experimentally by both authors so this lab was a success.

REFERENCES

1. Mallard, Bejamin F. Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual. California State University Northridge.

SECOND ORDER CIRCUITS DESIGN, SIMULATION AND EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ABSTRACT:

The purpose of this lab was to introduce second order circuits and their properties. Along with the design of a second order circuit to achieve a desired waveform.

KEYWORDS: RLC, Second Order, Differential, Overdamped, Underdamp, Critically Damped

11.1 INTRODUCTION

This lab involved two circuits with two cases each. The first circuit was an RLC circuit in a series configuration. Both cases of the series RLC circuit involved a 0.01 μF capacitors and 68 mH inductor, the cases involved a variating resistor. The first case was a 6.8kΩ resistor the second was instead used a 560Ω resistor. The second circuit was also an RLC circuit but in a parallel configuration using the same inductor and capacitor. Its cases are the same as the series RLC circuit.

The preliminary calculations involved finding a value for the resistor at which the circuits' output voltage waveform would become overdamped, critically damped or underdamped. These calculations were done both for the series and parallel RLC circuit.

Equations

$$\frac{d^2y}{dt^2} + 2\alpha\frac{dy}{dt} + \omega_0^2 y = f(t)$$

Preliminary Calculations 1

$$V = \frac{1}{C}\int i(t)\,dt + L\frac{di(t)}{dt} + v(t)$$

$$0 = \frac{1}{C}i(t) + L\frac{d^2i(t)}{dt} + \frac{dv(t)}{dt}$$

$$v(t) = R * i(t) \rightarrow i(t) = \frac{v(t)}{R}$$

$$0 = \frac{L}{R}\frac{d^2i(t)}{dt^2} + \frac{dv(t)}{dt} + \frac{1}{RC}v(t)$$

$$L = 68m\text{H}, \text{C} = 0.01\mu\text{F}$$

Overdamped

$$R > 5215.361924\ \Omega$$

Critically Damped

$$R = 5215.361924\ \Omega$$

Underdamped

$$R < 5215.361924\ \Omega$$

Preliminary Calculations 2

$$\frac{V - V_c(t)}{R} = \frac{1}{L}\int V_c(t)\,d + C\frac{dv_c(t)}{dt}$$

$$0 = C\frac{d^2v_c(t)}{dt^2} + \frac{1}{R}\frac{dv_c(t)}{dt} + \frac{1}{L}v_c(t)$$

$$L = 68m\text{H}, \text{C} = 0.01\mu\text{F}$$

Overdamped

$$R > 1303.840481\ \Omega$$

Critically Damped

$$R = 1303.840481\ \Omega$$

Underdamped

$$R < 1303.840481\ \Omega$$

11.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

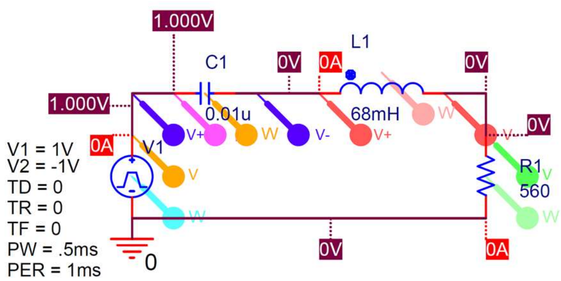


Figure 11.1 – Series RLC Circuit
68 mH, 560 Ω, 0.01 µF

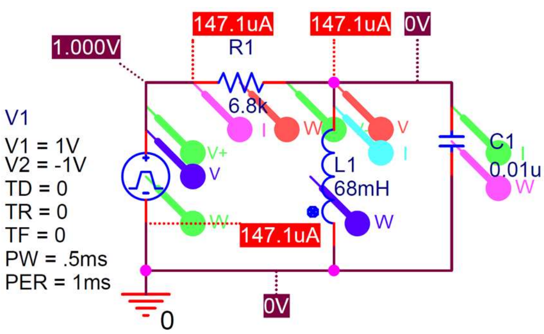


Figure 11.2 – Parallel RLC Circuit
68 mH, 6.8 kΩ, 0.01 µF

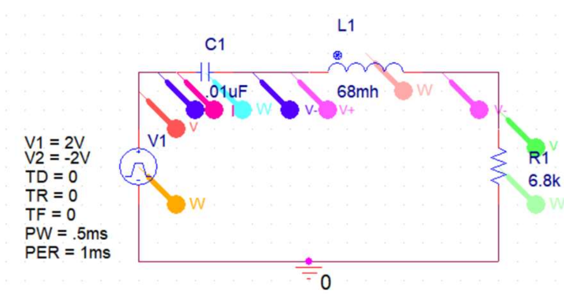


Figure 11.3- 1st Circuit RLC Circuit in Series
68 mH, 6.8 kΩ, 0.01 µF

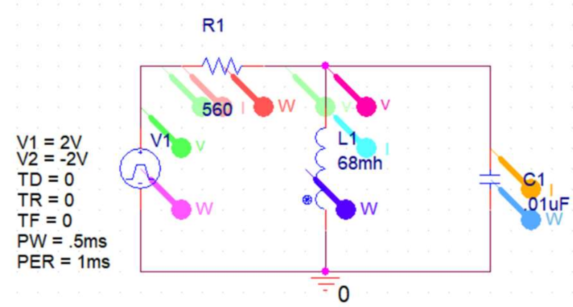
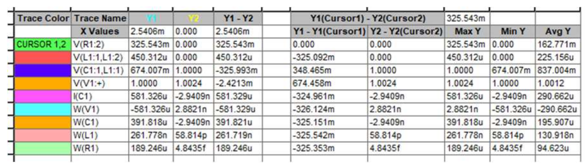


Figure 11.4 – 2nd Circuit RLC Circuit in Parallel
68 mH, 560 Ω, 0.01 µF

11.3 EXPERIMENTAL & SIMULATION ON DATA & RESULTS



Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		325.543m		
	X Values	2.5406m	0.000	2.5406m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(R1:2)	325.543m	0.000	325.543m		0.000	0.000	325.543m	0.000	162.771m
	V(L1:1,L1:2)	450.312u	0.000	450.312u		-325.092m	0.000	450.312u	0.000	225.156u
	V(C1:1,L1:1)	674.007m	1.0000	-325.993m		348.465m	1.0000	1.0000	674.007m	837.004m
	V(V1:+)	1.0000	1.0024	-2.4213m		674.458m	1.0024	1.0024	1.0000	1.0012
	I(C1)	581.326u	-2.9409n	581.329u		-324.961m	-2.9409n	581.326u	-2.9409n	290.662u
	W(V1)	-581.326u	2.8821n	-581.329u		-326.124m	2.8821n	2.8821n	-581.326u	-290.662u
	W(C1)	391.818u	-2.9409n	391.821u		-325.151m	-2.9409n	391.818u	-2.9409n	195.907u
	W(L1)	261.778n	58.814p	261.719n		-325.542m	58.814p	261.778n	58.814p	130.918n
	W(R1)	189.246u	4.8435f	189.246u		-325.353m	4.8435f	189.246u	4.8435f	94.623u

Figure 11.5 – Series RLC Circuit
560 Ω, Simulation Results

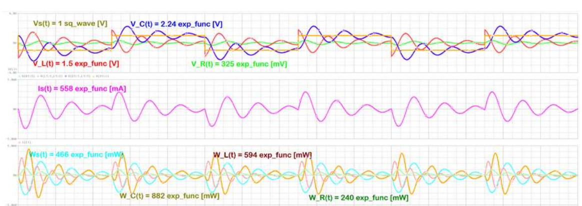


Figure 11.6 – Series RLC Circuit
560 Ω, Simulation Results, Waveforms

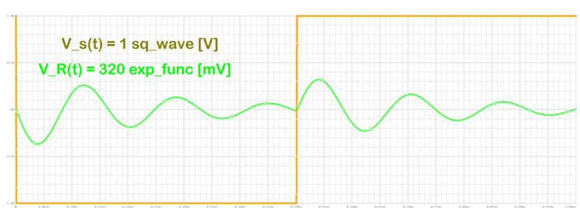


Figure 11.7 – Series RLC Circuit
560 Ω, Simulation Results, Resistor & Input Voltage Waveforms

The waveform showed the Resistor and Input voltage (Figure 11.7) show the output voltage as underdamped due to the sharp pulse in the beginning of the waveform followed by its stabilization down to zero.

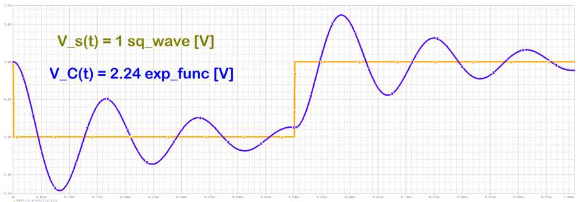


Figure 11.8 – Series RLC Circuit
560 Ω, Simulation Results, Capacitor & Input Voltage Waveforms

The voltage across the capacitor is also underdamped due to the same reasoning as the voltage across the resistor.

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		309.412m		
	X Values	2.6219m	0.000	2.6219m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(R1:1,R1:2)	1.3094	1.0000	309.412m		0.000	0.000	1.3094	1.0000	1.1547
	I(R1)	192.561u	144.118u	48.443u		-1.3092	-0.9999	192.561u	144.118u	168.339u
	V(V1:+)	1.0000	0.9988	1.2107m		-309.412m	-1.2107m	1.0000	0.9988	0.9994
	V(R1:2)	-309.412m	-2.9407u	-309.409m		-1.6188	-1.0000	-2.9407u	-309.412m	-154.708m
	-I(L1)	190.989u	147.059u	43.931u		-1.3092	-0.9999	190.989u	147.059u	169.024u
	W(V1)	-192.561u	-141.236u	-51.325u		-1.3096	-1.0001	-141.236u	-192.561u	-166.898u
	W(R1)	252.141u	141.236u	110.905u		-1.3092	-0.9999	252.141u	141.236u	196.689u
	W(L1)	-59.094u	-432.462p	-59.094u		-1.3095	-1.0000	-432.462p	-59.094u	-29.547u
	-I(C1)	1.5713u	-2.9407u	4.5121u		-1.3094	-1.0000	1.5713u	-2.9407u	-684.710n
	W(C1)	-486.187n	8.6480p	-486.195n		-1.3094	-1.0000	8.6480p	-486.187n	-243.089n

Figure 11.9 – Parallel RLC Circuit
6.8 kΩ, Simulation Results

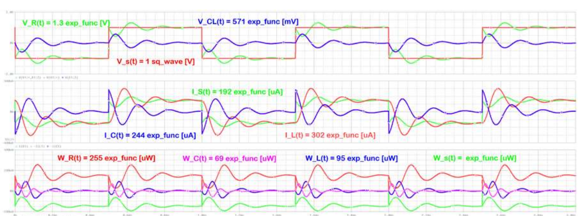


Figure 11.10 – Parallel RLC Circuit
6.8 kΩ, Simulation Results, Waveforms

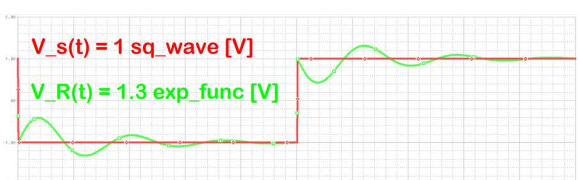


Figure 11.11 – Parallel RLC Circuit
6.8 kΩ, Simulation Results, Resistor & Input Voltage Waveforms

In the case of the parallel configuration RLC circuit, the voltage across the resistor is also underdamped.

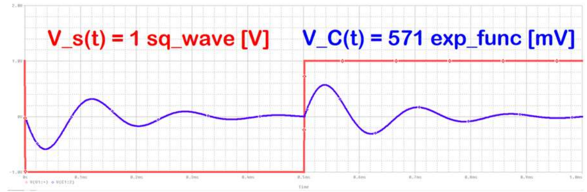


Figure 11.12 – Parallel RLC Circuit
6.8 kΩ, Simulation Results, Capacitor & Input Voltage Waveforms

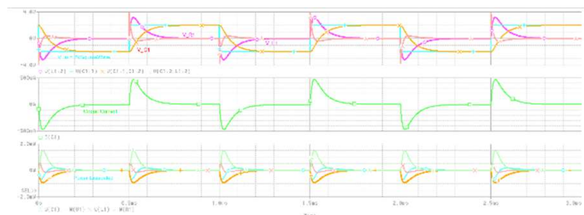


Figure 11.13- Circuit 1 - waveform, Voltage, Current, Power

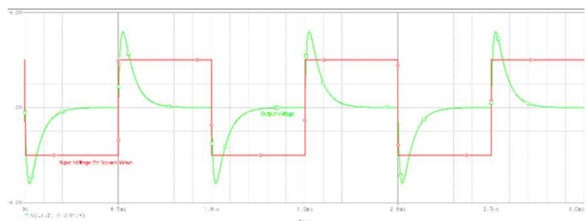


Figure 11.14- Circuit 1 - waveform, Voltage in, Voltage out

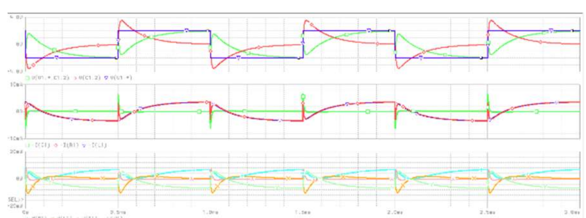


Figure 11.15- Circuit 2 - waveform, Voltage, Current, Power

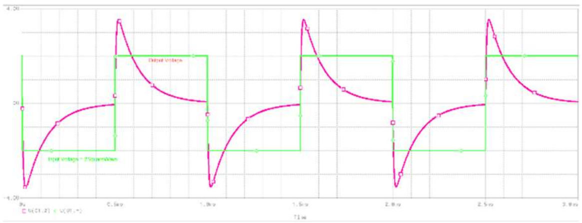


Figure 11.16- Circuit 2 - waveform, Voltage in, Voltage out=

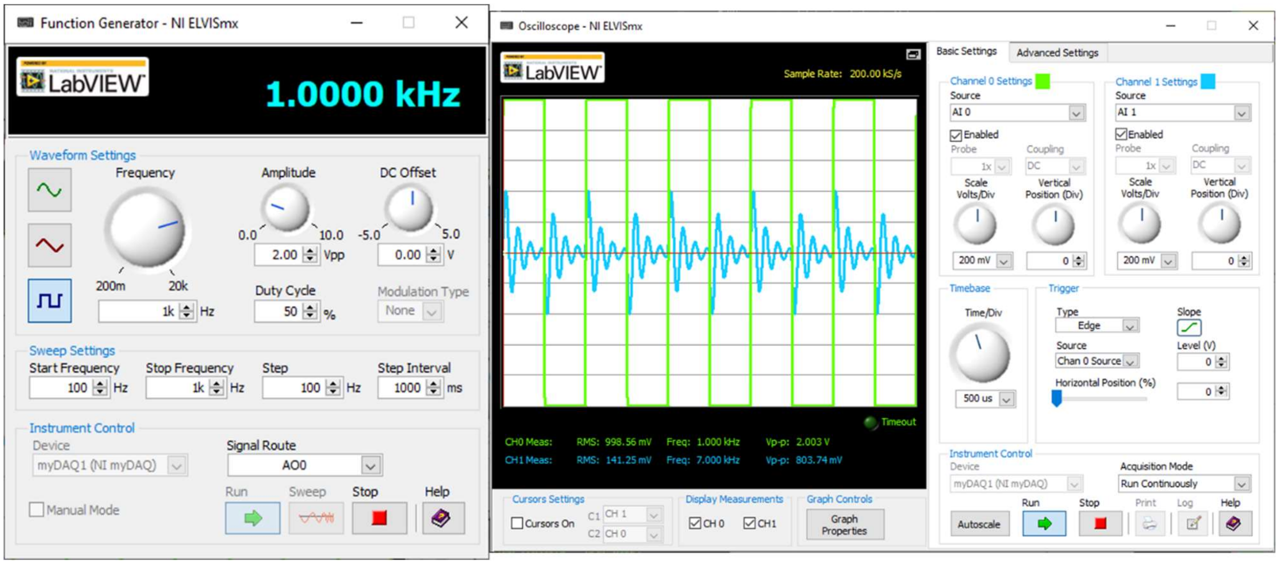


Figure 11.17 – Series RLC Circuit
560 Ω, Experimental Results, Resistor & Input Voltage Waveforms

Figure 11.18 – Series RLC Circuit
560 Ω, Experimental Results, Resistor & Input Voltage Waveforms, 1 Cycle

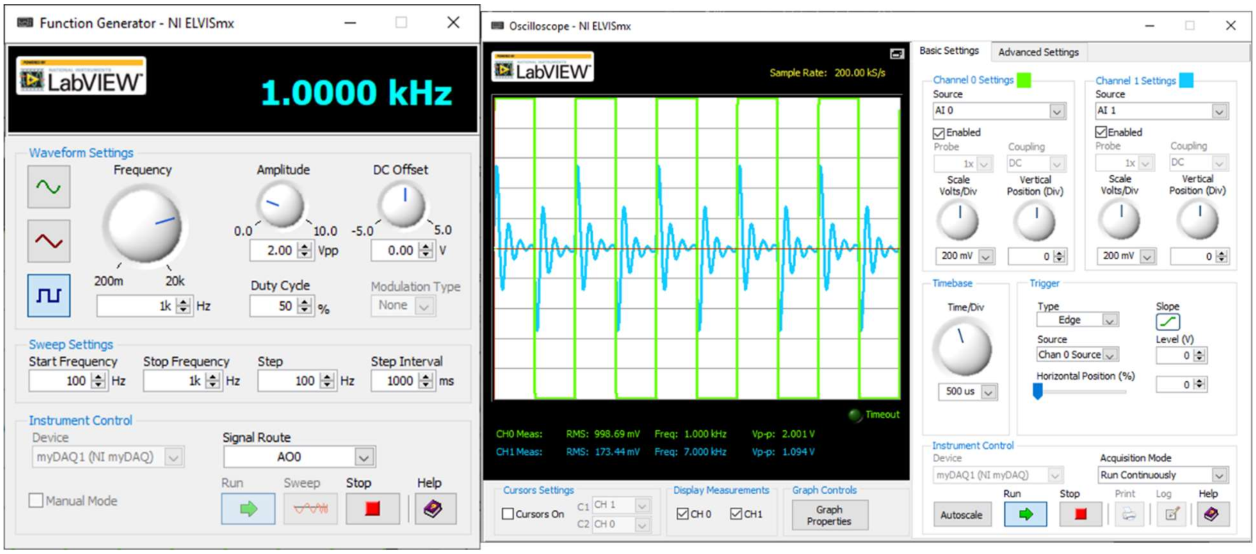


Figure 11.19 – Parallel RLC Circuit
6.8 kΩ, Experimental Results, Resistor & Input Voltage Waveforms

Figure 11.20 – Parallel RLC Circuit
6.8 kΩ, Experimental Results, Resistor & Input Voltage Waveforms, Cycle 1

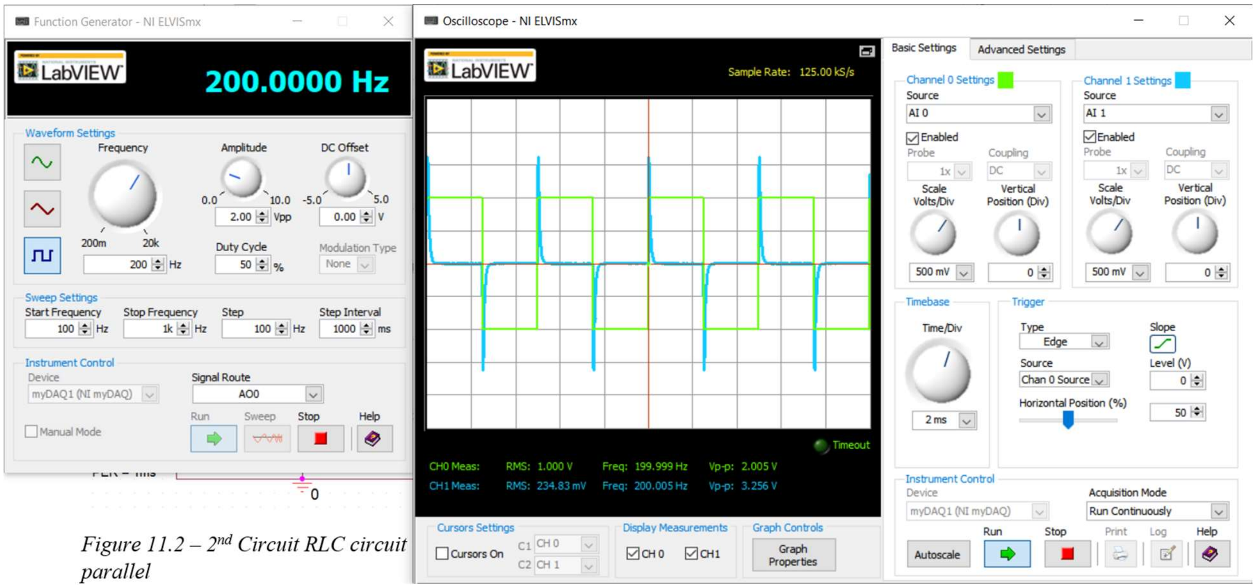


Figure 11.7 – myDAQ For Series RLC Circuit 3 Cycles

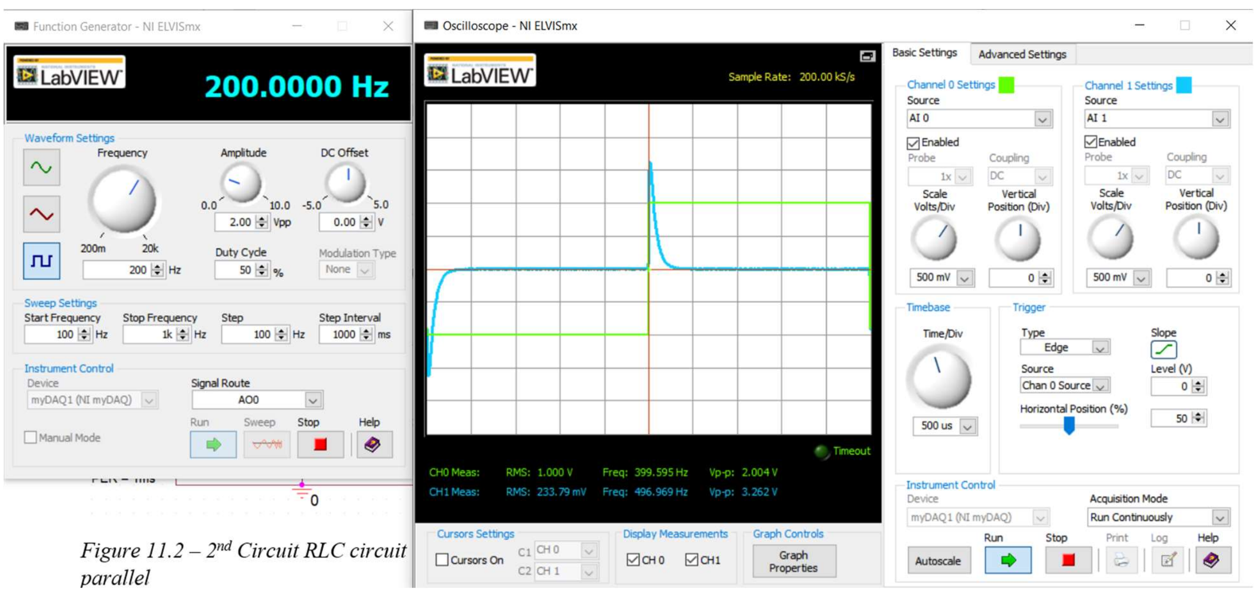


Figure 11.8 – myDAQ For Series RLC Circuit 1 Cycle

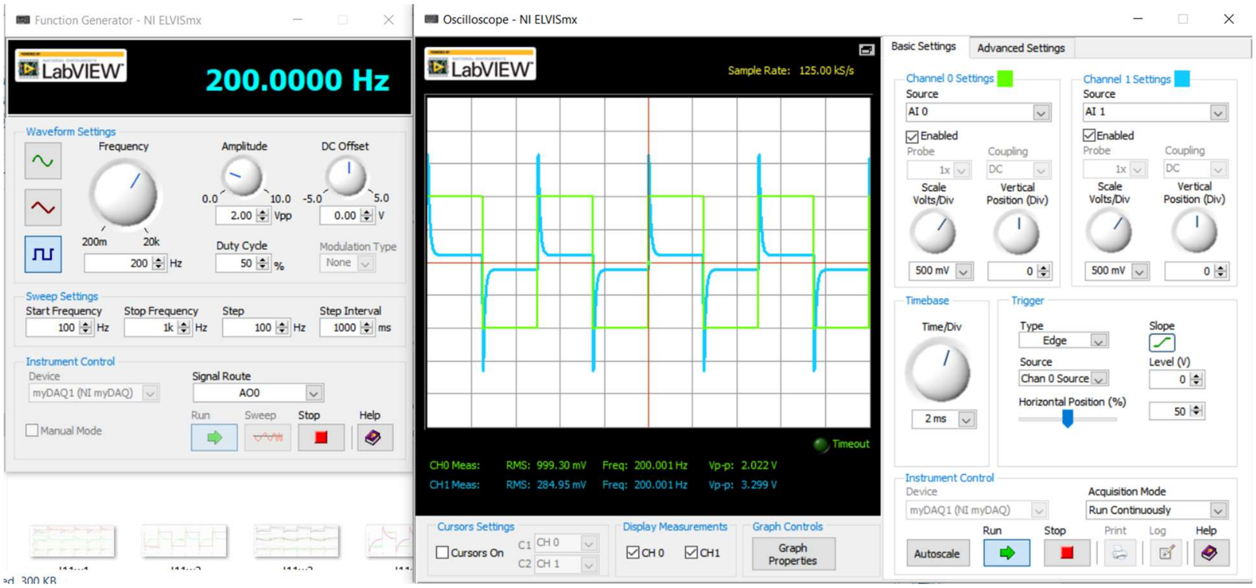


Figure 11.9 – myDAQ For Parallel RLC Circuit 3 Cycles

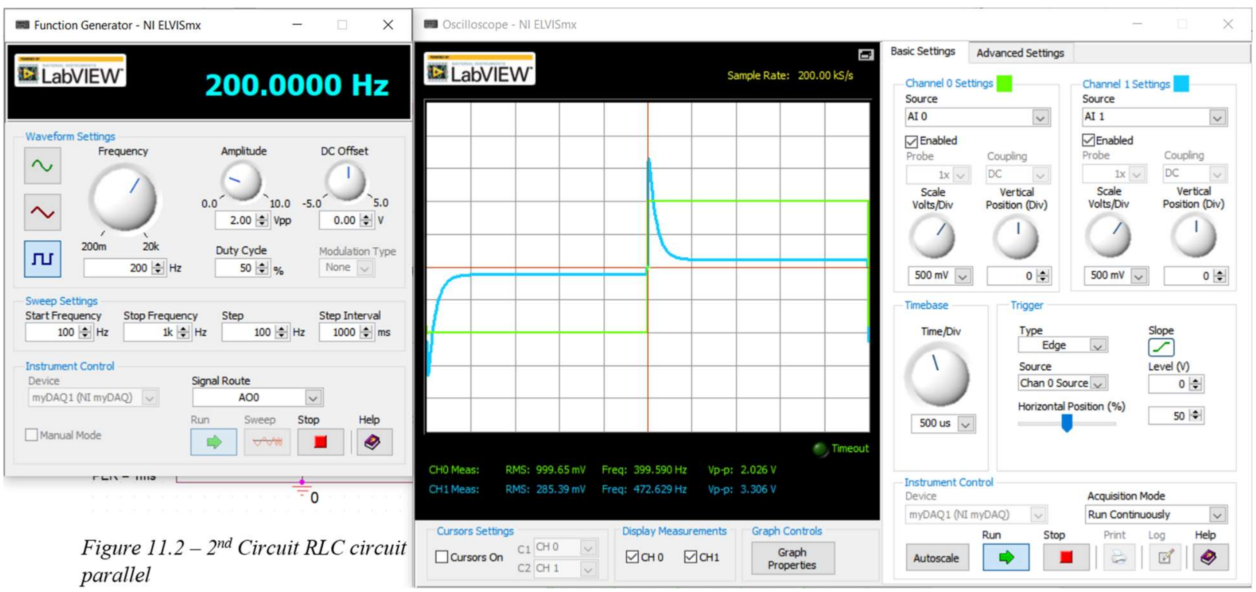


Figure 11.10 – myDAQ For Parallel RLC Circuit 1 Cycle

11.4 DISCUSSION & CONCLUSION

This experiments goal was to explore second order circuits and their responses to varying resistor values. I believe, case 2 and 4 were done successful due to the output waveforms being underdamped as expected.

REFERENCES

[1] Mallard, Bejamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

[2] Svoboda, James A., and Richard C. Dorf. Introduction to Electric Circuits. John Wiley & Sons, 2014.

[3] Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm

IMPEDANCE AND ADMITTANCE CIRCUITS DESIGN, SIMULATION & EXPERIMENTAL TEST AS WELL AS ANALYSIS

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Department of Electrical & Computer Engineering

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ABSTRACT: The purpose of this lab was to get an understanding of impedances and admittances as well as to test both experimentally and by simulation.

12.1 INTRODUCTION

Equations

$$\omega = 2\pi * f \tag{1}$$

$$Z = R + jX \tag{2}$$

$$X_R = 0, R = R \tag{3}$$

$$X_C = -\frac{1}{\omega C}, R_C = 0 \tag{4}$$

$$X_L = \omega L, R_L = 0 \tag{5}$$

12.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

Preliminary Calculations – Case 1
$Z_1 = 1\text{k}\Omega + j(2\pi * 1\text{kHz} * 68\text{mH})$ $Z_1 = 1000 + \text{j}427.26\ \Omega$ $Z_2 = 680\Omega - j\left(\frac{1}{(2\pi * 1\text{kHz} * .1\mu F}\right)$ $Z_2 = 680 - j1591.55\ \Omega$ $Z_S = 1680 - j1163.7\ \Omega$ $I = \left\lvert\frac{1\text{ V}}{1680 - j1163.7\ \Omega}\right\rvert = 1.937\ mA$ $V_1 = I * Z_1 = 2.764\text{ V}$ $V_2 = \left(\frac{Z_2}{Z_s}\right) * 1 = -1.766\text{ V}$

Preliminary Calculations – Case 2
$Z_1 = 1\text{k}\Omega + j(2\pi * 1\text{kHz} * 68\text{mH})$ $Z_1 = 1000 + \text{j}427.26\ \Omega$ $Z_2 = 680\Omega + j\left(-\frac{1}{(2\pi * 1\text{kHz} * 1\mu F}\right)$ $Z_2 = 680 - j159.155\ \Omega$ $Z_S = 1680 + j268.1\ \Omega$ $I = \left\lvert\frac{1\text{ V}}{1680 + j268.1\ \Omega}\right\rvert = 587.8\ \mu A$ $V_1 = I * Z_1 = 0.6392\text{ V}$ $V_2 = \left(\frac{Z_2}{Z_s}\right) * 1 = 0.4105\text{ V}$

Preliminary Calculations – Case 3
$Z_1 = 1\text{k}\Omega + j(2\pi * 500\text{Hz} * 68\text{mH})$ $Z_1 = 1000 + \text{j}213.63\ \Omega$ $Z_2 = 680\Omega - j\left(\frac{1}{(2\pi * 500\text{Hz} * .1\mu F}\right)$ $Z_2 = 680 - j3183.1\ \Omega$ $Z_S = 1680 - j2969.5\ \Omega$ $I = \left\lvert\frac{1\text{ V}}{1680 - j2969.5\ \Omega}\right\rvert = -775.8\ \mu A$ $V_1 = I * Z_1 = -0.9415\text{ V}$ $V_2 = \left(\frac{Z_2}{Z_s}\right) * 1 = 1.94\text{ V}$

Preliminary Calculations – Case 4
$Z_1 = 1\text{k}\Omega + j(2\pi * 100\text{Hz} * 68\text{mH})$ $Z_1 = 1000 + \text{j}42.73\ \Omega$ $Z_2 = 680\Omega + j\left(-\frac{1}{(2\pi * 100\text{Hz} * 1\mu F}\right)$ $Z_2 = 680 - j1591.55\ \Omega$ $Z_S = 1680 - j1548.82\ \Omega$ $I = \left\lvert\frac{1\text{ V}}{1680 - j1548.82\ \Omega}\right\rvert = 437.64\ \mu A$ $V_1 = I * Z_1 = 0.438\text{ V}$ $V_2 = \left(\frac{Z_2}{Z_s}\right) * 1 = 0.7574\text{ V}$

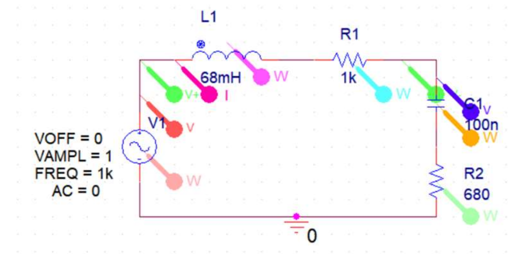

Figure 12.1 – Case 1 - RLC Circuit

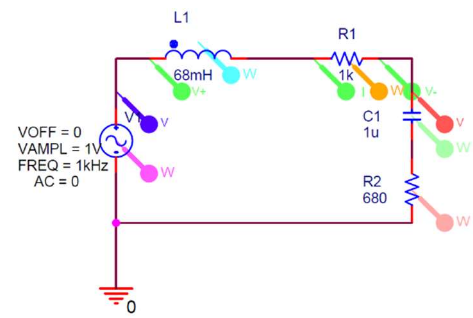

Figure 12.2 – Case 2 – RLC Circuit

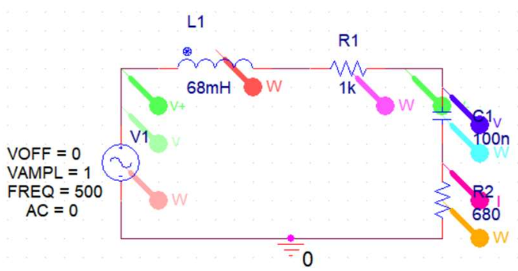

Figure 12.3 - Case 3-RLC Circuit

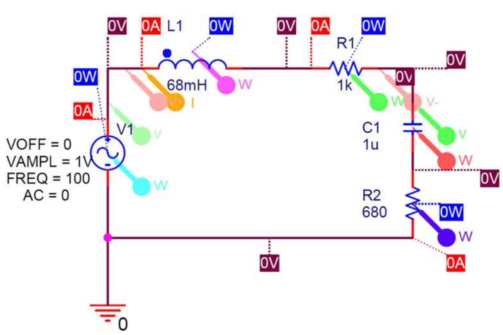

Figure 12.4 – Case 4 – RLC Circuit

12.3 EXPERIMENTAL & SIMULATION ON DATA & RESULTS

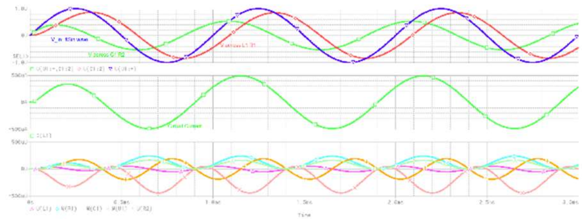

Figure 12.5 – Case 1 – Simulation results waveforms

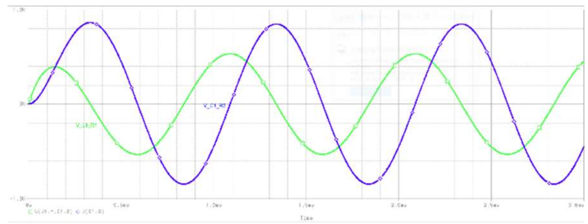

Figure 12.6 – Case 1 – Simulation results waveforms V1 and V2

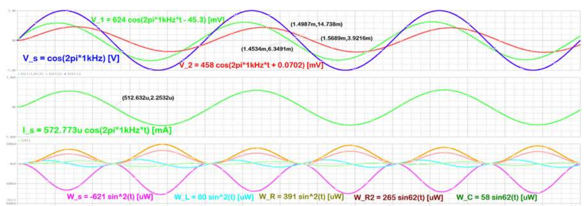

Figure 12.7 – Case 2 – Simulation Results Waveforms

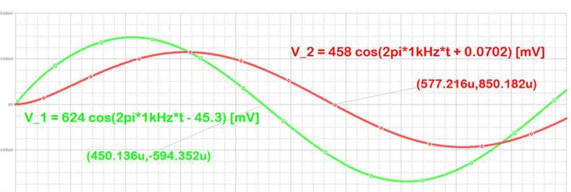

Figure 12.8 – Case 2 – Simulation Results Waveform, V_1 and V_2

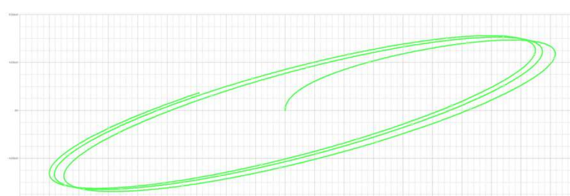

Figure 12.9 – Case 2 – Simulation Results Waveform, V_1 vs V_2

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		6.6737u		
	X Values	1.0166m	0.000	1.0166m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	W(V1)	6.6737u	0.000	6.6737u		0.000	0.000	6.6737u	0.000	3.3369u
	W(L1)	-18.824u	580.3E-18	-18.824u		-25.497u	580.3E-18	580.3E-18	-18.824u	-9.4118u
	W(R1)	4.0877u	85.34E-21	4.0877u		-2.5860u	85.34E-21	4.0877u	85.34E-21	2.0439u
	W(R2)	2.7796u	58.03E-21	2.7796u		-3.8941u	58.03E-21	2.7796u	58.03E-21	1.3898u
	W(C1)	2.5786u	853.4E-27	2.5786u		-4.0951u	853.4E-27	2.5786u	853.4E-27	1.2893u
	I(R1)	-63.935u	9.2377p	-63.935u		-70.609u	9.2377p	9.2377p	-63.935u	-31.968u
	V(L1:1,R1:2)	188.190m	62.826u	188.127m		188.183m	62.826u	188.190m	62.826u	94.126m
	V(C1:2)	-83.808m	6.2817n	-83.808m		-83.814m	6.2817n	6.2817n	-83.808m	-41.904m
	V(V1:+)	98.039m	62.832u	97.976m		98.033m	62.832u	98.039m	62.832u	49.051m

Figure 12.10 – Case 2 – Simulation Results Tabular Data

Case 2 – Time Delay & Phase Angle
$T_D = 127.08\ \mu sec$ $T_D * \omega = 0.7985°$ $\phi = 0.7985°$

