SW Implementation

Introduction

The goal of this lab is to create and implement two kinds of passive linear circuits in order to obtain maximum power transfer on a circuit that involves a 180 Ω load with a voltage source that has a 50 Ω input resistance. The desired frequency is between 5 and 10 MHz, and the schematic of the desired final circuit is as in Figure 1.

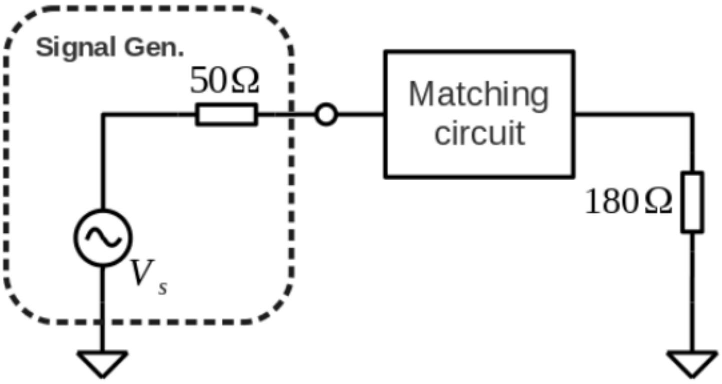

Figure 1: Desired Circuit Design

In this lab session the chosen frequency was 5 MHz and the two solutions were T and L section circuits. These solutions were useful in the sense that they match the resistance of the input, and their reactance do cancel one another, as these conditions have to be satisfied in order to obtain maximum power transfer.

Analysis

In order to obtain power transfer in the maximum amount as desired, the resistance of the load should be equal to the one of the voltage source and the reactance of the two should be eliminating each other. This simply means that the impedances of the two should be complex conjugates. To start with, the average power on the load can be expressed as:

$$P_{ave} = |I|^2 * \frac{R_L}{2}$$

$$|I| = \frac{|V|}{(R_L + R_s)}$$

These two lead to:

$$P_{ave} = \frac{|I|^2}{2(R_L + R_s)} * R_L \tag{1}$$

Since the impedances should be complex conjugates, their resistive parts, as these make up the real parts of the complex values, should be the same. Taking the load and input resistances as R, (1) turns out to:

$$P_{ave} = \frac{|V|^2}{8R} \tag{2}$$

Similarly, the maximum power should be two times the average, giving the following:

$$P_{max} = \frac{|V|^2}{4R} \tag{3}$$

In the chosen case where the voltage source has 10 Volts amplitude and 8 MHz frequency, and the load has a 180 Ω resistance against the load's internal 50 Ω, the maximum average power should be:

$$P_{maxave} = \frac{|10|^2}{8 * 50} = 250\ mW$$

Similarly, the maximum power should be:

$$P_{max} = \frac{|10|^2}{4 * 50} = 500\ mW$$

As the first solution, a T Section circuit is implemented. The chosen frequency is 8 MHz, and the peak voltage of the source is 10 Volts. The design of a T Section is as follows:

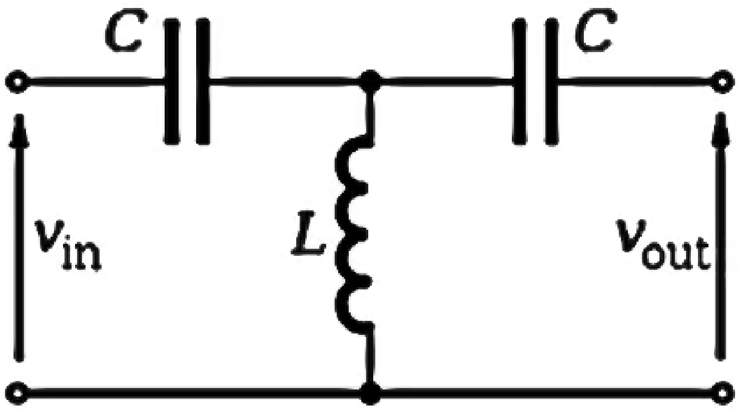

Figure 2: T Section Components

In order to find the capacitance and inductance values that make up the circuit:

$$Z_s * Z_L = X^2$$

$$X^2 = R_s * R_L \,, \;\; X^2 = 50 * 180$$

So, X is equal to:

$$X = \pm 94.87$$

$$-jX = \frac{1}{j\omega C}\,, \qquad jX = j\omega L \tag{4}$$

Making use of the positive 94.87 for X, the capacitance and inductance can be found as:

$$C = \frac{1}{2\pi f X} = \frac{1}{2 * \pi * 8 * 94.87 * 10^6}$$

$$L = \frac{X}{2\pi f} = \frac{94.87}{2 * \pi * 8 * 10^6}$$

These reveal the L and C values for the T Section as:

$$C \cong 1.89\ \mu H\,, \qquad L \cong 210\ pF \tag{5}$$

The second solution for the desired output is an L Section circuit. Similarly, the voltage source has a 10 Volts peak value and has an 8 MHz frequency. The structure of an L Section circuit is as in Figure 3.

