CMPE 263 ELECTRONIC CIRCUITS PROJECT

PROJECT REPORT

Project No: 2

Capacitance Measurement Using Bridge Circuit

Group 2

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1 INTRODUCTION

The main focus of this project is the analysis of bridge circuits through the study and implementation of concepts and processes such as circuit balancing and node voltage comparison.

Over the course of this project bridge circuits were extensively studied in order to determine capacitance values and observe phase changes via oscilloscope, The balance condition was established during this process so accurate measurements of the necessary capacitance and resistance values could be realized, in addition the project will also encompass a thorough comparison of experimental and theoretical values.

This report will outline the process, output and framework of the project, this includes circuit analysis, experimental process, results, and conclusions.

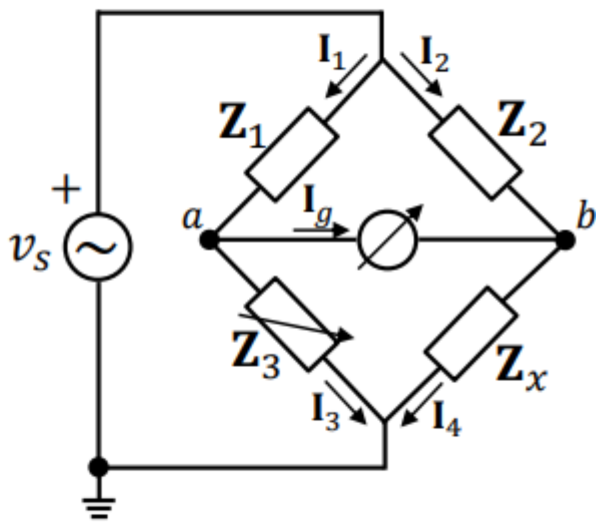

Figure 1.1 Wheatstone bridge circuit

1.1 Objectives

The main objectives of this project were the demonstration of capacitance measurements during the various steps of our project, such as pre and post circuit balancing, the observation and study of phase shifts in the RC circuits via oscilloscope, the analysis and discussion of experimental results, and finally the comparison of experimental results to nominal or computed quantities obtained theoretically.

1.2 Outline

This report will encompass a detailed analysis of the bridge circuits, this analysis will start by providing a theoretical overview of the bridge circuit, followed by a derivation of balance conditions and interplay between the different circuit elements employed.

The Experimental Data and Results section will encompass an overview of the simulation setup used, followed by an explanation of the measurements obtained, and an overview of how the balancing procedure was conducted using the various materials and tools employed over the course of this project, and a comparison between experimental values and computed theoretical values.

The Discussions section will encompass a general analysis of the conducted experiment, the experimental and theoretical data, and of encountered issues errors.

Finally, the Conclusion section will offer a summary of the outcomes and knowledge obtained following the realization of this project.

1.3 Materials used

The following materials and software were used during the execution of our project:

- Breadboard
- 4 resistors (R_1 (Two instances, one in each circuit), R_2, R_3)
- 4 capacitors (C_x (Two instances, one in each circuit),C_2, C_3)
- Multimeter
- Oscilloscope
- Potentiometer
- Capacitance Box
- Voltmeter
- Power supply
- 1 crocodile wire
- 3 jumper wires
- 2 banana-to-alligator wires
- 2 banana jack universal cables
- LTspice

2 CIRCUIT ANALYSIS

2.1 Z-Parameters

The circuits studied are Wheatstone based bridge circuits, each encompassing four main components Z_1 Z_2, Z_3, and Z_x.

Z_1 is purely resistive in both circuits (represented by R_1), Z_2 and Z_3 can be set to either capacitance or resistance depending on the circuit, finally Z_x represents the unknown capacitance values.

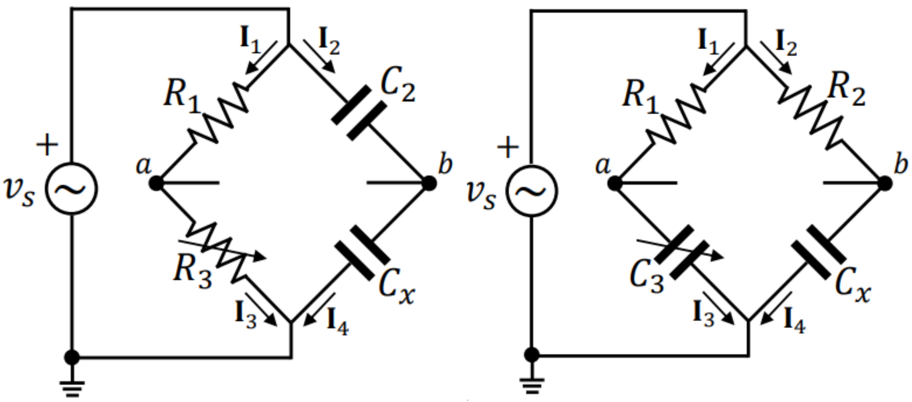

Figure 2.1.1 The circuits studied, 1st circuit on the left, 2nd circuit on the right.

Component	1st Circuit	2nd Circuit	Function
Z_1	R_1	R_1	Purely resistive in both circuits
Z_2	C_2	R_2	Capacitive in 1st resistive in 2nd
Z_3	R_3	C_3	Resistive in 1st capacitive in 2nd
Z_x	C_x	C_x	Capacitive in both circuits

Figure 2.1.2 Table of Z components and their Function in the circuits studied.

2.2 Circuit Characteristics

As seen in figure 2.1.1 the circuits studied in this project are bridge circuits, the configuration of both circuits is tailored to measuring the appropriate unknown C_x capacitance.

2.2.1 Power Source and Voltage

An AC Voltage generator was used during the conduction of this project, the source voltage was noted Vs, with $V_s(t) = 10cos(2\pi 10^4 t)$, The source voltage had a sinusoidal nature with an amplitude of 10V and a frequency of 10kHz, no initial phase shift as observed from the equation.

2.2.2 1st Circuit Setup and Elements

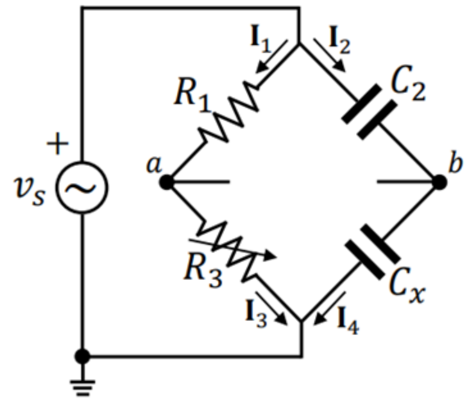

Figure 2.2.1 First bridge circuit

As seen from the figure 2.2.1 above the first circuit is a bridge circuit with four parameters, two resistors in series (R_1 and R_3) and two capacitors also in series (C_2 and C_x), resistors R_1 and R_3 are in parallel with capacitors C_2 and C_x respectively.