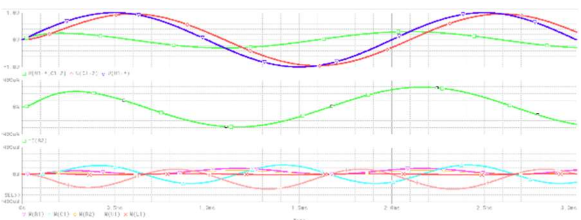

Figure 12.11 – Case 3 – Simulation results waveforms

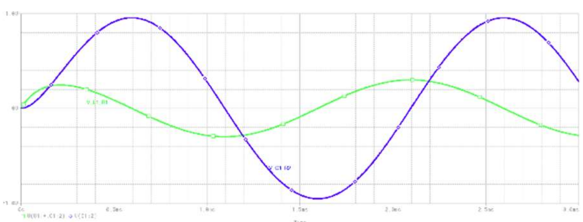

Figure 12.12 – Case 3 – Simulation results waveforms V1 and V2

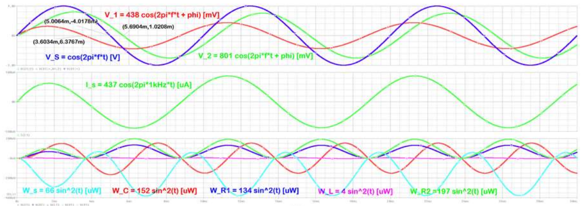

Figure 12.13 – Case 4 – Simulation Results Waveforms

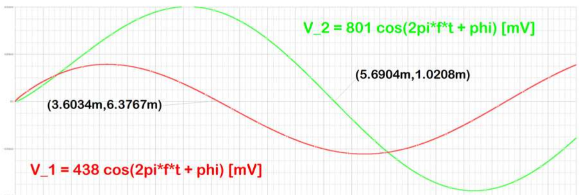

Figure 12.14 – Case 4 – Simulation Results Waveforms, V_1 and V_2

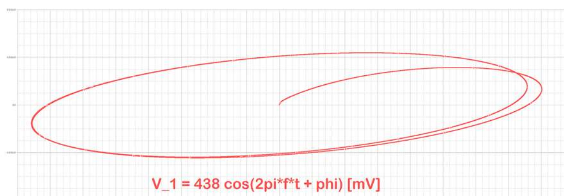

Figure 12.15 – Case 4 – Simulation Results Waveforms, V_1 vs V_2

Case 4 – Time Delay & Phase Angle
$T_D = -2.0866\ msec$ $T_D * \omega = 0.7985°$ $\phi = -1.3110°$

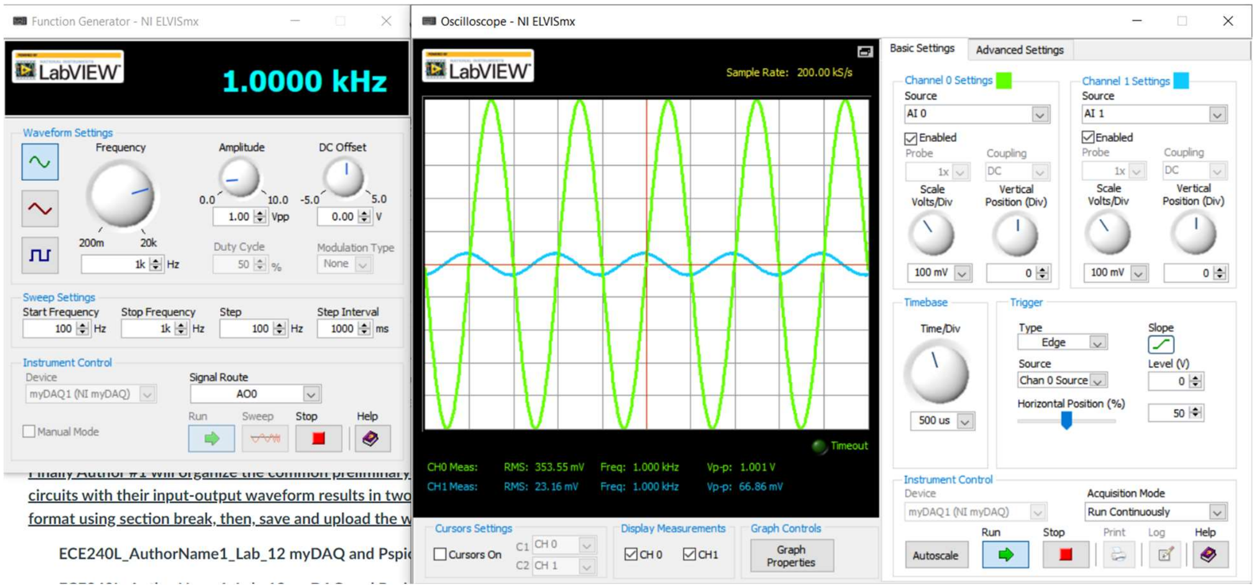

Figure 12.16 – Case 1 – Experimental Results
$V_s(t)$ and $V_1(t)$, 3 Cycles

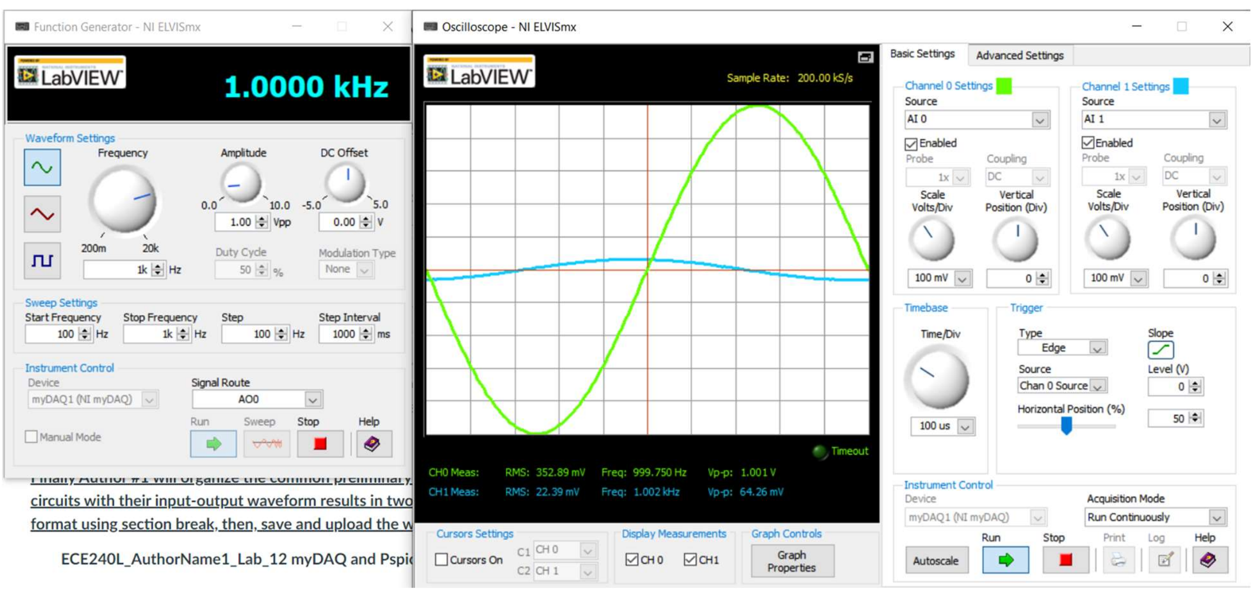

Figure 12.17 – Case 1 – Experimental Results
$V_s(t)$ and $V_1(t)$, 1 Cycle

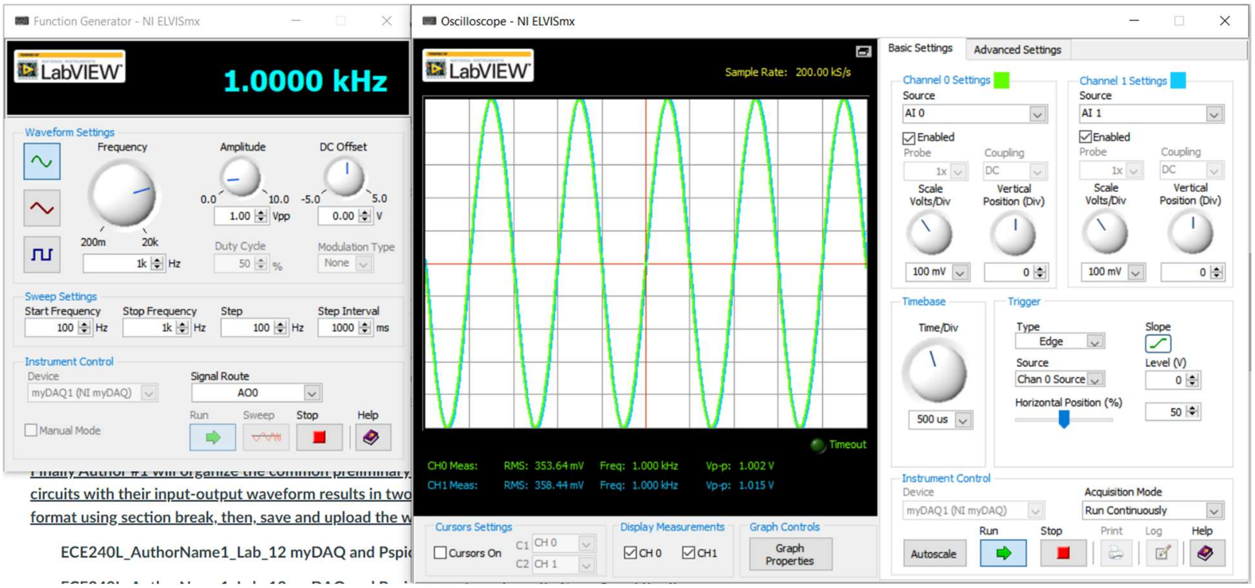

Figure 12.18 – Case 1 – Experimental Results
$V_s(t)$ *and* $V_2(t)$, 3 Cycles

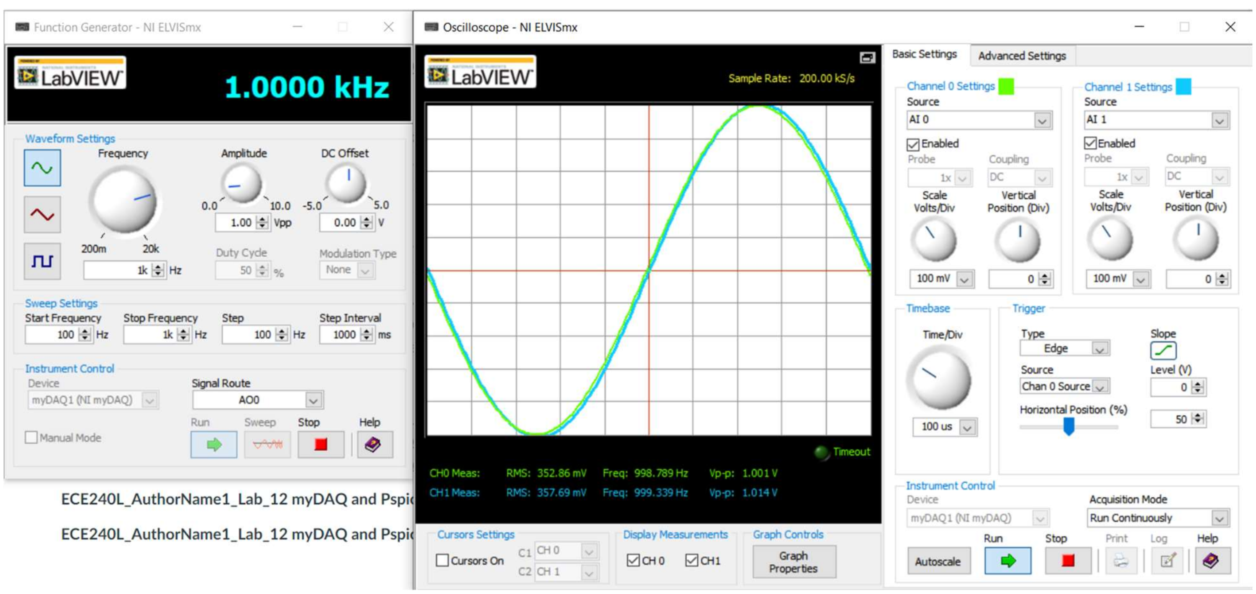

Figure 12.19 – Case 1 – Experimental Results
$V_s(t)$ *and* $V_2(t)$, 1 Cycles

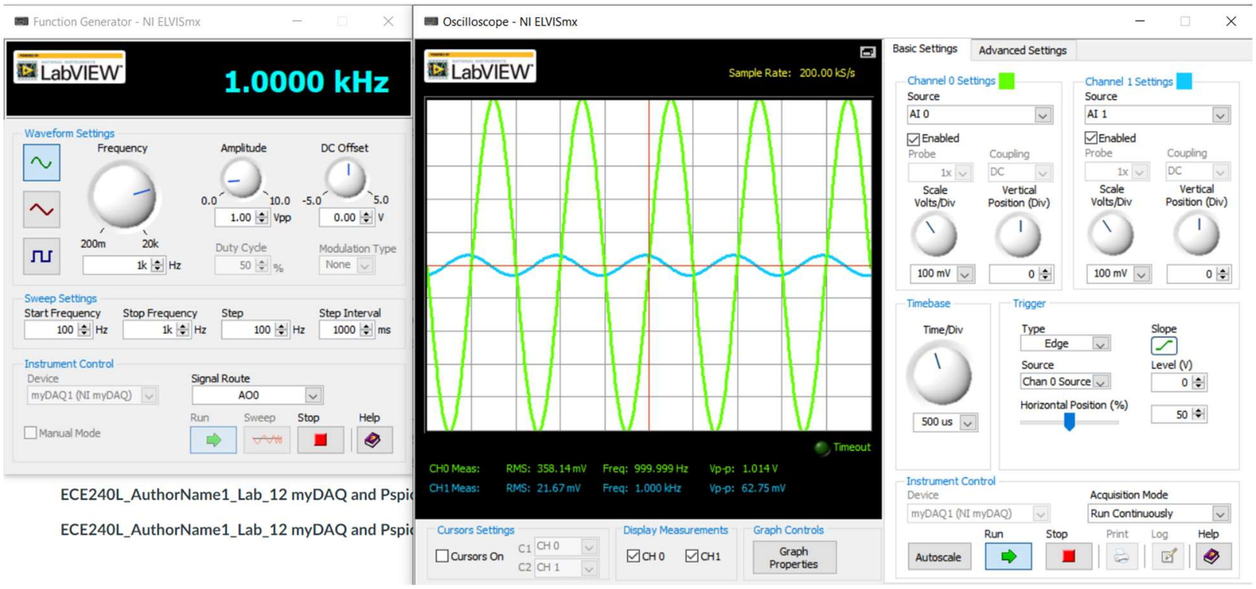

Figure 12.20 – Case 1 – Experimental Results
$V_1(t)$ and $V_2(t)$, 1 Cycles

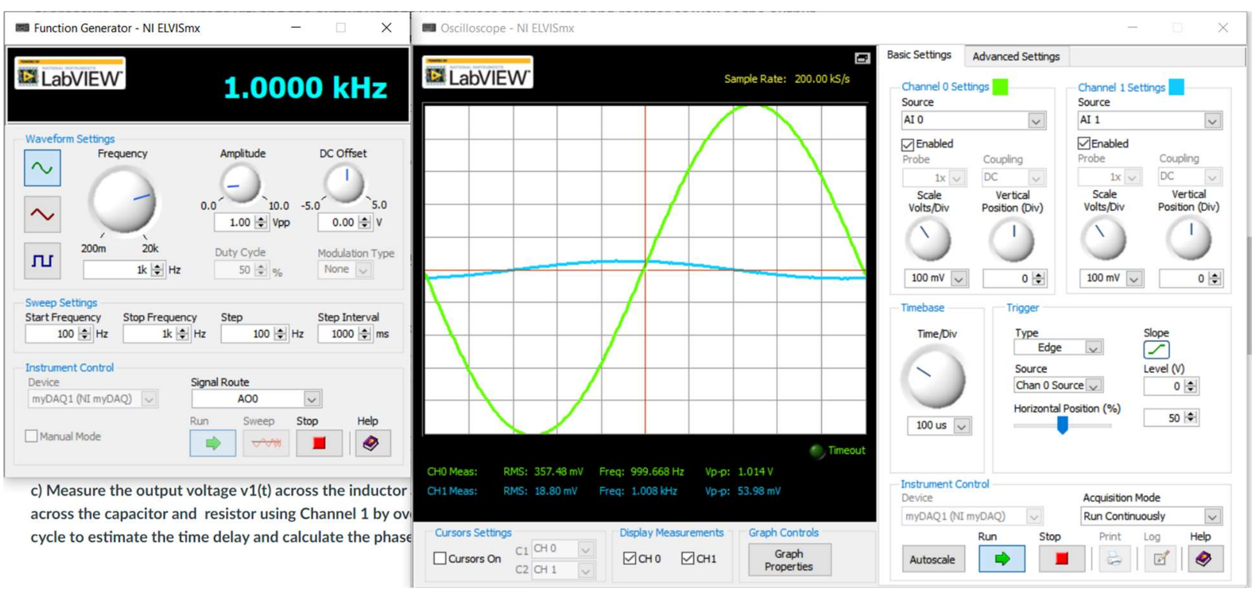

Figure 12.21 – Case 1 – Experimental Results
$V_1(t)$ and $V_2(t)$, 1 Cycles

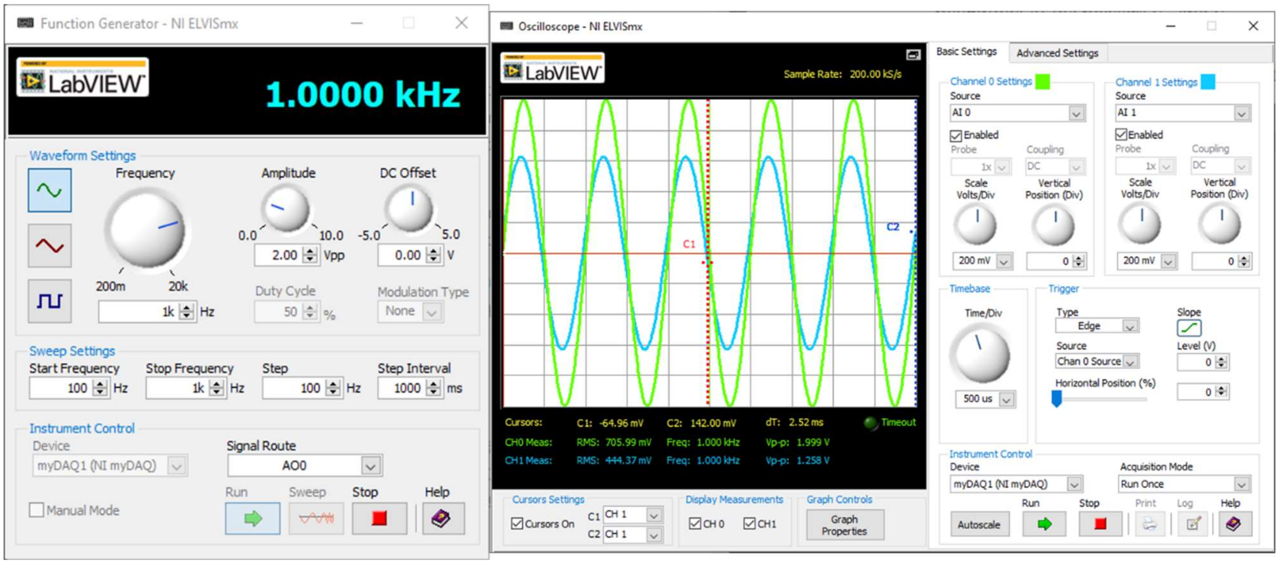

Figure 12.22 – Case 2 – Experimental Results
$V_s(t)$ *and* $V_1(t)$, 3 Cycles

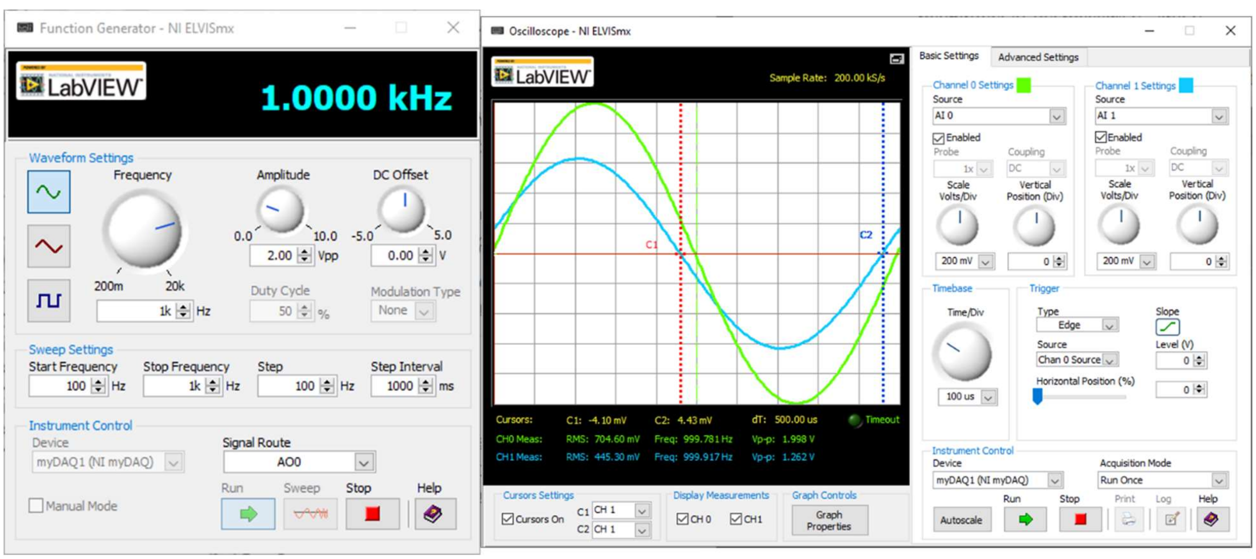

Figure 12.23 – Case 2 – Experimental Results
$V_s(t)$ *and* $V_1(t)$, 1 Cycle

$$\boxed{\begin{array}{c} T_D = \ -35\ \mu\text{sec} \\ \phi = -0.2199° \end{array}}$$

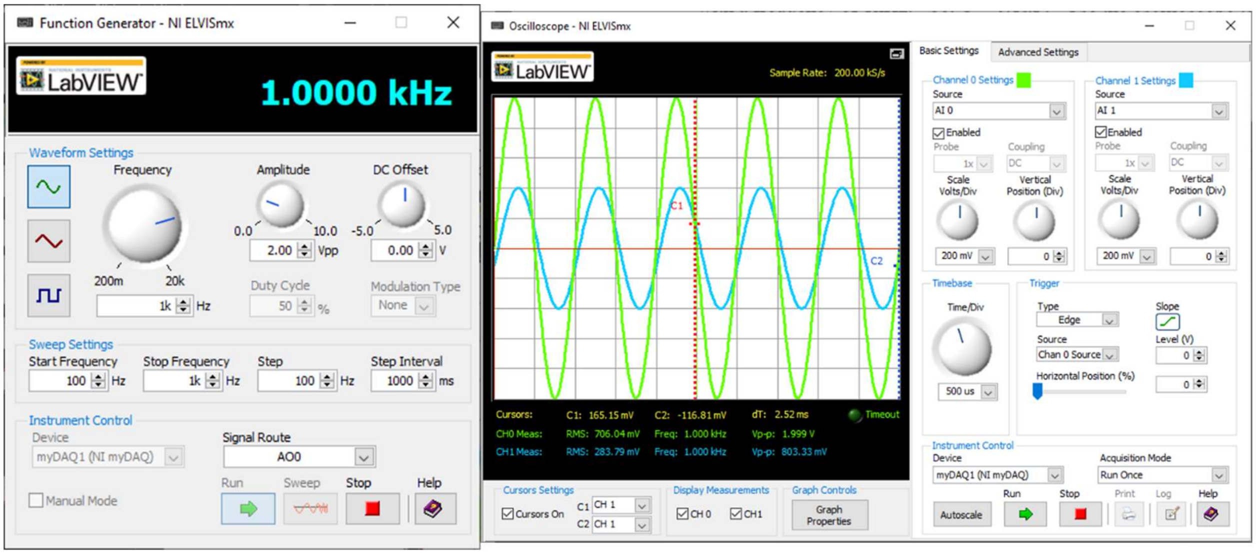

Figure 12.24 – Case 2 – Experimental Results

$V_s(t)$ *and* $V_2(t)$, 3 Cycles

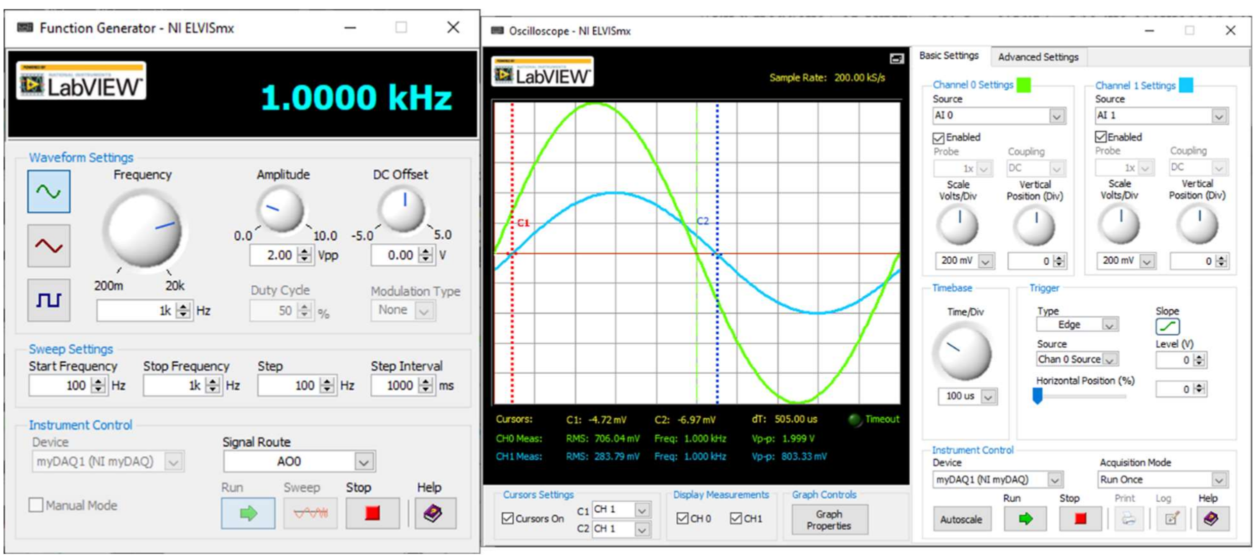

Figure 12.25 – Case 2 – Experimental Results

$V_s(t)$ *and* $V_2(t)$, 1 Cycle

$$\boxed{\begin{aligned} T_D &= 50\ \mu\text{sec} \\ \phi &= 0.3146^\circ \end{aligned}}$$

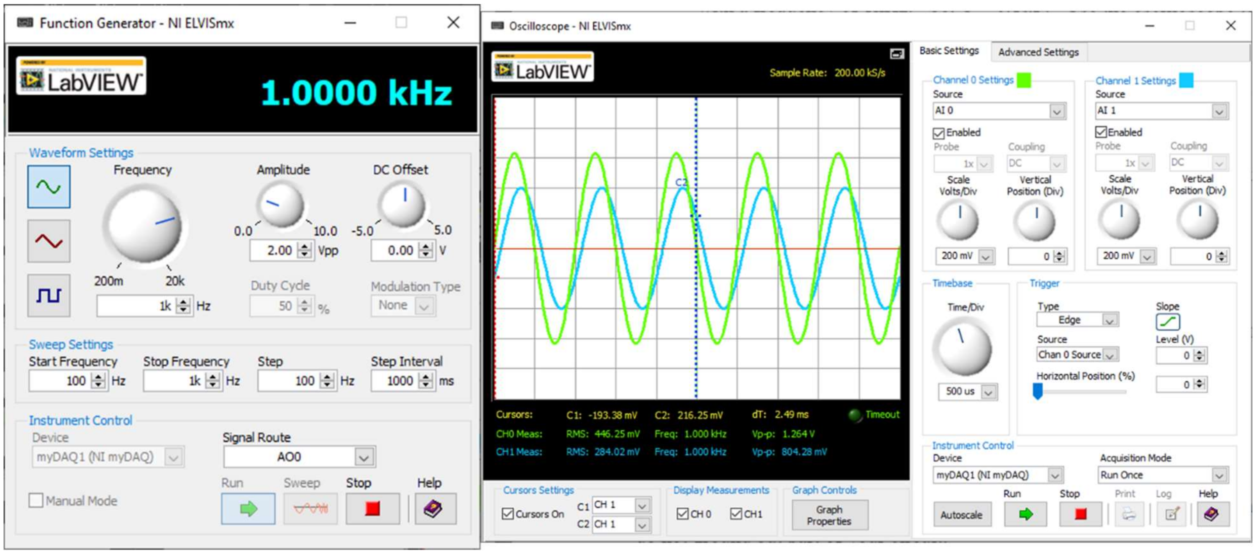

Figure 12.26 – Case 2 – Experimental Results
$V_1(t)$ *and* $V_2(t)$, 3 Cycles

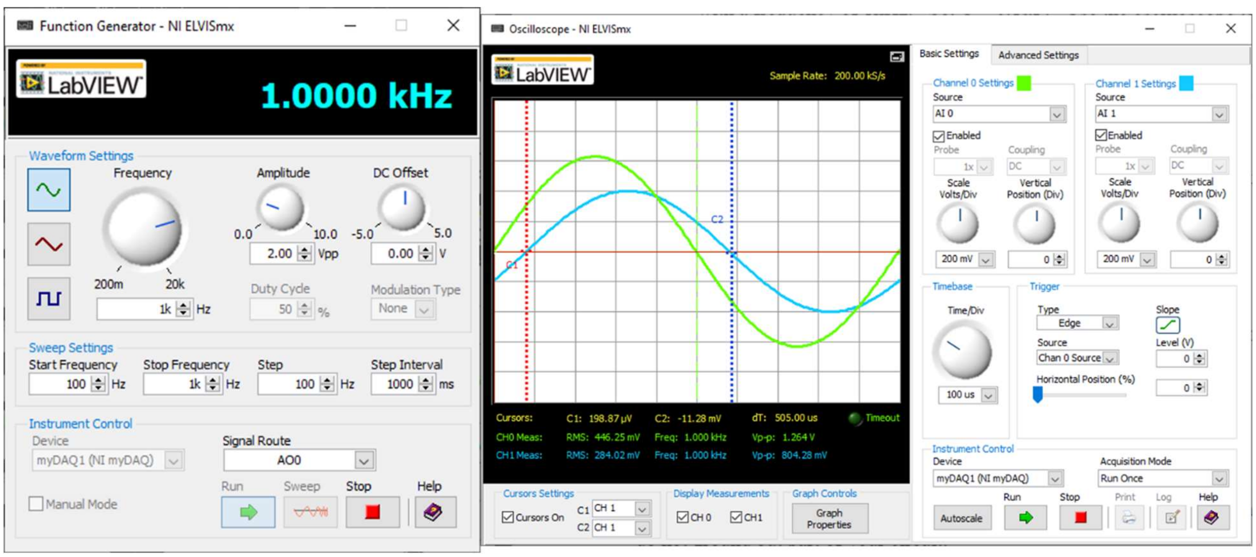

Figure 12.27 – Case 2 – Experimental Results
$V_1(t)$ *and* $V_2(t)$, 1 Cycles

$$\boxed{\begin{array}{c} T_D = 250\ \mu\text{sec} \\ \phi = 1.57^\circ \end{array}}$$