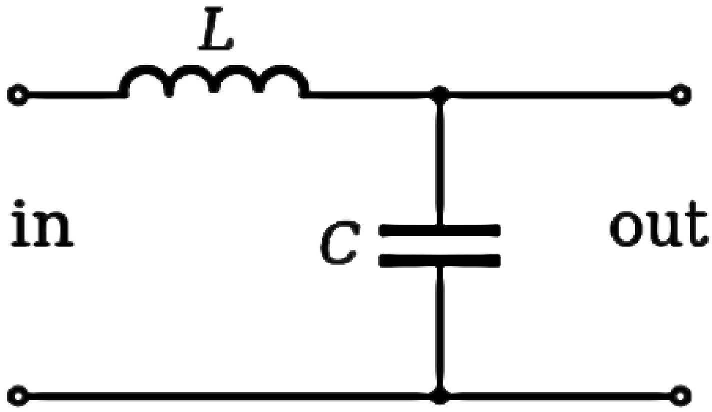

Figure 3: L Section Components

The quality factor of the circuit can be used for finding the capacitance and inductance values for the L Section.

$$R_L = (Q^2 + 1) * R_s$$

$$Q = \sqrt{\frac{R_L}{R_s} - 1} = \sqrt{\frac{180}{50} - 1} = 1.612 \tag{6}$$

The value of Q helps us find the inductance as:

$$Q = \frac{2 * \pi * f * L}{R_s}, \qquad L = \frac{50 * 1.612}{2 * \pi * 8 * 10^6} \cong 1.6\ \mu H \tag{7}$$

In similar fashion, we can find the capacitance as:

$$\omega = 2 * \pi * f = \sqrt{\frac{1}{L * C * (1 + \frac{1}{Q^2})}}$$

$$C = \frac{1}{4 * \pi^2 * f^2 * L * (1 + \frac{1}{Q^2})} \cong 179\ pF$$

These found values are used for the implementations of T and L Section circuits.

Simulations

An initial circuit that involves only the 180 Ω load is implemented in order to find out the power that the load resistor goes through when there is no additional circuitry. The input has the chosen 10 V amplitude and 8 MHz frequency that will stay constant for all the solutions.

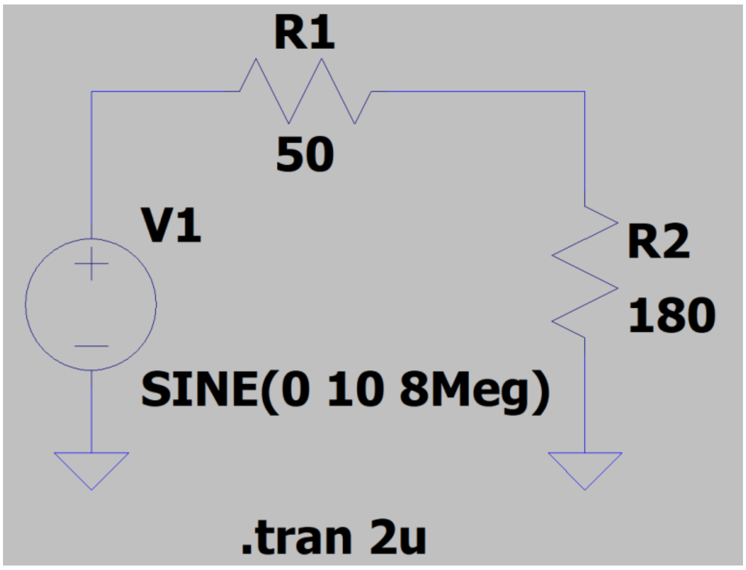

Figure 4: Initial Circuit

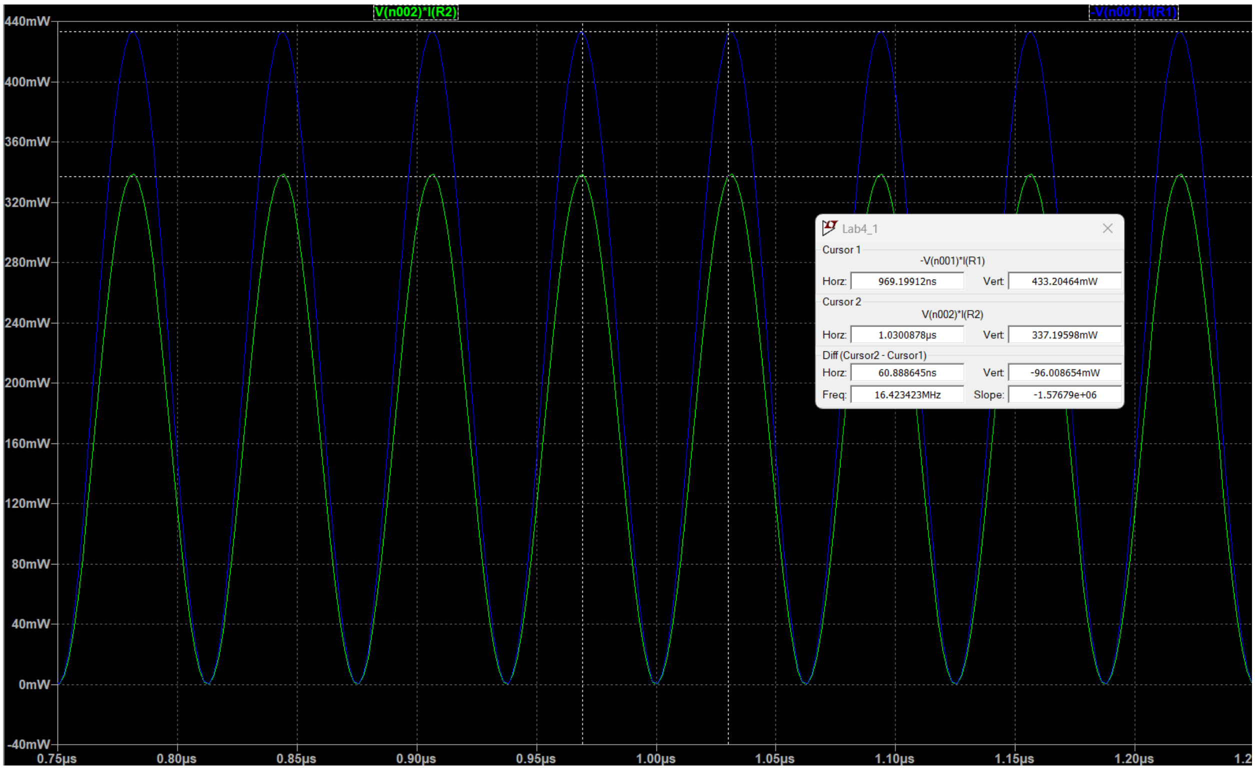

Figure 5: Power on The Load Without Additional Circuitry

This also implies that the average power in this case is half the found maximum, 168.6 mW.