The first circuit is basically composed of two branches that are connected in parallel, the first branch consists of two resistors in series (R_1 and R_3), the second branch consists of two capacitors in series (C_2 and C_x), these branches are connected between the source voltage V_s and the ground.

In addition, as seen from the figure above the nodes a and b are formed at the junctions within R_1-R_3 and C_2-C_x respectively.

R_1 has a value of 1.5 kΩ , R_3 has a value of 1kΩ at the start of the experiment but is later swapped for 10kΩ potentiometer employed in balancing.

Capacitors wise C_2 has a value of 10nF and C_x is given a value of 22nF, as specified in the project guideline C_x should be initialized to a value between 5nF and 50nF.

The voltages V_a and V_b represent the voltages at nodes a and b respectively, as seen above Va is influenced by R_1 and R_3 while V_b is influenced by C_2 and C_x. V_{ab} designates the potential difference between node a and node b with $V_{ab} = V_a - V_b$.

2.2.3 2nd Circuit Setup and Elements

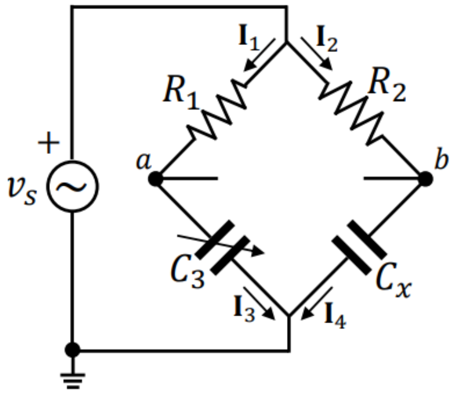

Figure 2.2.2 Second bridge circuit

As seen from the figure 2.2.2 above, the second circuit is a bridge circuit with four parameters, two resistors R_1 and R_2 and two capacitors C_2 and C_x, resistors R_1 and C_3 are in series forming one branch of the circuit, the other branch is formed by R_2 and C_x (also in series), the two branches (R_1-C_3 and R_2-C_x) are in parallel with each other and connected between the source voltage Vs and the ground.

Additionally, as seen from the figure above the nodes a and b are formed at the junctions within R_1-C_3 and R_2-C_x respectively.

R1 has a value of 1.5 kΩ , R2 has a value of 2.2kΩ, as for capacitors C3 initially has a value of 51nF, a capacitance box is later used for C3 in order to balance the bridges, finally Cx is given a value of 22nF.

Va and Vb again designate the voltages at nodes a and b respectively, as seen above Va is influenced by R1 and C3 while Vb is influenced by R2 and Cx. Vab designates the potential difference between node a and node b with $V_{ab} = V_a - V_b$

2.4 Derivation of Capacitance and Resistance Values

Throughout the report the following formulas were used to derive R3 and C3:

$$C_x = \frac{R_1}{R_3} C_2 \; And \; C_x = \frac{R_1}{R_2} C_3$$

3 EXPERIMENTAL DATA AND RESULTS

3.1 Experimental Setup and Procedure

After all the appropriate components and tools were selected and all appropriate connections were made, the experiment commenced by verifying the value of the source voltage V_s for the first circuit which was confirmed to equal 10V.

The constructed circuit was a bridge circuit composed of two branches (first branch had two resistors in series (R1 and R3), second branch had two capacitors in series (C2 and Cx), the junctions within these two branches contained nodes a and b respectively.

At the current pre-balancing state of the circuit R3 designates a 1kΩ resistor, this would later be swapped for a 10kΩ potentiometer.

The experiment continued by measuring the voltages at nodes a and b, noted Va and Vb respectively, via the oscilloscope.

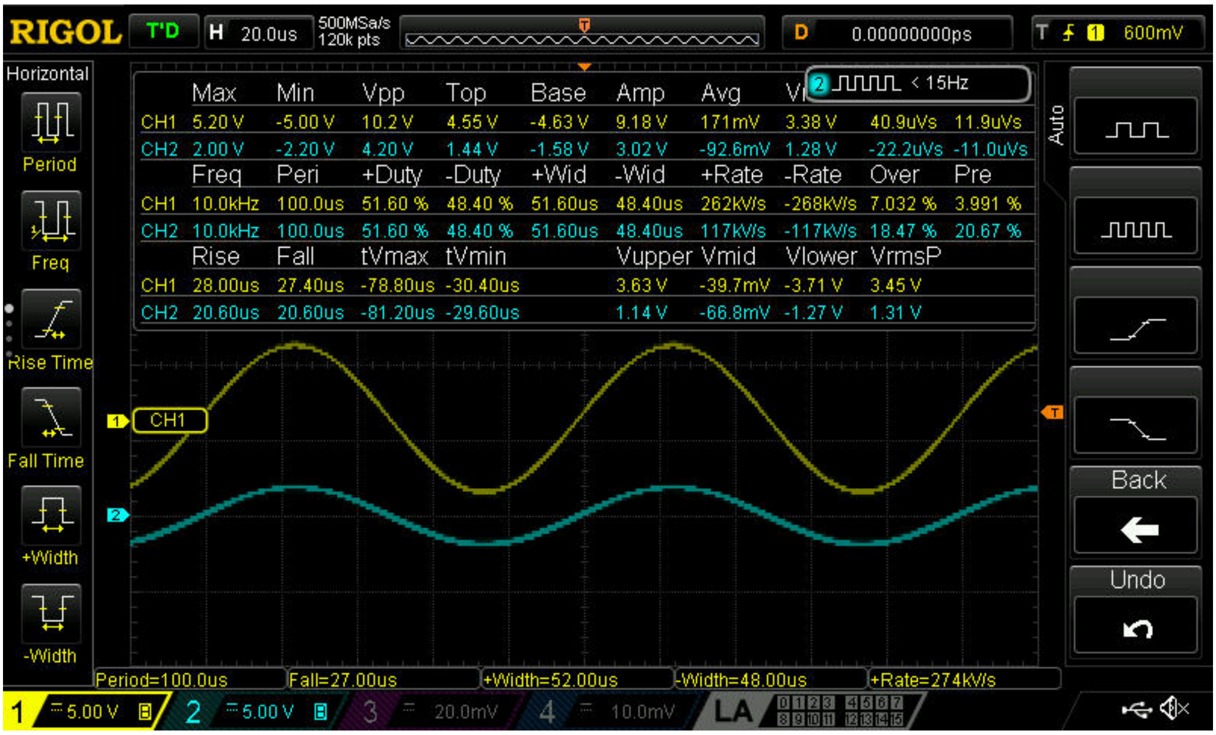

Figure 3.1.1 Oscilloscope reading showcasing the graphs of Vs (CH1) and Va (CH2) for the first circuit pre-balancing