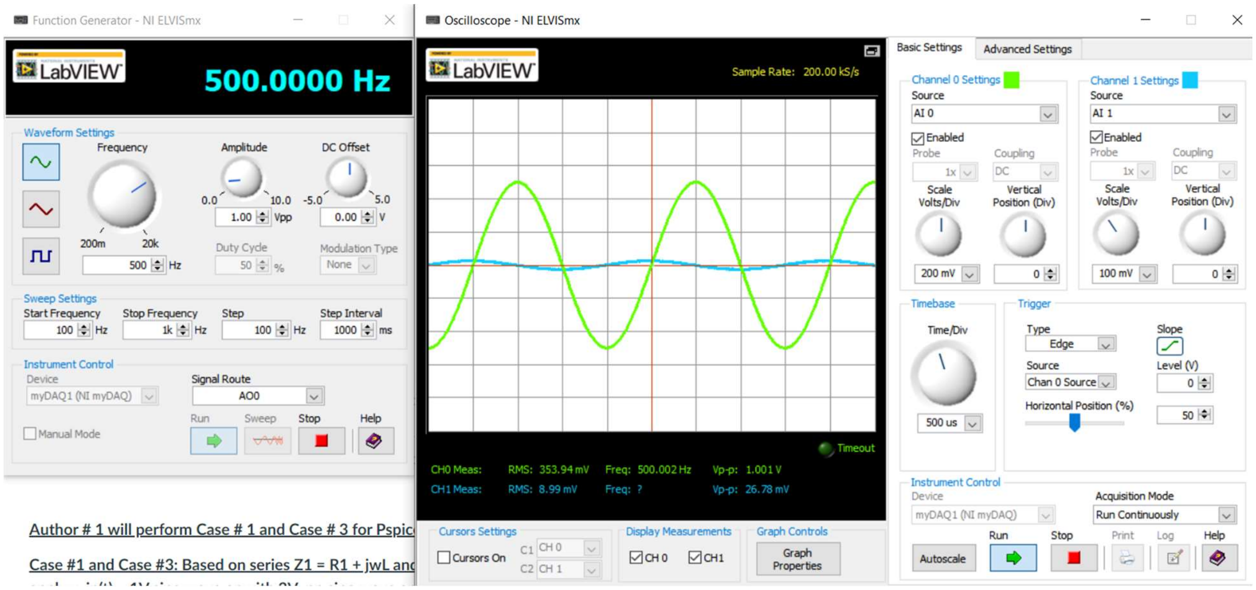

Figure 12.27 – Case 3 – Experimental Results
$V_s(t)$ *and* $V_1(t)$, 3 Cycles

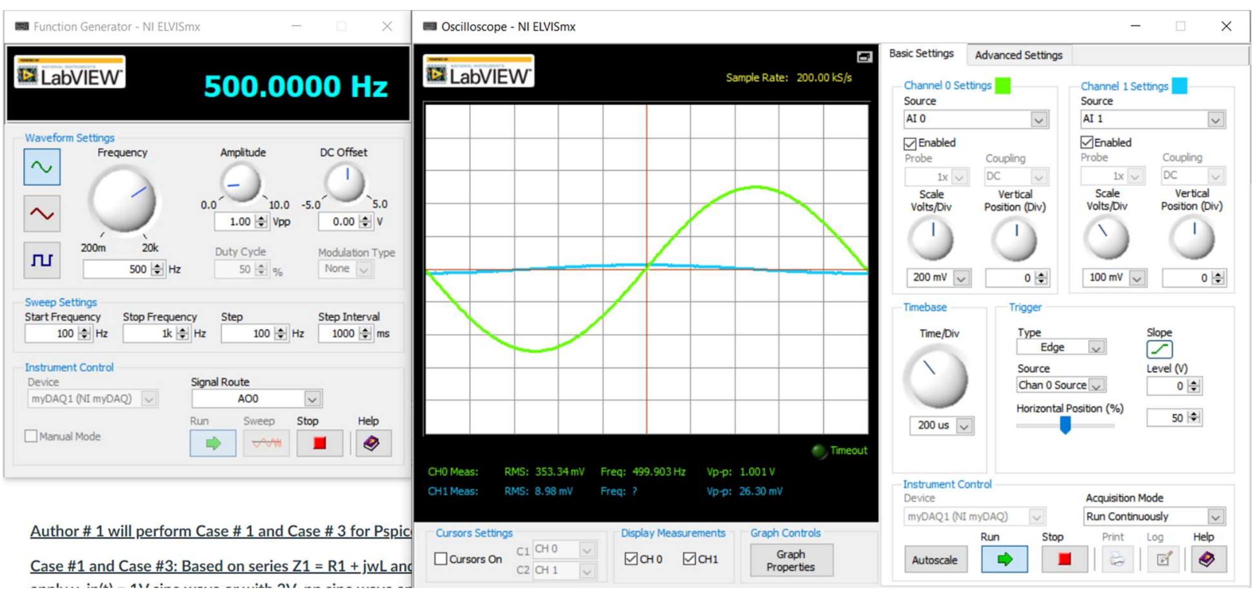

Figure 12.28 – Case 3 – Experimental Results
$V_s(t)$ *and* $V_1(t)$, 3 Cycles

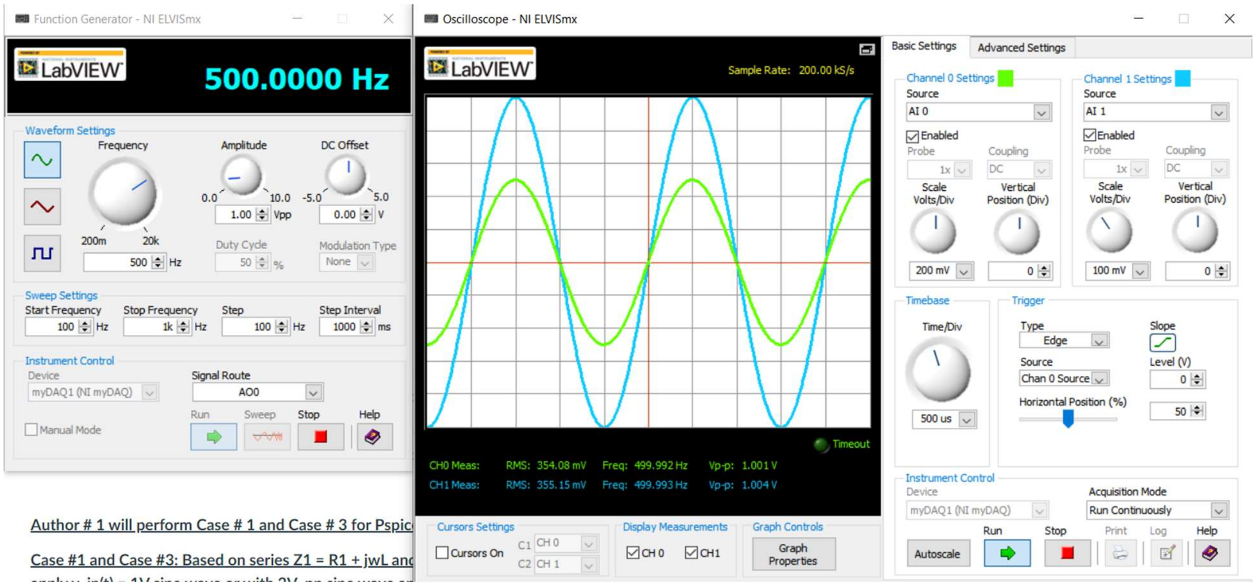

Figure 12.29 – Case 3 – Experimental Results
$V_s(t)$ *and* $V_2(t)$, 3 Cycles

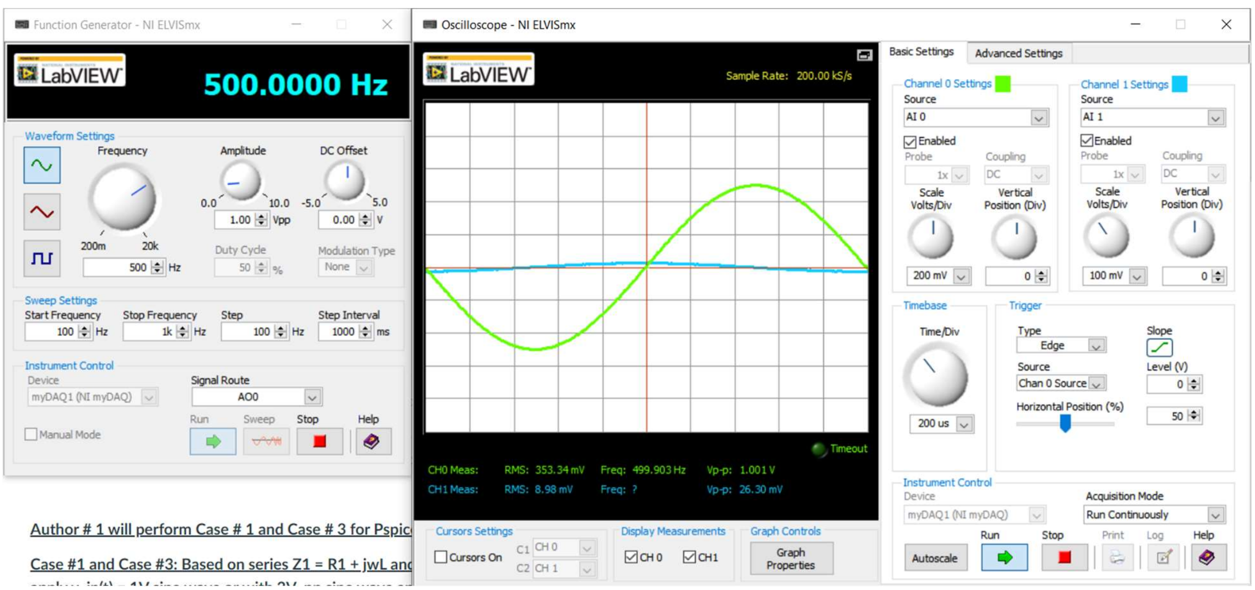

Figure 12.30 – Case 3 – Experimental Results
$V_s(t)$ *and* $V_2(t)$, 1 Cycles

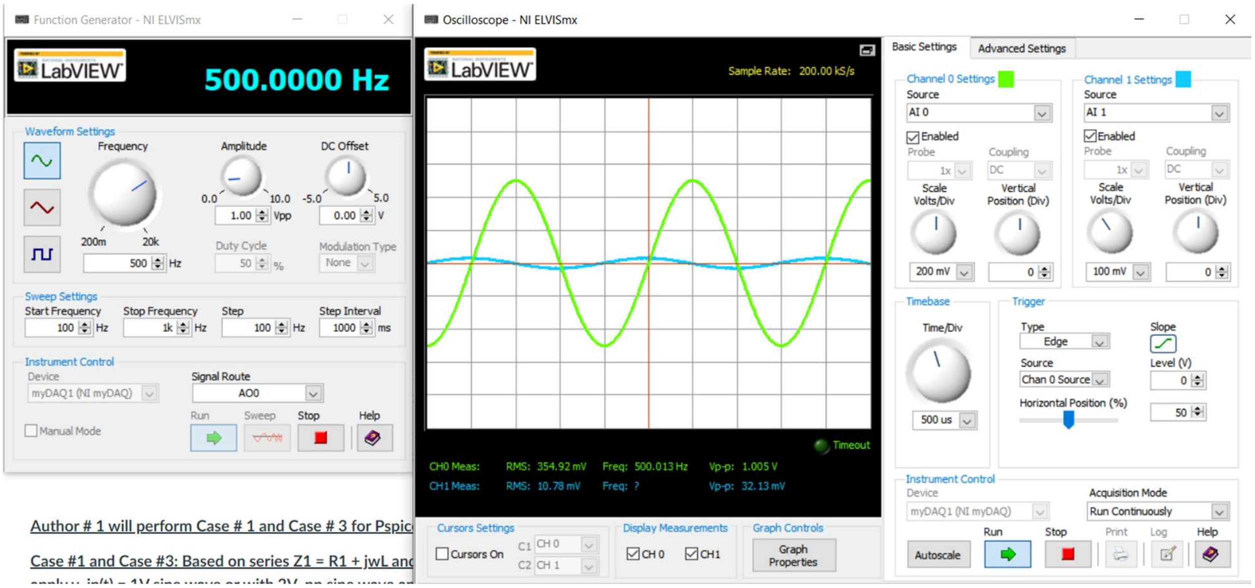

Figure 12.31 – Case 3 – Experimental Results
$V_1(t)$ and $V_2(t)$, 3 Cycles

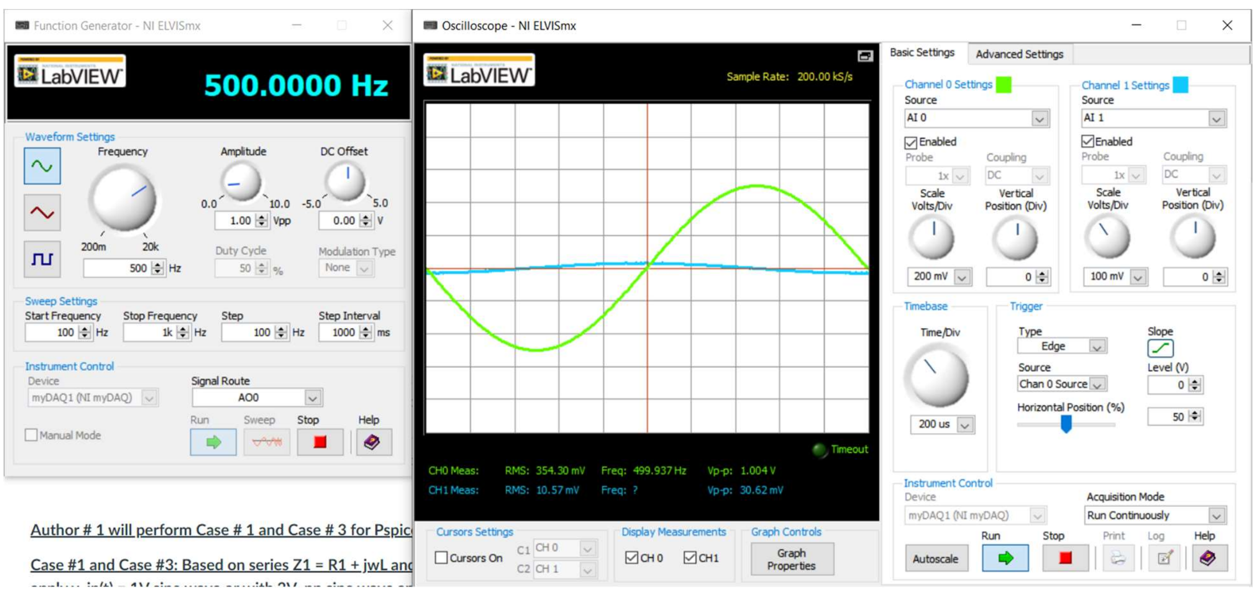

Figure 12.32 – Case 3 – Experimental Results
$V_1(t)$ and $V_2(t)$, 1 Cycles

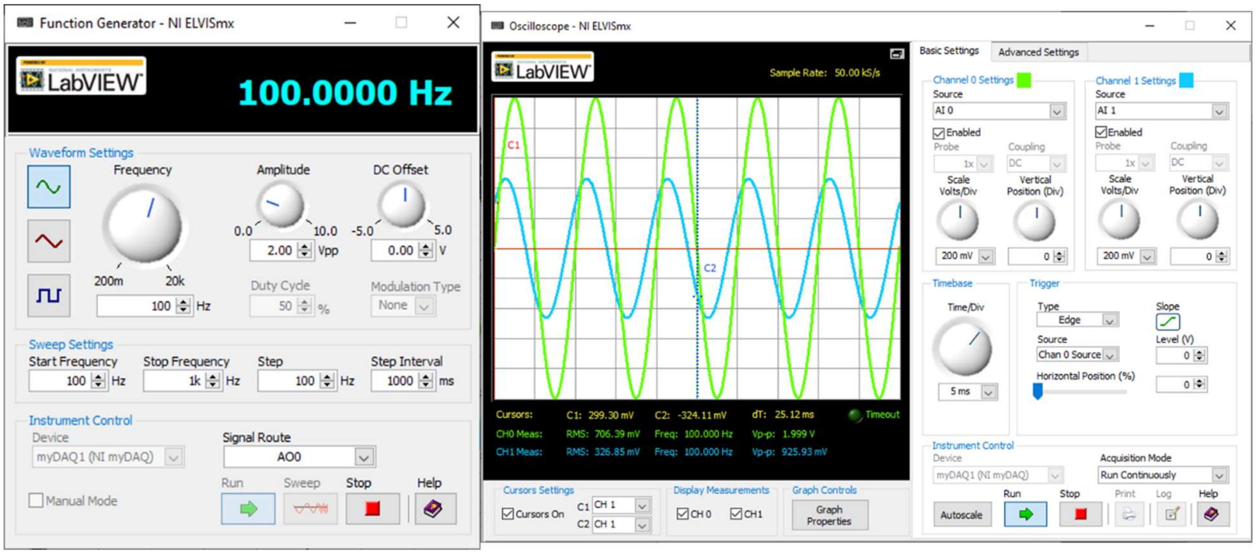

Figure 12.33 – Case 4 – Experimental Results
$V_s(t)$ *and* $V_1(t)$, 3 Cycles

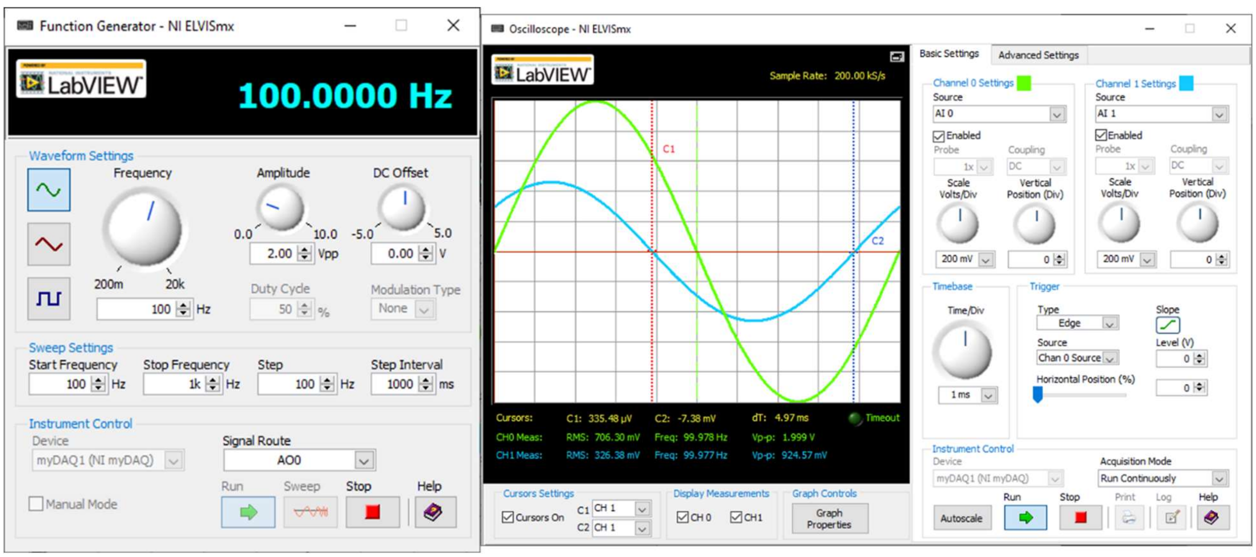

Figure 12.34 – Case 4 – Experimental Results
$V_s(t)$ *and* $V_1(t)$, 1 Cycles

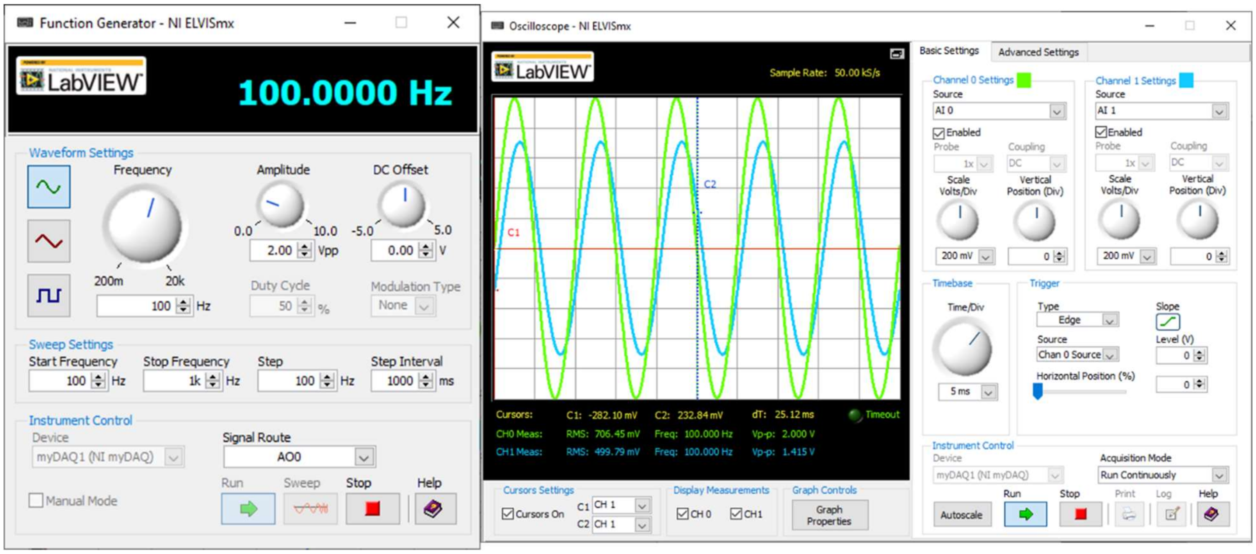

Figure 12.35 – Case 4 – Experimental Results

$V_S(t)$ *and* $V_2(t)$, 3 Cycles

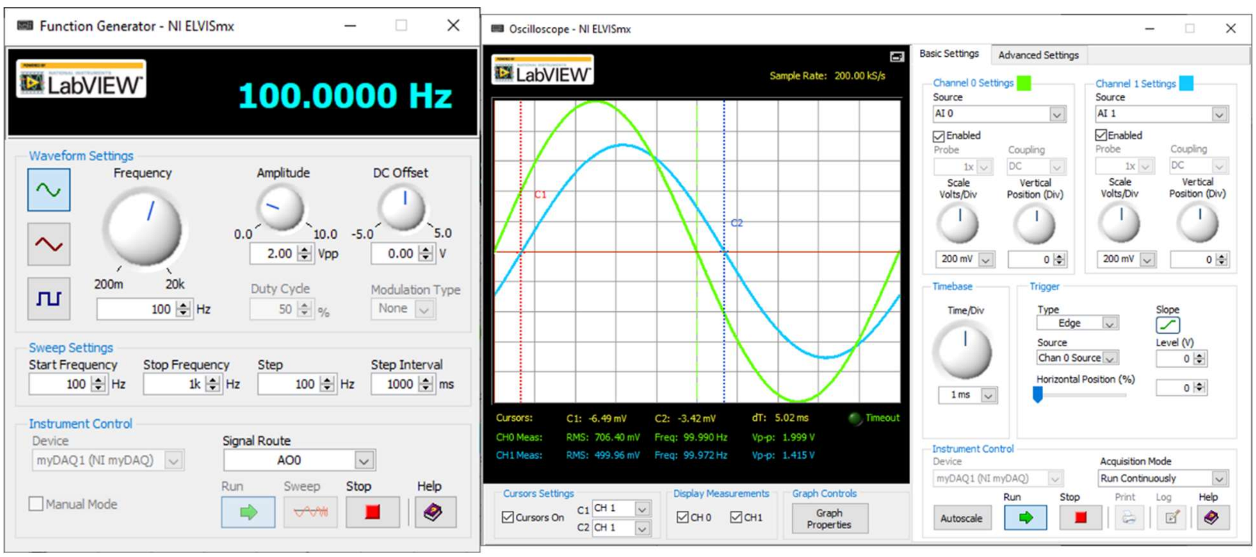

Figure 12.36 – Case 4 – Experimental Results

$V_S(t)$ *and* $V_2(t)$, 1 Cycles

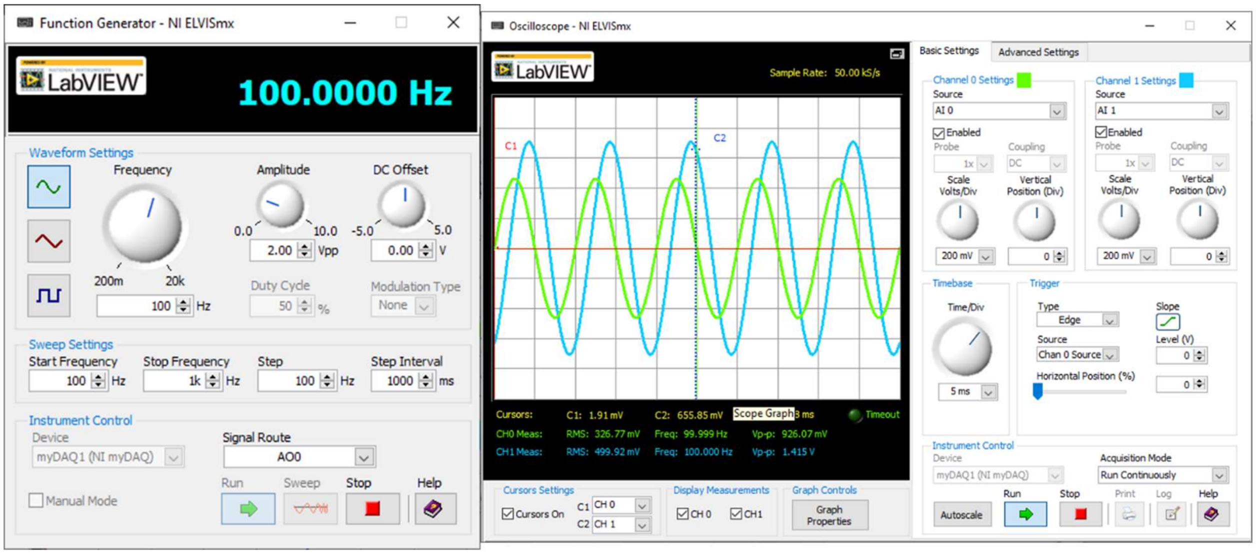

Figure 12.37 – Case 4 – Experimental Results
$V_1(t)$ *and* $V_2(t)$, 3 Cycles

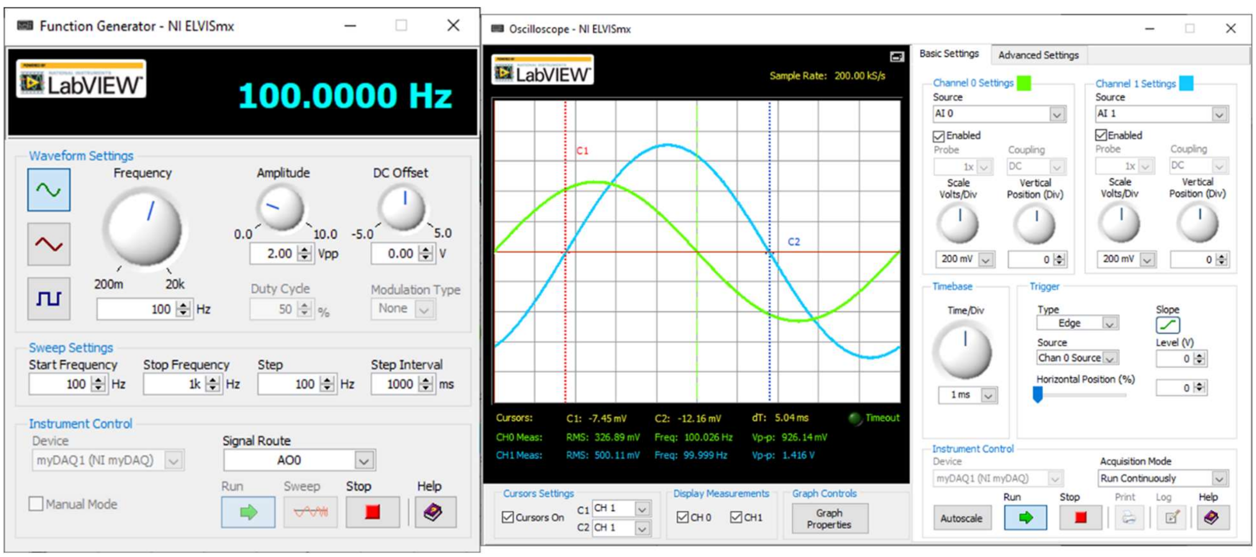

Figure 12.38 – Case 4 – Experimental Results
$V_1(t)$ *and* $V_2(t)$, 1 Cycles

12.4 DISCUSSION & CONCLUSION

The purpose of this lab was to calculate and test impedances and admittance in an RLC circuit experimentally and by simulation.

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[2] Svoboda, James A., and Richard C. Dorf. Introduction to Electric Circuits. John Wiley & Sons, 2014.

[3] Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm

FREQUENCY RESPONSE AC CIRCUITS DESIGN, SIMULATION AND EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ABSTRACT: The purpose of this lab was to get an understanding of how circuits can be affected by the frequency at which their voltage source is running at. In the case of this lab, it dessired to see what frequency are allowed to pass through a first order circuit. Through this we determined where the respective circuit is a low or high pass filter.

KEYWORDS: Ohm's Law, Phasor, Transfer Function, Impedance, Inductive Reactance, Capacitive Reactance, Series Circuit, Resistor, Capacitor, Inductor, NI myDAQ, PSpice, MATLAB

13.1 INTRODUCTION

The purpose of this lab was to test three types of circuits. consisting of either two of three comments resistor, capacitor and an inductor, and examine their frequency response via PSpice. Secondly, we manually test the circuits, inputting different frequencies and measure the output voltage to see the effect on the output caused by the change in frequency. This is done through simulation and also experimentally. Then those experimental values measured are plotted in order to see if the PSpice frequency response matches the experimental results.

Equations

$$V = I * R \tag{1}$$

$$X_C = \frac{1}{j\omega C} \tag{2}$$

$$X_L = j\omega L \tag{3}$$

$$H(j\omega) = \frac{V_{out}}{V_{in}} \tag{4}$$

$$V_{out} = \left(\frac{Z_2}{Z_1 + Z_2}\right) * V_{in} \tag{5}$$

$$H(j\omega) = |H(j\omega)| \angle \phi(j\omega) \tag{6}$$

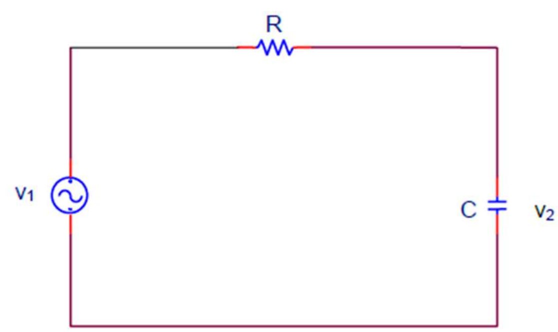


Figure 13.1 – General RC Low Pass Filter Circuit

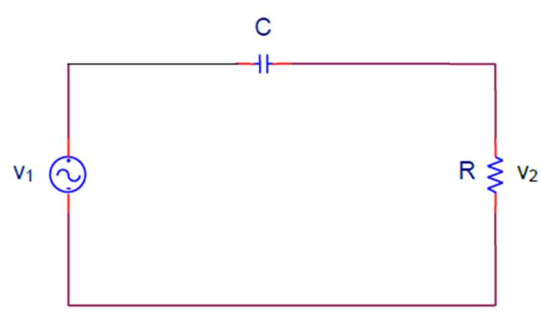


Figure 13.2 – General RC High Pass Filter Circuit

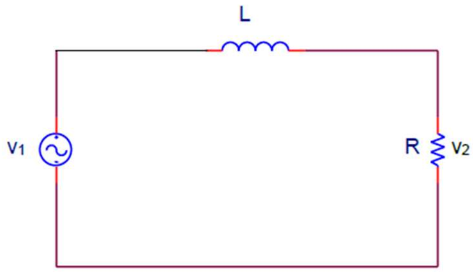


Figure 13.3 – General RL Low Pass Filter Circuit

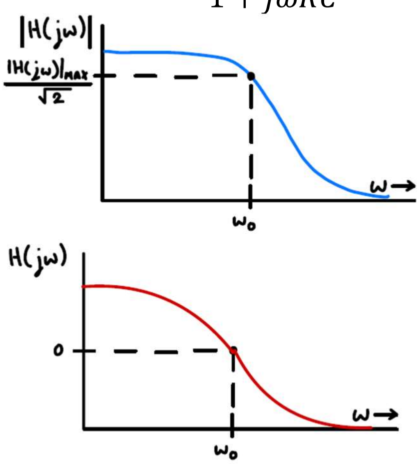
13.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

Preliminary Calculations – Figure 13.1

$$V_1 = \left(\frac{j\omega RC + 1}{j\omega C}\right) * I$$

$$V_2 = \frac{\left(\frac{1}{j\omega C}\right)}{\left(\frac{j\omega RC + 1}{j\omega C}\right)} * V_1 \rightarrow \frac{1}{j\omega C} * I$$

$$H(j\omega) = \frac{1}{1 + j\omega RC}$$



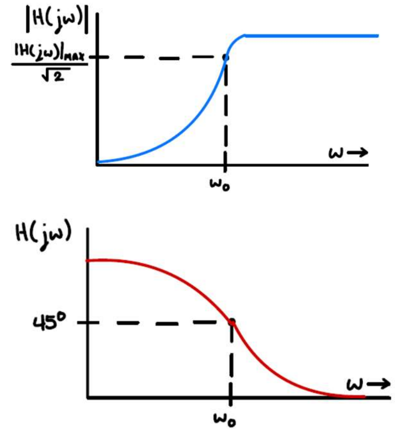
Low Pass Filter Circuit

Preliminary Calculations – Figure 13.2

$$V_1 = \frac{1 + j\omega RC}{j\omega C} * I$$

$$V_2 = \frac{R}{\left(\frac{1 + j\omega RC}{j\omega C}\right)} * V_1$$

$$H(j\omega) = \frac{j\omega RC}{1 + j\omega RC}$$



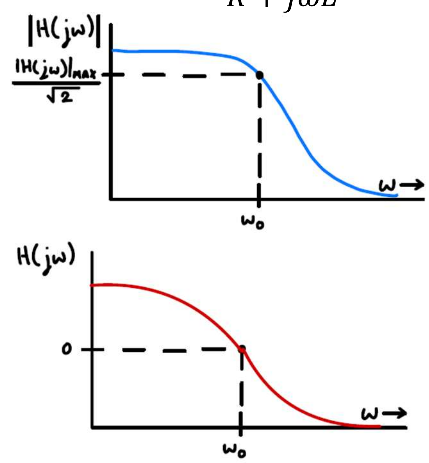
High Pass Filter Circuit

Preliminary Calculations – Figure 13.3

$$V_1 = I * (j\omega L + R)$$

$$V_2 = \frac{R}{j\omega L + R} * V_1 \rightarrow R * I$$

$$H(j\omega) = \frac{R}{R + j\omega L}$$



Low Pass Filter Circuit

Preliminary Calculations – Case 1 & 3

Case 1: Fig 13.2, 5.1kOhms, 0.01microF

$$H(jw) = \frac{1}{1 + j\omega * 5.1k * 0.01\mu F}$$

$$f_c = \frac{1}{2\pi RC}$$

$$f_c = 3.1207kHz$$

Case 3: Fig 13.4, 3.3kOhms, 68mH

$$H(j\omega) = \frac{3.3k\Omega}{3.3k\Omega + j\omega * 68mH}$$

$$f_c = \frac{R}{2\pi L}$$

$$f_c = 7.7237kHz$$

Preliminary Calculations – Case 2 & 4

$$R = 5.1k\Omega, C = 0.01\mu F$$

$$H(jw) = \frac{j\omega * 51\mu sec}{1 + j\omega 0.01\mu F}$$

$f_c = 3.1207kHz$, High Pass Filter

$$R = 3.3k\Omega, L = 68mH$$

$$H(j\omega) = \frac{3.3k\Omega}{3.3k\Omega + j\omega * 68mH}$$

$f_c = 7.7237kHz$, Low Pass Filter

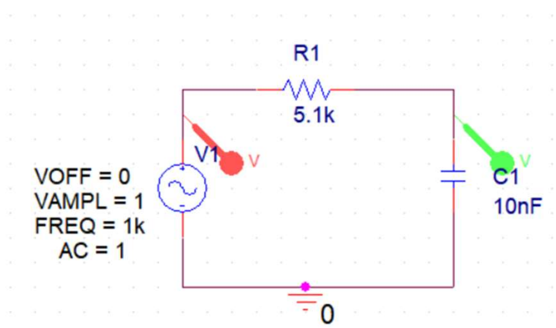


Figure 13.4 – Simulated RC Circuit, Case 1
C = 0.01µF, R = 5.1kΩ @

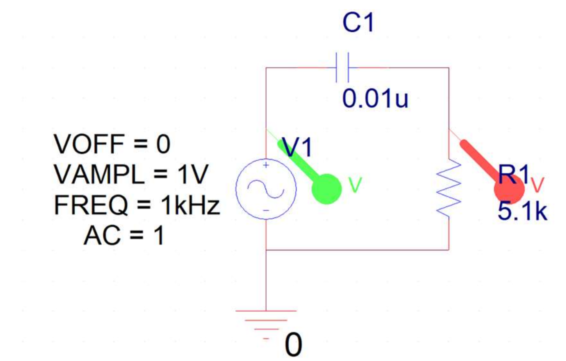


Figure 13.5 – Simulated RC Circuit, Case 2
C = 0.01µF, R = 5.1kΩ

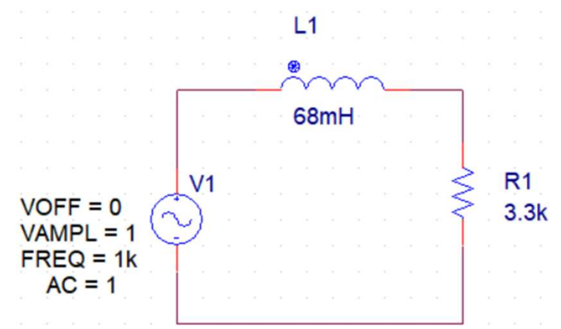


Figure 13.6 – Case 3 – RL Circuit

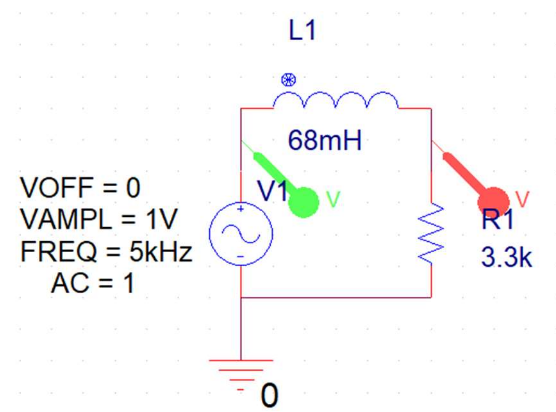


Figure 13.7 – Simulated RL Circuit, Case 4
L = 68 mH, R = 3.3kΩ

13.3 EXPERIMENTAL & SIMULATION ON DATA & RESULTS

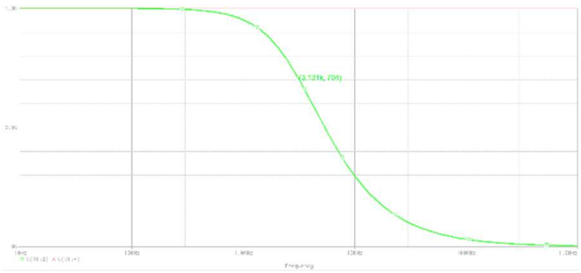


Figure 13.8 – Simulation Results – Case 1 Waveform, H(jω) vs ω

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		-295.292m		
	X Values	3.1418K	10.000	3.1318K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(R1:2)	704.703m	1.0000	-295.292m		0.000	0.000	1.0000	704.703m	852.349m
	V(V1:+)	1.0000	1.0000	0.000		295.297m	5.1341u	1.0000	1.0000	1.0000

Figure 13.9 – Simulation Results – Case 1 Waveform, H(jω) vs ω

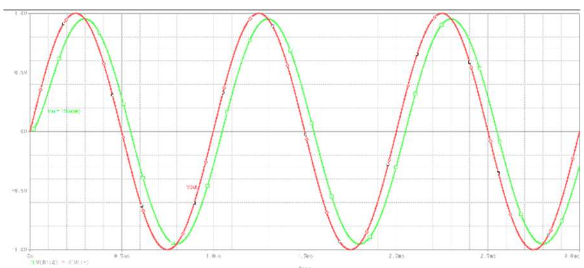


Figure 13.10 – Simulation Results – Case 1 Waveform, 1kHz

Figure 13.11 – Simulation Results – Case 1 Waveform, 3.120kHz

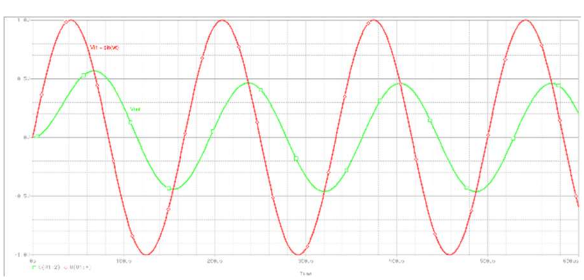


Figure 13.12 – Simulation Results – Case 1 Waveform, 5kHz

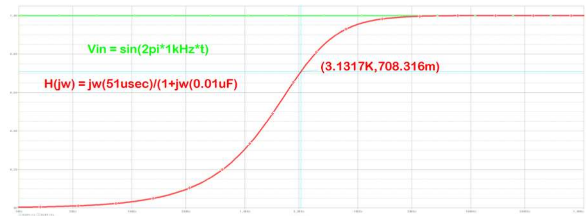


Figure 13.13 – Simulation Results – Case 2 Waveform, H(jω) vs ω

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		-291.190m		
	X Values	3.1361K	10.000	3.1261K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 2	V(V1:+)	1.0000	1.0000	0.000		291.190m	0.000	1.0000	1.0000	1.0000
CURSOR 1	V(R1:2)	708.810m	3.2044m	705.606m		0.000	-0.9968	708.810m	3.2044m	356.007m

Figure 13.14 – Simulation Results– Case 2 Data, H(jω) vs ω

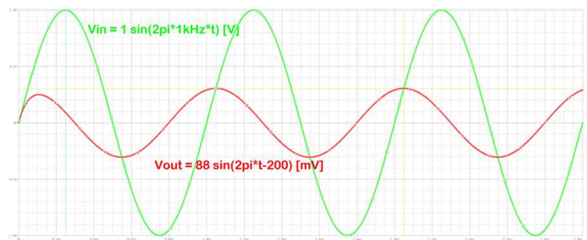


Figure 13.15 – Simulation Results– Case 2 Waveform, @ 1kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		694.841m		
	X Values	250.109u	2.0492m	-1.7990m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(V1:+)	1.0000	303.934m	696.066m		0.000	-1.2246m	1.0000	303.934m	651.967m
CURSOR 2	V(R1:2)	88.843m	305.159m	-216.316m		-911.157m	0.000	305.159m	88.843m	197.001m

Figure 13.16 – Simulation Results– Case 2 Data, @ 1kHz

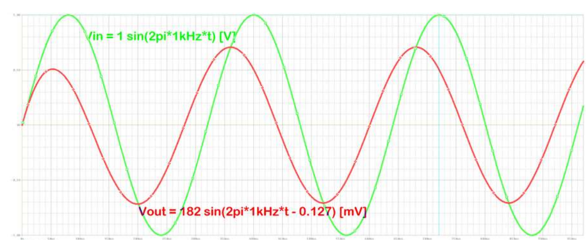


Figure 13.17 – Simulation Results – Case 2 Waveform, @ 3.1207kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		1.0000		
	X Values	720.884u	0.000	720.884u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(V1:+)	1.0000	0.000	1.0000		0.000	0.000	1.0000	0.000	499.999m
	V(R1:2)	503.680m	196.041u	503.484m		-496.318m	196.041u	503.680m	196.041u	251.938m

Figure 13.18 – Simulation Results– Case 2 Data, @ 3.1207kHz

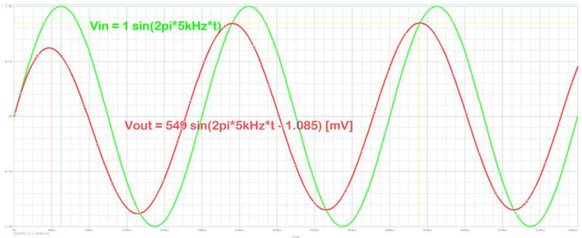


Figure 13.19 – Simulation Results– Case 2 Waveform, @ 5kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		151.734m		
	X Values	50.171u	432.179u	-382.009u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(V1:+)	1.0000	846.477m	153.508m		0.000	-1.7740m	1.0000	846.477m	923.232m
CURSOR 2	V(R1:2)	549.947m	848.251m	-298.304m		-450.038m	0.000	848.251m	549.947m	699.099m

Figure 13.20 – Simulation Results– Case 2 Data, @ 5kHz

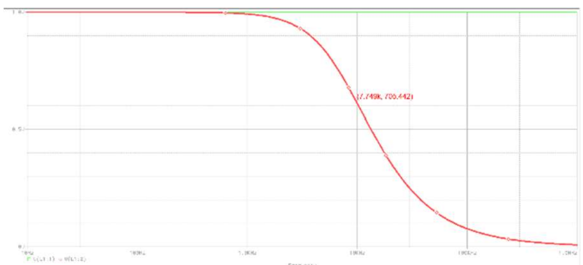


Figure 13.21 – Simulation Results – Case 3 Waveform, H(jω) vs ω

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	7.7594K	10.000	7.7494K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(L1:1)	1.0000	1.0000	0.000		0.000	0.000	1.0000	1.0000	1.0000
	V(L1:2)	705.442m	1.0000	-294.557m		-294.558m	-838.145n	1.0000	705.442m	852.721m

