Lab 4

Date: 13.04.2022

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Section: 2

Purpose:

The purpose of this lab is to design at least two passive linear circuits that transfer maximum power to 220 Ω load from a voltage source with output impedance 50 Ω at a frequency between 10 and 15Mhz.

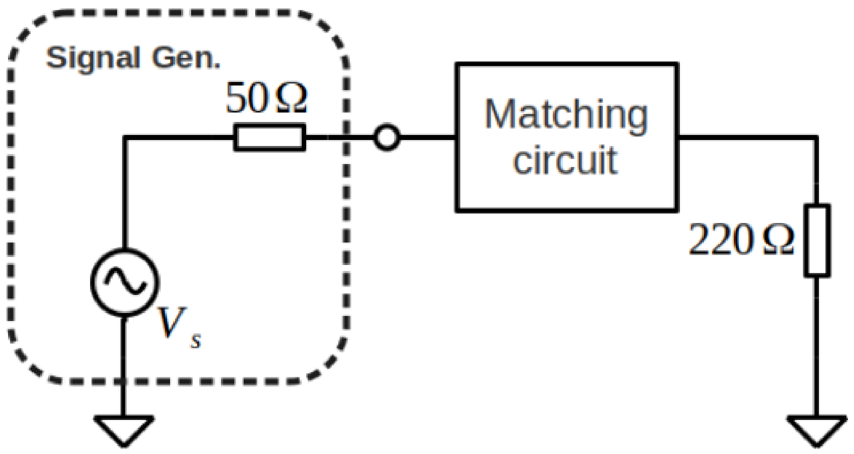

Figure 1 - The Task Design

Methodology:

In the schematic part, as it can be seen on the Figure 1 below there will be matching circuit. The goal of the matching circuit is to match the impedances of the source and the load in order to obtain maximum power transfer. As mathematically, it can be expressed as $Z_s = Z_L^*$

formula. Before we choose our methods, first it should be explained how to maximize power transfer. The formulas down below can be used to compute the transmitted power in a circuit with only a real voltage source and a load resistor.

$$I_L = \frac{V}{R_S + R_L}$$

$$P_{ave} = \frac{|I_L|^2 * R_L}{2} = \frac{|V|^2 * R_L}{2(R_S + R_L)^2}$$

In order to achieve maximum power transfer, load and source impedances must be equal. Then the equation turns into below;

$$P_A = P_L = \frac{|V_S|^2}{8R_S}$$

In this lab, it will be used L-Section and T-Section as a 2 method to achieve impedance matching and maximum power transfer.

Simulation Part:

<u>Method 1: L-Section</u>

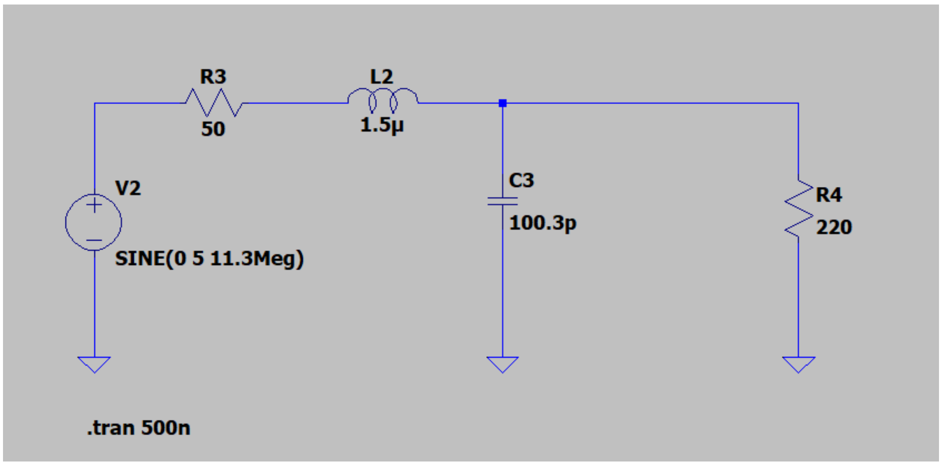

Figure 2 - L-Section Configuration

To find inductor and capacitor values, the following steps should be done in order:

$$220 = (Q^2 + 1) * 50$$

$$Q \cong 1.8439$$

$$Q = \frac{w_0 * L_S}{R_S} \cong 1.8439$$

$$Q = \frac{2\pi * f * L_S}{R_S} \cong 1.8439$$

We give the frequency values in order to find near values of capacitor and inductor that available on the lab.