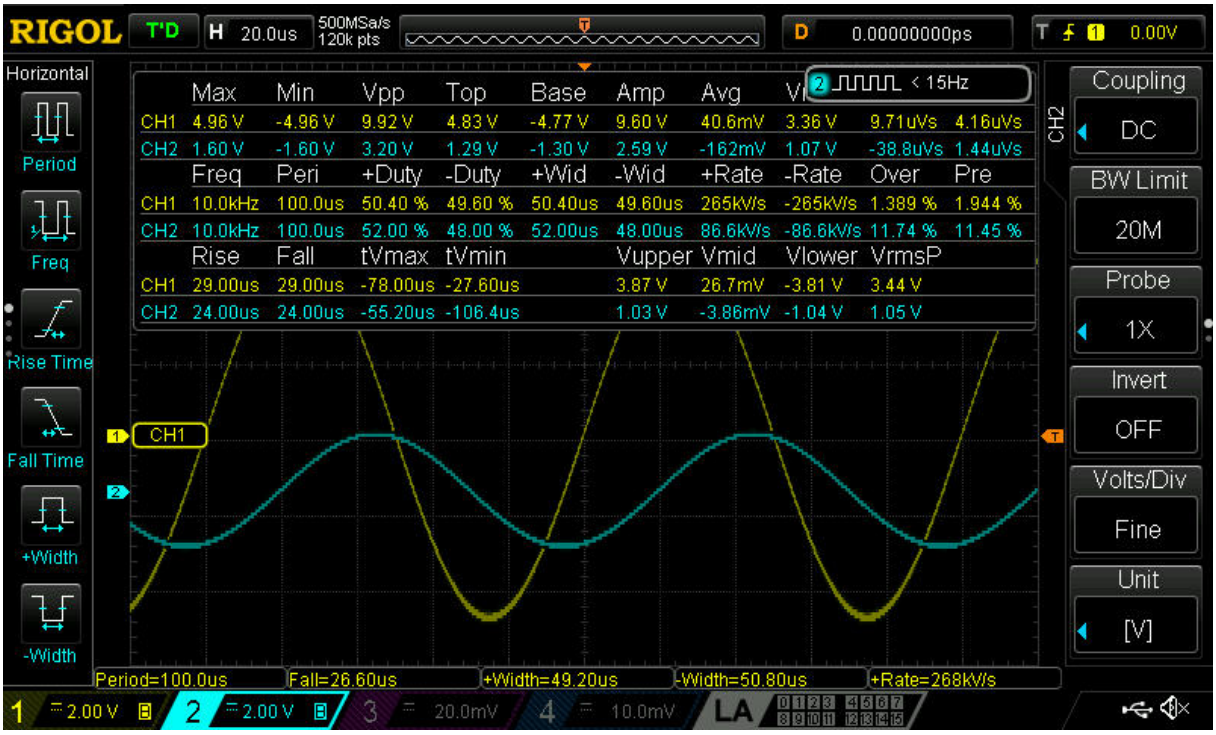

Figure 3.1.2 Oscilloscope reading showcasing the graph of Vb (CH2) for the second circuit pre-balancing

The next step of the experiment was measuring Vab which is the potential difference between Va and Vb designated by the equation $V_{ab} = V_a - V_b$

Finally, R3 was swapped for a 10kΩ potentiometer that was used to balance the bridges and the measurement procedure for Va, Vb, Vab, and Vs were reconducted.

In addition to the lab measurements above, theoretical calculations were also done, moreover measurements were also conducted using LTspice.

The above steps were naturally repeated for the second circuit except instead of swapping R3 for a potentiometer (R3 not being an element of the second circuit) a capacitance box was on C3 to balance the bridges instead.

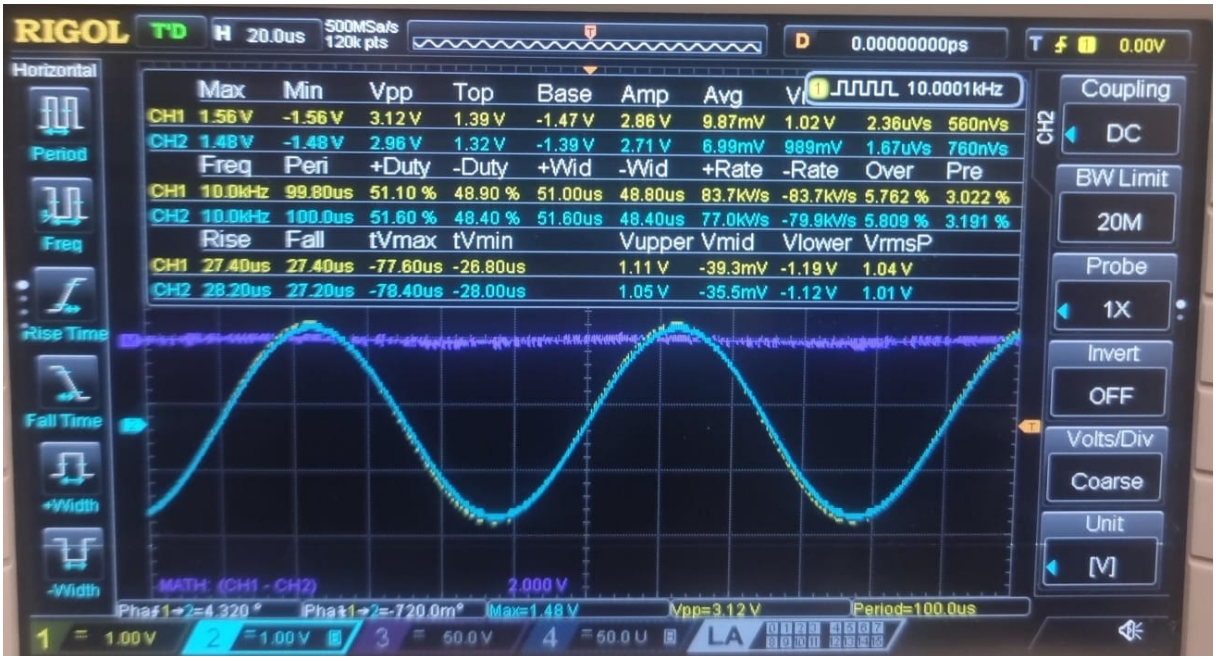

Figure 3.1.3 Oscilloscope reading showcasing the graphs of Va (CH1) and Vb (CH2) for the first circuit post-balancing