Figure 13.22 – Simulation Results – Case 3 Waveform, H(jω) vs ω

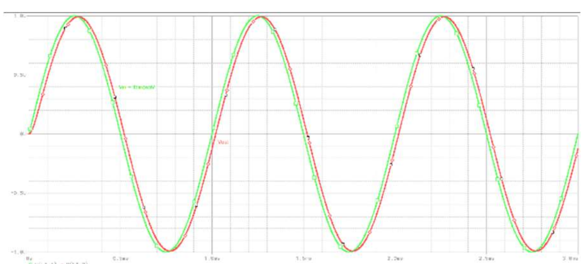


Figure 13.23 – Simulation Results – Case 3 Waveform, 1kHz

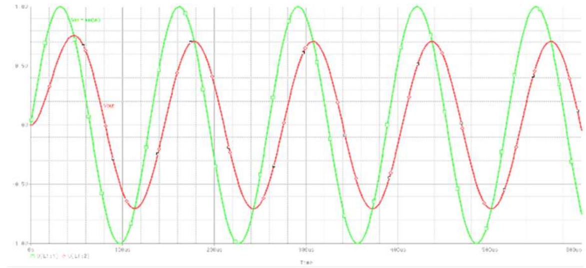


Figure 13.24 – Simulation Results – Case 3 Waveform, 7.723kHz

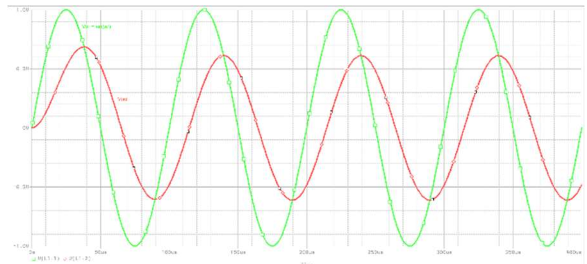


Figure 13.25 – Simulation Results – Case 3 Waveform, 10kHz

Figure 13.26 – Simulation Results – Case 4 Waveform, H(jω) vs ω

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		-291.684m		
	X Values	7.6957K	10.000	7.6857K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 2	V(L1:1)	1.0000	1.0000	0.000		291.684m	0.000	1.0000	1.0000	1.0000
CURSOR 1	V(R1:2)	708.316m	1.0000	-291.683m		0.000	-838.145n	1.0000	708.316m	854.158m

Figure 13.27 – Simulation Results – Case 4 Data, H(jω) vs ω

Figure 13.28 – Simulation Results– Case 4 Waveform, @ 1kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		10.139m		
	X Values	250.225u	1.2803m	-1.0300m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(L1:1)	1.0000	981.995m	18.004m		0.000	-7.8649m	1.0000	981.995m	990.997m
CURSOR 2	V(R1:2)	983.693m	989.860m	-6.1675m		-16.306m	0.000	989.860m	983.693m	986.777m

Figure 13.29 – Simulation Results– Case 4 Data, @ 1kHz

Figure 13.30 – Simulation Results– Case 4 Waveform, @ 7.7237kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		243.958m		
	X Values	161.769u	46.767u	115.003u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(L1:1)	1.0000	768.665m	231.330m		0.000	12.628m	1.0000	768.665m	884.329m
CURSOR 2	V(R1:2)	498.384m	756.036m	-257.652m		-501.610m	0.000	756.036m	498.384m	627.210m

Figure 13.31 – Simulation Results– Case 4 Data, @ 7.7237kHz

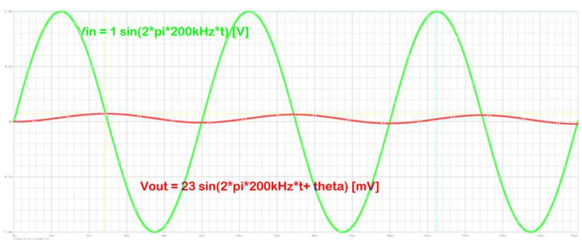


Figure 13.32 – Simulation Results– Case 4 Waveform, @200kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		927.181m		
	X Values	11.250u	2.4424u	8.8075u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(L1:1)	1.0000	69.797m	930.203m		0.000	-3.0219m	1.0000	69.797m	534.898m
CURSOR 2	V(R1:2)	23.680m	72.819m	-49.139m		-976.320m	0.000	72.819m	23.680m	48.249m