Later, the L and T Section circuits are implemented as in Figures 6-9.

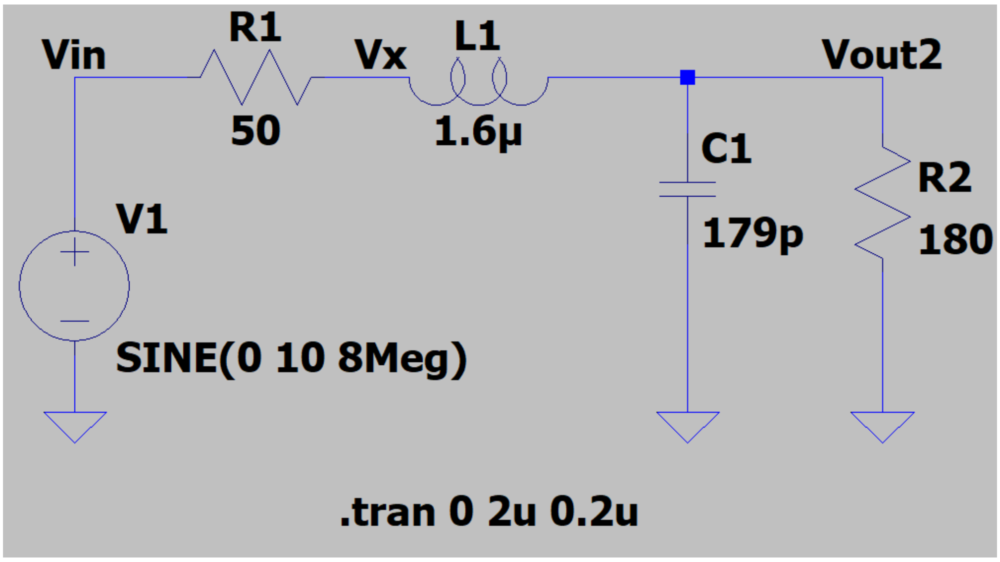

Figure 6: L Section Circuit

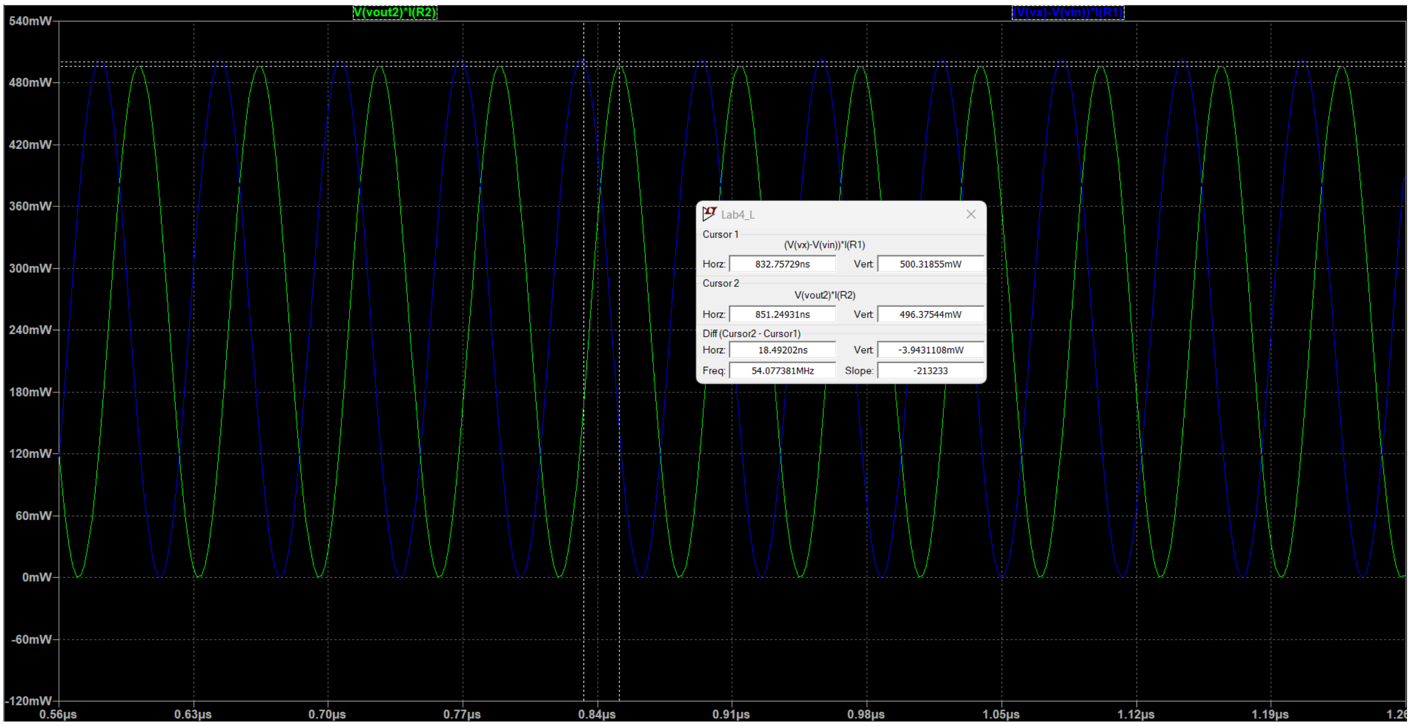

Figure 7: Power Output of L Section Circuit

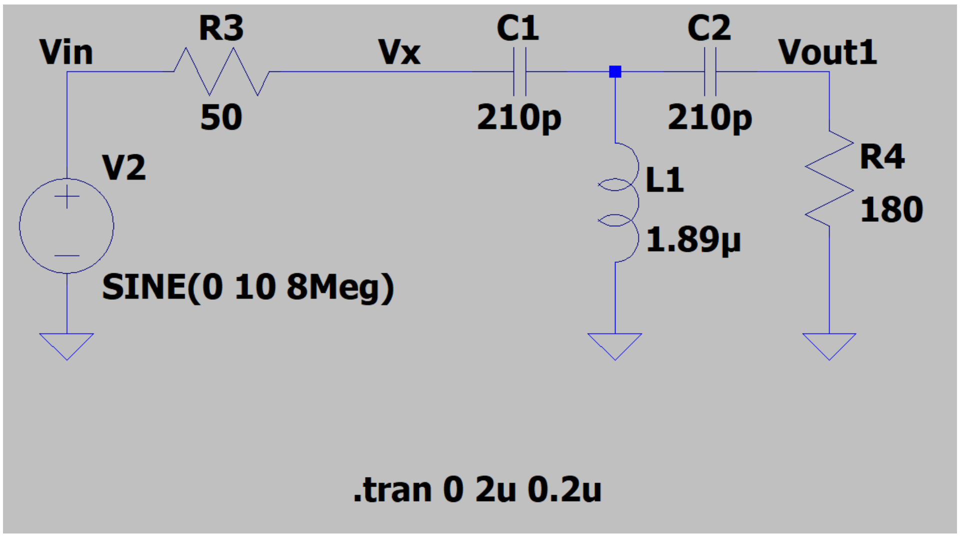

Figure 8: T Section Circuit

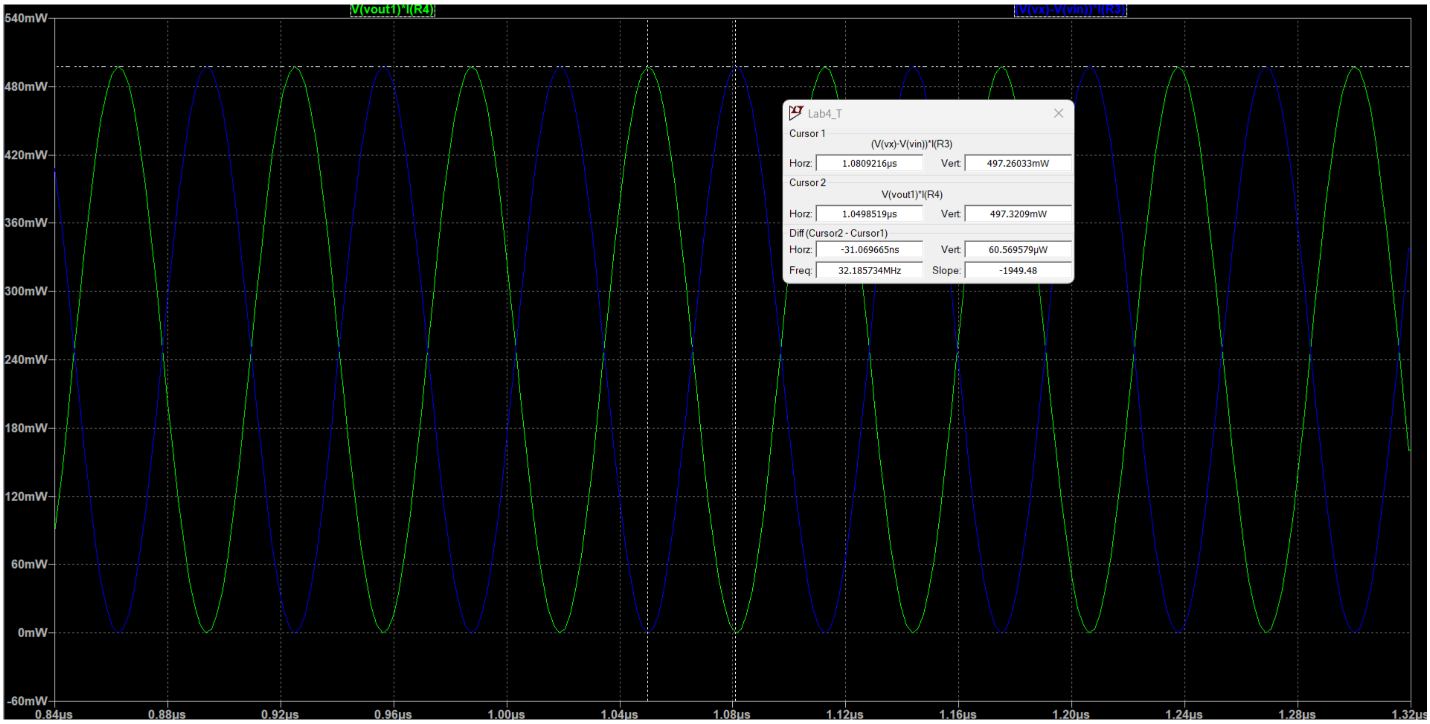

Figure 9: Power Output of T Section Circuit

These results can be portrayed with their error percentages as in Tables 1 and 2.

	Maximum Power (calculated)	Power on the Load	Ratio of the Delivered Power
Initial Circuit	250 mW	168.6 mW	67.44 %

Table 1: Initial Circuit Results

	Maximum Power at The Source	Power on the Load	Ratio of the Delivered Power	Error Percentage
L Section	249.66 mW	248.19 mW	99.41%	0.59%
T Section	248.66 mW	248.63 mW	99.99%	0.01%

Table 2: L and T Section Results

HW Implementation

A circuit for obtaining the value for the maximum power output is firstly connected, later its output peak to peak voltage is compared with the ones of the L and T Section circuits.