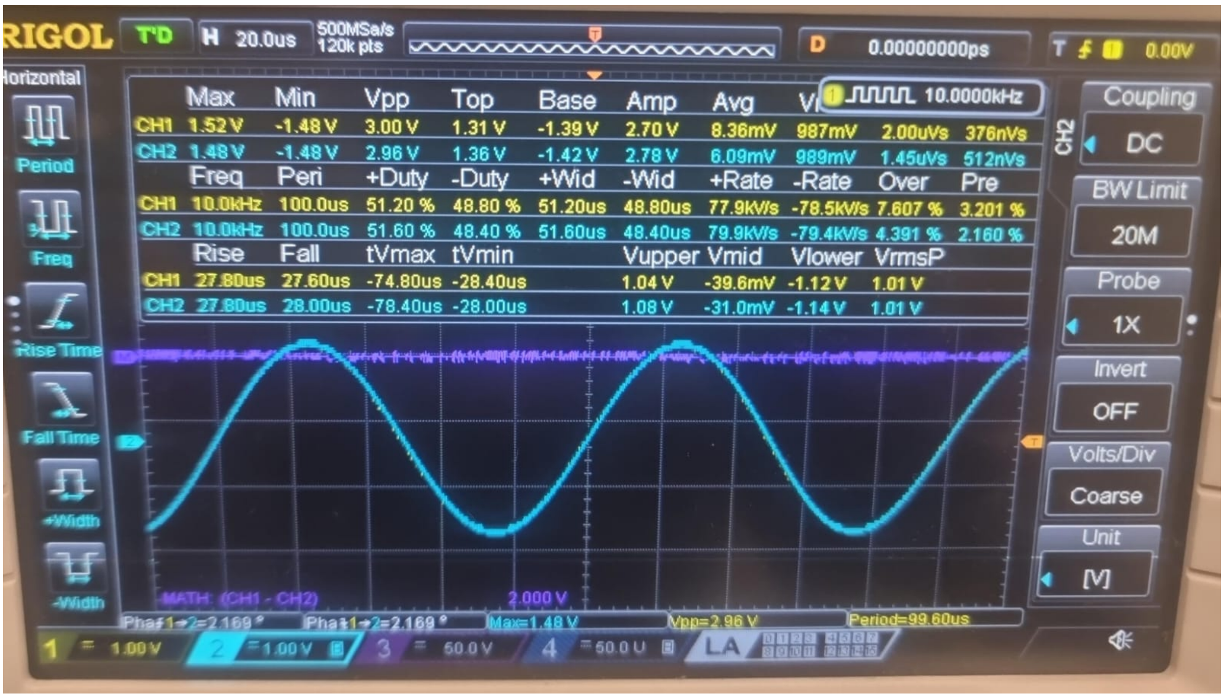

Figure 3.1.4 Oscilloscope reading showcasing the graphs of Va (CH1) and Vb (CH2) for the second circuit post-balancing

Values / Circuit	R_1 (kΩ)	R_2 (kΩ)	R_3 (kΩ)	C_2 (nF)	C_3 (nF)	Cx (nF)	Va (V)	Vb (V)	Vab (V)
1	1.5	_	1	10	_	22	4	2.8	1.2
2	1.5	2.2	_	_	51	22	3.12	2	1.12

Figure 3.1.6 Table of experimental measurements for both circuits before balancing the bridges

Values / Circuit	R_1 (kΩ)	R_2 (kΩ)	R_3 (kΩ)	C_2 (nF)	C_3 (nF)	Cx (nF)	Va (V)	Vb (V)	Vab (V)
1	1.5	_	0.4	10	_	22	3.12	2.32	$\cong 0$
2	1.5	2.2	_	_	52	22	3	2.96	$\cong 0$

Figure 3.1.5 Table of experimental measurements for both circuits after balancing the bridges

After the bridges are balanced by manipulating the R3 resistance via potentiometer for the first circuit, and the C3 capacitance via capacitance box for the second circuit, the voltage Vab defined as the potential difference between nodes a and b approaches 0, meaning the voltages Va and Vb become equal.

3.2 Circuit simulation using LTspice

In addition to the lab work conducted, the first circuit was also constructed and simulated in LTspice to gain better insight into the values obtained.