Figure 13.33 – Simulation Results– Case 4 Data, @200kHz

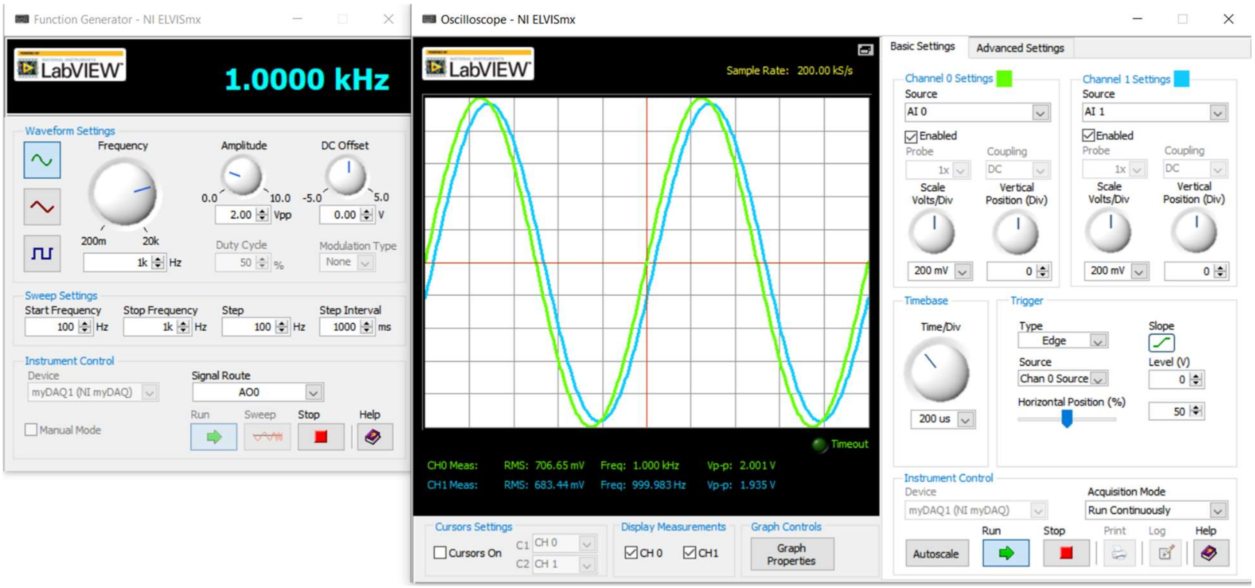


Figure 13.34 – Experimental Results – Case 1 – Waveform, 1kHz

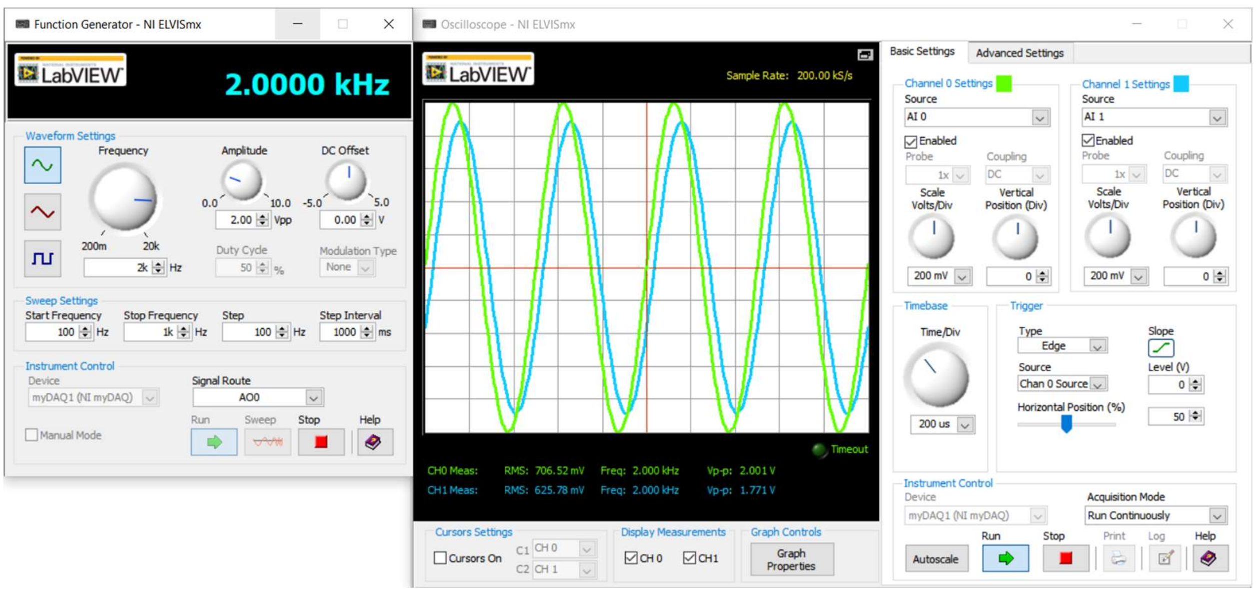


Figure 13.35 – Experimental Results – Case 1 – Waveform, 2kHz

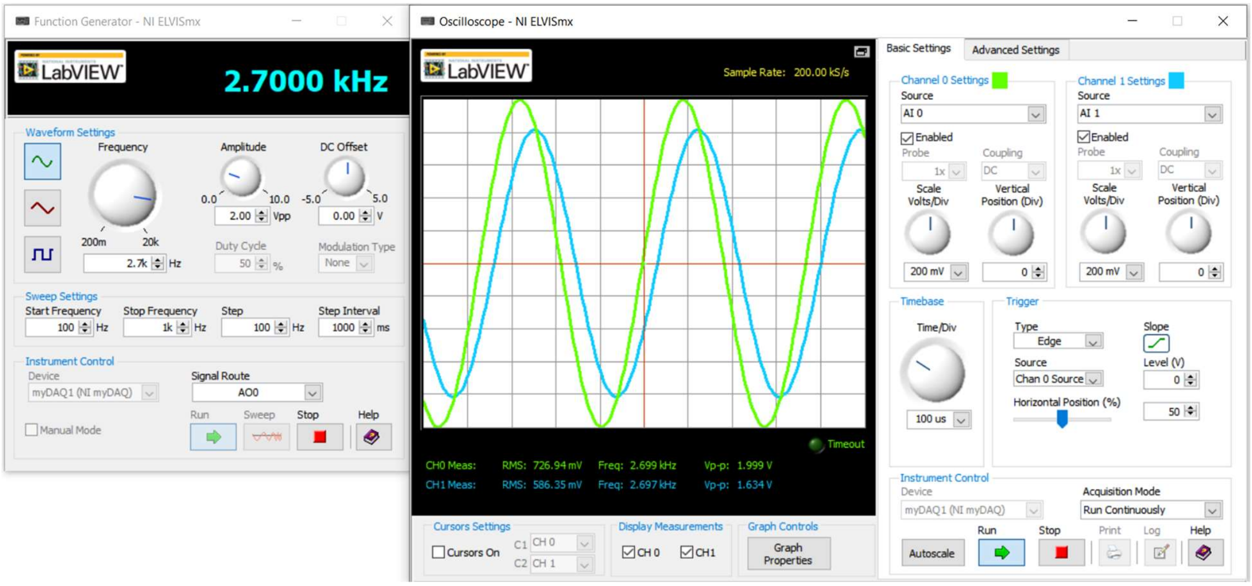


Figure 13.36 – Experimental Results – Case 1 – Waveform, 2.7kHz

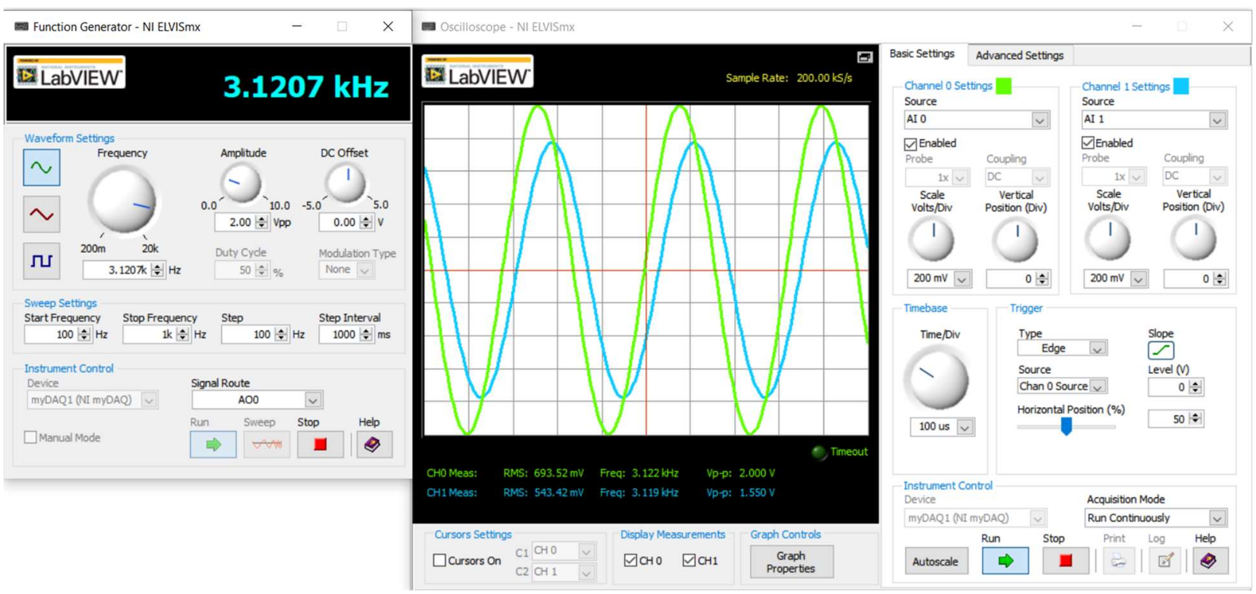


Figure 13.37 – Experimental Results – Case 1 – Waveform, 3.1207kHz

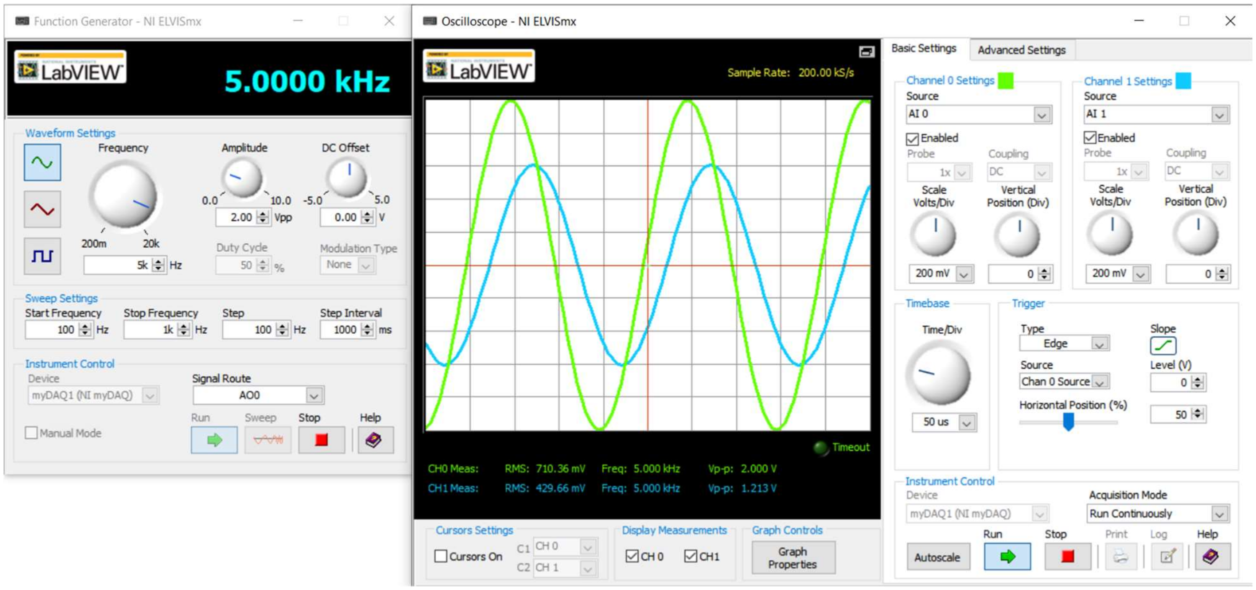


Figure 13.38 – Experimental Results – Case 1 – Waveform, 5kHz

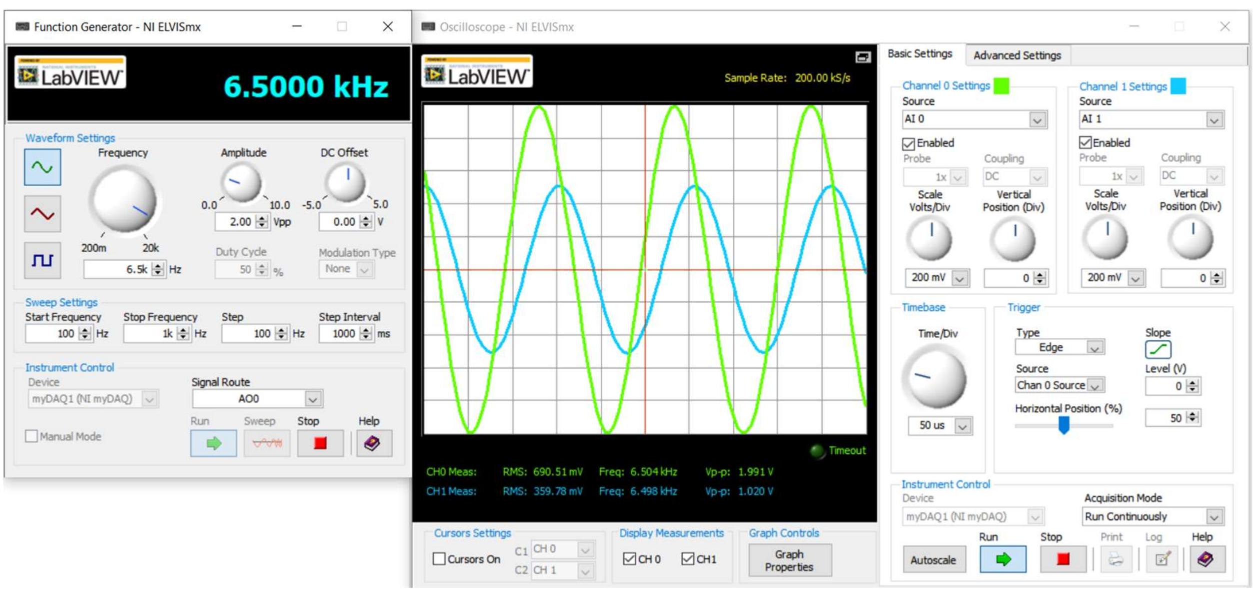


Figure 13.39 – Experimental Results – Case 1 – Waveform, 6.5kHz

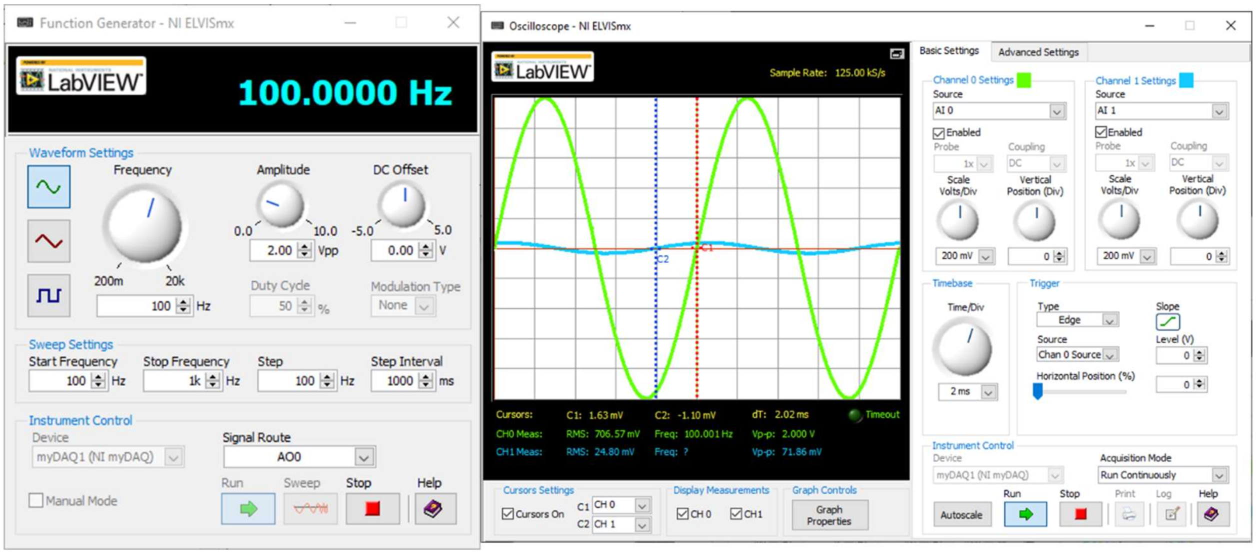


Figure 13.40 – Experimental Results – Case 2 – Waveform, @ 100Hz

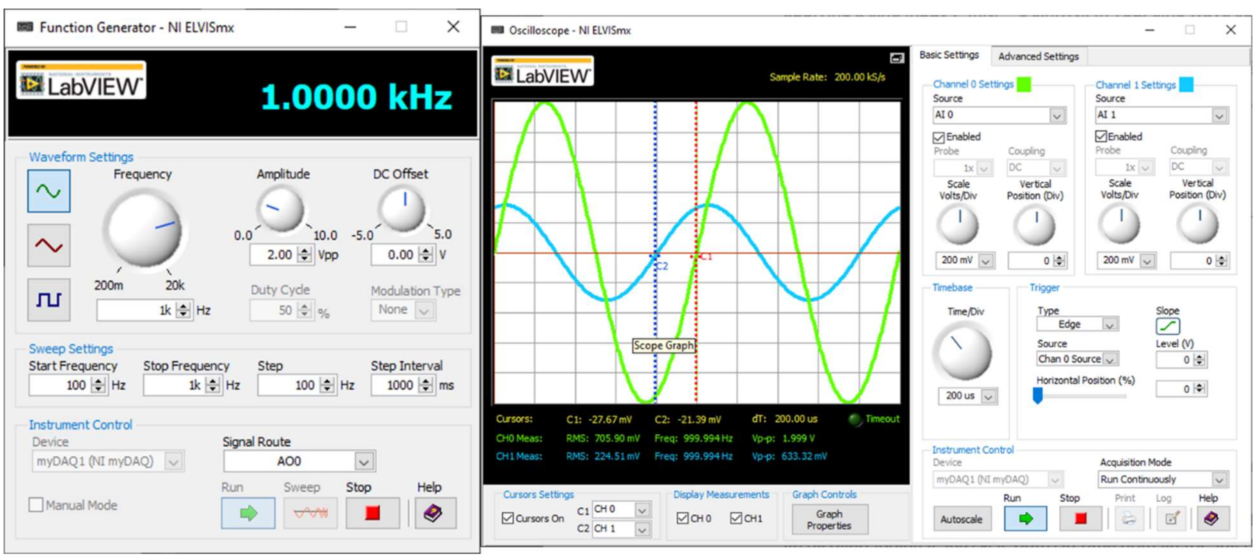


Figure 13.41 – Experimental Results – Case 2 – Waveform, @ 1kHz

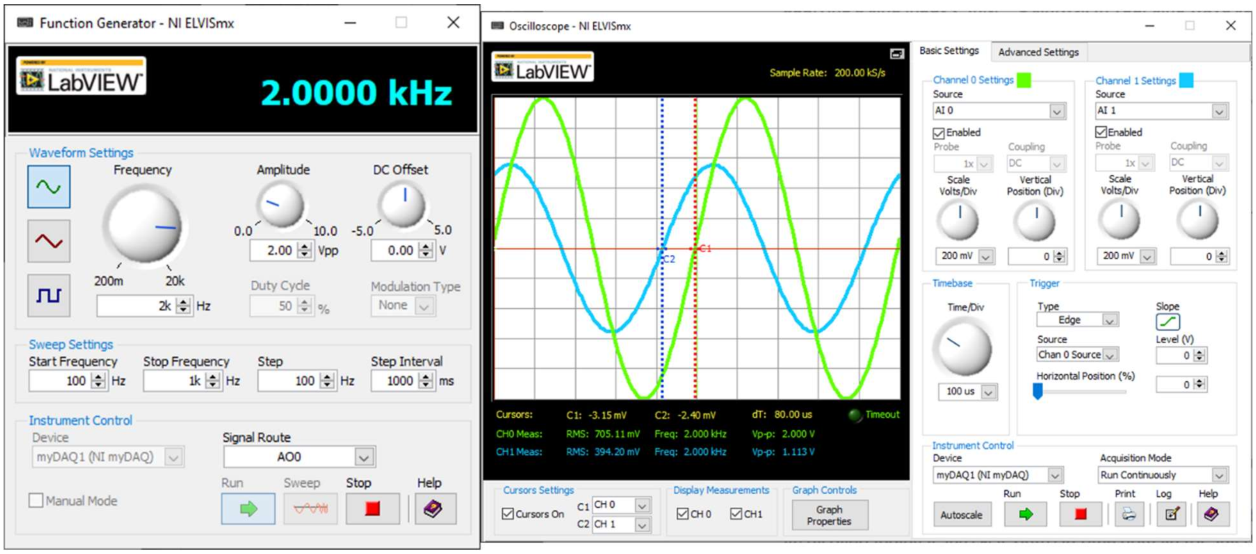


Figure 13.42 – Experimental Results – Case 2 – Waveform, @ 2kHz

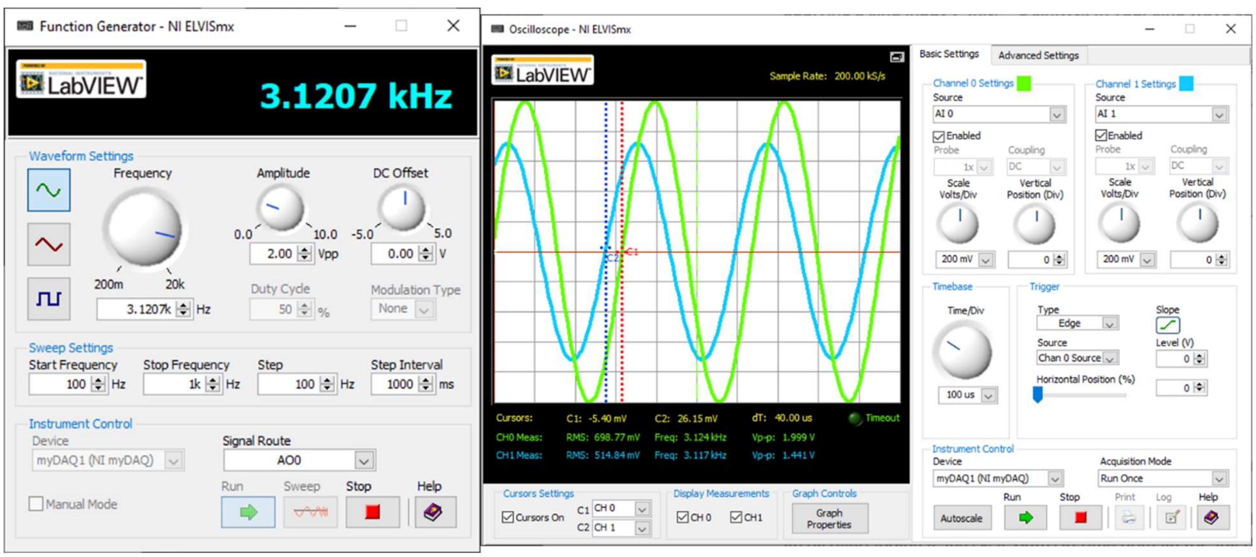


Figure 13.43 – Experimental Results – Case 2 – Waveform, @ 3.1207kHz

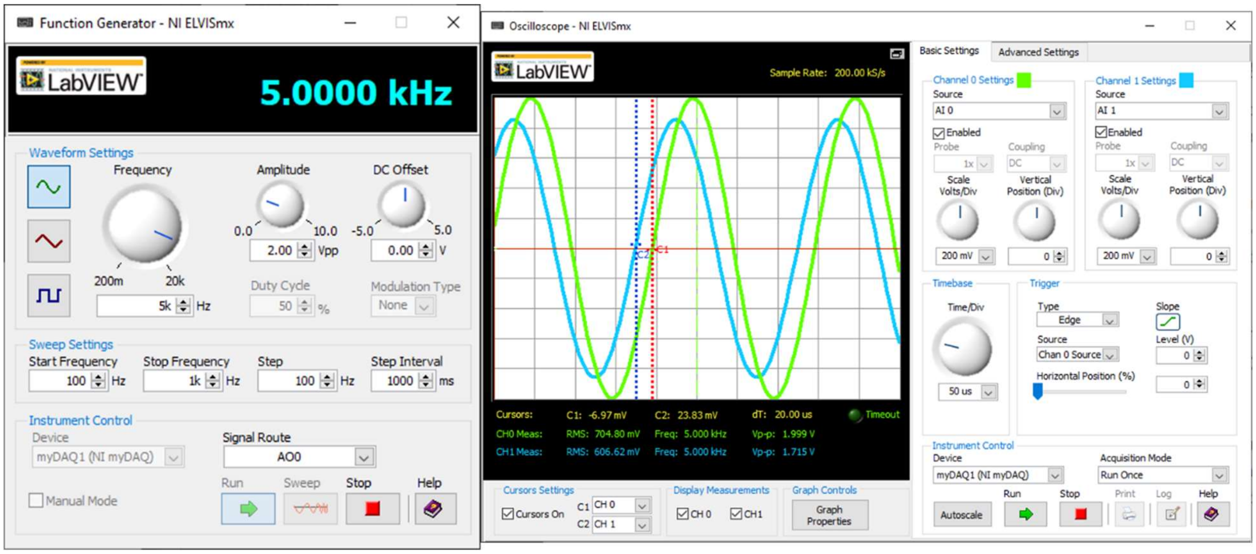


Figure 13.44 – Experimental Results – Case 2 – Waveform, @ 5kHz

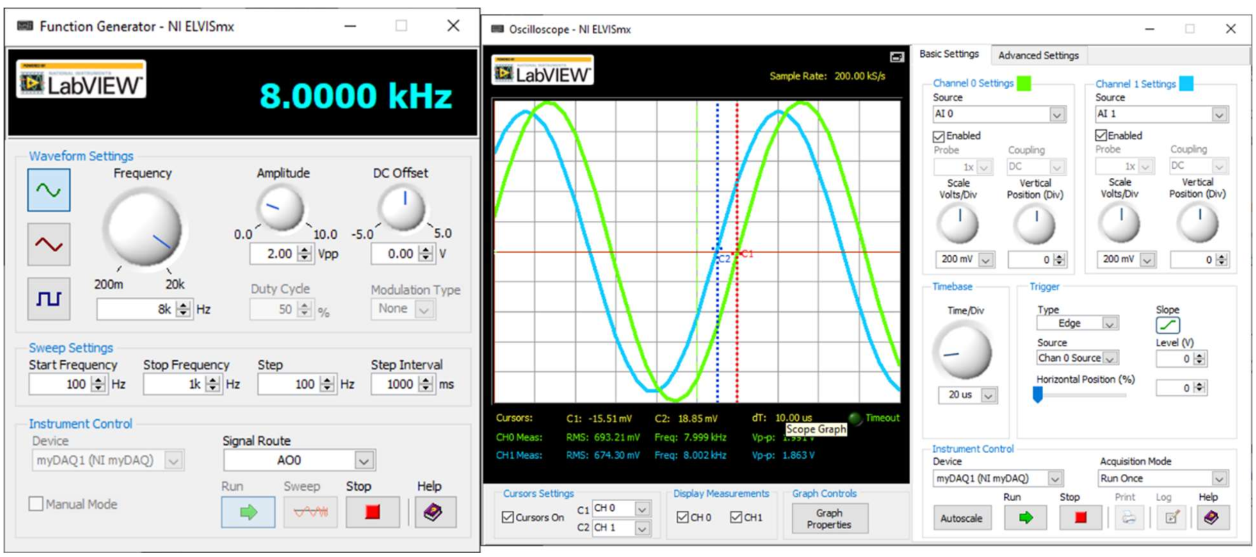


Figure 13.45 – Experimental Results – Case 2 – Waveform, @ 8kHz

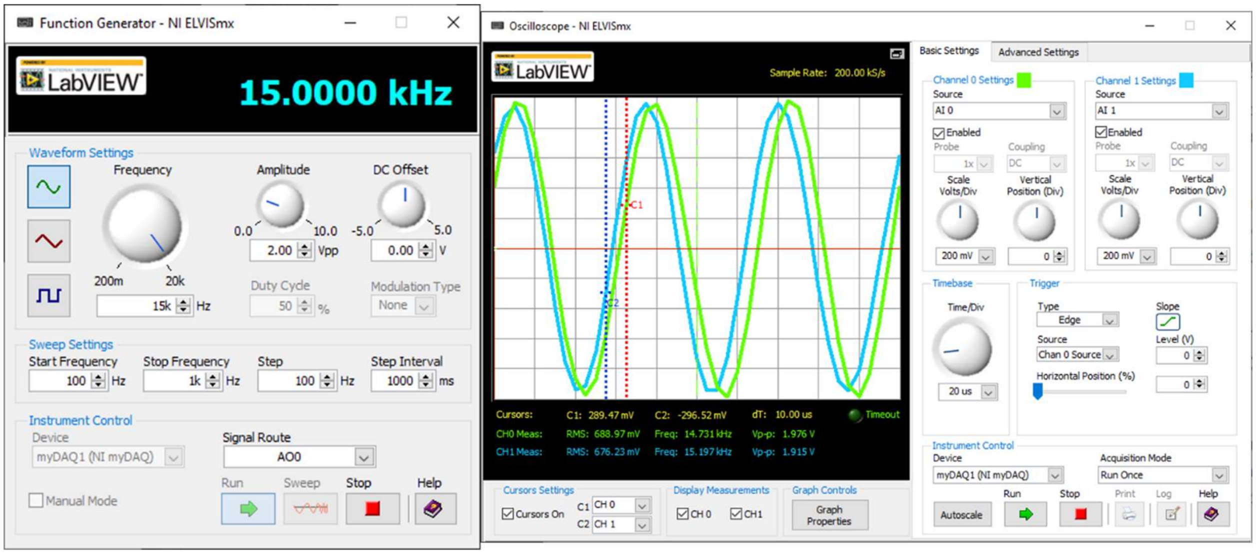


Figure 13.46 – Experimental Results – Case 2 – Waveform, @ 15kHz

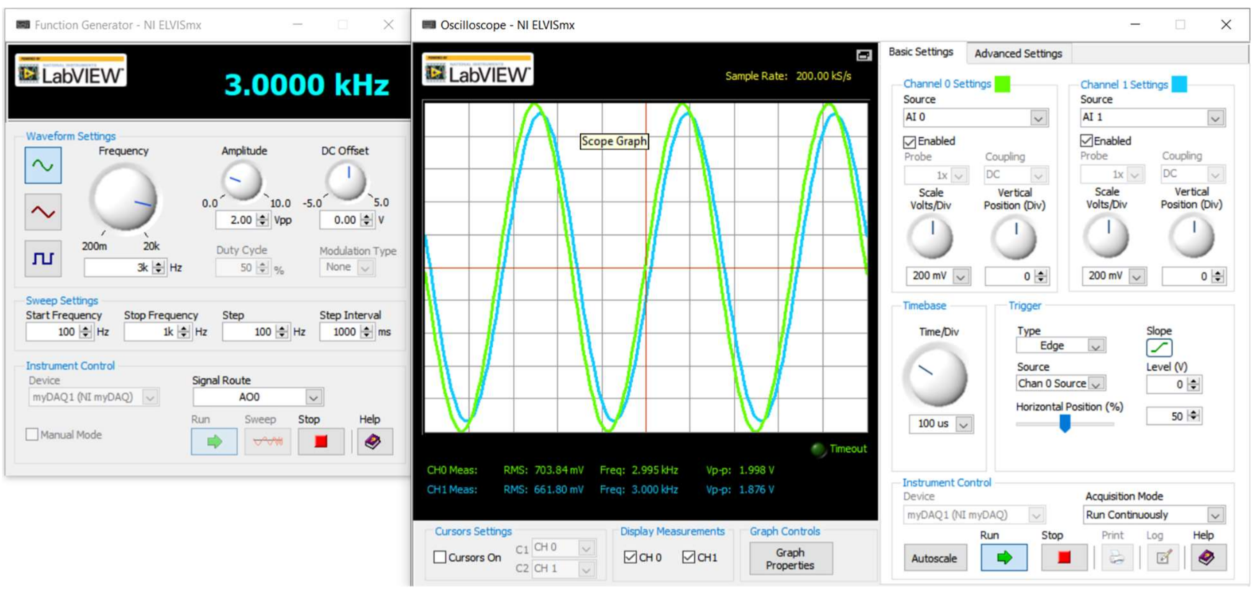


Figure 13.47 – Experimental Results – Case 3 – Waveform, 3kHz

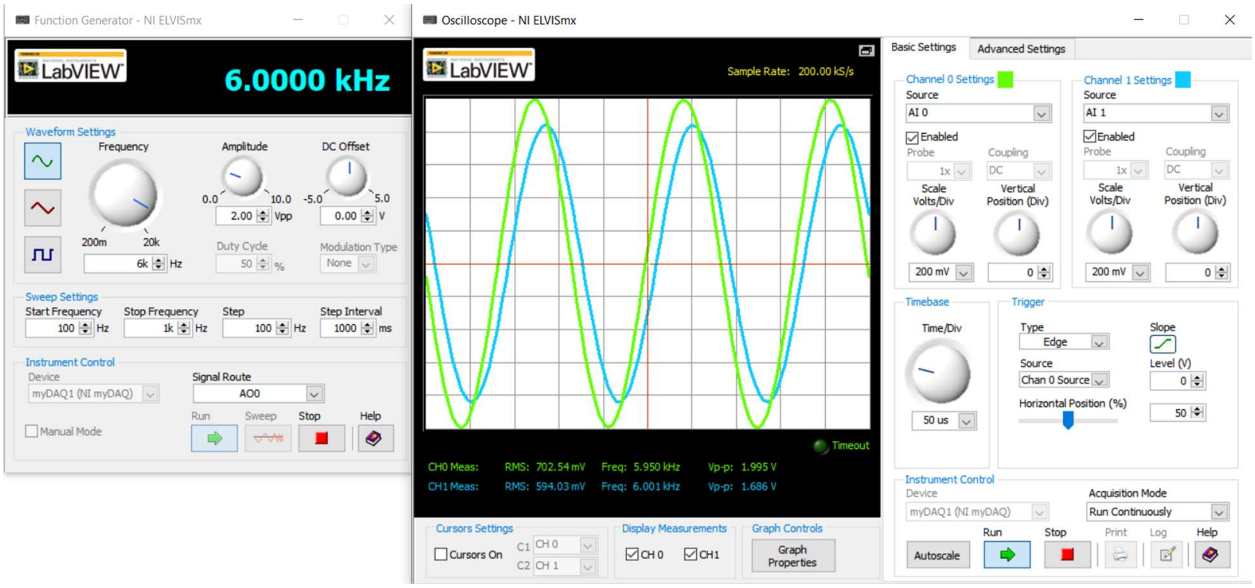


Figure 13.48 – Experimental Results – Case 3 – Waveform, 6kHz

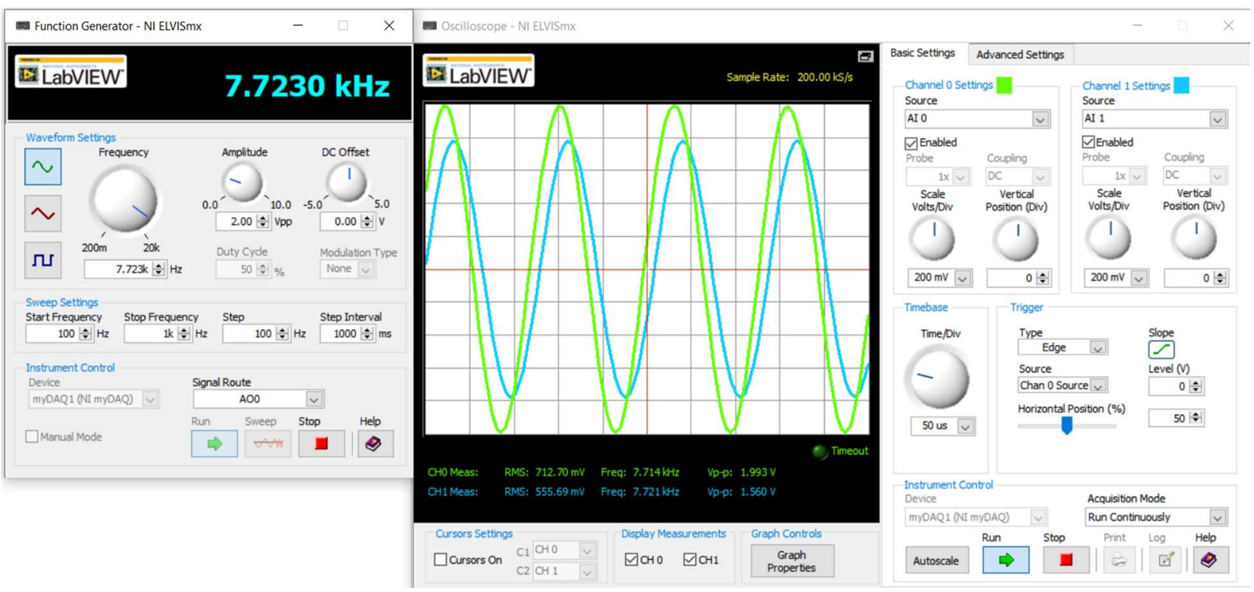


Figure 13.49 – Experimental Results – Case 3 – Waveform, 7.723kHz

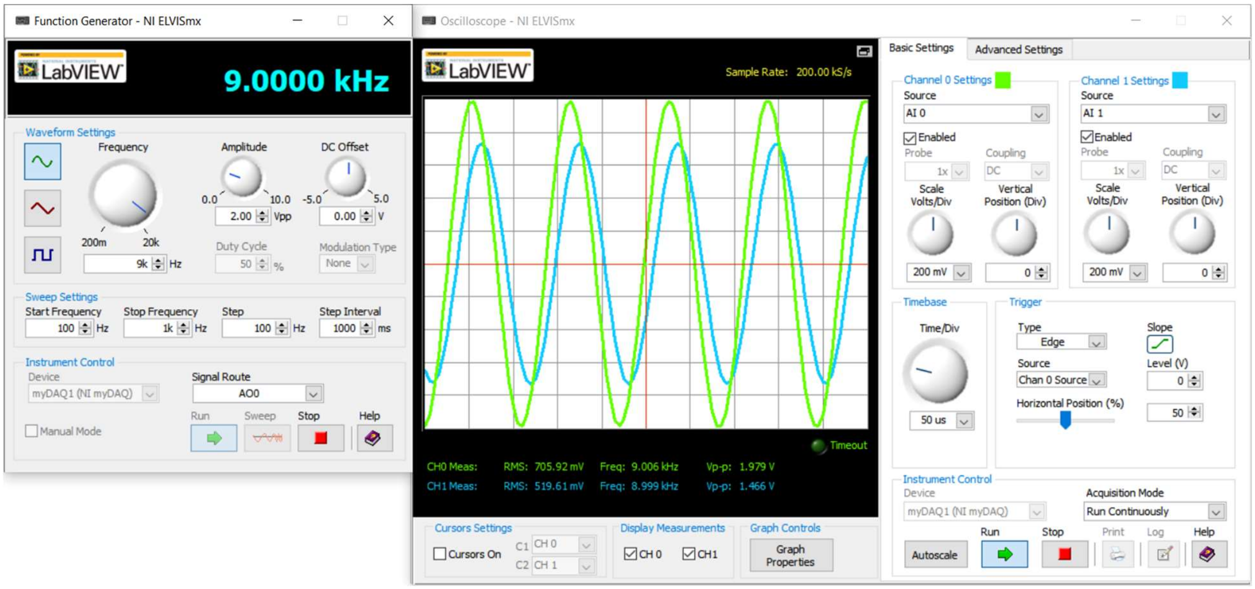


Figure 13.50 – Experimental Results – Case 3 – Waveform, 9kHz

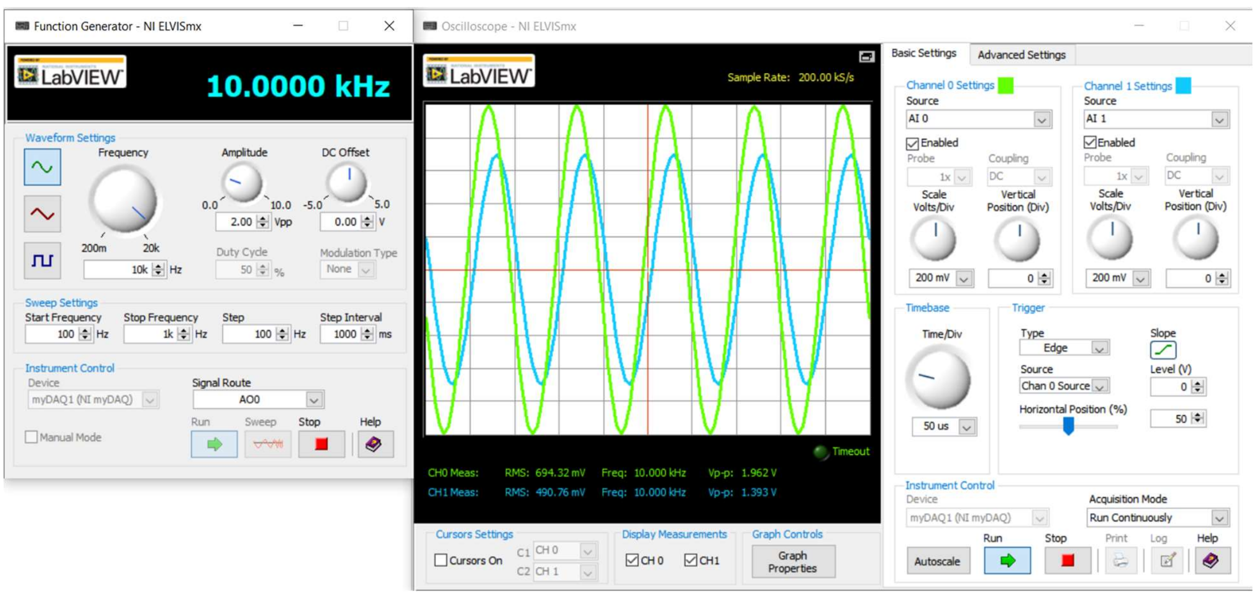


Figure 13.51 – Experimental Results – Case 3 – Waveform, 10kHz

Figure 13.52 – Experimental Results – Case 3 – Waveform, 12kHz

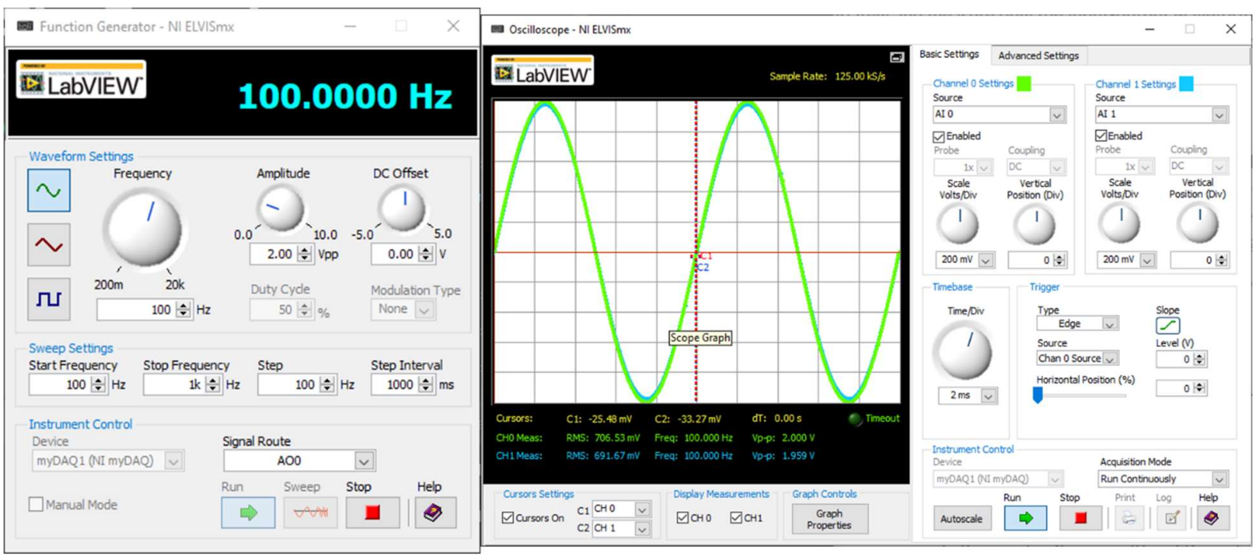


Figure 13.53 – Experimental Results – Case 4 – Waveform, @ 100Hz

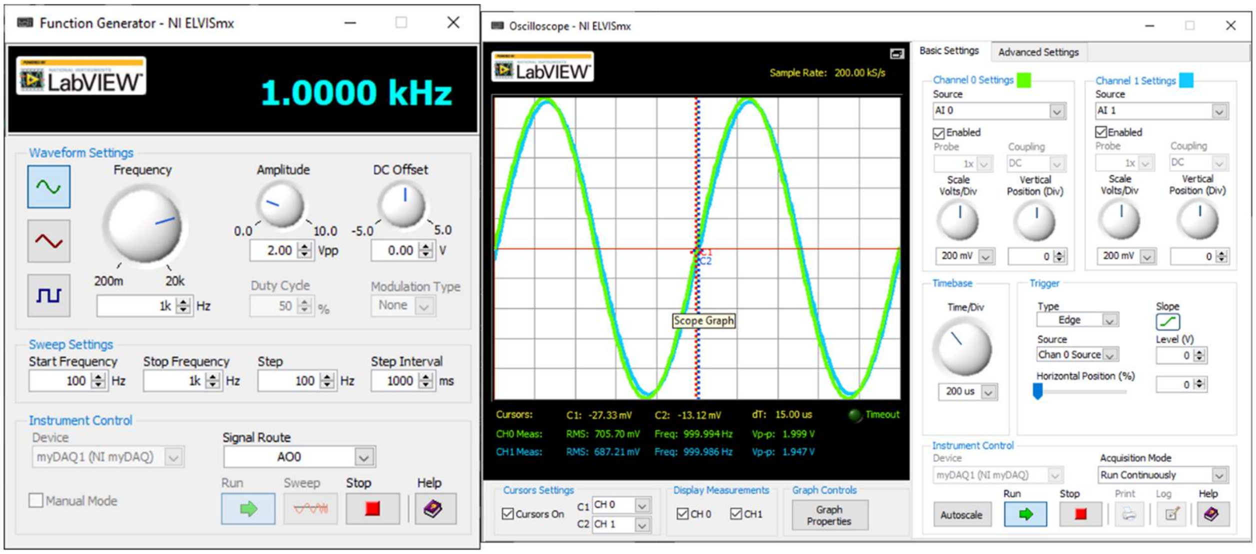


Figure 13.54 – Experimental Results – Case 4 – Waveform, @ 1kHz

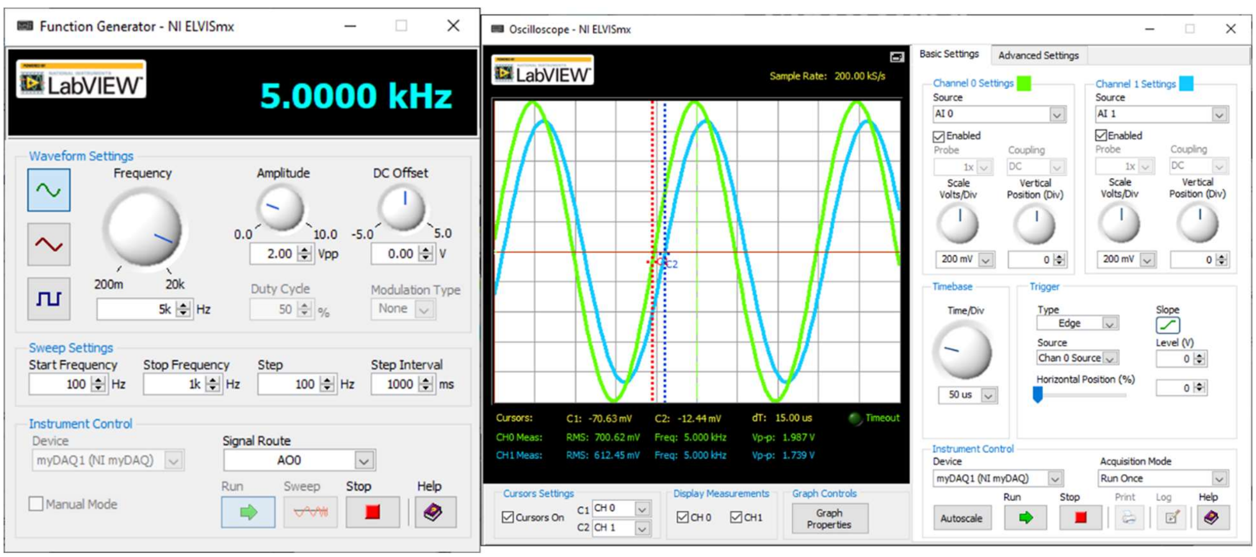


Figure 13.55 – Experimental Results – Case 4 – Waveform, @ 5kHz

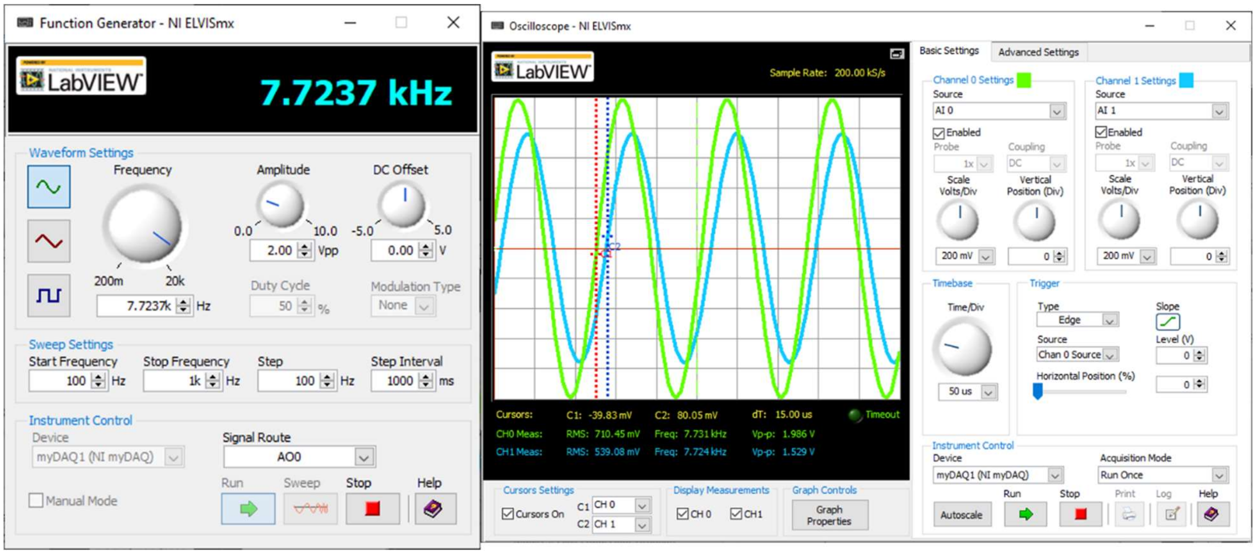


Figure 13.56 – Experimental Results – Case 4 – Waveform, @ 7.7237kHz

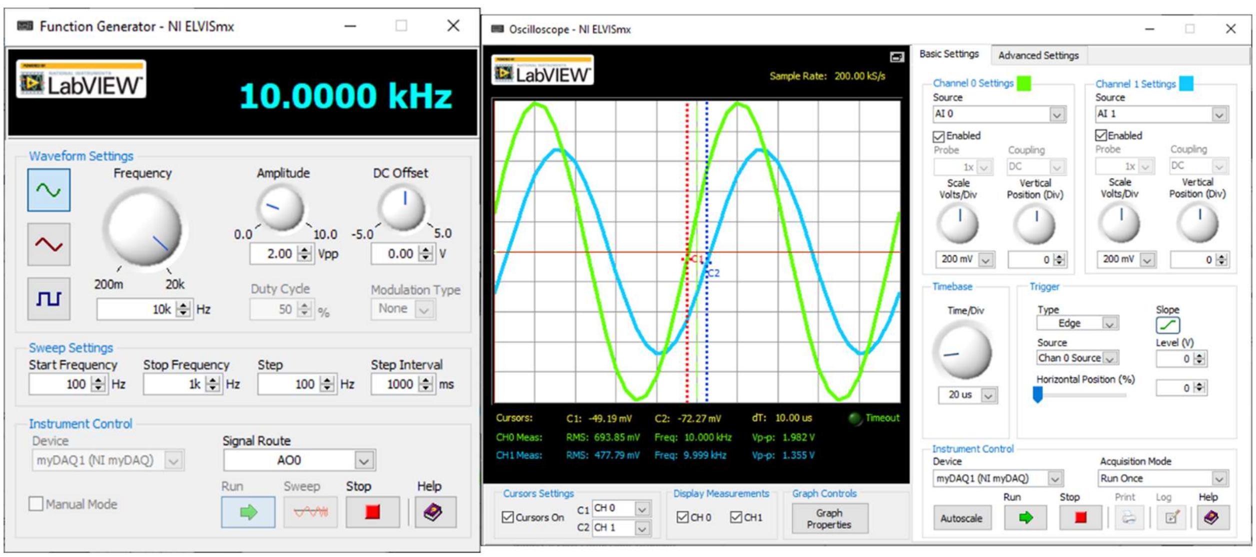


Figure 13.57 – Experimental Results – Case 4 – Waveform, @ 10kHz

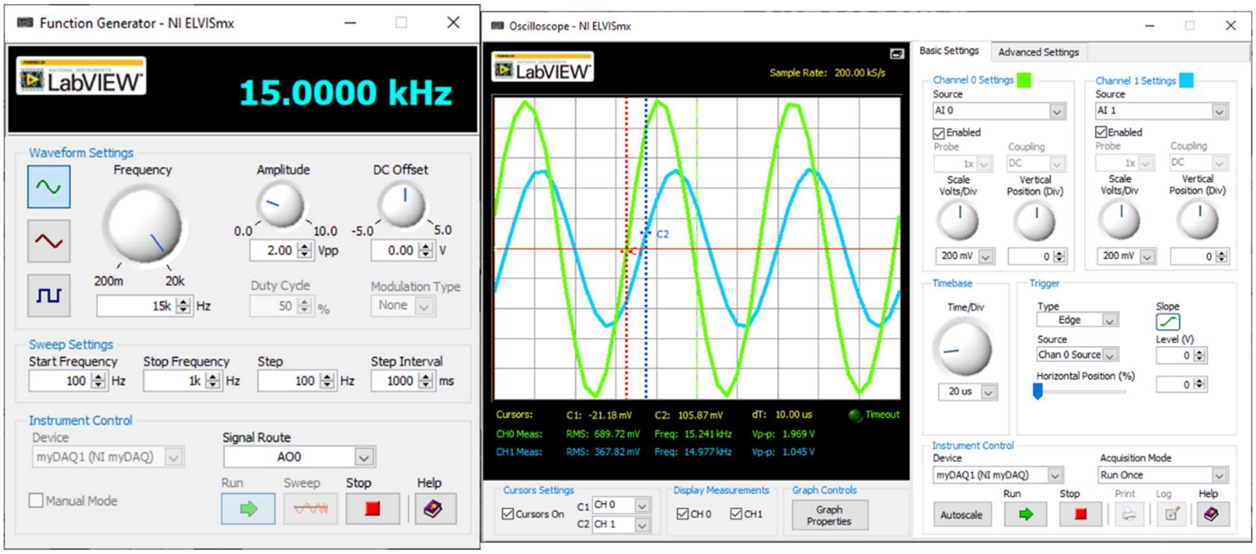


Figure 13.58 – Experimental Results – Case 4 – Waveform, @ 15kHz

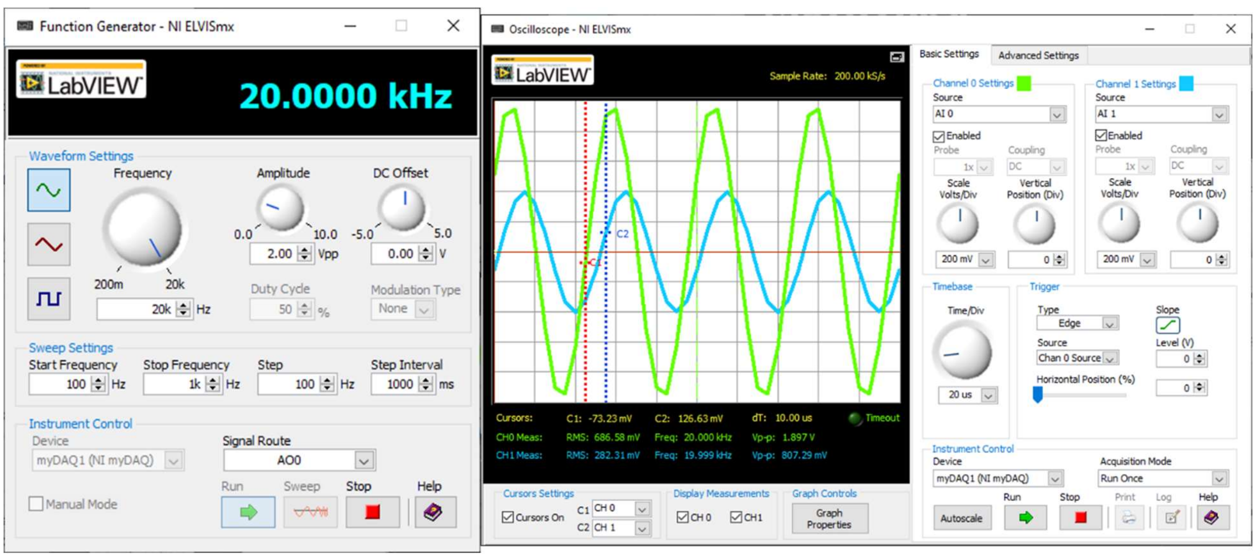


Figure 13.59 – Experimental Results – Case 4 – Waveform, @ 20kHz

$V_{out}(t)$ [V]	Frequency [Hz]
.9504	1k
.8392	2k
.7534	2.7k
.7048	3.120k
.5285	5000
.4322	6.5k
.3624	8k

Figure 13.27 – Experimental Results
Case 1, Sampled Data

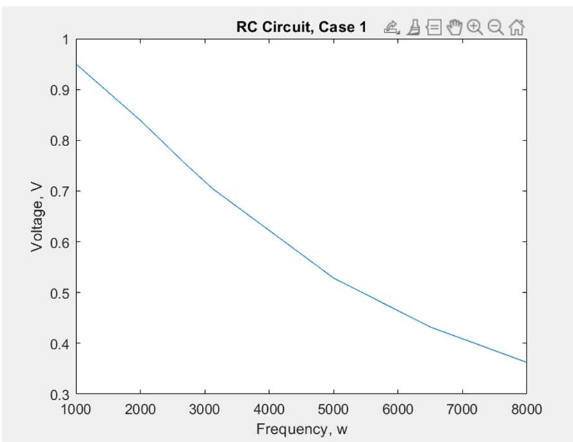


Figure 13.28 – Experimental Results
Case 1, Sampled Data Plotted

$V_{out}(t)$ [V]	Frequency [Hz]
0.03593	100
0.31666	1k
0.5565	2k
0.7205	$f_C = 3120.7$
0.8575	5k
0.9315	8k
0.9575	15k

Figure 13.60 – Experimental Results
Case 2, Sampled Data

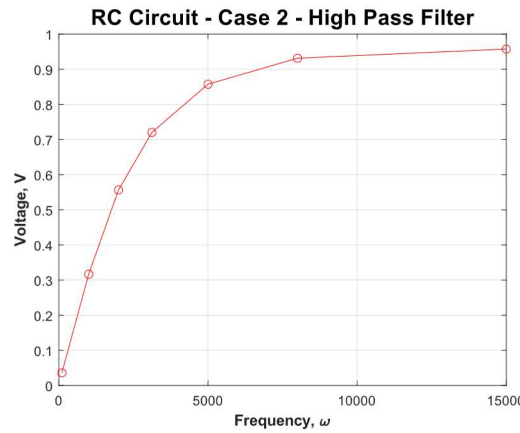


Figure 13.61 – Experimental Results
Case 2, Sampled Data Plotted

$V_{out}(t)$ [V]	Frequency [Hz]
0.9795	100
0.9735	1k
0.8695	5k
0.7645	$f_C = 7723.7$
0.6775	10k
0.5225	15k
0.403645	20k

Figure 13.62 – Experimental Results
Case 4, Sampled Data

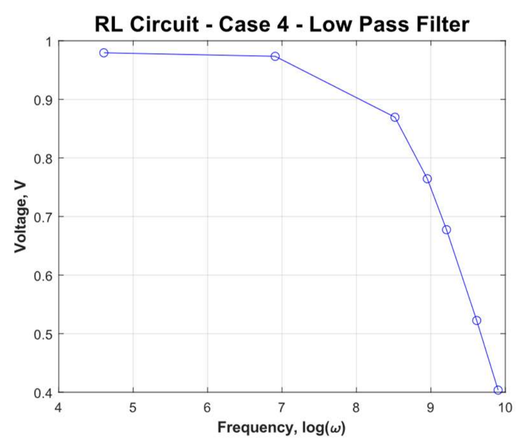


Figure 13.63 – Experimental Results
Case 4, Sampled Data Plotted

13.4 DISCUSSION & CONCLUSION

To conclude, the purpose of this lab was to test the frequency response of the circuits previously shown. The experimental results line up with the simulated measurements.

The simulated response for all circuits matches the plots of the sampled circuits. For example, the frequency response plot seen in Figure 13.13 acquired via PSpice, matches it respective data acquired from experimentally sampling the circuit, its data shown in Figure 13.61. Proving that the case 2 circuit is truly a high pass filter.

REFERENCES

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[2] Svoboda, James A., and Richard C. Dorf. Introduction to Electric Circuits. John Wiley & Sons, 2014.

[3] Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm

PASSIVE FILTERS DESIGN, SIMULATION AND EXPERIMENTAL TEST AS WELL AS ANALYSIS

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ABSTRACT: The purpose of this lab is to familiarize with passive filters which in this case was a band pass. We did this by designing 4 different circuits experimentally and by simulation as well.