$$L_S \cong 1.5\ \mu H \qquad\qquad f = 11.3\ MHz$$

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

$$C \cong 100.3\ pF$$

Method 1: T-Section

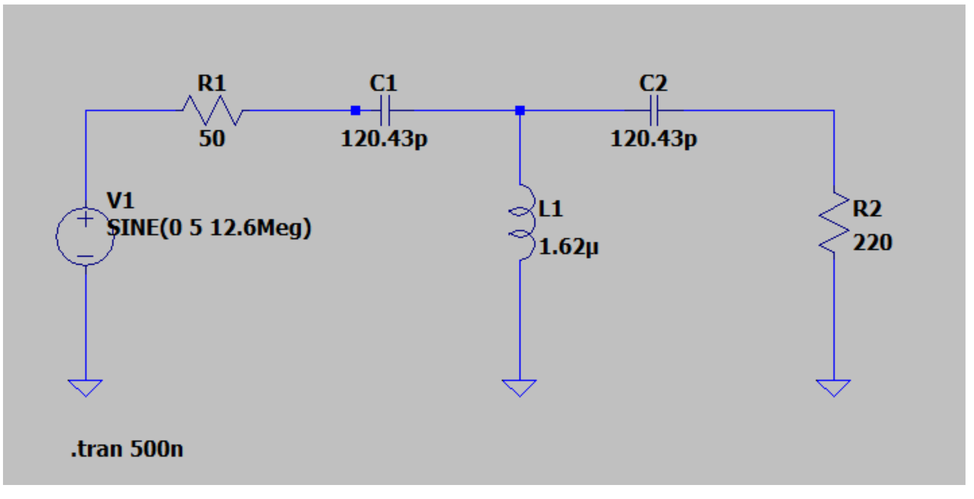

Figure 3 - T-Section Configuration

To find inductor and capacitor values, the following steps should be done in order:

$$Z_{in} = \frac{X^2}{Z_L}$$

$$X^2 = Z_{in} * Z_L$$

$$X \cong 104.88\ \Omega$$

For jX element, use an inductor:

$$jX = jwL$$

$$L = \frac{X}{w} = \frac{X}{2\pi * f}$$

$$L_S \cong 1.62\ \mu H \qquad f = 12.6\ MHz$$

For -jX element, use a capacitor:

$$-jX = \frac{1}{jwC}$$

$$C = \frac{1}{X * w} = \frac{1}{2\pi * f * X}$$

$$C = 120.43\ pF$$

Hardware Part:

In the hardware part, the simulation design is implemented on a small PCB as can be seen on *Figure 4*. A signal generator generates the sine wave with 12.6 MHz and 11.3 MHz frequencies for each section, 5 Vpp. For resistance the 50 Ω is changed with 47 Ω. For L-Section, 100.3 pF capacitor changed with 100 pF and T-50 toroid winded 16 times in order to get 1.5 μH. For

T-Section, 120.43 pF capacitor changed with 120 pF and T-50 toroid winded 19 times in order to get 1.62 μH. After that, since we cannot measure power on an oscilloscope, we first measured the voltage difference of the source resistor and then measured the voltage difference of the part between the voltage and the load resistor, so we calculated the voltages of the two parts and found their respective power. We applied this in both methods.

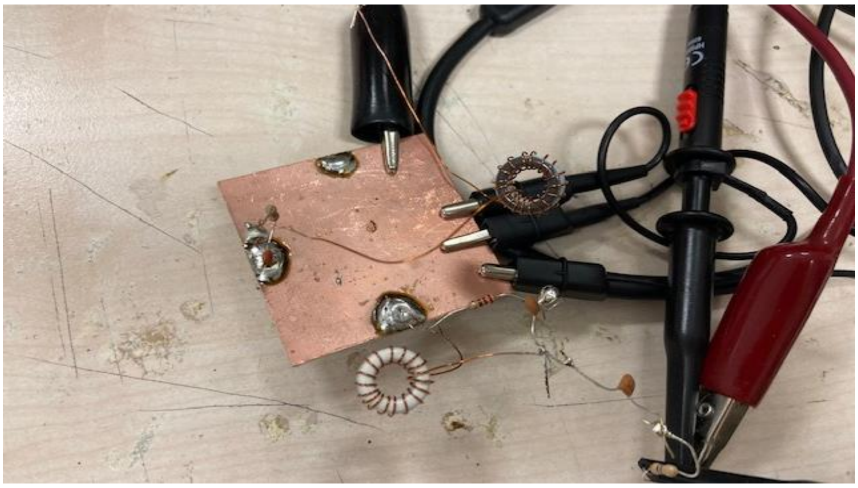

Figure 4- Hardware Implementation

Results:

Simulation Results:

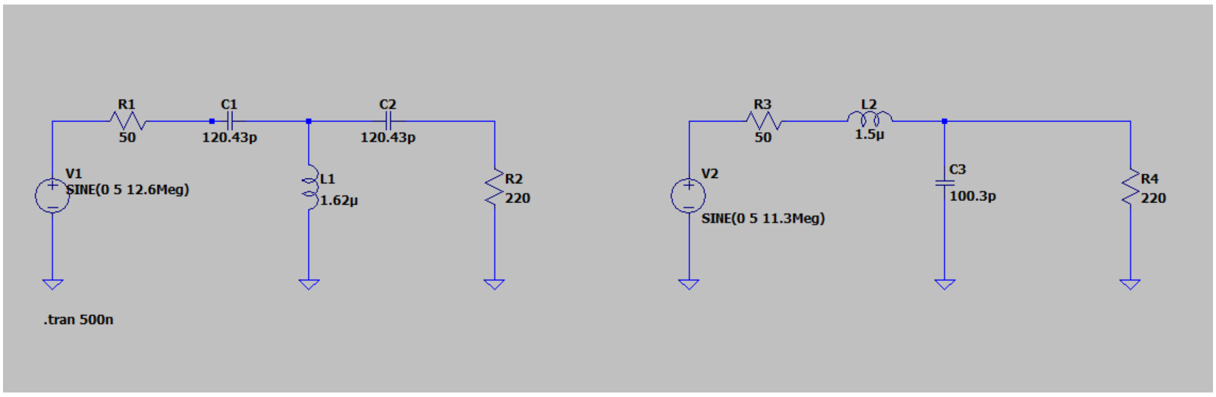

Figure 5- Simulation Design

For T-Section

The simulation graph can be seen on *Figure 6*. The power available at source is 59.093 mW and power available at load is 58.395mW. Hence, the power delivers ratio is % 98.936008.

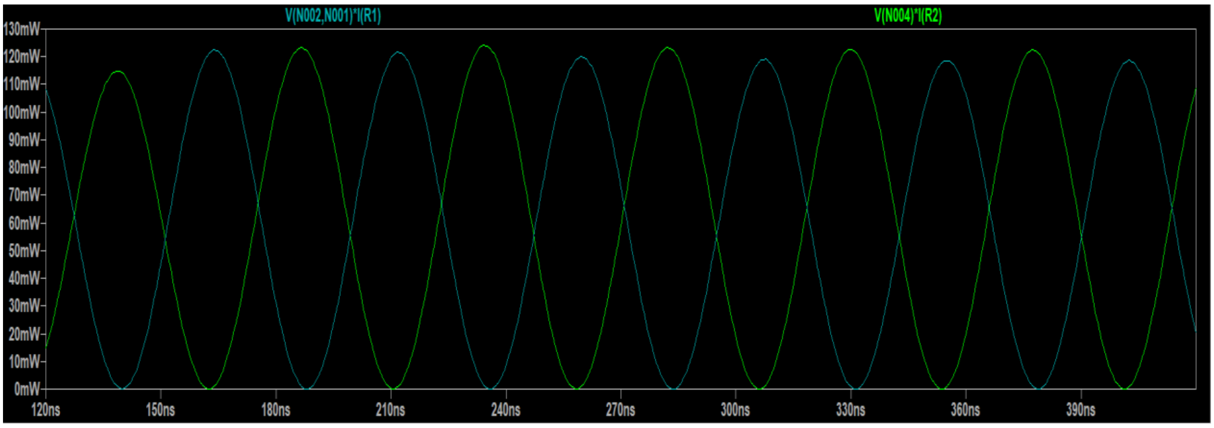

Figure 6 - T-section Power Graph

The power available at source:

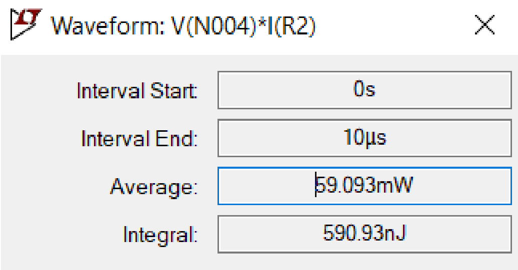

Figure 7- Power at Source

The power available at load:

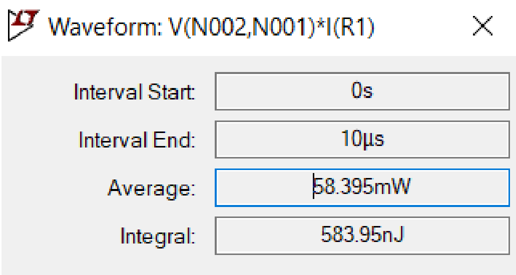

Figure 8- Power at Load

For L-Section

The simulation graph can be seen on *Figure 9*. The power available at source is 55.051 mW and power available at load is 54.381 mW. Hence, the power delivers ratio is % 98.78294672.