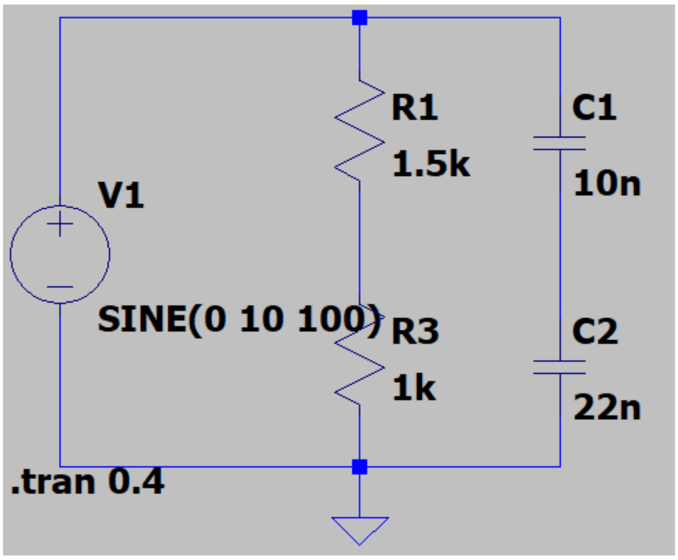

Figure 3.2.1 First circuit before balancing (R3 = 1kΩ) in LTspice

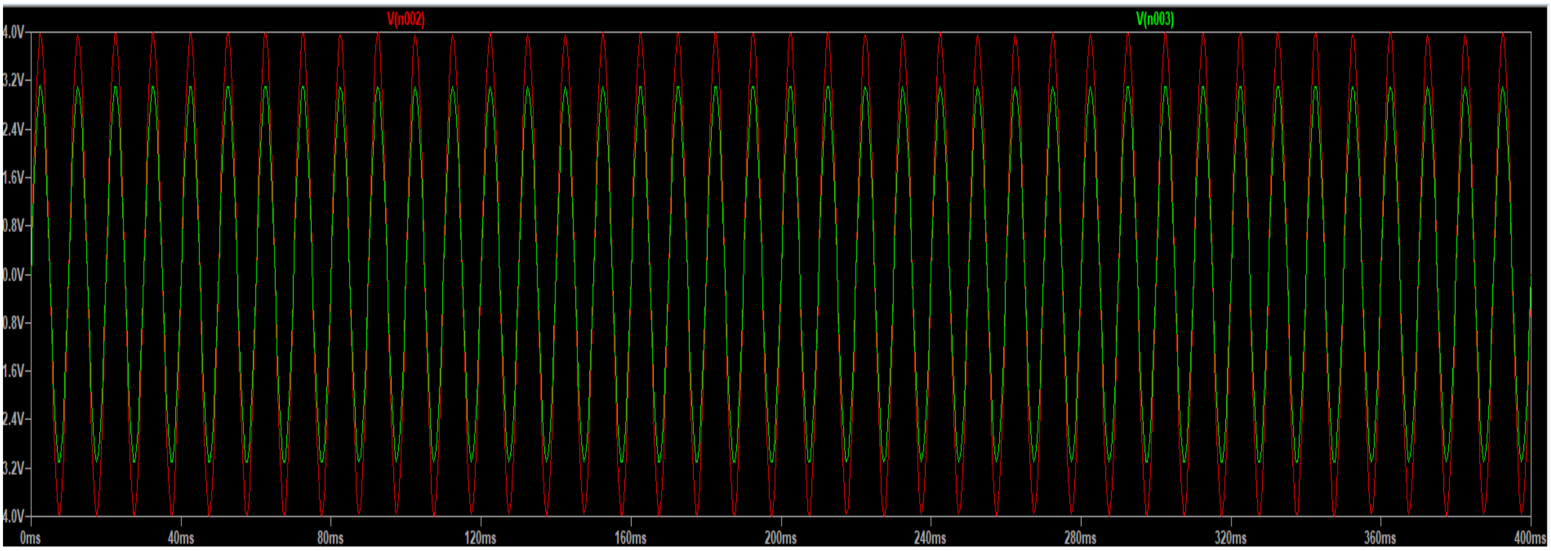

Figure 3.2.2 Voltages Va(red) and Vb(green) after simulation on the unbalanced circuit.

As seen in the figure 3.2.2 above before balancing Va is equal to 4V while Vb is approximately equal to 3.1V.

To obtain the new values after balancing the resistance value of R3 resistance was consistently modified and a new simulation was started after every modification until the graphs for Va and Vb showcased an equal voltage, according to our simulation in LTspice the bridges were balanced when R3 was equal to 0.65kΩ.

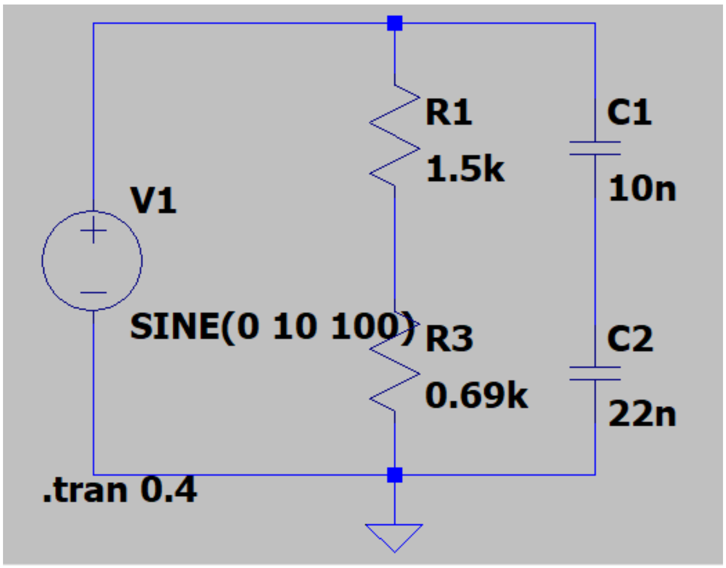

Figure 3.2.3 First after balancing (R3 = 0.69kΩ) in LTspice

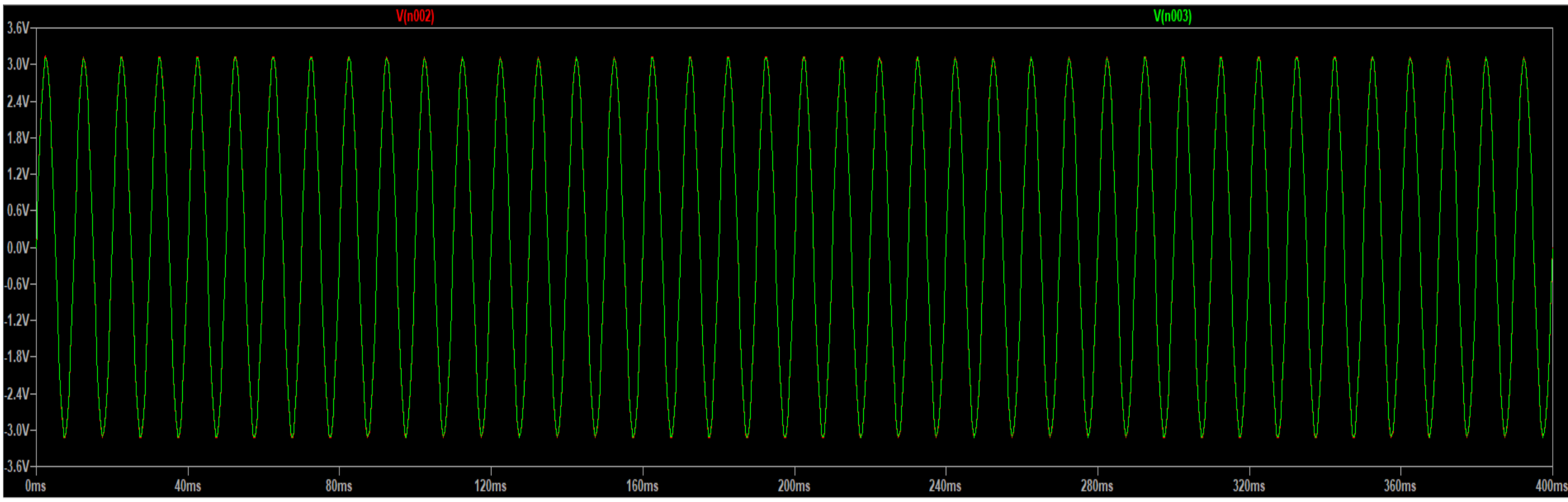

Figure 3.2.4 Voltages Va(red) and Vb (green) after simulation on the balanced circuit.