KEYWORDS: Ohm's Law, Phasor, Transfer Function, Impedance, Inductive Reactance, Capacitive Reactance, Series Circuit, Resistor, Capacitor, Inductor, NI myDAQ, PSpice, MATLAB

14.1 INTRODUCTION

Equations

$$V = I * R \tag{1}$$

$$X_C = \frac{1}{j\omega C} \tag{2}$$

$$X_L = j\omega L \tag{3}$$

$$H(j\omega) = \frac{V_{out}}{V_{in}} \tag{4}$$

$$V_{out} = \left(\frac{Z_2}{Z_1 + Z_2}\right) * V_{in} \tag{5}$$

$$H(j\omega) = |H(j\omega)|\angle\phi(j\omega) \tag{6}$$

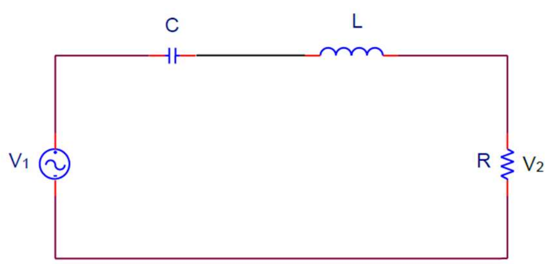


Figure 14.1 – General Series RLC Band Pass Filter Circuit

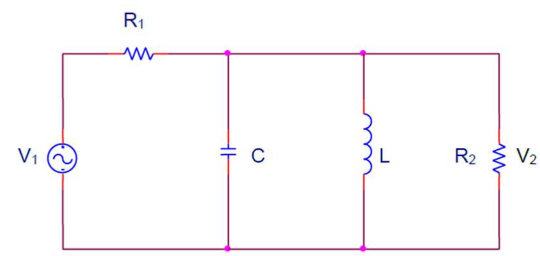


Figure 14.2 – General Parallel RLC Band Pass Filter Circuit

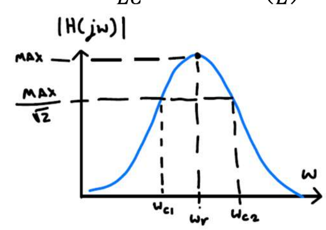
14.2 EXPERIMENTAL & SIMULATION SETUP PROCEDURES

Preliminary Calculations – Figure 14.1

$$Z_1 = \frac{1 - LC\omega^2}{Cj\omega}, Z_2 = R$$

$$\frac{V_2}{V_1} = \frac{Z_2}{Z_1 + Z_2} \rightarrow \frac{RCj\omega}{1 - LC\omega^2 + RCj\omega}$$

$$H(j\omega) = \frac{j\omega\left(\frac{R}{L}\right)}{\frac{1}{LC} - \omega^2 + j\omega\left(\frac{R}{L}\right)}$$



$$j\omega L + \frac{1}{j\omega C} = 0 \rightarrow \omega_0 = \frac{1}{\sqrt{LC}}$$

$$\frac{1}{\sqrt{2}} = \frac{\omega\left(\frac{R}{L}\right)}{\sqrt{\left(\frac{1}{LC} - \omega^2\right)^2 + \left(\omega\left(\frac{R}{L}\right)\right)^2}}$$

$$\omega_{C1}, \omega_{C1} = \pm\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

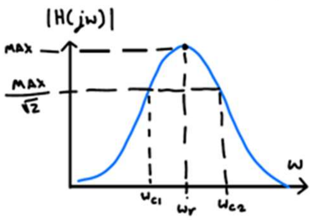
$$\beta = \frac{R}{L}, Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Preliminary Calculations – Figure 14.2

$$Z_1 = R_1, Z_2 = \frac{R_2 Lj\omega}{-R_2 LC\omega^2 + Lj\omega + R_2}$$

$$\frac{V_2}{V_1} = \frac{Z_2}{Z_1 + Z_2} \rightarrow \frac{R_2 Lj\omega}{R_1 R_2(1 - LC\omega^2) + j\omega L(R_1 + R_2)}$$

$$H(j\omega) = \frac{R_2 Lj\omega}{R_1 R_2(1 - LC\omega^2) + j\omega L(R_1 + R_2)}$$



$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$\beta = \frac{1}{RC} \;, Q = R\sqrt{\frac{C}{L}}$$

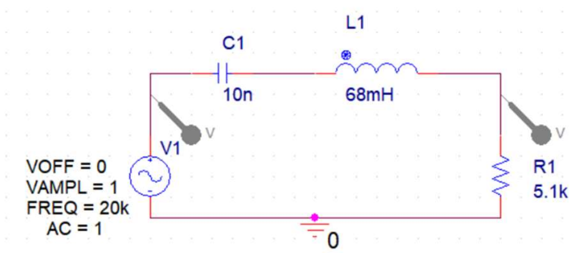


Figure 14.3 – Simulated RC Circuit, Case 1
C = 0.01μF, R = 5.1kΩ

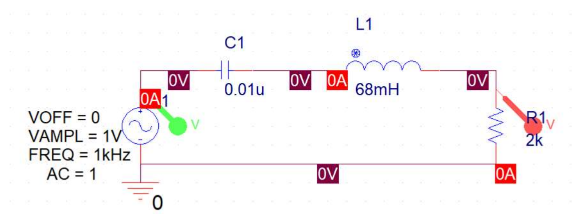


Figure 14.4 – Simulated RC Circuit, Case 2
C = 0.01μF, R = 5.1kΩ

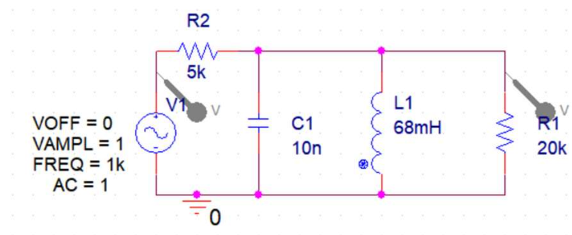


Figure 14.5 – Simulated RL Circuit, Case 3
L = 68 mH, R = 20kΩ,5kΩ

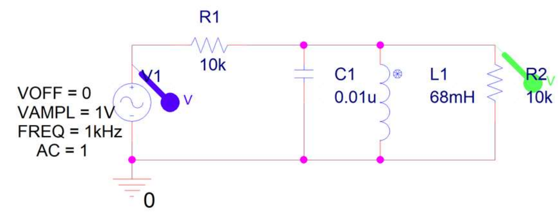


Figure 14.6 – Simulated RL Circuit, Case 4
L = 68 mH, R = 3.3kΩ

14.3 EXPERIMENTAL & SIMULATION ON DATA & RESULTS

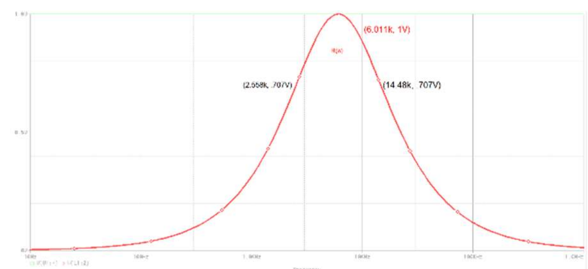


Figure 14.7 – Simulation Results – Case 1
Waveform, H(jω) vs ω

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	6.0997K	10.000	6.0897K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(V1:+)	1.0000	1.0000	0.000		0.000	0.000	1.0000	1.0000	1.0000
	V(L1:2)	0.9999	3.2044m	0.9967		-80.670u	-0.9968	0.9999	3.2044m	501.562m

Figure 14.8 – Simulation Results– Case 1
Data, H(jω) vs ω

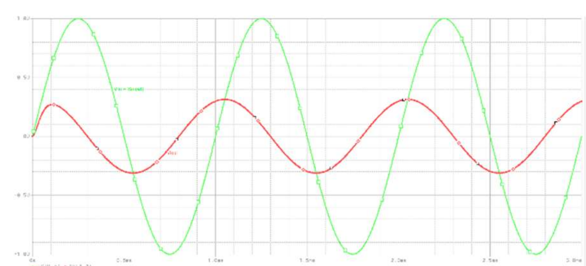


Figure 14.9 – Simulation Results– Case 1
Waveform, Before lower cutoff frequency

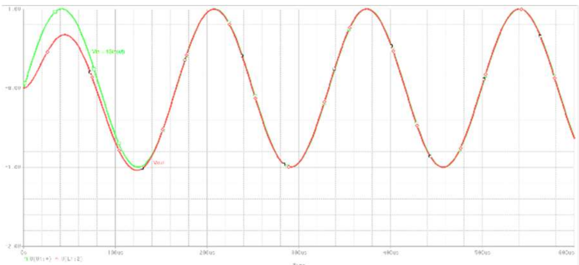


Figure 14.10 – Simulation Results– Case 1
Waveform, At center frequency

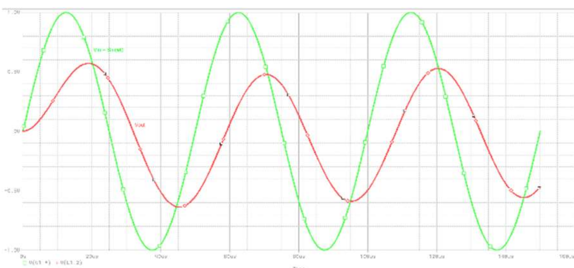


Figure 14.11 – Simulation Results– Case 1
Waveform, After higher cutoff frequency

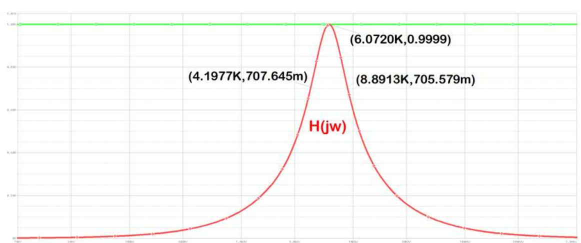


Figure 14.12 – Simulation Results – Case 2
Waveform, H(jω) vs ω

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		89.824u		
	X Values	10.000	6.0720K	-6.0620K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(V1:+)	1.0000	1.0000	0.000		0.000	89.824u	1.0000	1.0000	1.0000
CURSOR 2	V(R1:2)	1.2566m	0.9999	-0.9987		-0.9987	0.000	0.9999	1.2566m	500.583m

Figure 14.13 – Simulation Results– Case 2
Data, H(jω) vs ω

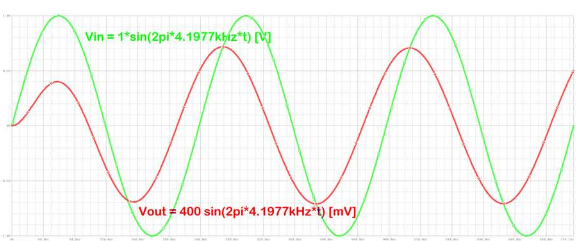


Figure 14.14 – Simulation Results– Case 2
Waveform, @ 4.1977kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		281.968m		
	X Values	59.405u	268.410u	-209.005u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(V1:+)	1.0000	714.643m	285.349m		0.000	-3.3814m	1.0000	714.643m	857.318m
CURSOR 2	V(R1:2)	399.925m	718.024m	-318.099m		-600.067m	0.000	718.024m	399.925m	558.975m

Figure 14.15 – Simulation Results– Case 2
Data, @ 4.1977kHz

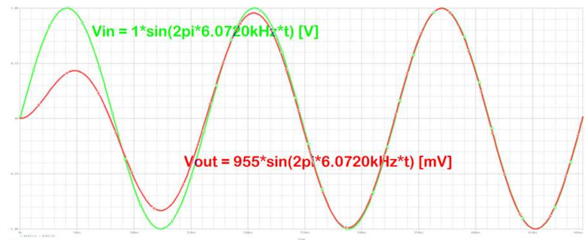


Figure 14.16 – Simulation Results – Case 2
Waveform, @ 6.0720kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		1.0000		
	X Values	205.913u	0.000	205.913u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(V1:+)	1.0000	0.000	1.0000		0.000	0.000	1.0000	0.000	499.999m
	V(R1:2)	955.070m	112.177n	955.070m		-44.928m	112.177n	955.070m	112.177n	477.535m