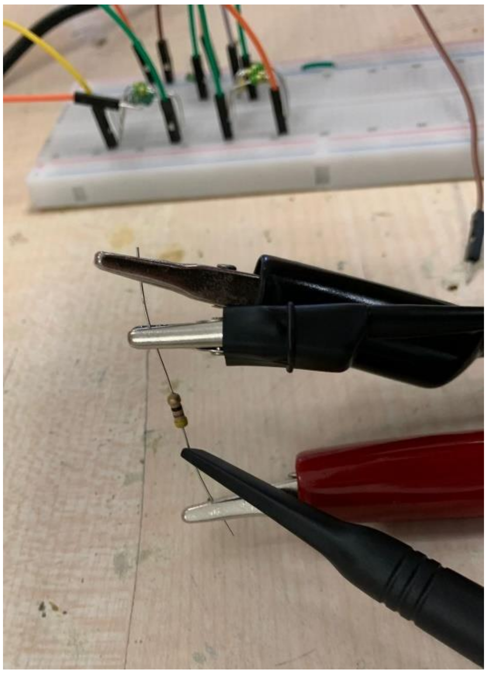

Figure 10: 50 Ω Resistor connected to the ends of the signal generator

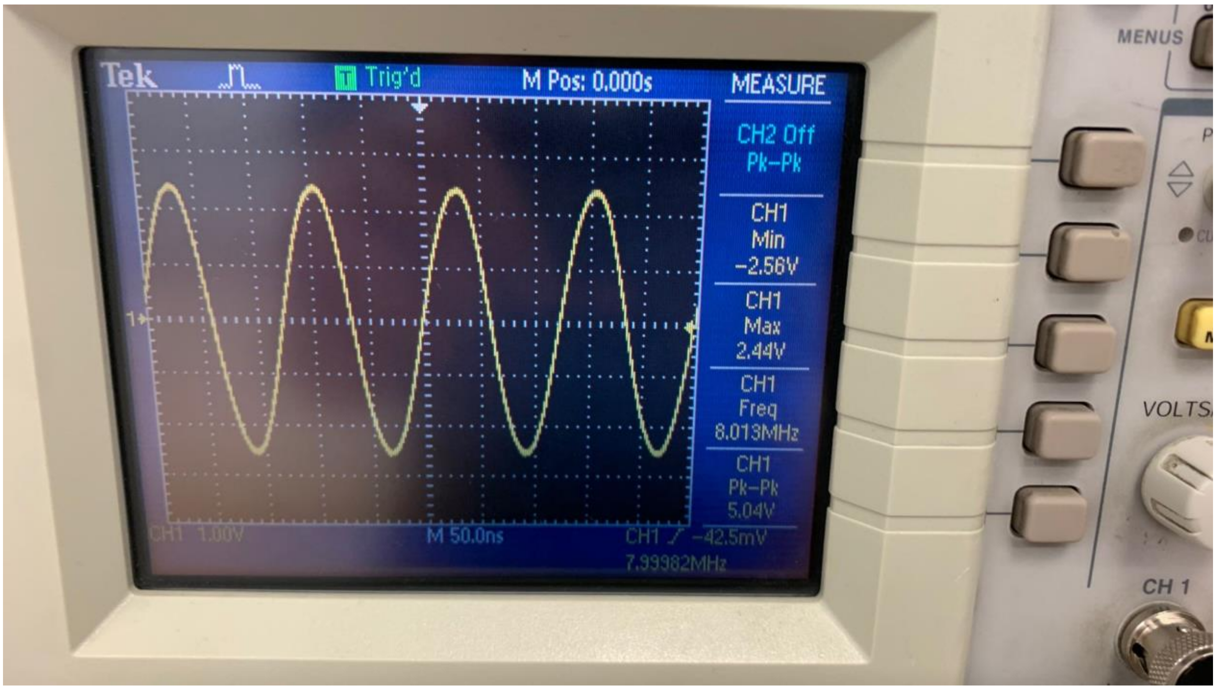

Figure 11: Voltage on the Resistor Circuit

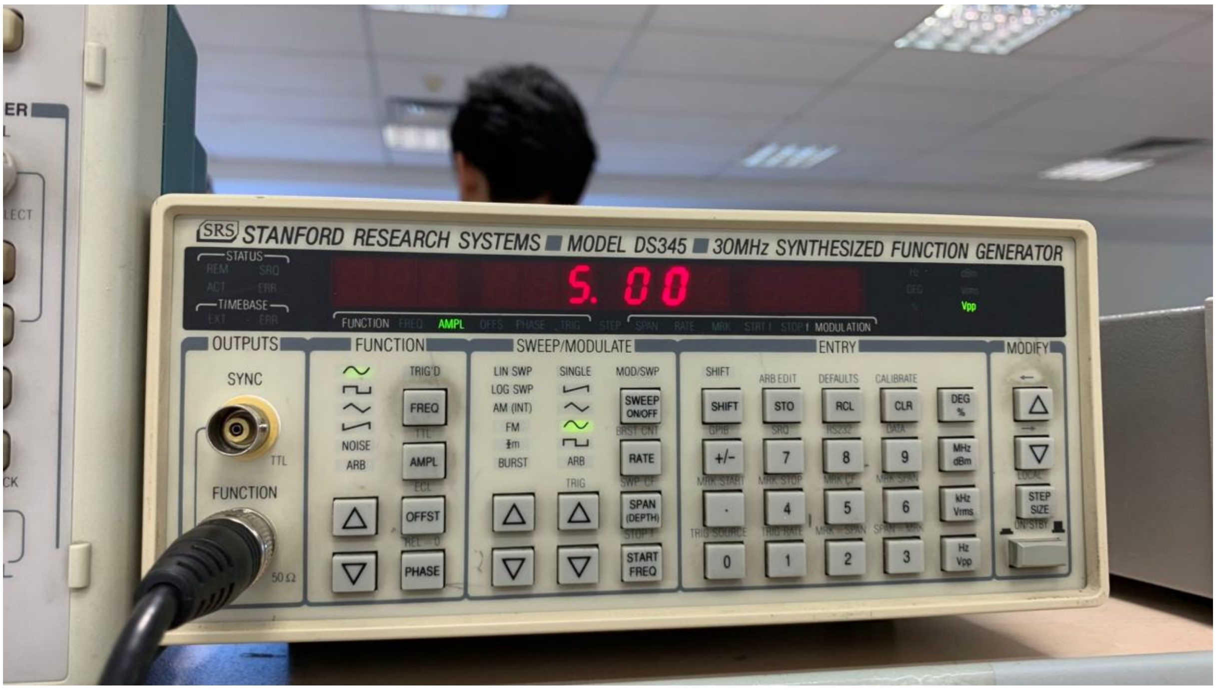

Figure 12: Peak to peak voltage setting

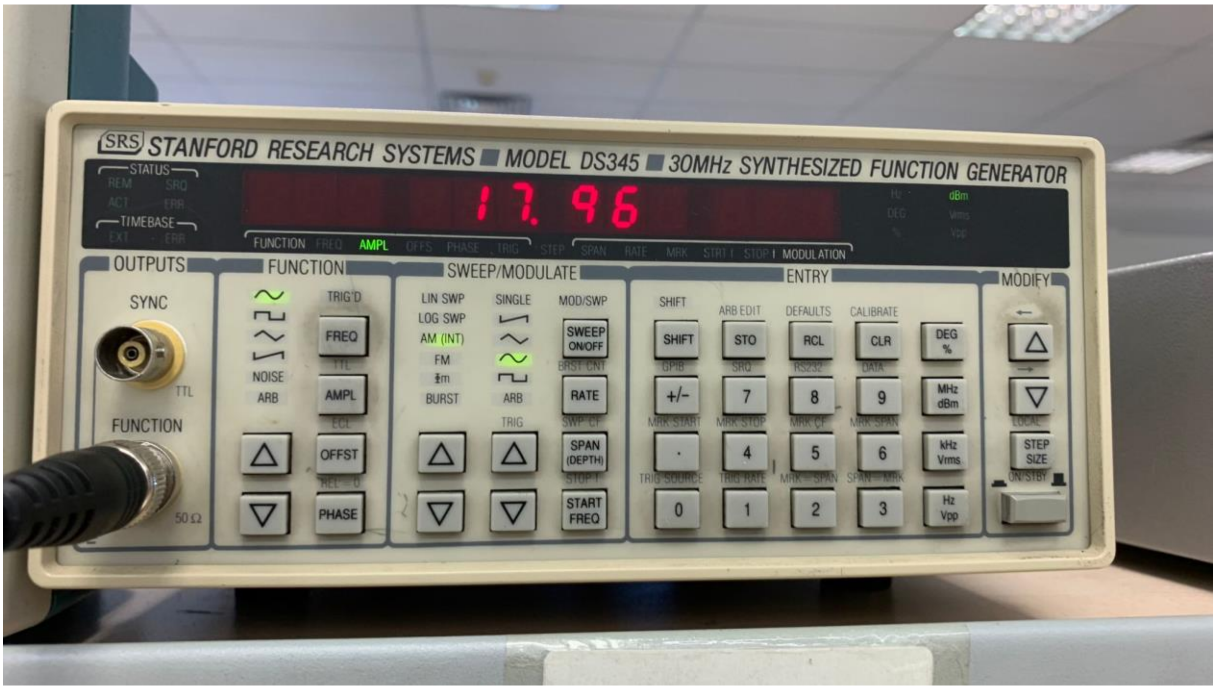

Figure 13: Vpp in dBm

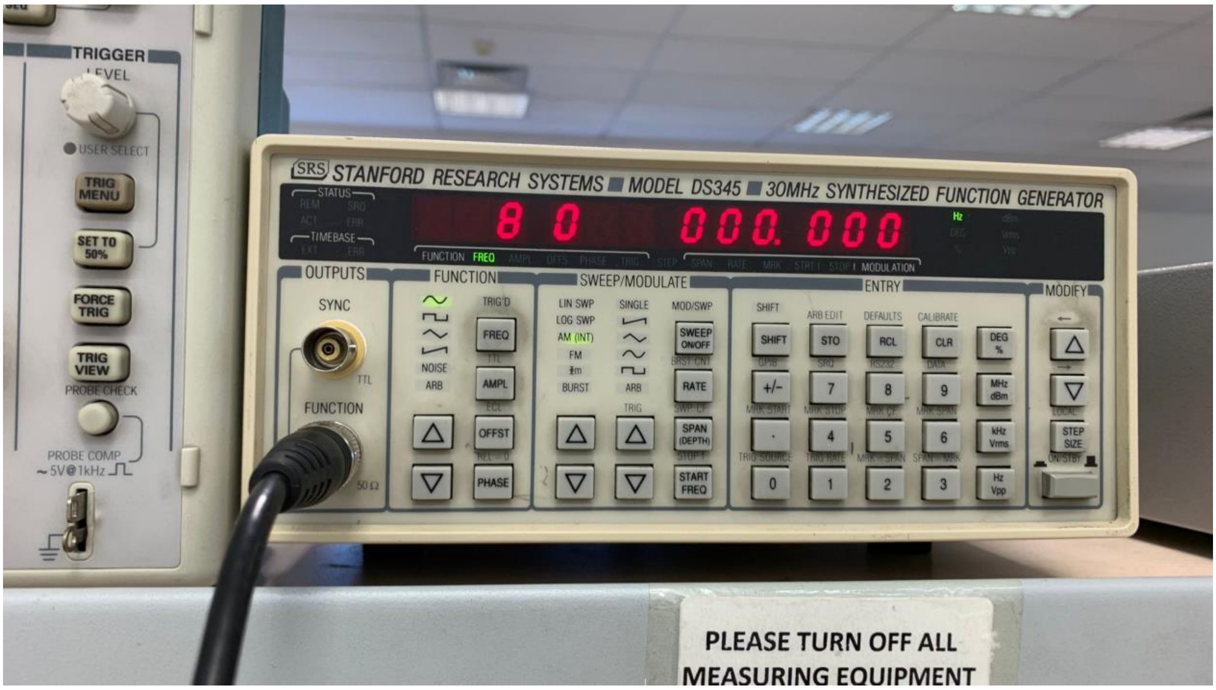

Figure 14: Input Frequency of 8 MHz

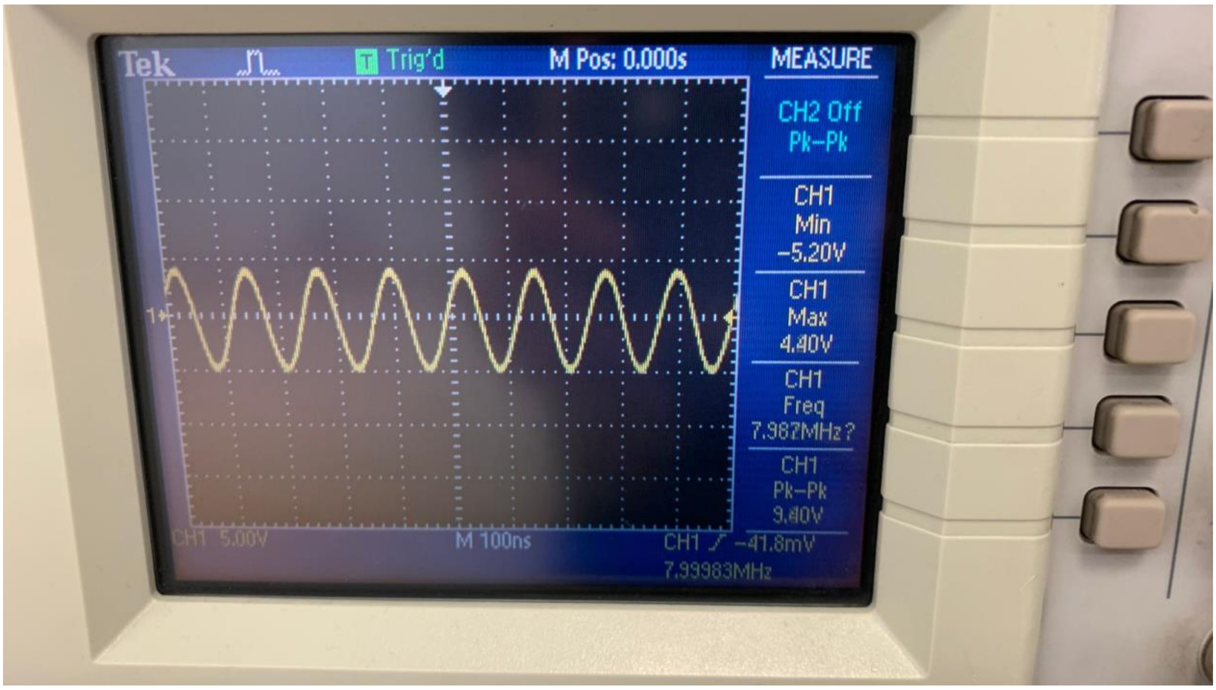

Figure 15: Output of the T Section

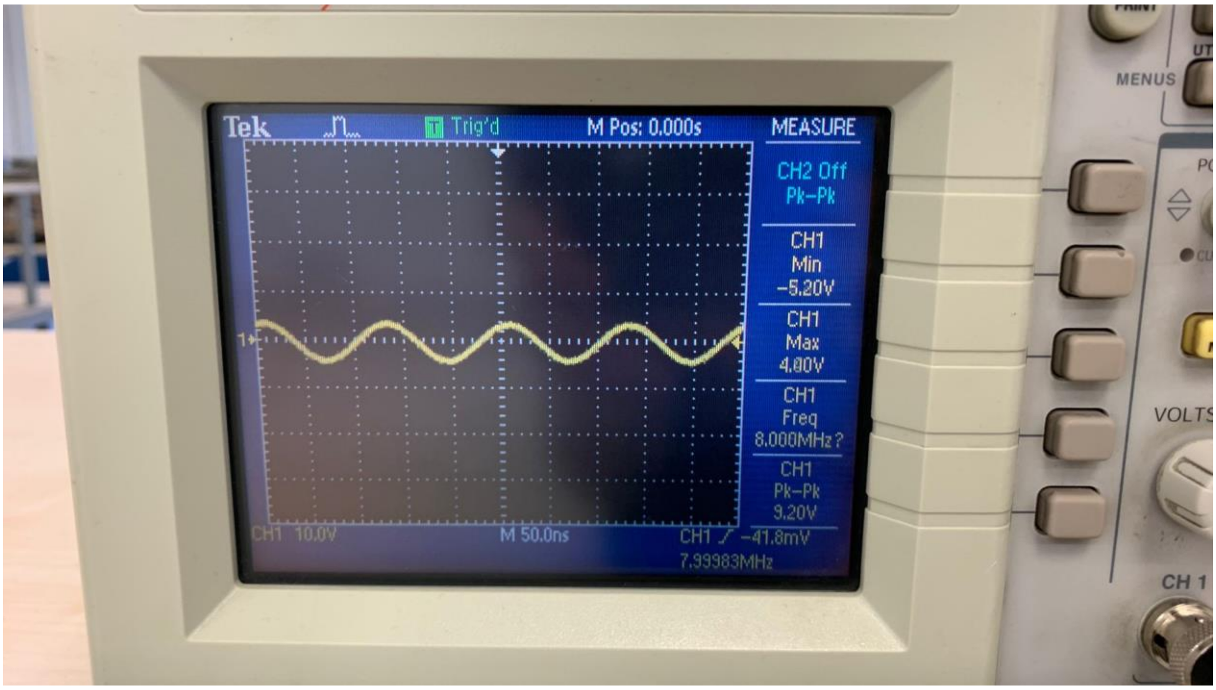

Figure 16: Output of the L Section

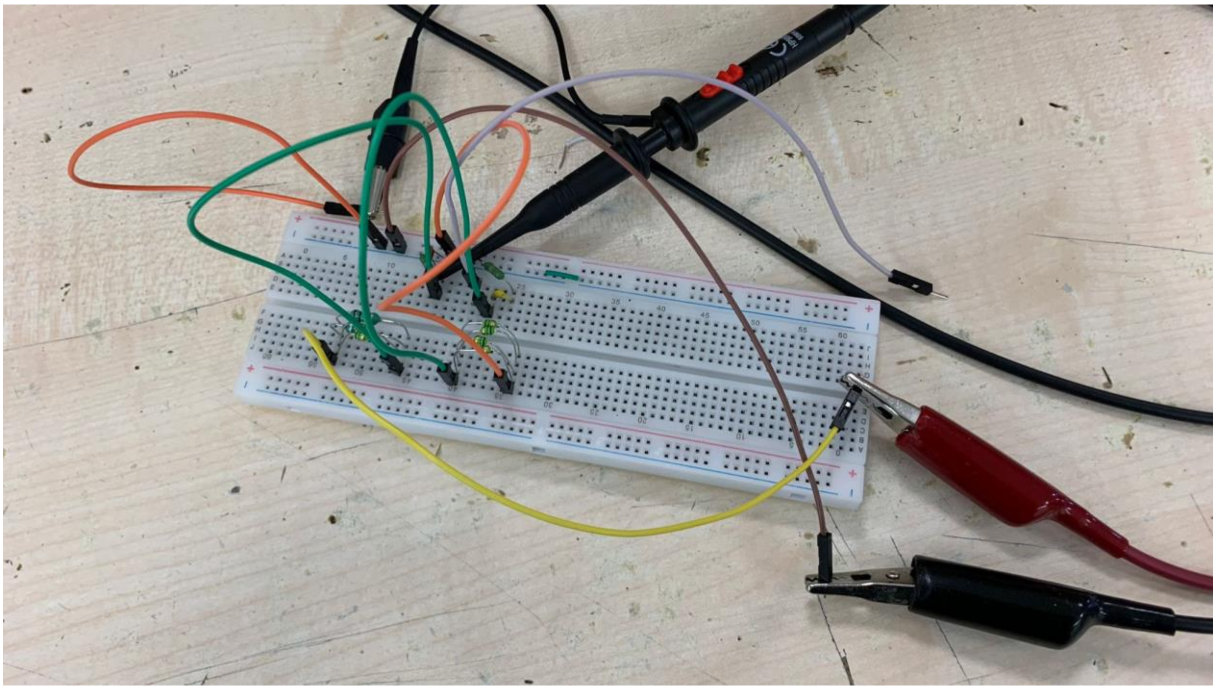

Figure 17: Implementation on the Breadboard (T Section on the Left, L on the Right)

	Maximum Power (calculated)	Power on the Load	Ratio of the Delivered Power
Initial Circuit	250 mW	254.02 mW	0.016 %

Table 4: Results for the Circuit for the Finding Maximum Power

	Maximum Power	Peak to Peak Voltage of the Load	Power on the Load	Ratio of the Delivered Power	Error Percentage