As we can see from the figure 3.2.4 above, when R3 = 0.69kΩ the bridges are balanced and thus the voltages Va and Vb are equal to the same value, approximately 3.2V, the sinusoidal graphs for both voltages are in sync.

3.3 Experimental Result Analysis

After the bridge is balanced, the ratio equalities $\left(\frac{R_1}{R_3} = \frac{C_2}{C_x}\right)$ for the first circuit and $\left(\frac{R_1}{C_3} = \frac{R_2}{C_x}\right)$ for the second circuit are satisfied, thus the impedance of the first branch (R1-R3 for the first circuit and R1-C3 for the second circuit) equal is to the impedance of the second branch (C2-Cx for the first circuit and R2-Cx for the second circuit), thus the potential difference between nodes a and b set at the junctions of these branches becomes 0.

The values used to balance the bridges are R_3 = 4kΩ for the first circuit and C_3 = 52nF for the second circuit .

Another keynote of experimental are phase shifts:

- For Circuit 1 (before balancing)
    - Capacitive reactance (X_a) = 462.7 Ω (from C2 and Cx)
    - Phase angle (α_1) = $\tan^{-1}(X_a / R_1) = \tan^{-1}(462.7 / 1500) \approx 17.1°$
- For Circuit 2 (before balancing)
    - Resistance (R_1) = 1500 Ω
    - Capacitive reactance (X_a) = 206.8 Ω (from C3 and Cx)
    - Phase angle (α_2) = $\tan^{-1}(X_a / R_1) = \tan^{-1}(206.8 / 1500) \approx 7.9°$
- After balancing:
    - -Phase Angles for both circuits ≈ 0° (since Vab ≈ 0 after balancing).

3.4 Theoretical Results and Analysis

Voltage	Before balancing (R3 = 1kΩ)	After balancing (R3 = 4kΩ)
Va	$\frac{Vs}{R1+R3}\,R3 = 4V$	$\frac{Vs}{R1+R3}\,R3 = 3.1V$
Vb	$\frac{Vs}{Z2+Zx}\,Zx = 3.12V$	$\frac{Vs}{Z2+Zx}\,Zx = 3V$
Vab	$\frac{Vs}{R1+R3}\,R3 - \frac{Vs}{Z2+Zx}\,Zx = 0.88V$	$\frac{Vs}{R1+R3}\,R3 - \frac{Vs}{Z2+Zx}\,Zx = 0.1V$

Figure 3.3.1 Theoretical values for the first circuit

Voltage	Formula and Values
Va	$\frac{Vs}{R1 + Z3} Z3 = 2.9V$
Vb	$\frac{Vs}{R2 + Zx} Zx = 2.1V$
Vab	$\frac{Vs}{R1 + Z3} Z3 - \frac{Vs}{R2 + Zx} Zx = 0.8V$

Figure 3.3.2 Theoretical values for the second circuit

3.4.1 Key Points in the Theoretical Values

The theoretical results are in accordance to the principle established after obtaining the experimental results V_{ab} approaches zero post balancing as a result of the established equality between V_a and V_b.

3.5 Comparison of Experimental and Theoretical Results :

Overall theoretical results vary little from experimental results, albeit some differences are present, however both results show a decrease in V_{ab} for both circuits after the bridges are balanced, as V_{ab} approaches in both cases, there is virtually no major differences in the theoretical and practical work done for the first circuit, especially concerning V_a.

Nevertheless, some variation between theoretical and experimental V_b values does exist, but nothing that would jeopardize the basic function of bridge circuits pre and post balancing.

4 ERROR HANDLING

4.1 Error Analysis

To fully Comprehend differences and variations between theoretical and experimental values, error analysis is crucial.

In both circuits constructed throughout this project differences between theoretical and measured voltages can occur due to various reasons.

4.1.1 Sources of Error

One of the common sources of error is resistance tolerance, most resistors have a tolerance of ±1% or ±5% which can lead to slight deviations.

Another important reason is inaccuracies and deviations within the multimeter itself, which is used to measure voltage and current.

Environmental factors such as temperature and humidity also play a role in error occurrence as they can lead to increases in resistance within the circuit, especially for highly sensitive components.

Faulty wires, and corrupted components can also lead to frustration and mistakes during circuit construction.

.4.2 Outcome in Tackling Error

Various Errors were encountered during this project mainly faulty wires, nonfunctioning potentiometer and slightly inaccurate oscilloscope readings.

Overall error was mitigated and despite some frustration during the construction of the circuit and measurement of the voltages, the desired outputs and voltages were obtained.

5 DISCUSSIONS

The project encompassed detailed principles of bridge circuits, their function, and their application in capacitance measurement. One of the crucial keynotes in this project was the role balancing bridge plays in voltage measurements of nodes. Before balancing, inequality in node voltages was observed by manipulating resistance and capacitance values in both circuits via potentiometers and capacitance boxes respectively, the bridges were balanced, and the needed measurements were conducted successfully.

The experimental results generally aligned with theoretical expectations, thus giving validity to the experimental arrangement, albeit there was a slight deviation in voltage values, which could be the result of component tolerances and environmental factors. LTspice simulations offered a unique perspective on comparing theoretical calculations with experimental data, especially in observing conditions where the bridge achieves balance.

Faulty wires and non-functioning potentiometers during the project required testing components before use in the circuit.

6 CONCLUSIONS

The project successfully demonstrated the principles and practical applications of bridge circuits in capacitance measurement via theoretical analysis, experimental work, and simulation, knowledge of how bridge circuit's function and operate was gained by realizing the project's objective and conducting the necessary voltage measurements.

By balancing the bridge circuit, the evolution of voltage was observed and the necessary resistance and capacitance values for this phenomenon to take place were derived. Simulation tools, such as LTspice were also used to offer a new perspective on the project.

The project's objectives were achieved by providing valuable information about design, analysis, and troubleshooting in electronic circuits.