Figure 14.17 – Simulation Results– Case 2
Data, @ 6.0720kHz

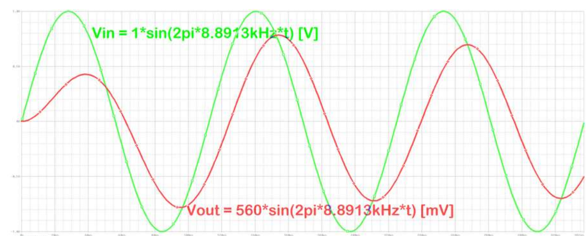


Figure 14.18 – Simulation Results– Case 2
Waveform, @ 8.8913kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		1.0000		
	X Values	140.563u	0.000	140.563u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(V1:+)	1.0000	0.000	1.0000		0.000	0.000	1.0000	0.000	500.000m
	V(R1:2)	583.901m	164.263n	583.901m		-416.098m	164.263n	583.901m	164.263n	291.950m

Figure 14.19 – Simulation Results– Case 2
Data, @ 8.8913kHz

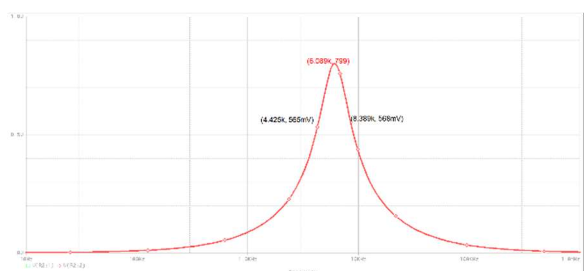


Figure 14.20 – Simulation Results – Case 3
Waveform, H(jω) vs ω

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	6.0997K	10.000	6.0897K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(R2:1)	1.0000	1.0000	0.000		0.000	0.000	1.0000	1.0000	1.0000
	V(R2:2)	799.423m	854.515u	798.568m		-200.577m	-0.9992	799.423m	854.515u	400.139m

Figure 14.21 – Simulation Results – Case 3 Data, H(jω) vs ω

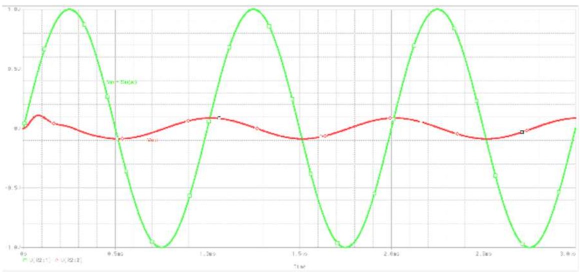


Figure 14.22 – Simulation Results– Case 3 Waveform, At center frequency

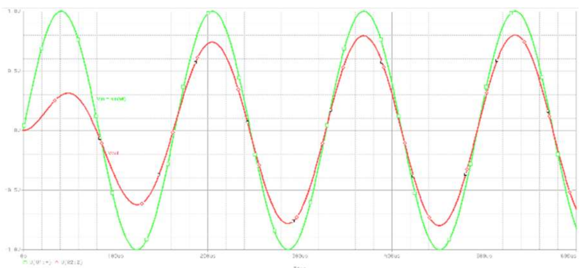


Figure 14.23 – Simulation Results– Case 3 Waveform, At center frequency

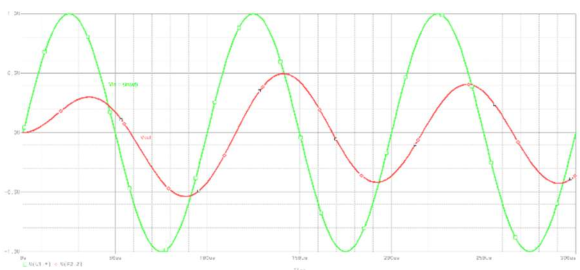


Figure 14.24 – Simulation Results– Case 3 Waveform, After higher cutoff frequency

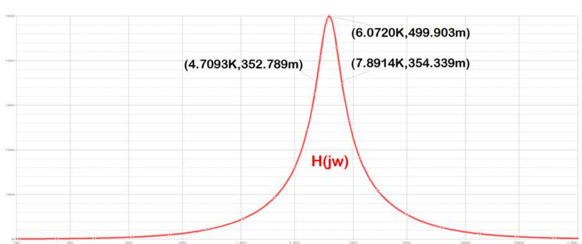


Figure 14.25 – Simulation Results – Case 4 Waveform, H(jω) vs ω

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		499.476m		
	X Values	6.0720K	10.000	6.0620K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(R2:2)	499.903m	427.258u	499.476m		0.000	0.000	499.903m	427.258u	250.165m

Figure 14.26 – Simulation Results – Case 4 Data, H(jω) vs ω

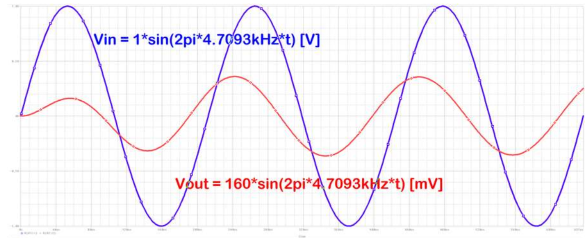


Figure 14.27 – Simulation Results– Case 4 Waveform, @ 4.7093kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		639.729m		
	X Values	53.081u	242.086u	-189.004u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(V1:+)	1.0000	768.665m	231.335m		0.000	408.393m	1.0000	768.665m	884.332m
CURSOR 2	V(R2:2)	160.570m	360.271m	-199.701m		-839.430m	0.000	360.271m	160.570m	260.421m

Figure 14.28 – Simulation Results– Case 4 Data, @ 4.7093kHz

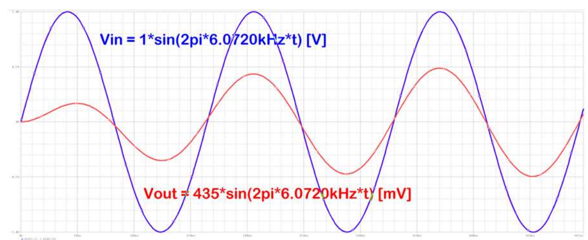


Figure 14.29 – Simulation Results– Case 4 Waveform, @ 6.0720kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		511.787m		
	X Values	205.887u	369.891u	-164.004u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(V1:+)	1.0000	0.9996	409.404u		0.000	511.378m	1.0000	0.9996	0.9998
CURSOR 2	V(R2:2)	435.193m	488.212m	-53.020m		-564.807m	0.000	488.212m	435.193m	461.703m

Figure 14.30 – Simulation Results– Case 4 Data, @ 6.0720kHz

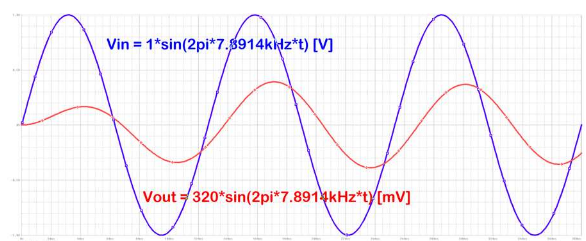


Figure 14.31 – Simulation Results– Case 4 Waveform, @200kHz

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		607.349m		
	X Values	158.454u	171.454u	-13.000u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1	V(V1:+)	1.0000	800.210m	199.786m		0.000	407.563m	1.0000	800.210m	900.103m
CURSOR 2	V(R2:2)	320.620m	392.647m	-72.028m		-679.377m	0.000	392.647m	320.620m	356.633m

Figure 14.32 – Simulation Results– Case 4 Data, @200kHz

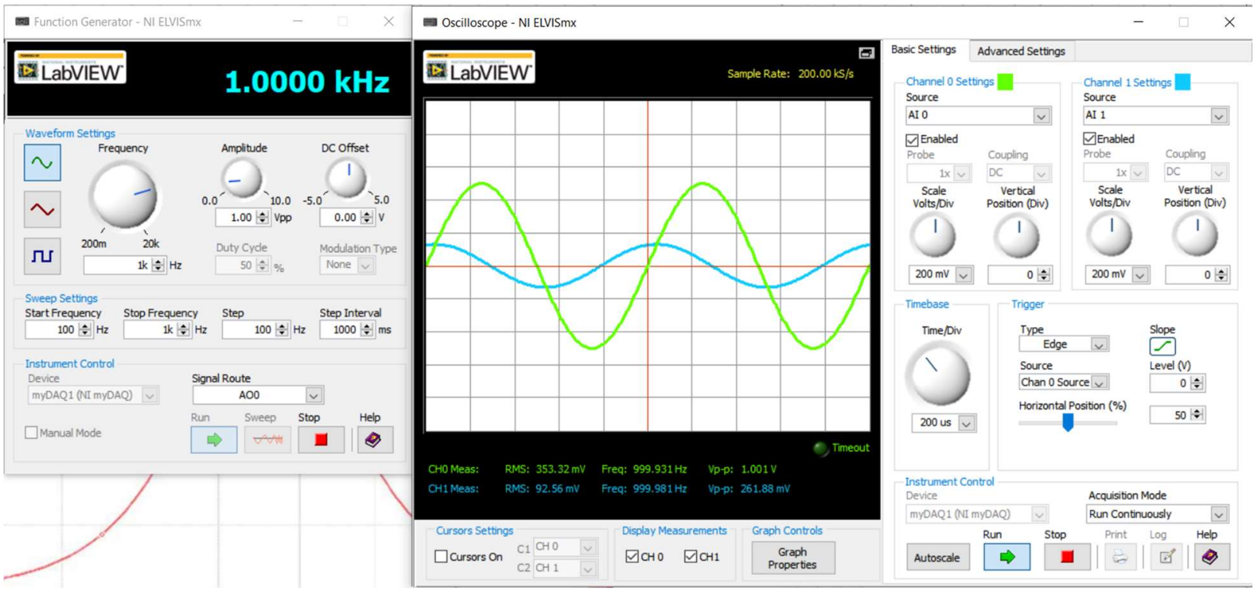


Figure 14.33 – Experimental Results – Case 1 – Waveform, @ 1000Hz

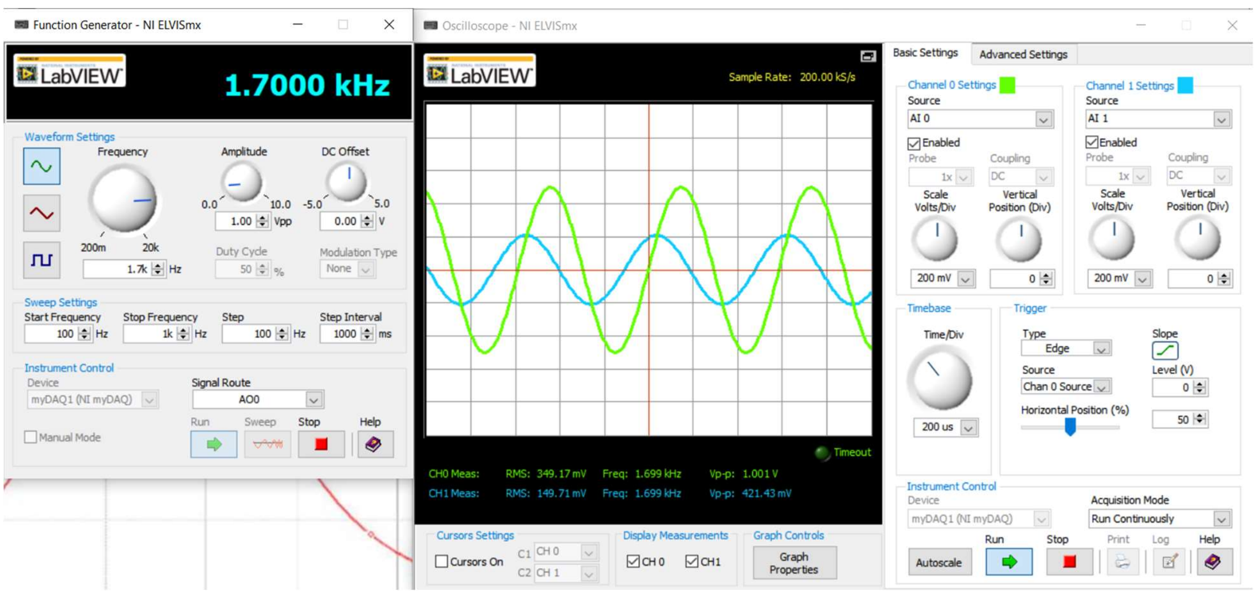


Figure 14.34 – Experimental Results – Case 1 – Waveform, @ 1.7kHz

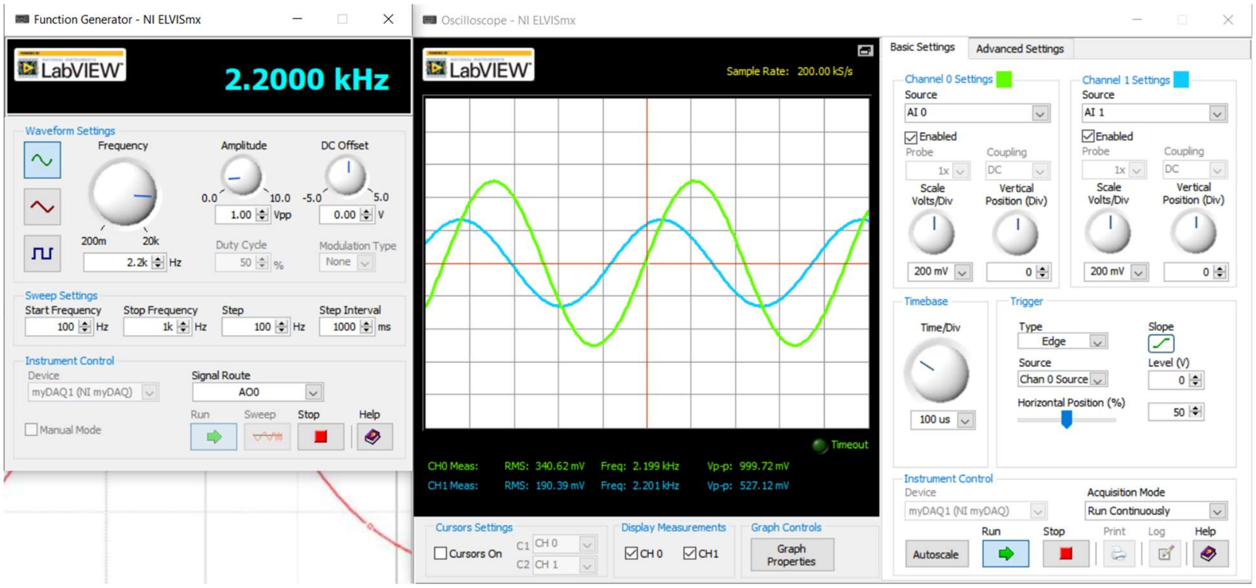


Figure 14.35 – Experimental Results – Case 1 – Waveform, @ 2.2kHz

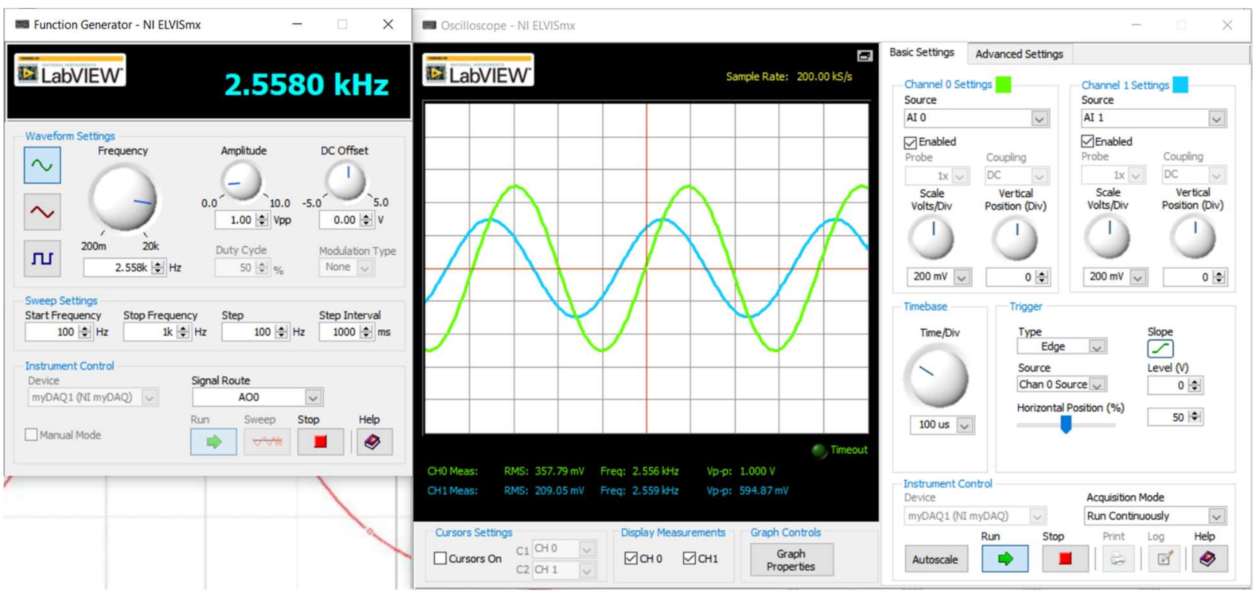


Figure 14.36 – Experimental Results – Case 1 – Waveform, @ 2.558kHz

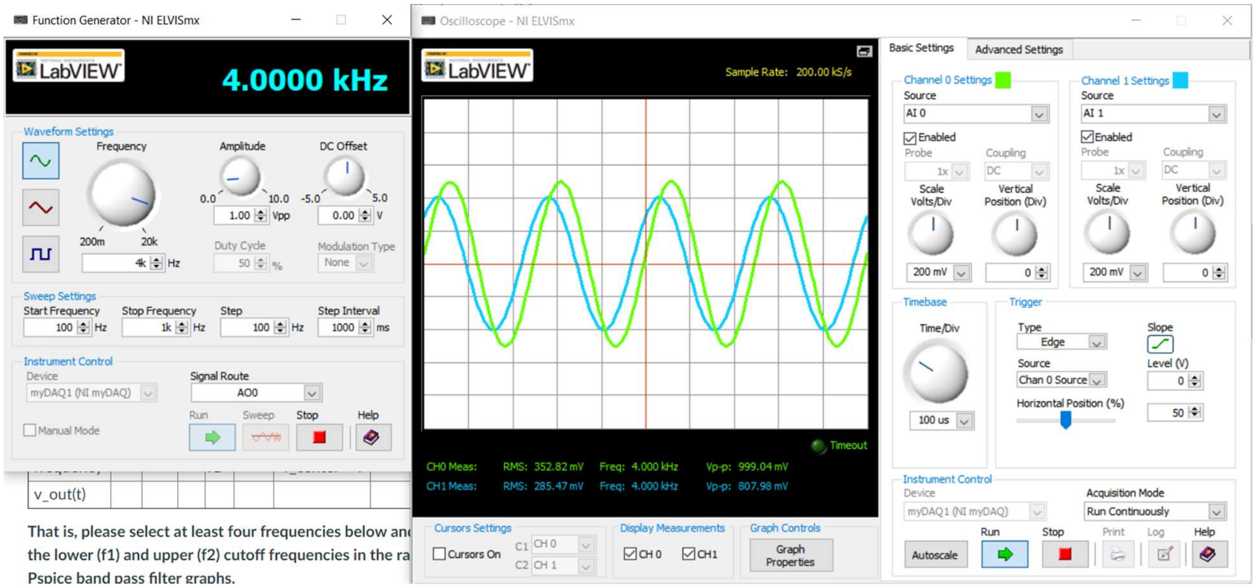


Figure 14.37 – Experimental Results – Case 1 – Waveform, @ 4kHz

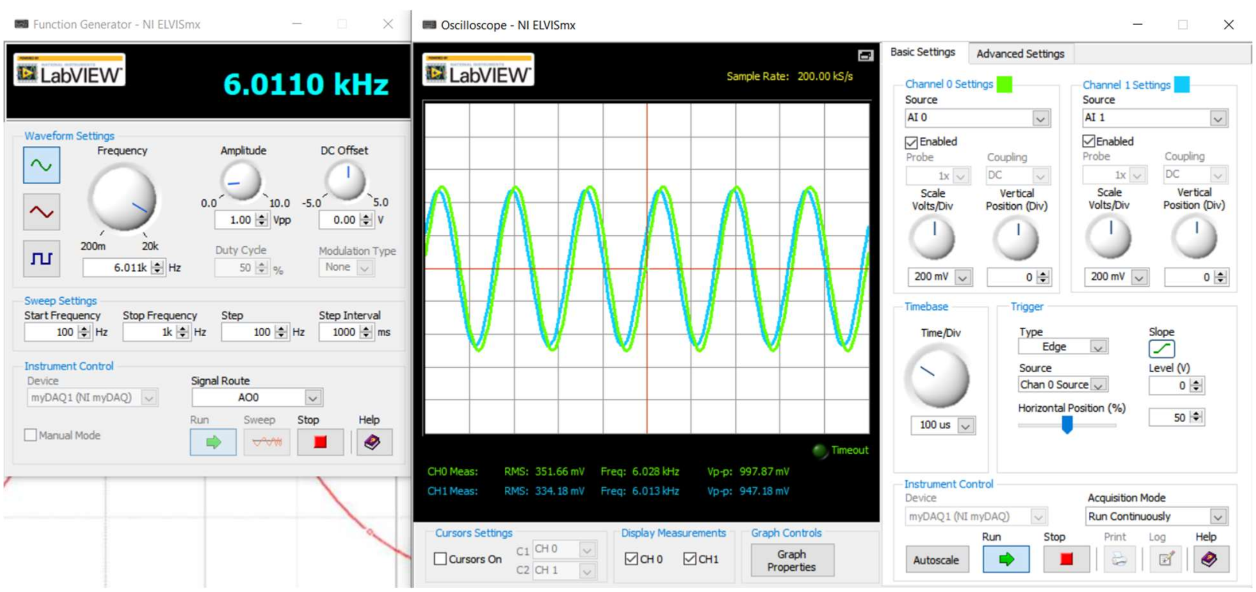


Figure 14.38 – Experimental Results – Case 1 – Waveform, @ 6.011kHz

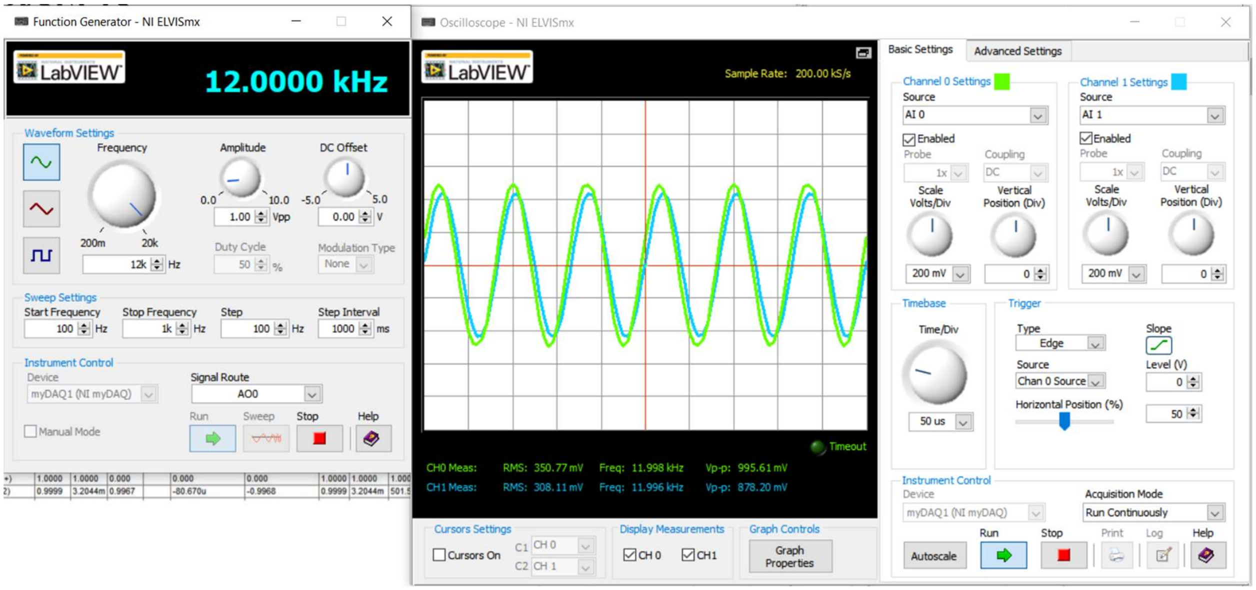


Figure 14.39 – Experimental Results – Case 1 – Waveform, @ 12kHz

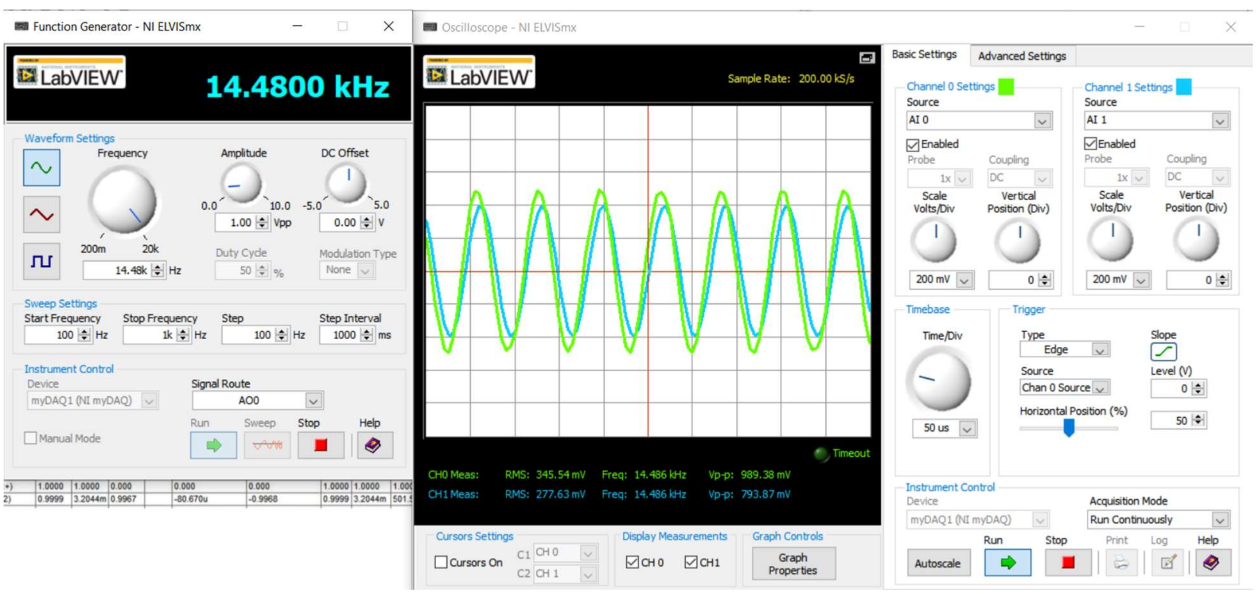


Figure 14.40 – Experimental Results – Case 1 – Waveform, @ 14.48kHz

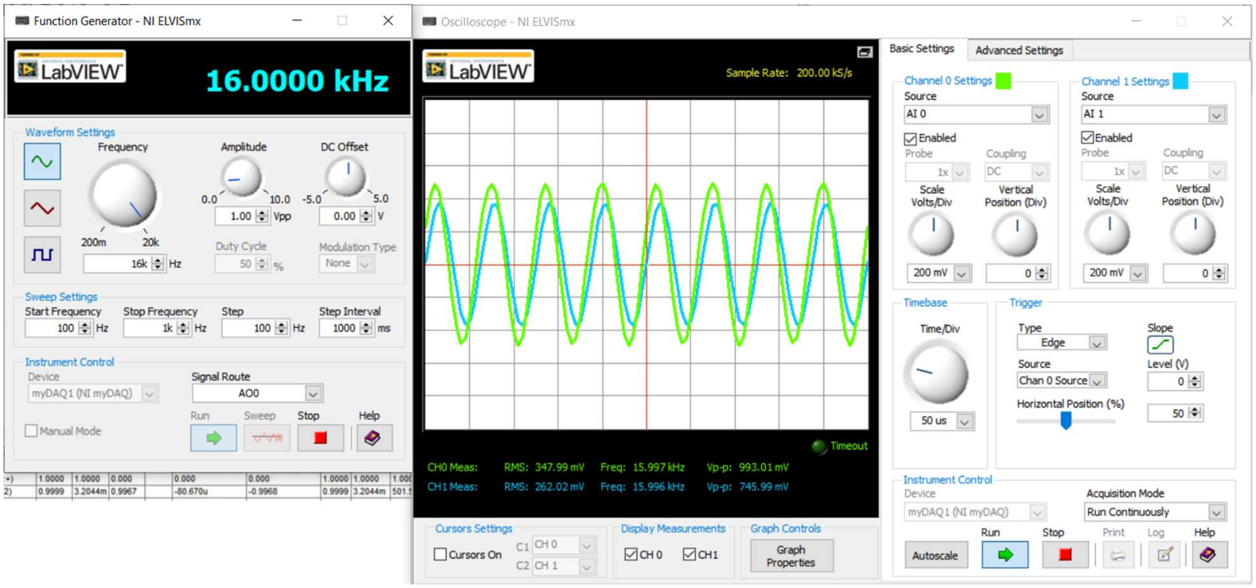


Figure 14.41 – Experimental Results – Case 1 – Waveform, @ 16kHz

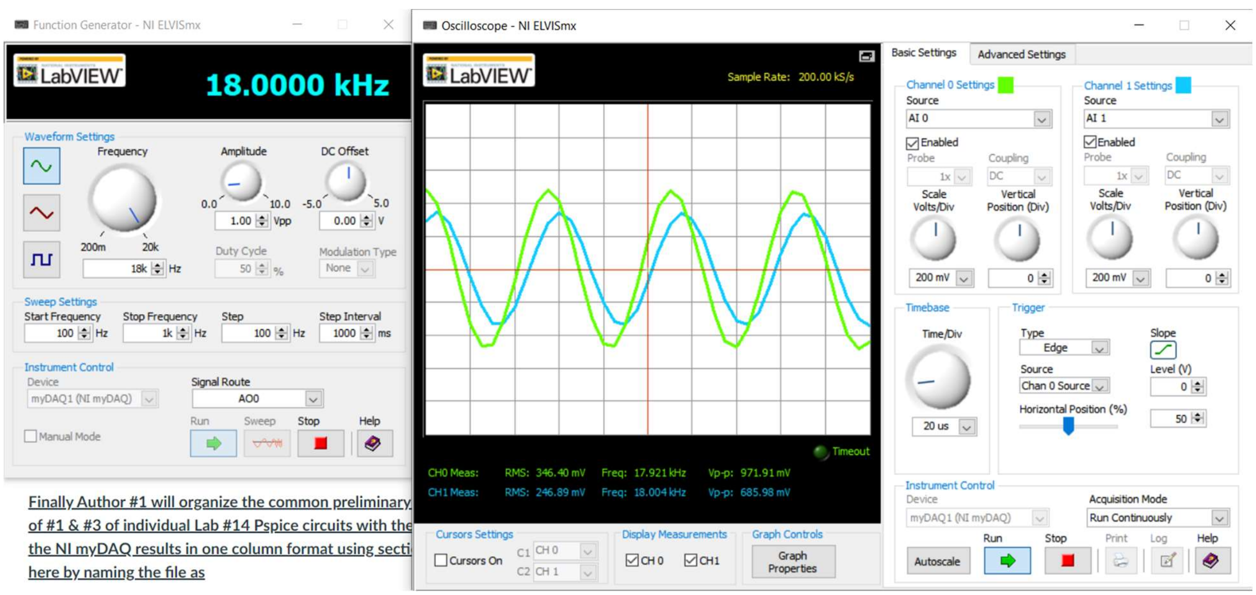


Figure 14.42 – Experimental Results – Case 1 – Waveform, @ 18kHz

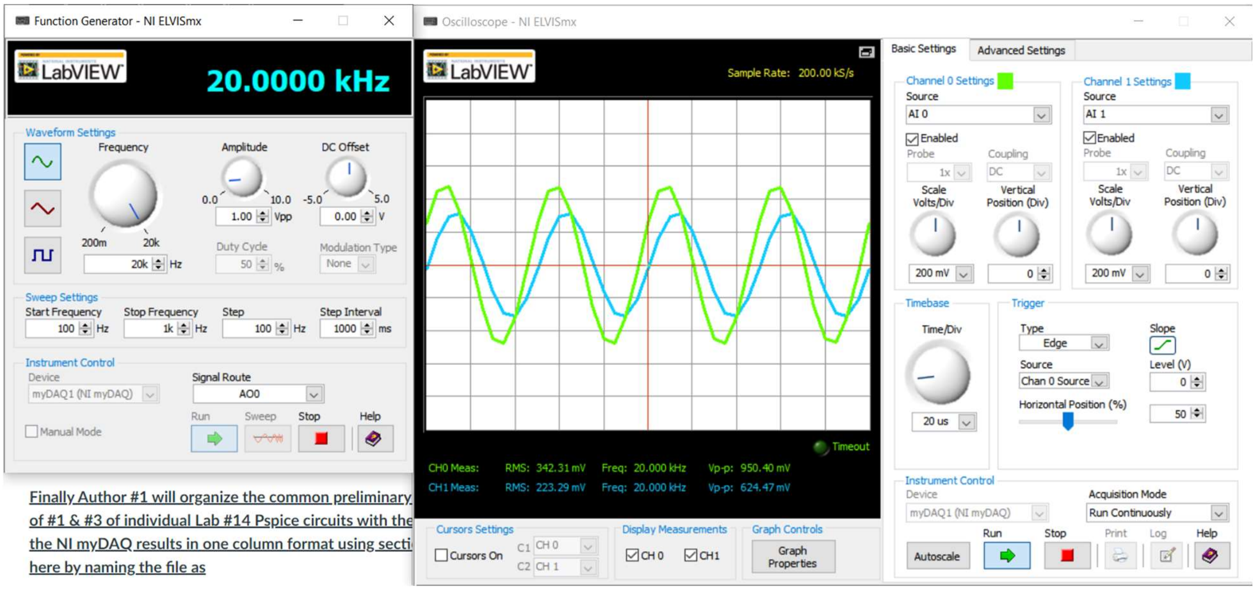


Figure 14.43 – Experimental Results – Case 1 – Waveform, @ 20kHz

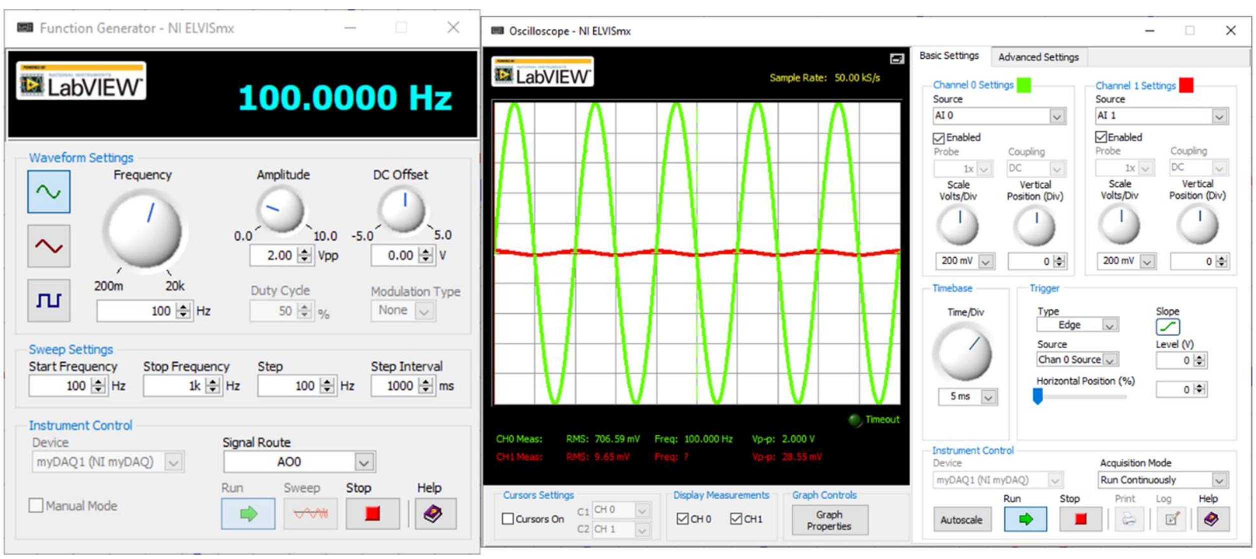


Figure 14.44 – Experimental Results – Case 2 – Waveform, @ 100Hz

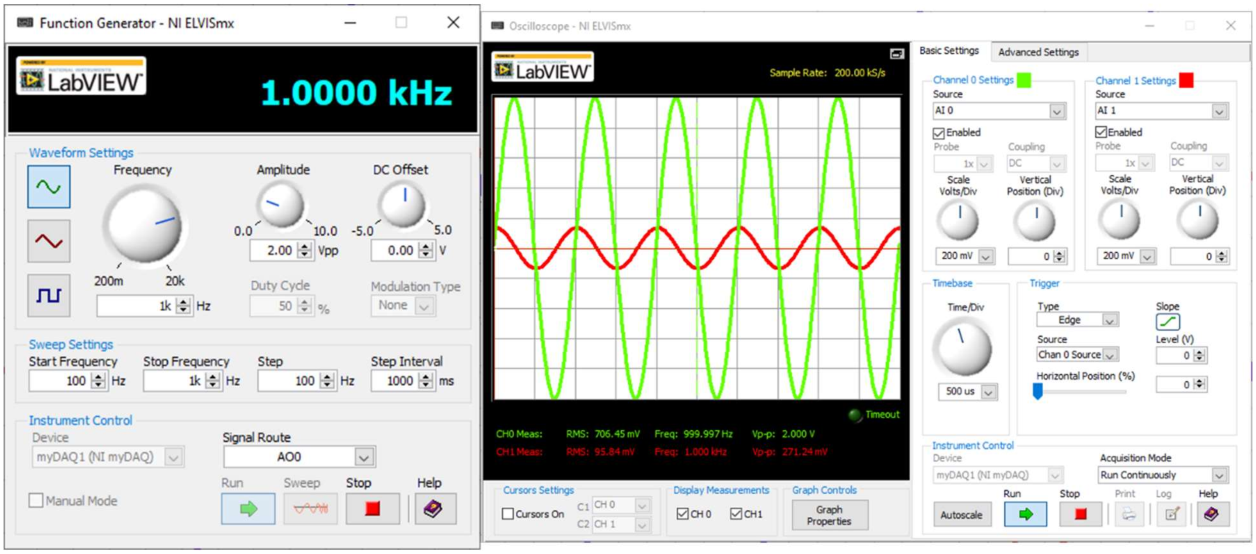


Figure 14.45 – Experimental Results – Case 2 – Waveform, @ 1kHz

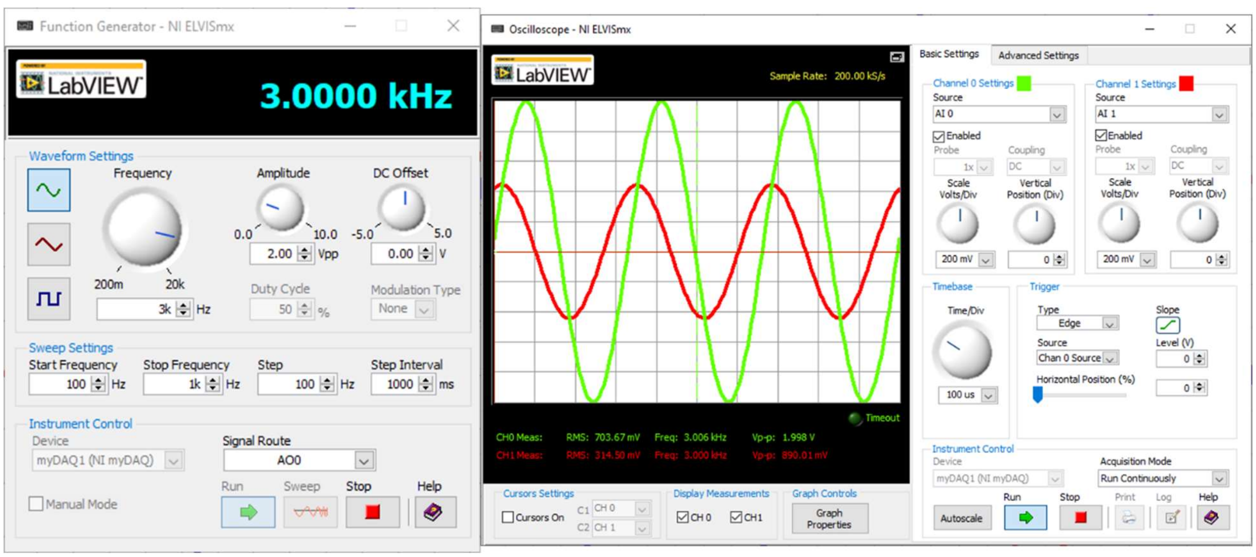


Figure 14.46 – Experimental Results – Case 2 – Waveform, @ 3kHz

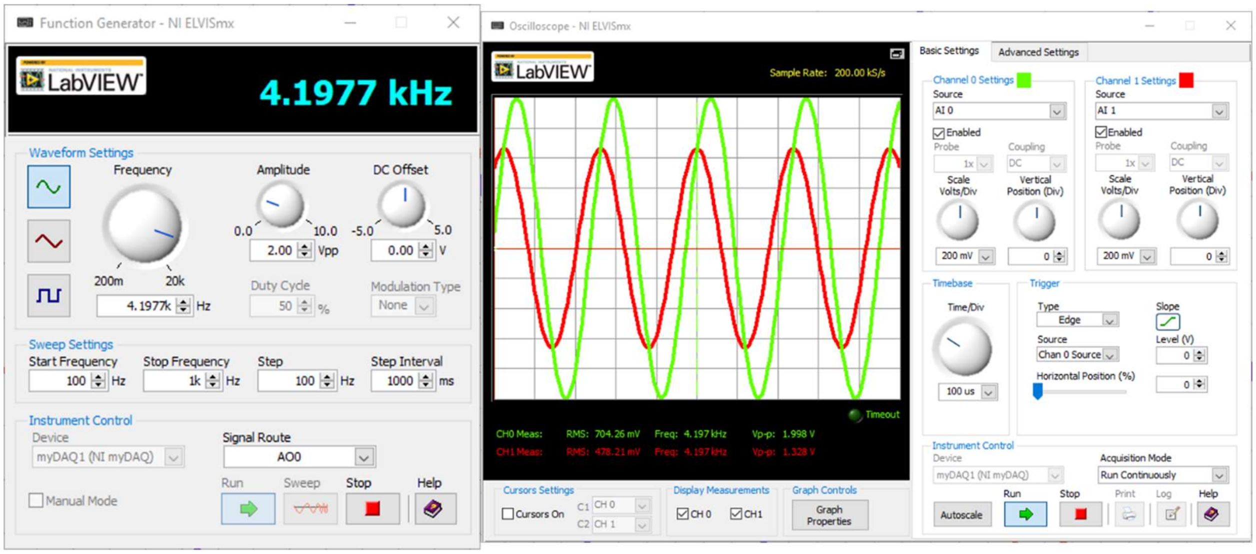


Figure 14.47 – Experimental Results – Case 2 – Waveform, @ $f_1 = 4.1977\text{kHz}$