L Section	254.02 mW	9.2 V	235.11 mW	94.04%	5.96%
T Section	254.02 mW	9.4 V	245.44 mW	96.62%	3.38%

Table 5: Table 4: HW Implementation Results of the L and T Section Circuits

Conclusion

The design of L and T Sections provide 0.59% and 0.01% error percentages for the software implementation against 5.96% and 3.38% error percentages in the hardware implementation. The ideal condition of the circuit components in LTSpice cause the percentages to be lower in comparison, but still some error exists. This may be due to the fact that the values for the capacitance and inductance in the implementations were rounded and not exactly the same as the results to the calculations in the analysis section. In this part the T Section had a minorly less error, as the T Section delivered the 99.99% of the possible maximum power against 99.41%.

On the other hand, the hardware implementation caused more errors and this may be reasoning from the fact that the components were not ideal, the wires, capacitors and inductors had inner resistances and the values for the components were not exactly correctly calculated due to the tolerances of the lab equipment. Additionally, the desired values for inductance in the simulations could not be satisfied by using single inductors that can be found in the lab, and several ones had to be parallelly connected, causing more space for nonideal situations to come and more error to occur. Extra problems with breadboards and observing equipment such as the oscilloscope, probe or the signal generator could cause problems. In this implementation, the T Section was again more ideal, as it had 96.62% of the possible power delivered against 94.04% of the L Section. The difference of the designs, and the remaining nonideality could be eliminated by adjusting the inputted values for the voltage supply or by making further experimentation to come closer to the desired values of the circuit components.

All in all, this lab was useful in the sense that students had the opportunity to create maximum power transferring circuits on both software and hardware applications. The opportunity to create impedance matching circuits and designing linear passive circuits was beneficial. This experiment revealed the structure and function of L and T Section circuits and provided possible designs for students to use in the future for implementing circuits that require maximum power transfer among components.

References

[1] "What is T Section," engineeringslab.com, Aug. 12, 2019. [Online]. Available: https://engineeringslab.com/tutorial_electrical/t-section-1851.htm. [Accessed: Apr. 03, 2024].

[2] "What is L Section," engineeringslab.com, Aug. 12, 2019. [Online]. Available: https://engineeringslab.com/tutorial_electrical/l-section-1853.htm. [Accessed: Apr. 03, 2024].