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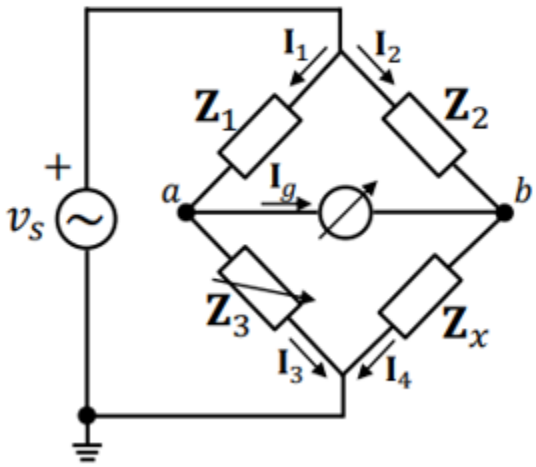

Figure 1.1 Wheatstone bridge circuit

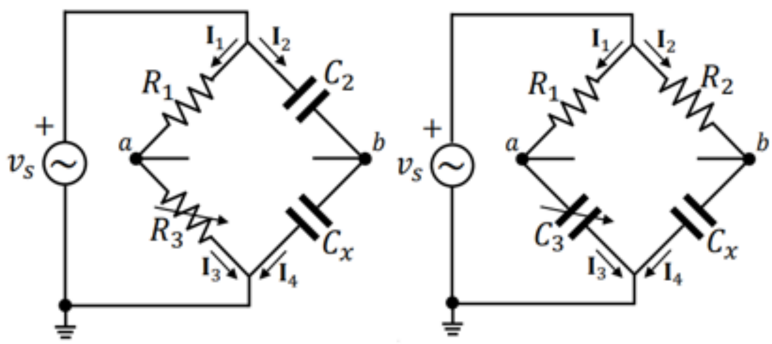

Figure 2.1.1 The circuits studied, 1st circuit on the left, 2nd circuit on the right.

Component	1st Circuit	2nd Circuit	Function
Z_1	R_1	R_1	Purely resistive in both circuits
Z_2	C_2	R_2	Capacitive in 1st resistive in 2nd
Z_3	R_3	C_3	Resistive in 1st capacitive in 2nd
Z_x	C_x	C_x	Capacitive in both circuits

Figure 2.1.2 Table of Z components and their Function in the circuits studied.

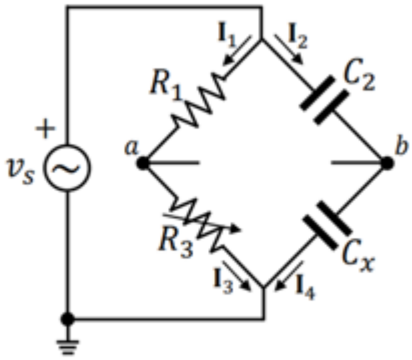

Figure 2.2.1 First bridge circuit

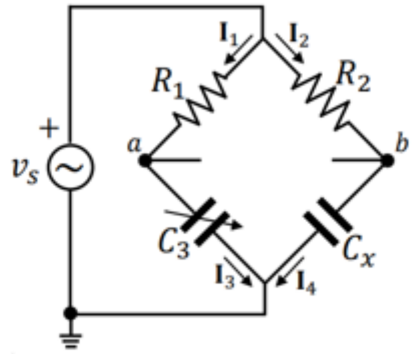

Figure 2.2.2 Second bridge circuit

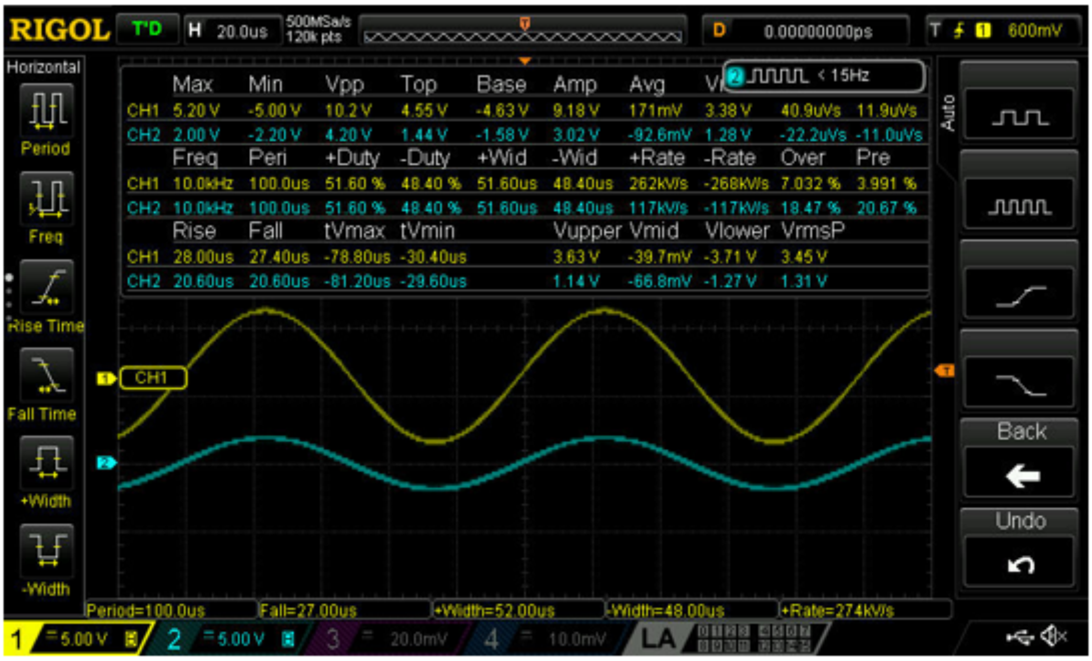

Figure 3.1.1 Oscilloscope reading showcasing the graphs of Vs (CH1) and Va (CH2) for the first circuit pre-balancing

Figure 3.1.2 Oscilloscope reading showcasing the graph of Vb (CH2) for the second circuit pre-balancing

Figure 3.1.3 Oscilloscope reading showcasing the graphs of Va (CH1) and Vb (CH2) for the first circuit post-balancing

Figure 3.1.4 Oscilloscope reading showcasing the graphs of Va (CH1) and Vb (CH2) for the second circuit post-balancing

Values / Circuit	R_1 (kΩ)	R_2 (kΩ)	R_3 (kΩ)	C_2 (nF)	C_3 (nF)	Cx (nF)	Va (V)	Vb (V)	Vab (V)
1	1.5	_	1	10	_	22	4	2.8	1.2
2	1.5	2.2	_	_	51	22	3.12	2	1.12

Figure 3.1.6 Table of experimental measurements for both circuits before balancing the bridges

Values / Circuit	R_1 (kΩ)	R_2 (kΩ)	R_3 (kΩ)	C_2 (nF)	C_3 (nF)	Cx (nF)	Va (V)	Vb (V)	Vab (V)
1	1.5	_	0.4	10	_	22	3.12	2.32	≅ 0
2	1.5	2.2	_	_	52	22	3	2.96	≅ 0