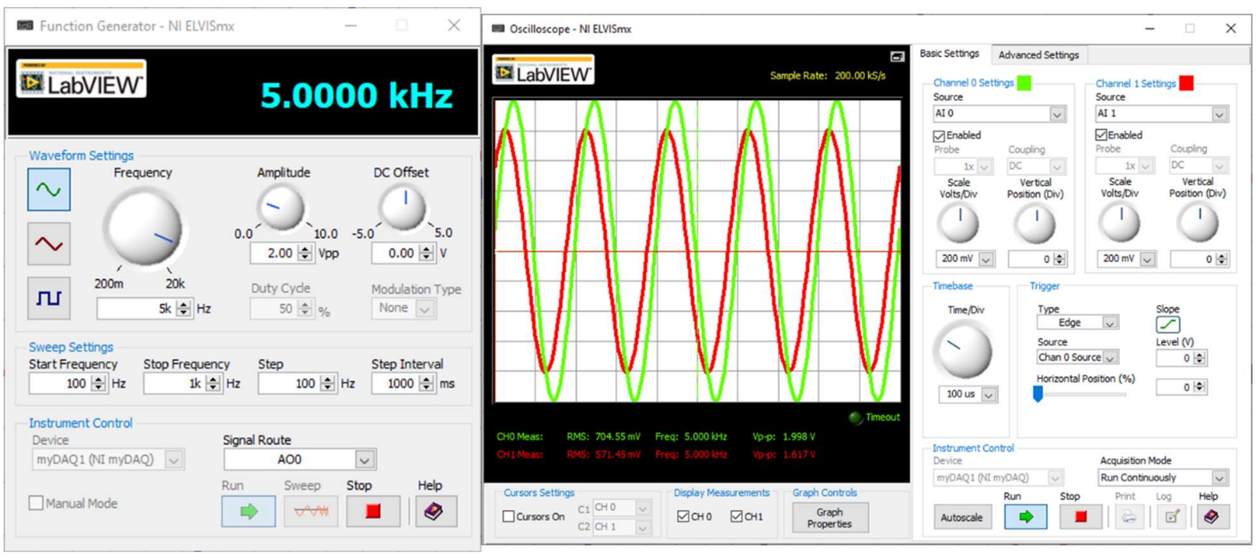


Figure 14.48 – Experimental Results – Case 2 – Waveform, @ 5kHz

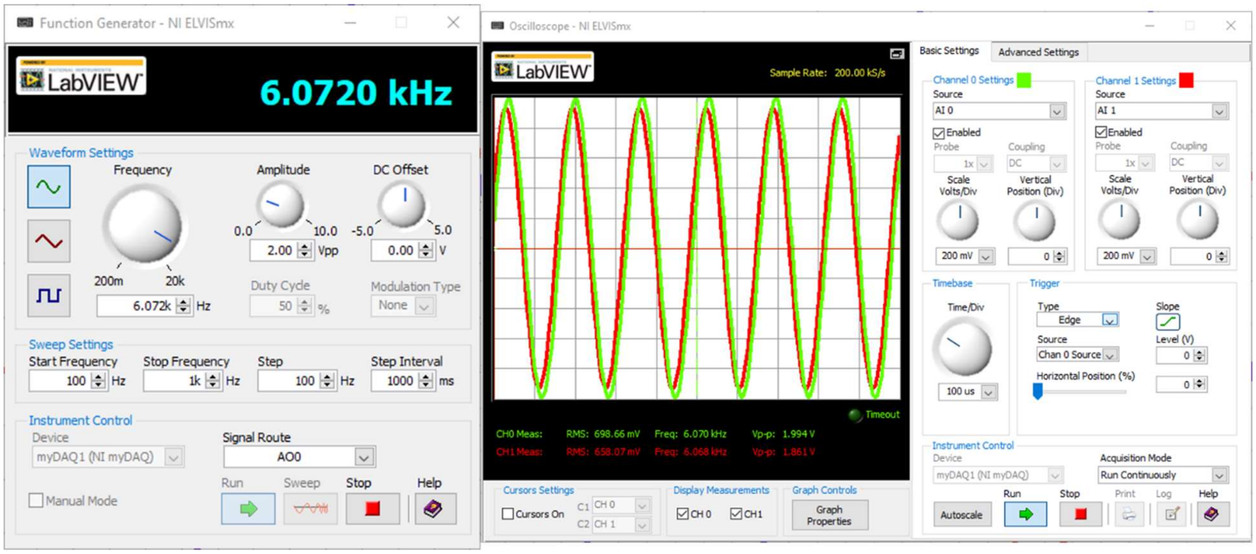


Figure 14.49 – Experimental Results – Case 2 – Waveform, @ f_C = 6.0720kHz

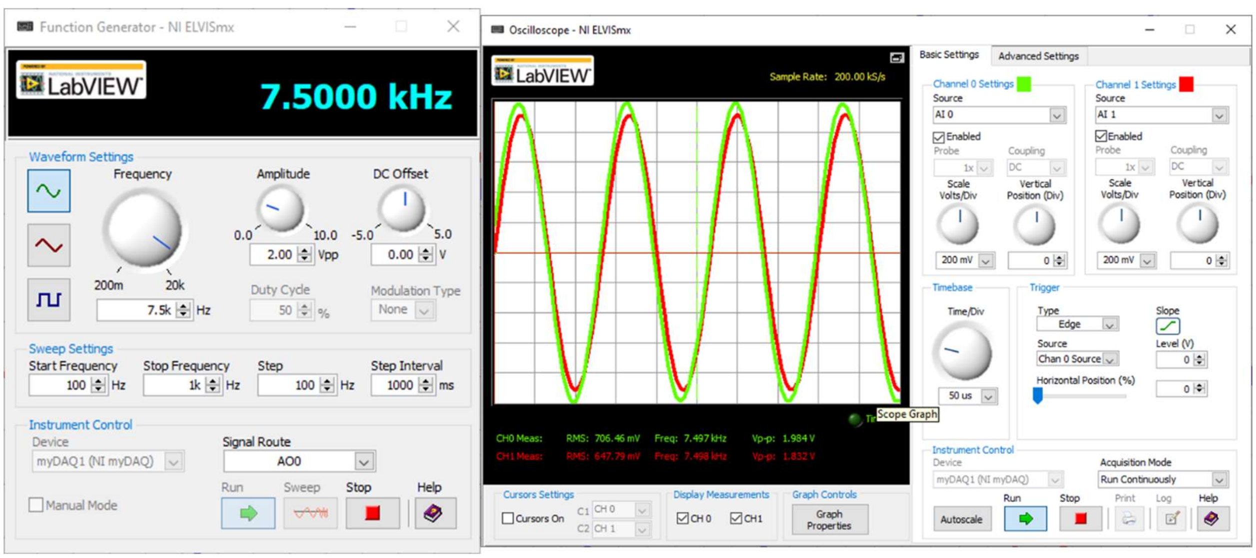


Figure 14.50 – Experimental Results – Case 2 – Waveform, @ 7.5kHz

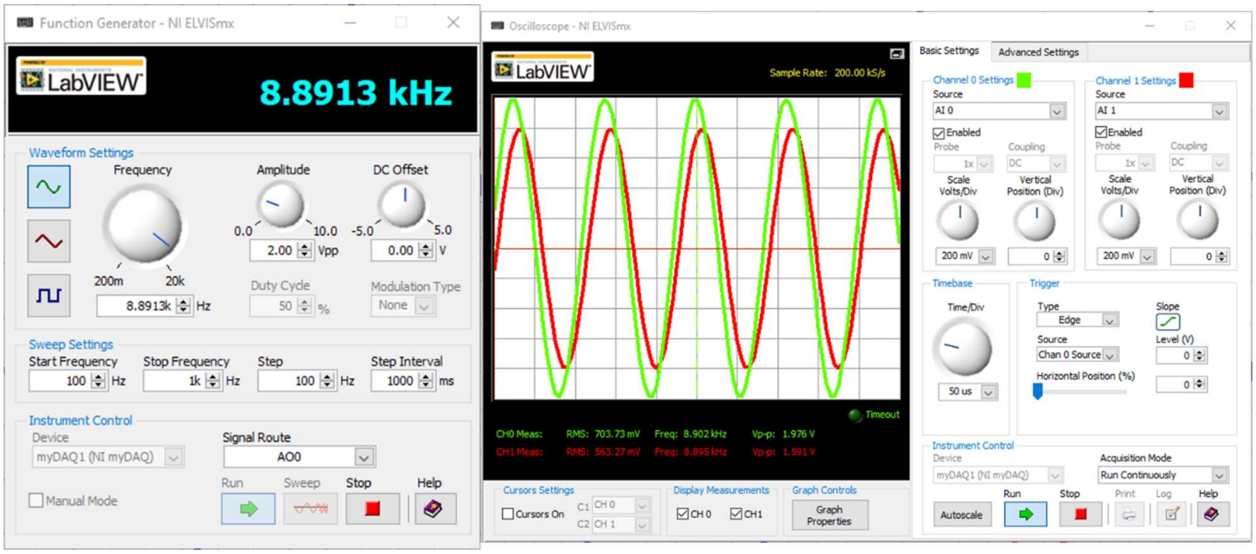


Figure 14.51 – Experimental Results – Case 4 – Waveform, @ f_2 = 8.8913kHz\

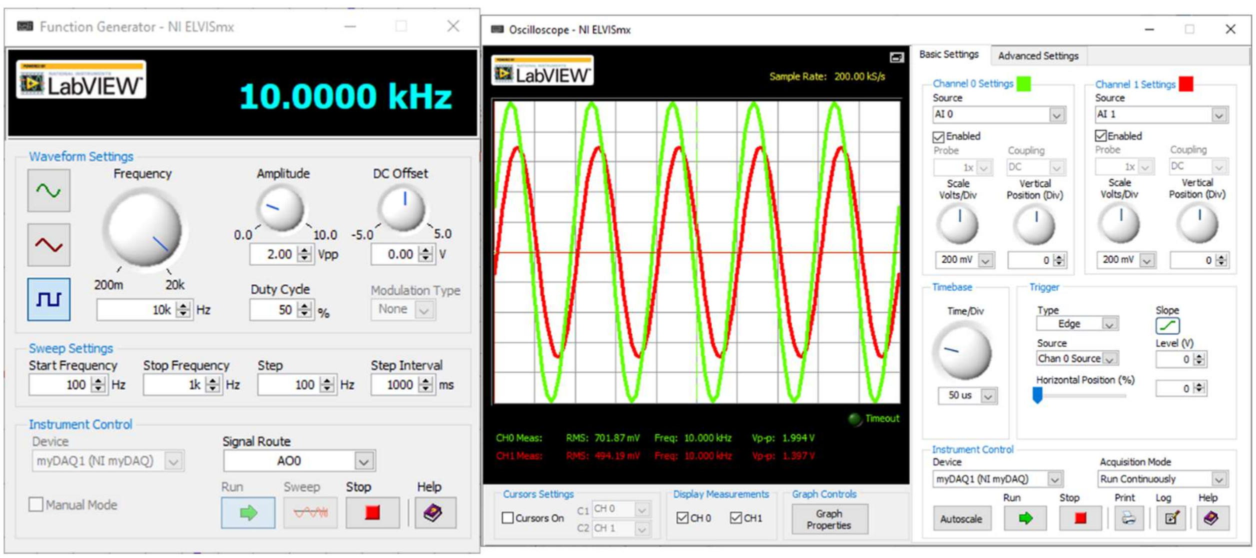


Figure 14.52 – Experimental Results – Case 2 – Waveform, @ 10kHz

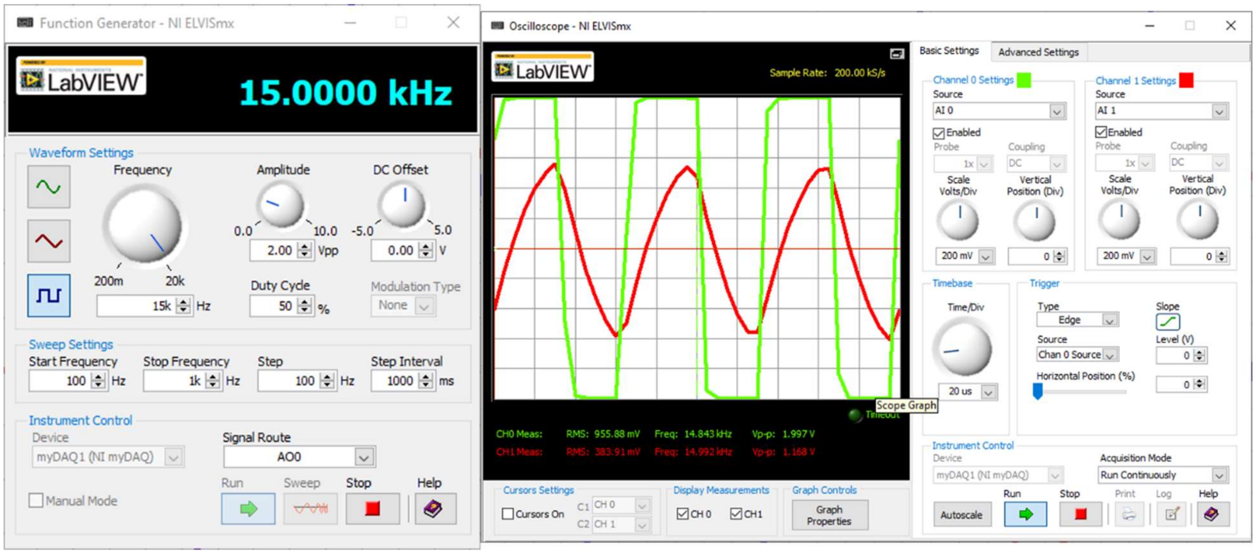


Figure 14.53 – Experimental Results – Case 2 – Waveform, @ 15kHz

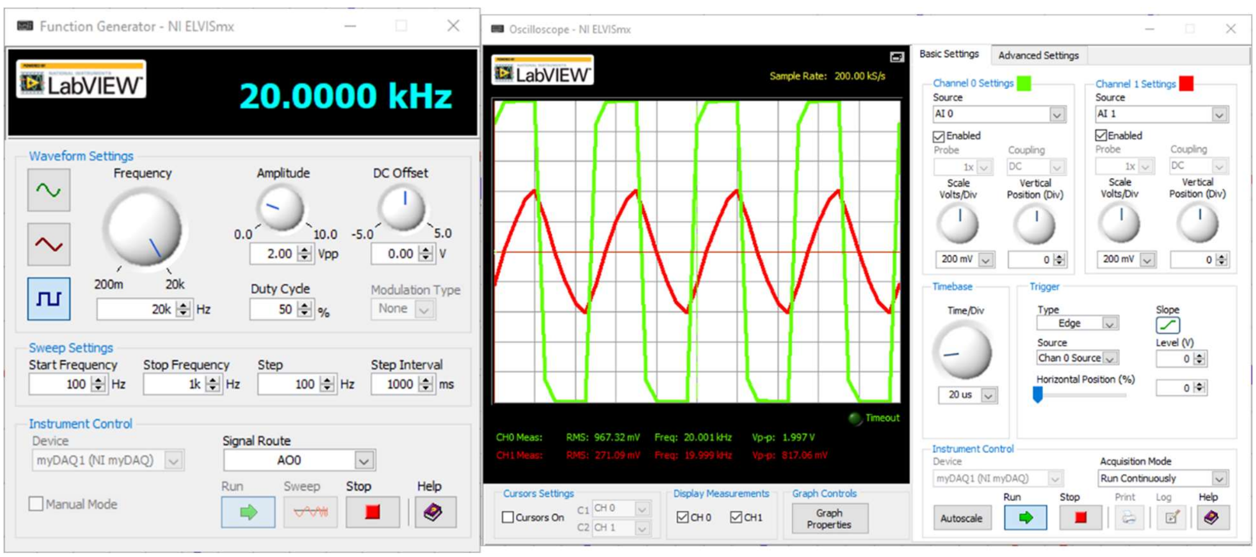


Figure 14.54 – Experimental Results – Case 2 – Waveform, @ 20kHz

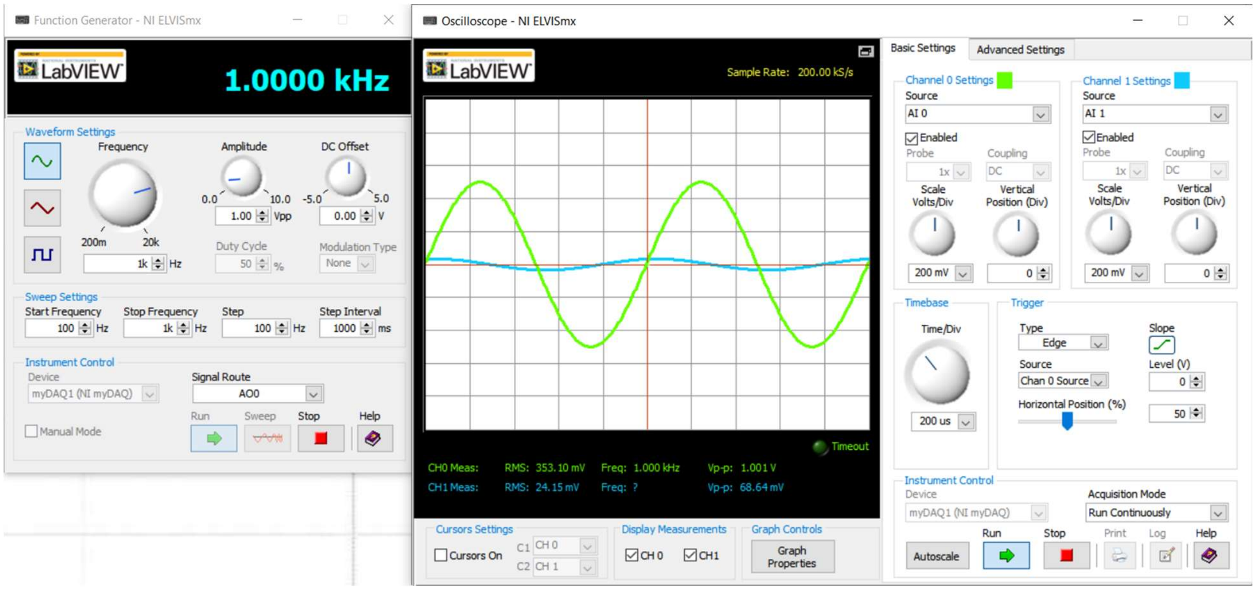


Figure 14.55 – Experimental Results – Case 3 – Waveform, @ 1kHz

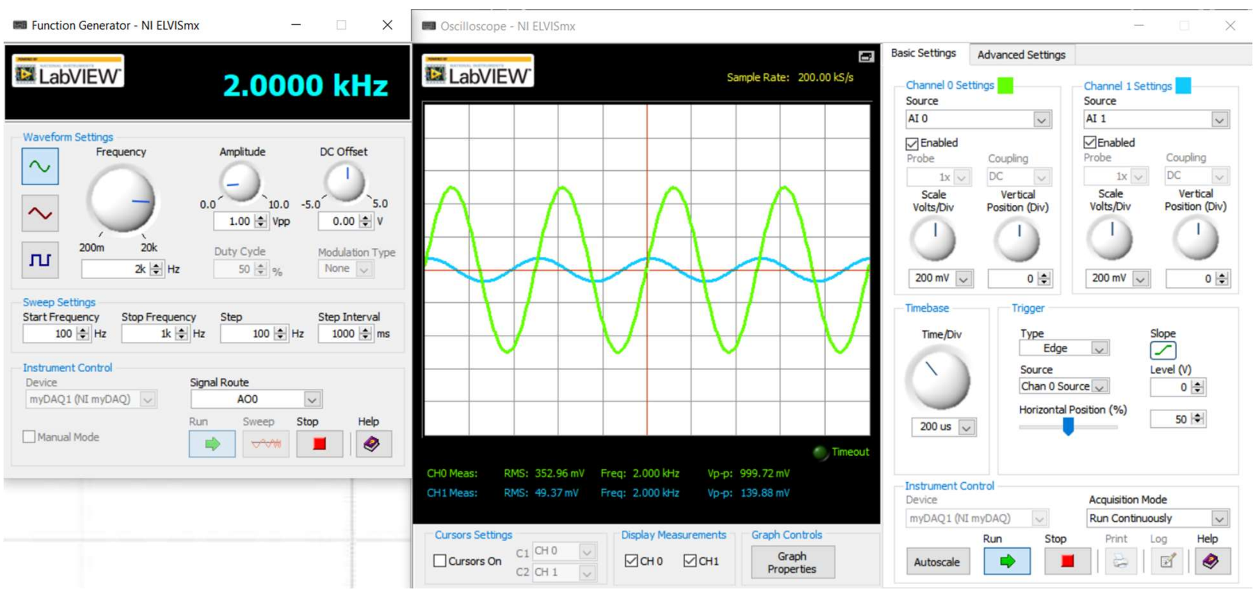


Figure 14.56 – Experimental Results – Case 3 – Waveform, @ 2kHz

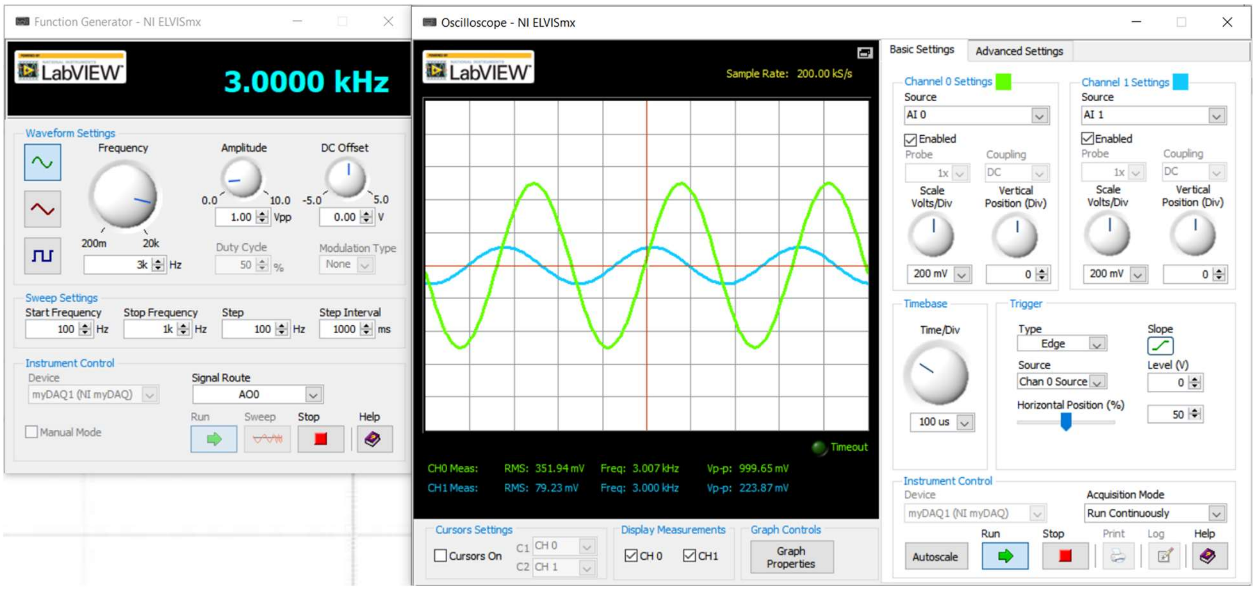


Figure 14.57 – Experimental Results – Case 3 – Waveform, @ 3kHz

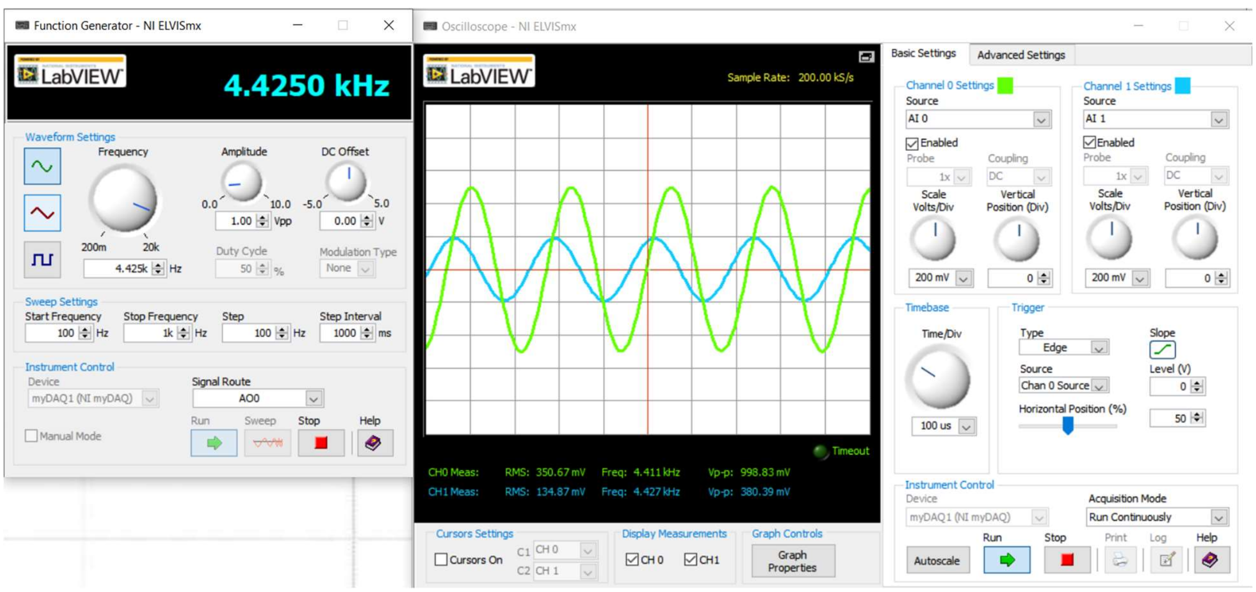


Figure 14.58 – Experimental Results – Case 3 – Waveform, @ 4.425kHz

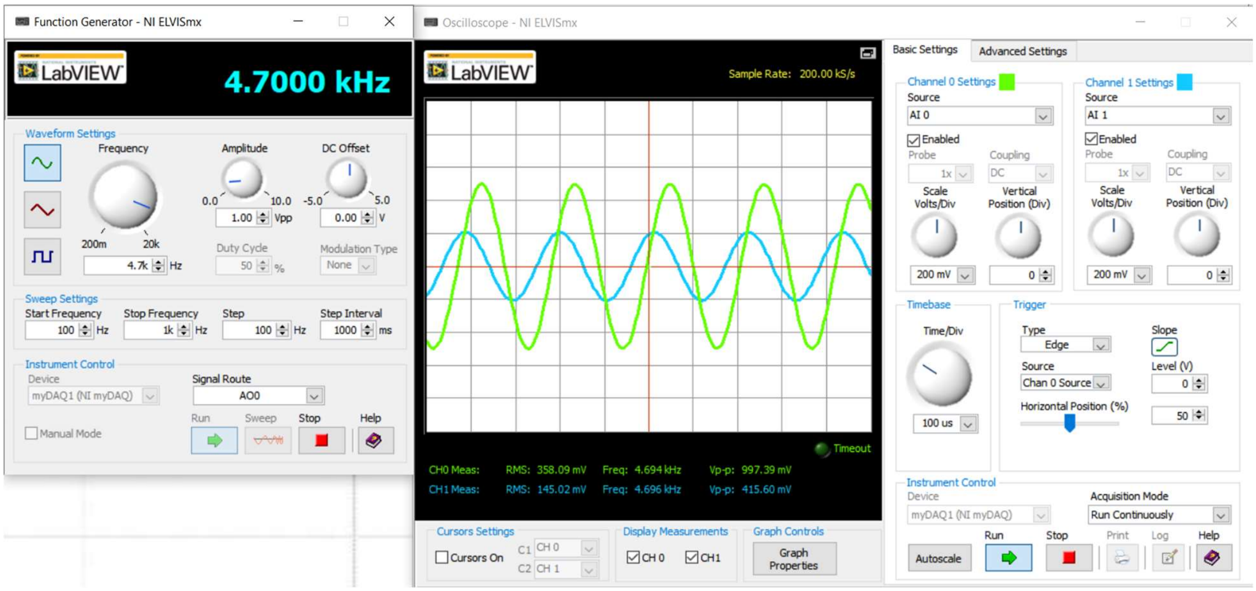


Figure 14.59 – Experimental Results – Case 3 – Waveform, @ 4.7kHz

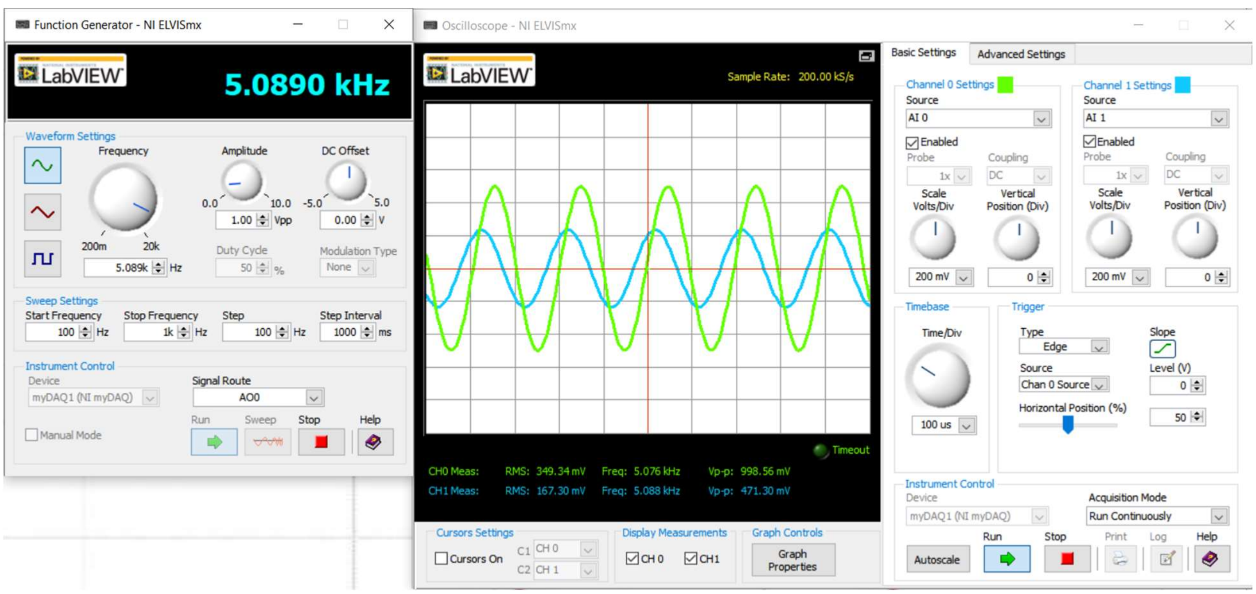


Figure 14.60 – Experimental Results – Case 3 – Waveform, @ 5.089kHz

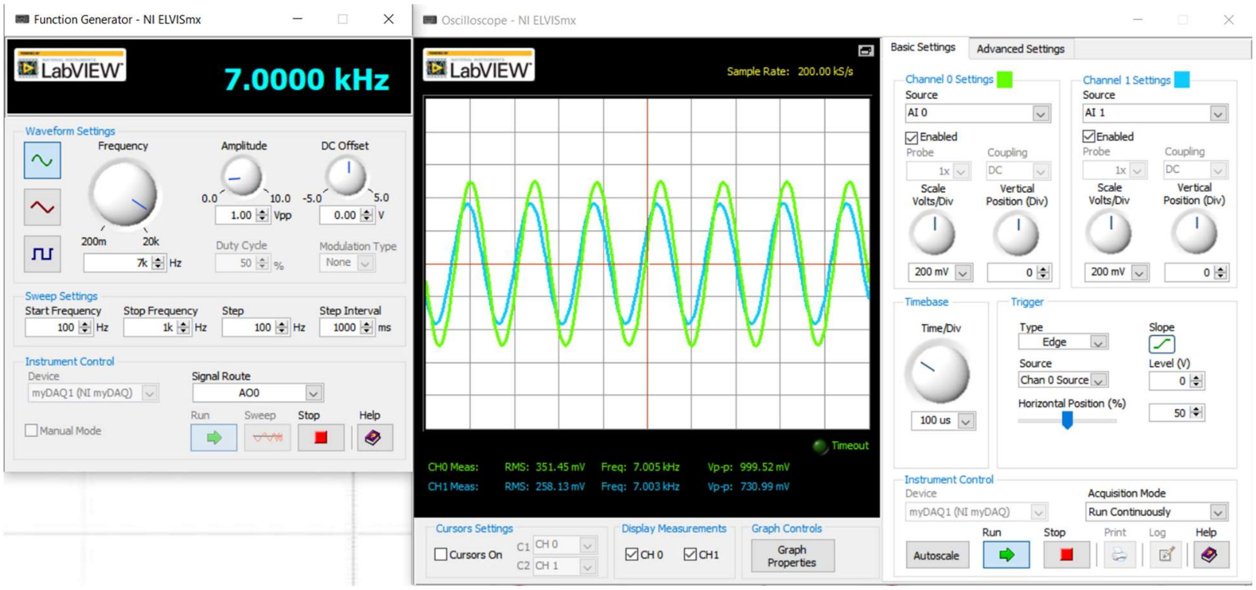


Figure 14.61 – Experimental Results – Case 3 – Waveform, @ 7kHz

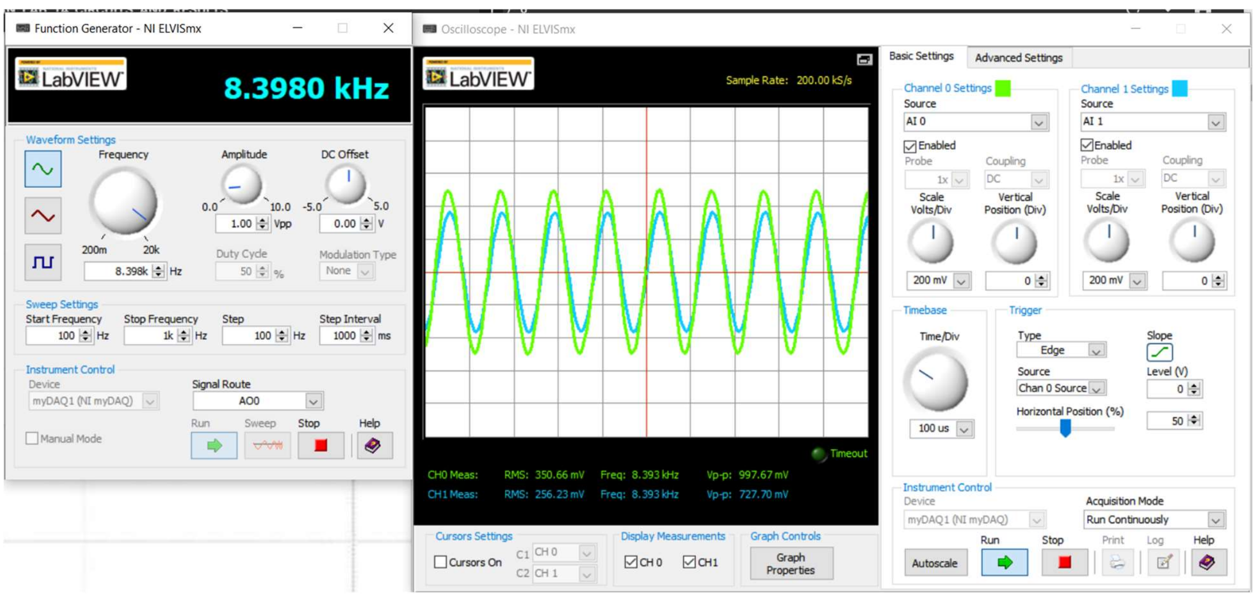


Figure 14.62 – Experimental Results – Case 3 – Waveform, @ 8.398kHz

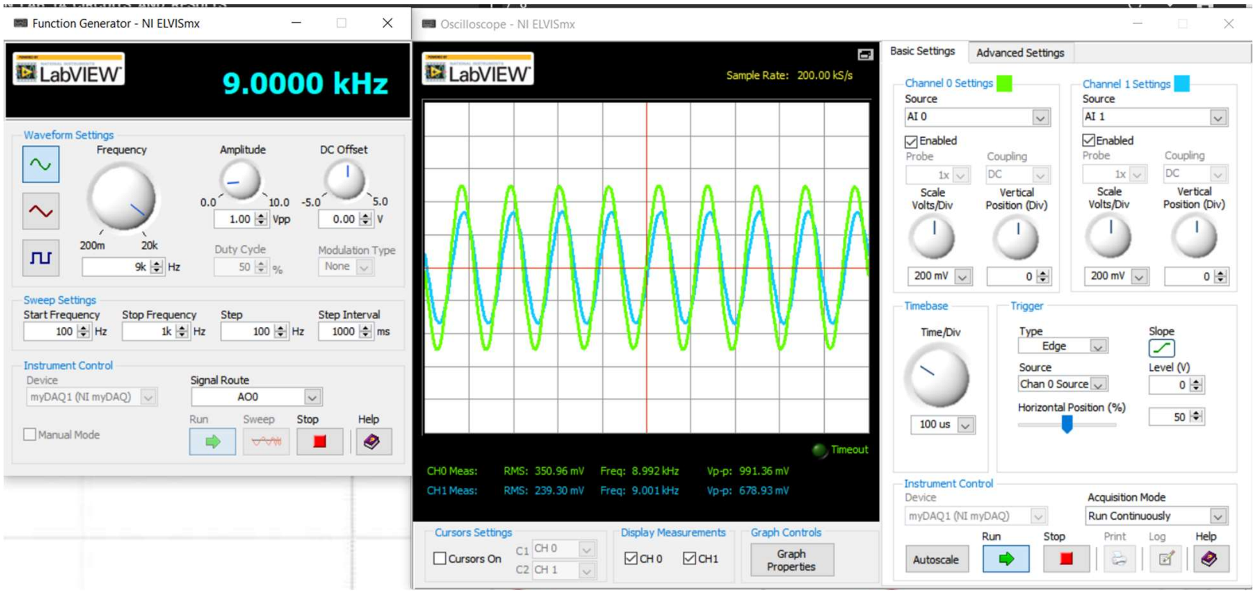


Figure 14.63 – Experimental Results – Case 3 – Waveform, @ 9kHz

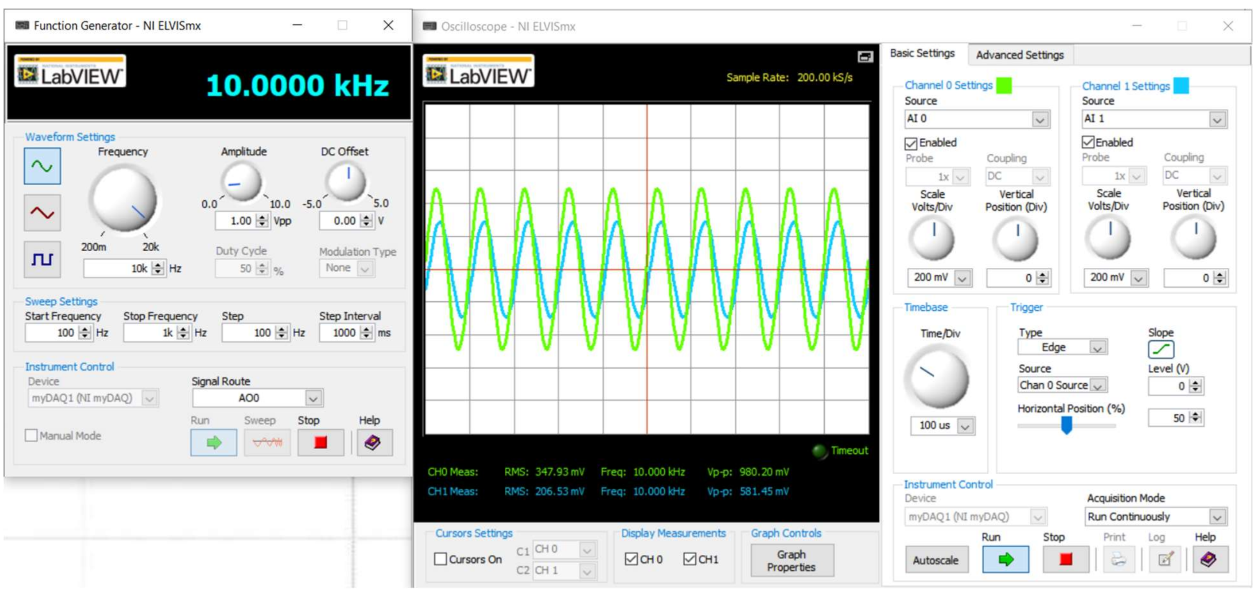


Figure 14.64 – Experimental Results – Case 3 – Waveform, @ 10kHz

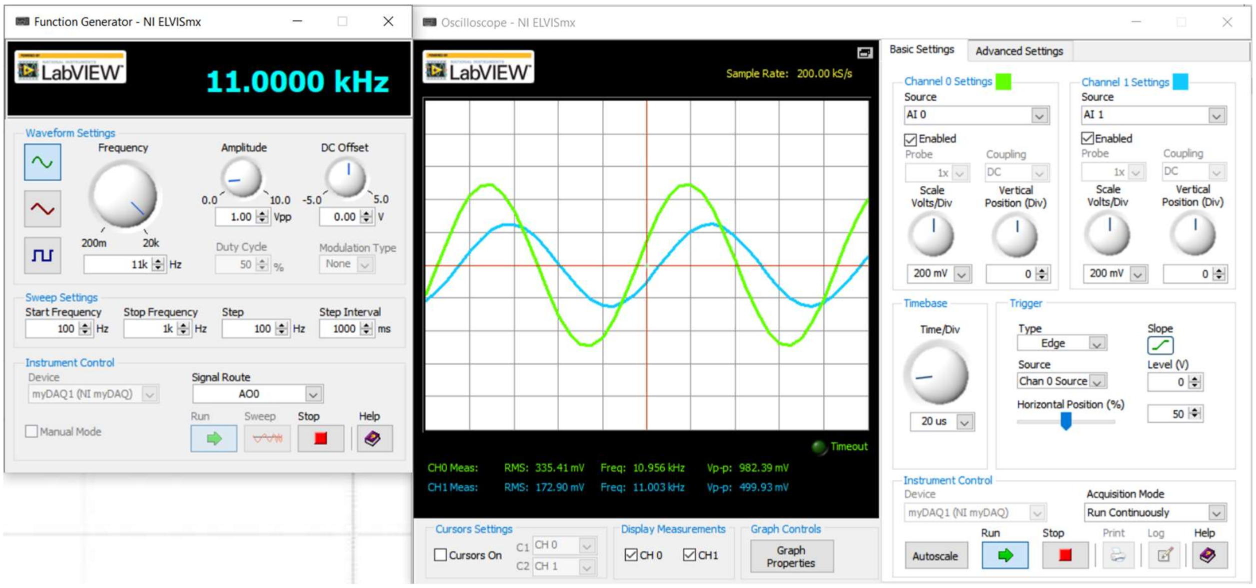


Figure 14.65 – Experimental Results – Case 3 – Waveform, @ 11kHz

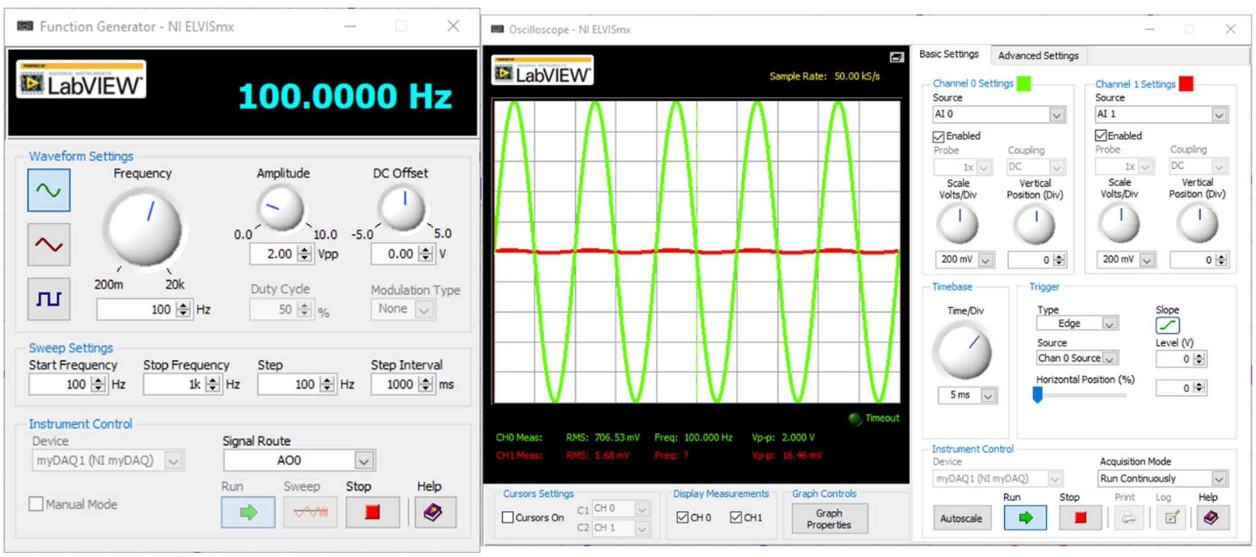


Figure 14.66 – Experimental Results – Case 4 – Waveform, @ 100Hz

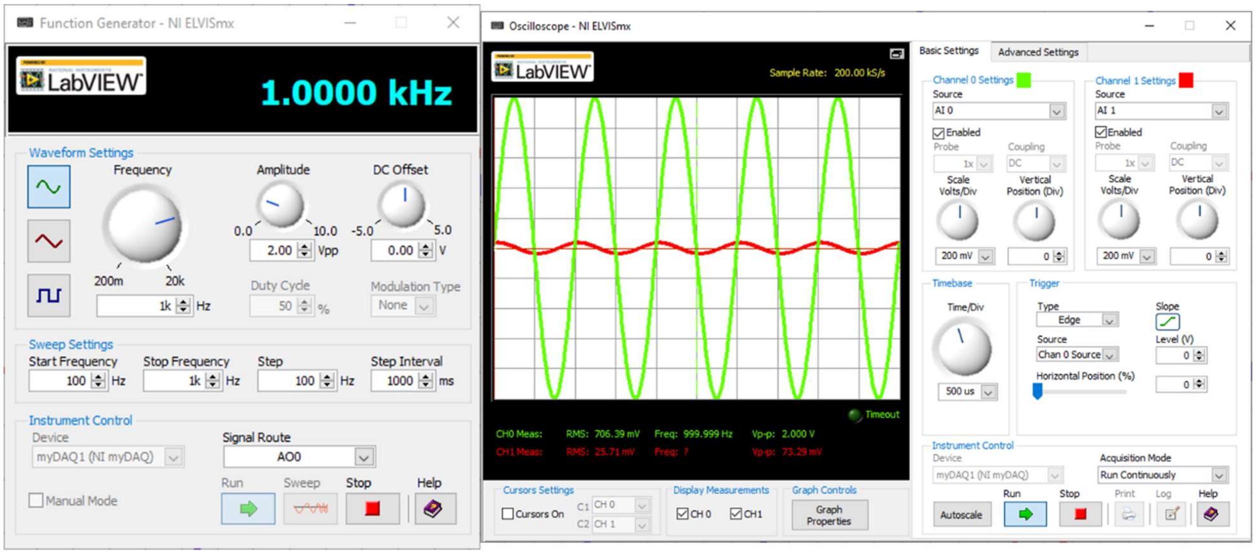


Figure 14.67 – Experimental Results – Case 4 – Waveform, @ 1kHz

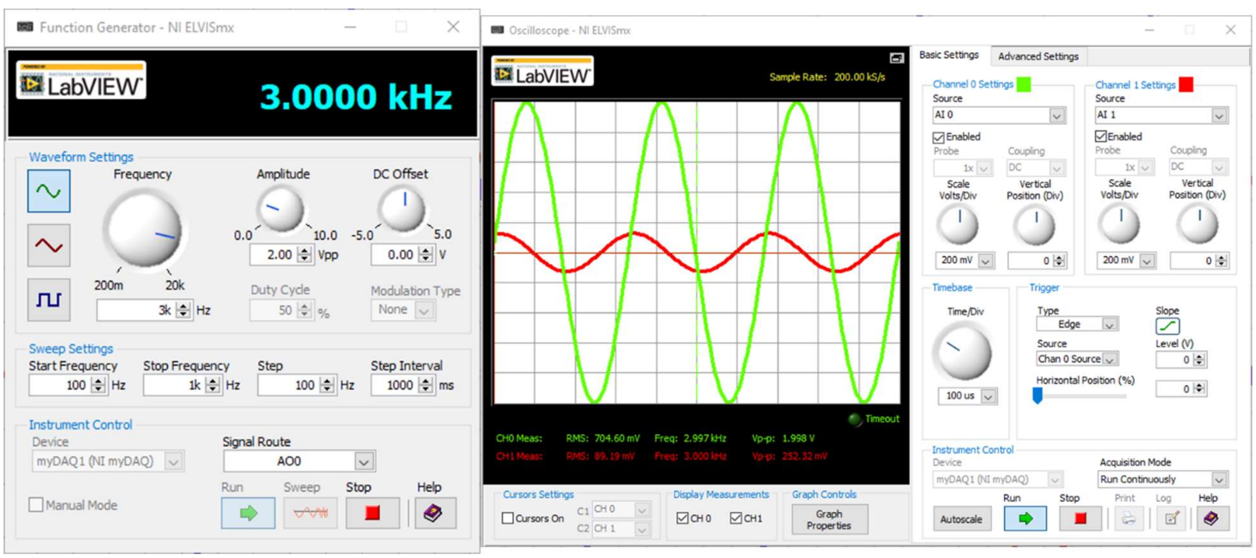


Figure 14.68 – Experimental Results – Case 4 – Waveform, @ 3kHz

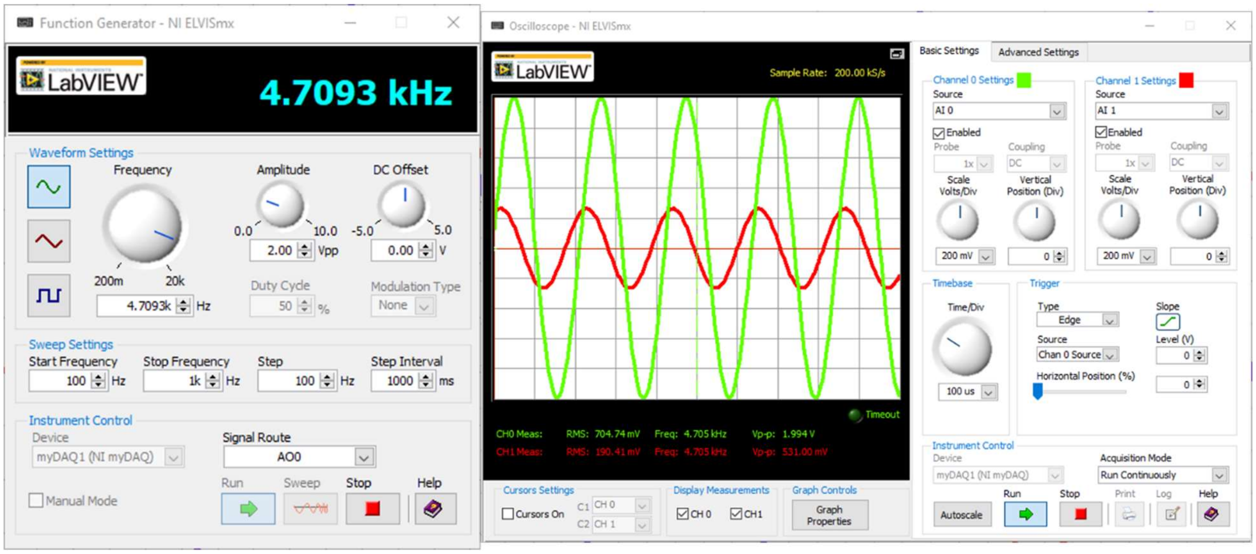


Figure 14.69 – Experimental Results – Case 4 – Waveform, @ $f_1 = 4.7093\text{kHz}$

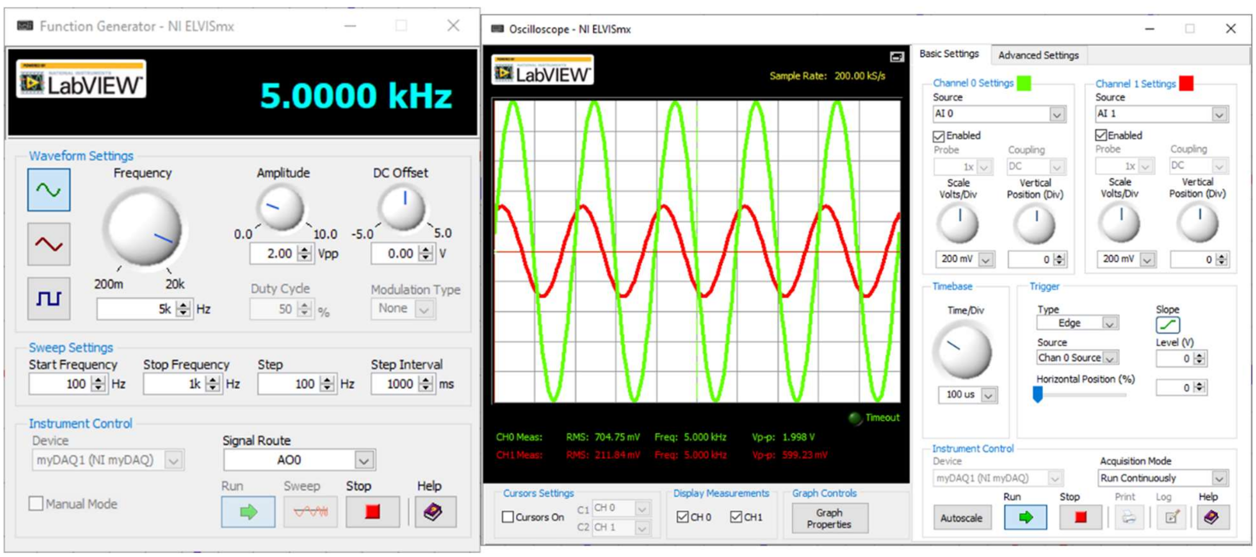


Figure 14.70 – Experimental Results – Case 4 – Waveform, @ 5kHz

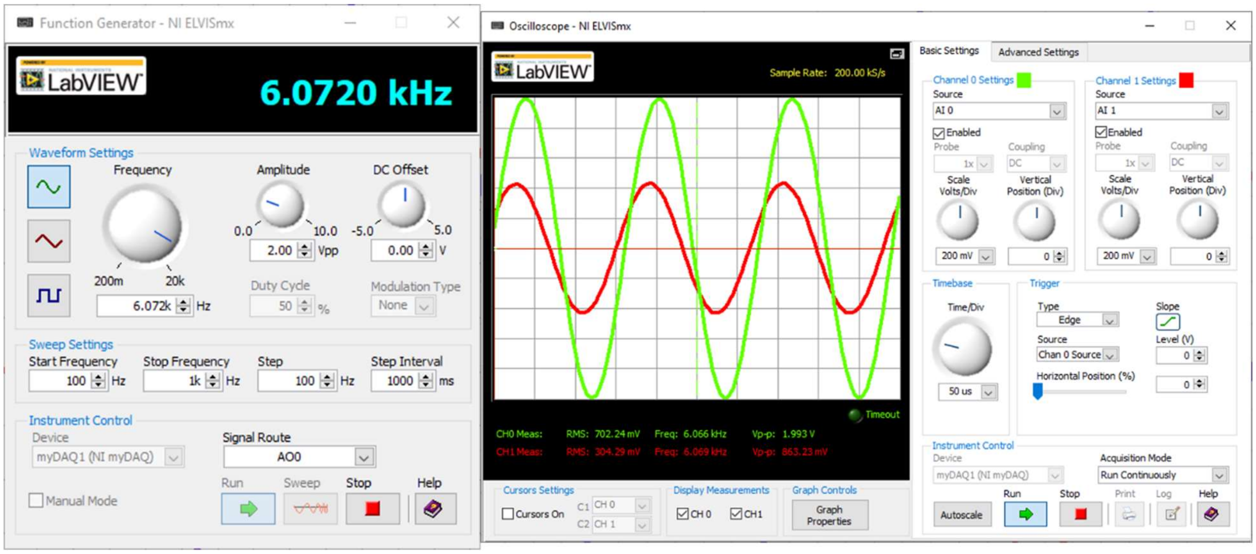


Figure 14.71 – Experimental Results – Case 4 – Waveform, @ $f_C = 6.0720$kHz

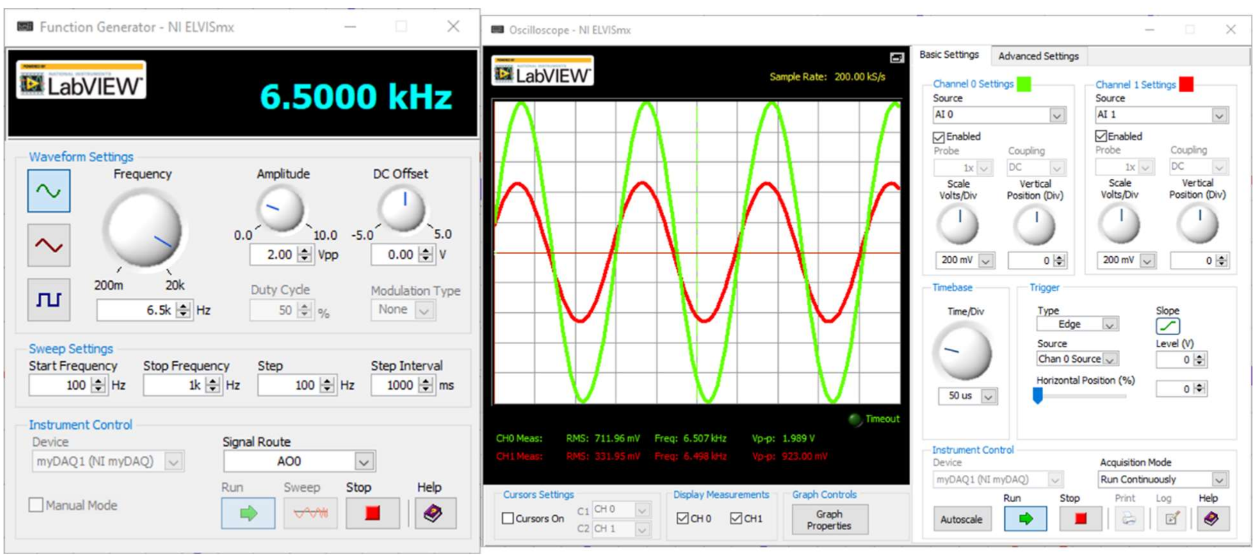


Figure 14.72 – Experimental Results – Case 4 – Waveform, @ 6.5kHz

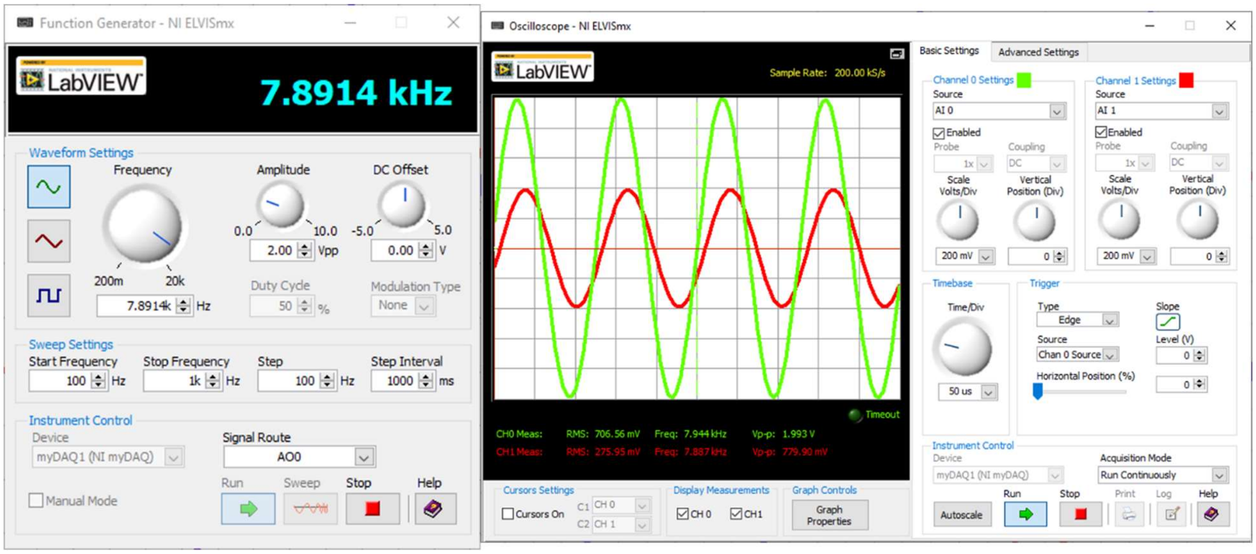


Figure 14.73 – Experimental Results – Case 4 – Waveform, @ $f_2 = 7.8914\text{kHz}$

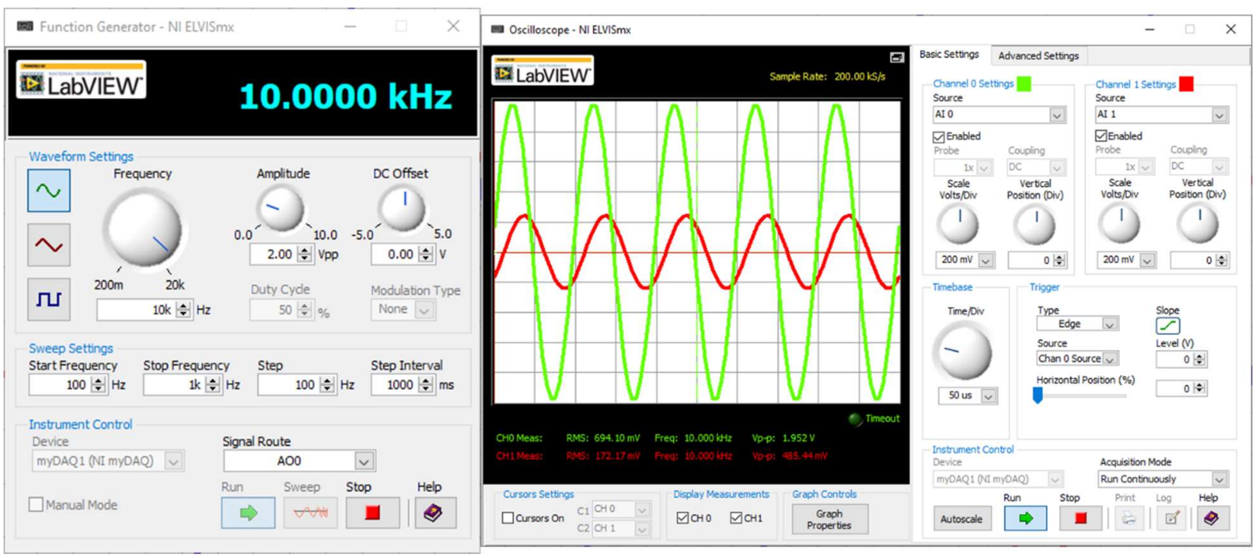


Figure 14.74 – Experimental Results – Case 4 – Waveform, @ 10kHz

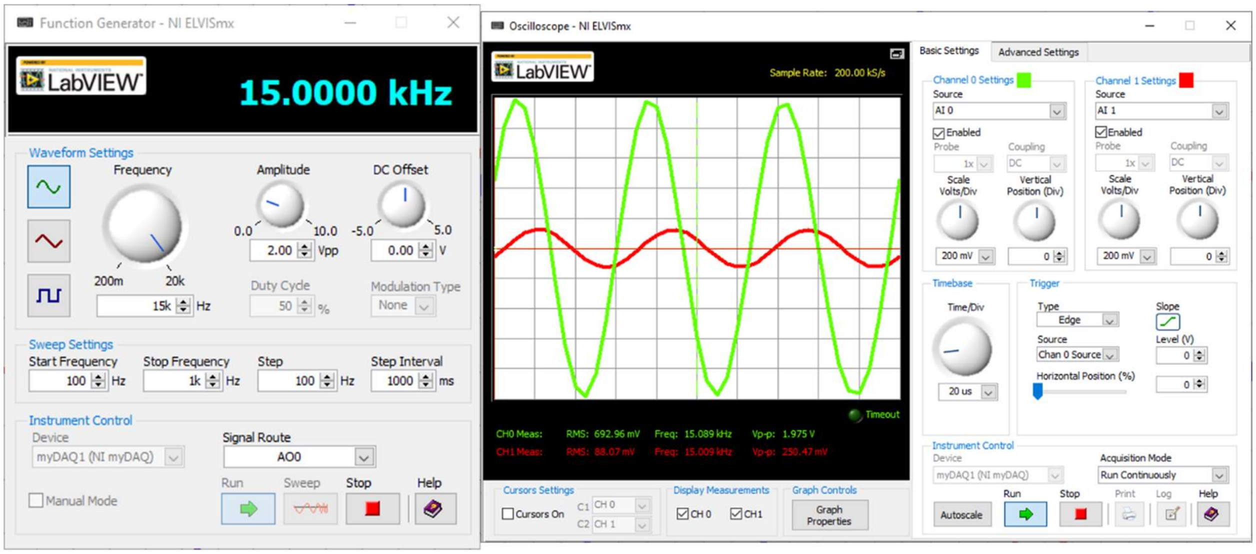


Figure 14.75 – Experimental Results – Case 4 – Waveform, @ 15kHz

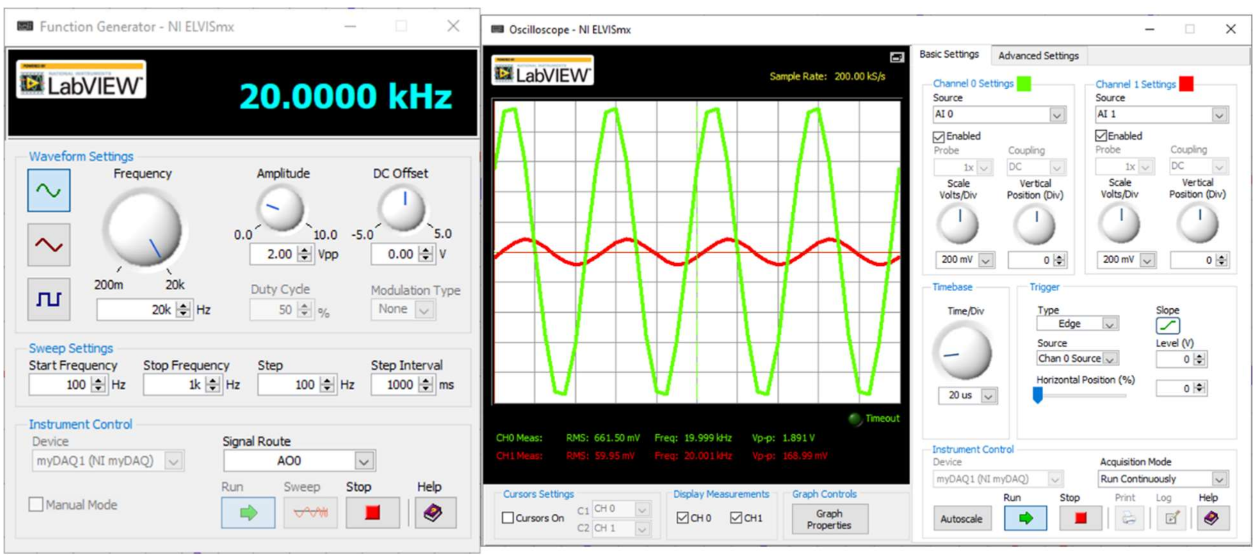


Figure 14.76 – Experimental Results – Case 4 – Waveform, @ 20kHz

$V_{out}(t)$ [mV]	Frequency [Hz]
312	1k
457	1.5k
581	2k
704	2558
954	4.5k
1k	6011
885	10k
706	14.48k
626	17k
572	19k
547	20k

Figure 14.77 – Experimental Results
Case 1, Sampled Data

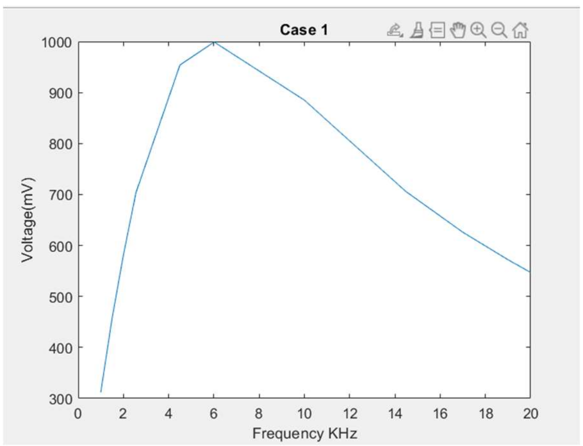


Figure 14.78 – Experimental Results
Case 1, Sampled Data Plotted

$V_{out}(t)$ [V]	Frequency [Hz]
0.014275	100
0.13562	1k
0.445005	3k
0.664	4709.3
0.8085	5k
0.9305	6072
0.916	6.5k
0.7955	7891.4
0.6985	10k
0.584	15k
0.40703	20k

Figure 14.79 – Experimental Results
Case 2, Sampled Data

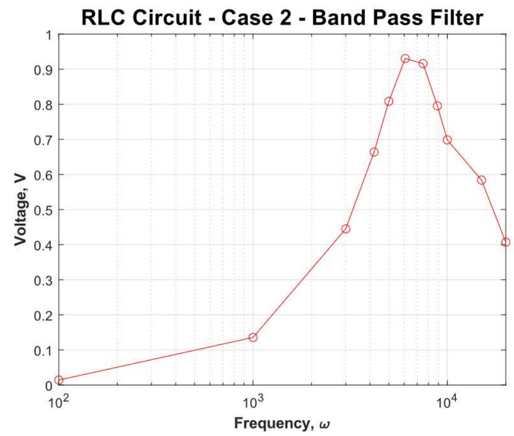


Figure 14.80 – Experimental Results
Case 2, Sampled Data Plotted

$V_{out}(t)$ [mV]	Frequency [Hz]
87	1k
186	2k
311	3k
565	4425
769	5.5k
799	6089
697	7.3k
568	8389
428	10k
369	11k
290	13k

Figure 14.81 – Experimental Results
Case 3, Sampled Data

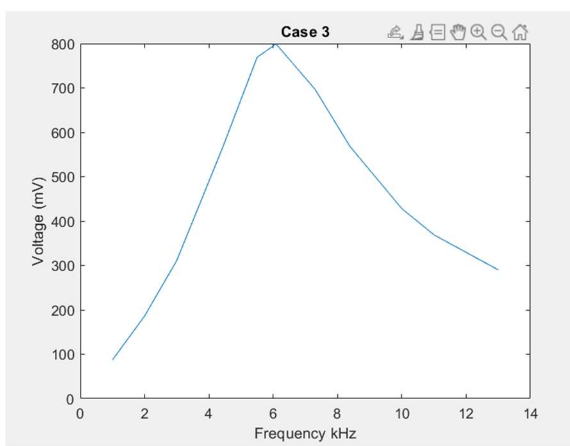


Figure 14.82 – Experimental Results
Case 3, Sampled Data Plotted

$V_{out}(t)$ [V]	Frequency [Hz]
0.00823	100
0.036645	1k
0.12616	3k
0.2655	4709.3
0.2995	5k
0.431615	6072
0.4615	6.5k
0.38995	7891.4
0.24272	10k
0.125235	15k
0.084495	20k

Figure 14.83 – Experimental Results Case 4, Sampled Data

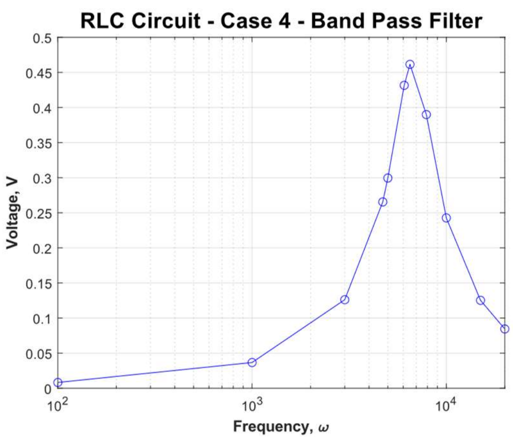


Figure 14.84 – Experimental Results Case 4, Sampled Data Plotted

14.4 DISCUSSION & CONCLUSION

In the experimental part of case 3 there seemed to be values that were off by a bit. After testing with a multimeter, I found that it could have been because of the tolerance of the resistor which was throwing off my values slightly by R1 not being exactly at 5k Ohms. Besides this everything else went as expected, simulation and experimental testing of the different cases for the band pass filter were successful.

REFERENCES

[1] Mallard, Bejamin F. *Electrical Engineering Fundamentals Laboratory Experiments 1-14 Electrical Engineering ECE 240L Laboratory Manual*. California State University Northridge.

[2] Svoboda, James A., and Richard C. Dorf. Introduction to Electric Circuits. John Wiley & Sons, 2014.

[3] Ou, Jack, et al. *PSPICE Simulation*, California State University, Northridge, 2020, www.csun.edu/~jou/classes/ece240l/2020f/website/20f/20f.htm