Figure 3.1.5 Table of experimental measurements for both circuits after balancing the bridges

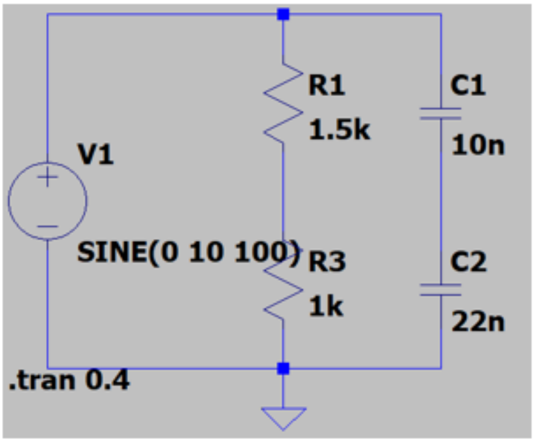

Figure 3.2.1 First circuit before balancing (R3 = 1kΩ) in LTspice

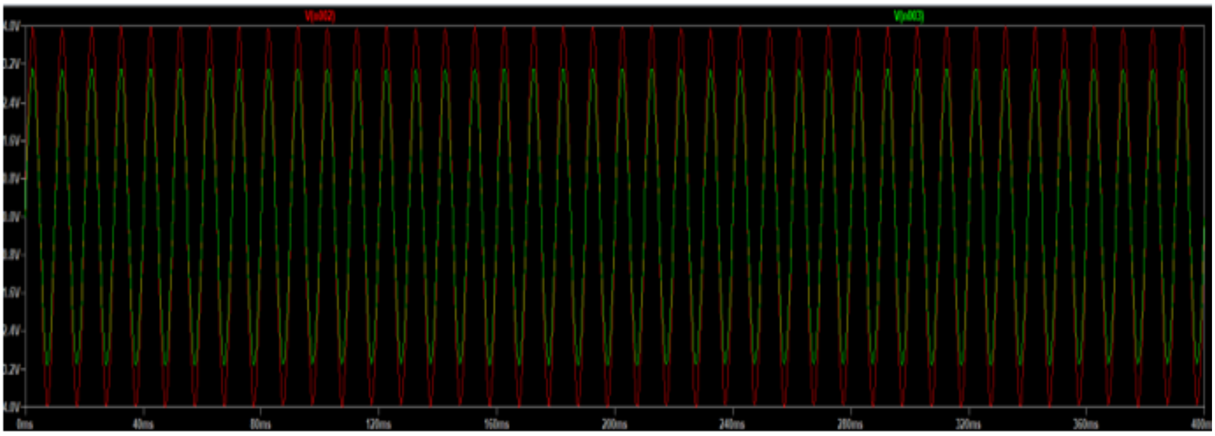

Figure 3.2.2 Voltages Va(red) and Vb(green) after simulation on the unbalanced circuit.

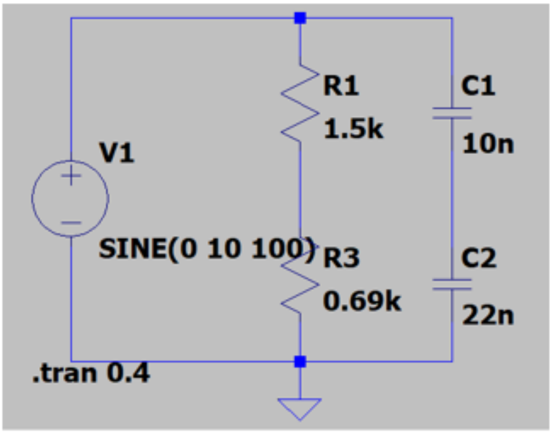

Figure 3.2.3 First after balancing (R3 = 0.69kΩ) in LTspice

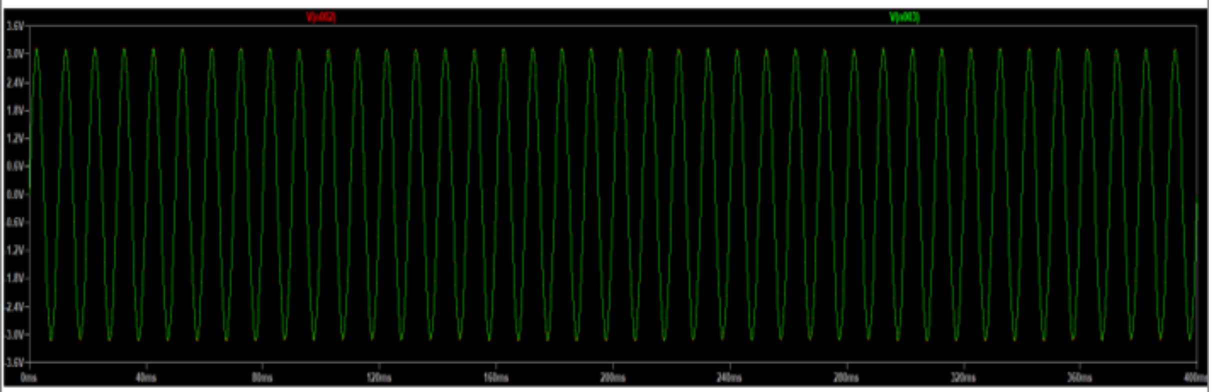

Figure 3.2.4 Voltages Va(red) and Vb (green) after simulation on the balanced circuit.

Voltage	Before balancing (R3 = 1kΩ)	After balancing (R3 = 4kΩ)
Va	$\frac{Vs}{R1+R3}R3 = 4V$	$\frac{Vs}{R1+R3}R3 = 3.1V$
Vb	$\frac{Vs}{Z2+Zx}Zx = 3.12V$	$\frac{Vs}{Z2+Zx}Zx = 3V$
Vab	$\frac{Vs}{R1+R3}R3 - \frac{Vs}{Z2+Zx}Zx = 0.88V$	$\frac{Vs}{R1+R3}R3 - \frac{Vs}{Z2+Zx}Zx = 0.1V$

Figure 3.3.1 Theoretical values for the first circuit

Voltage	Formula and Values
Va	$\frac{Vs}{R1+Z3}Z3 = 2.9V$
Vb	$\frac{Vs}{R2+Zx}Zx = 2.1V$
Vab	$\frac{Vs}{R1+Z3}Z3 - \frac{Vs}{R2+Zx}Zx = 0.8V$

Figure 3.3.2 Theoretical values for the second circuit

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