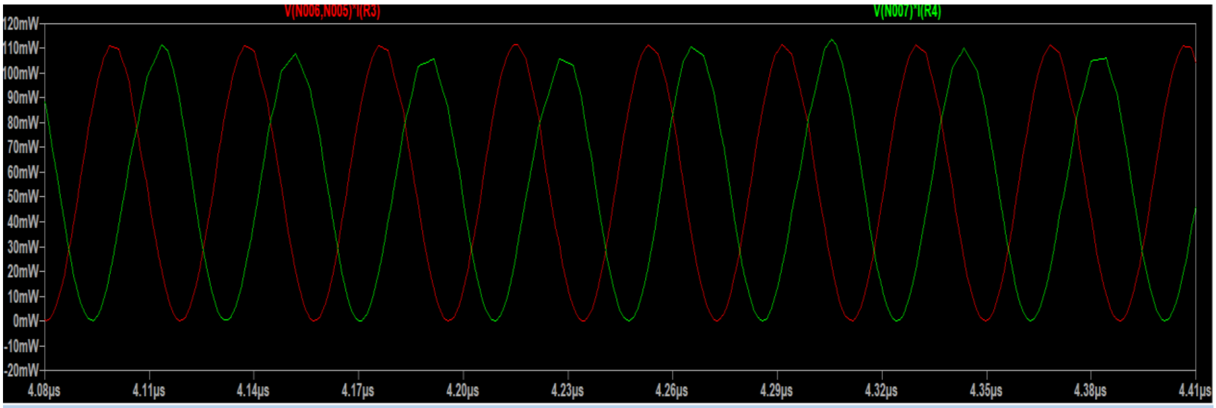

Figure 9 - L-section Power Graph

The power available at source:

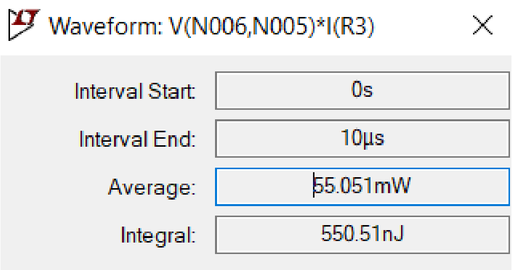

Figure 10 - Power at Source

The Power available at load:

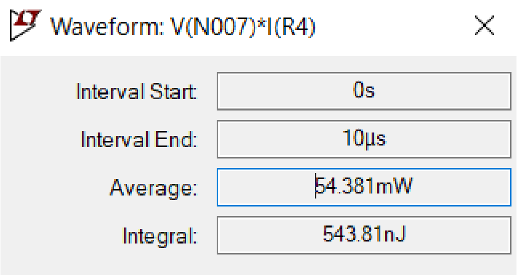

Figure 11 - Power at Load

Table 1 – Power Table for Both Method

	Power Available	Power Transferred	Power Ratio
T-Section	59.093 mW	55.051 mW	% 98.936008
L-Section	58.395 mW	54.381 mW	% 98.78294672

Hardware Results:

For T-Section

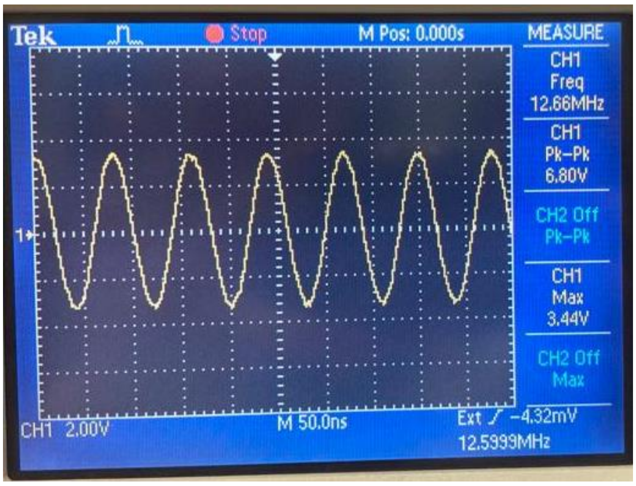

Figure 12 - Voltage Difference of Source Resistor

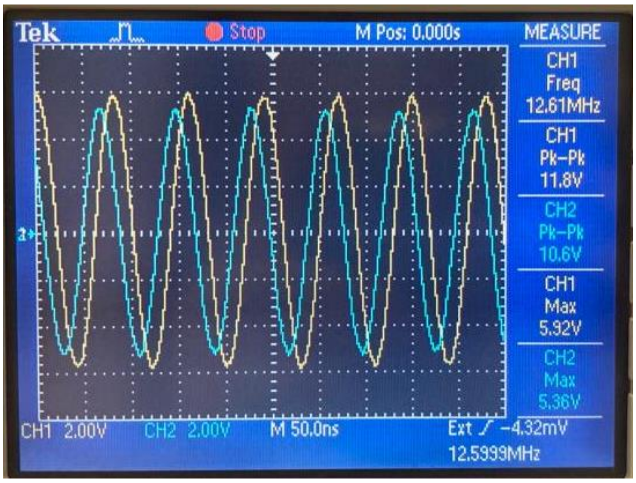

Figure 13 – Voltages of Input and Load Resistor

In order to calculate power on Hardware part, it must be use formula which is;

$$P_A = P_L = \frac{|V|^2}{2R}$$

The voltage difference between source resistor is 3.44 V_{max} , the input voltage is 5.92 V_{max} and the voltage of the load resistor is 5.36 $V_{max.}$ As it can be seen on the Figure 13 the input voltage will be subtracted from the source resistor voltage and calculate the source power.

$$Ps = \frac{(5.92 - 3.44)}{2 * 47} \cong 66.4\, mW$$

$$P_L = \frac{(5.36)^2}{2 * 220} \cong 65.2\, mW$$

Power Transferred Ratio: %98.19277108

<u>For L-Section</u>

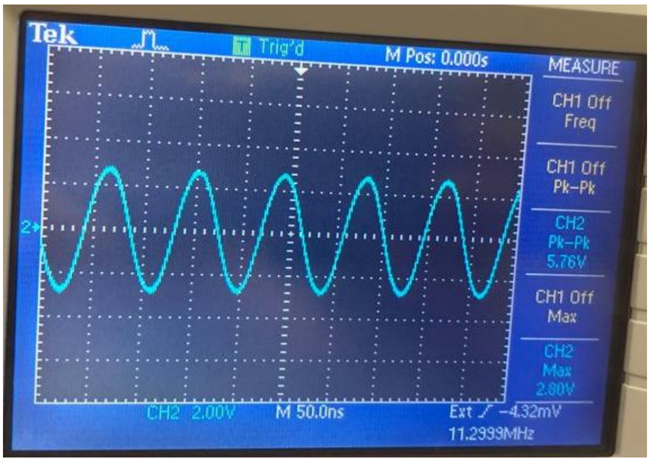

Figure 14 - Voltage Difference of Source Resistor

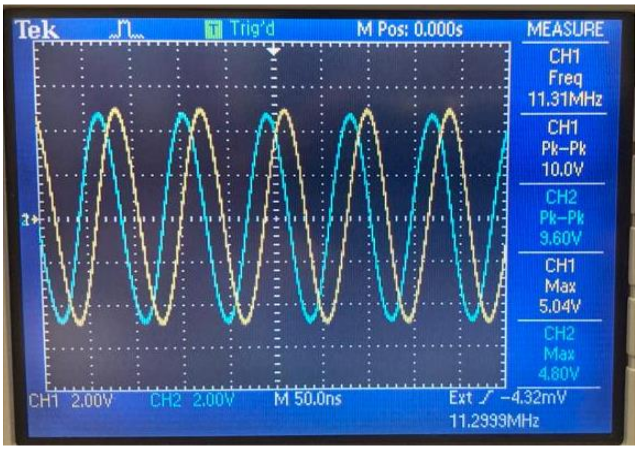

Figure 15 – Voltages of Input and Load Resistor

The voltage difference between source resistor is 2.80 $V_{max,}$ input voltage is 5.04 V_{max} and the voltage of load resistor is 4.80 $V_{max.}$ As it can be seen on the Figure 15 the input voltage will be subtracted from the source resistor voltage and calculate the source power.

$$Ps = \frac{(5.04 - 2.80)}{2 * 47} \cong 54.1\, mW$$

$$P_L = \frac{(4.80)^2}{2 * 220} \cong 52.7\, mW$$

Power Transferred Ratio: % 97.41219963

Table 2 – Power Table for Both Method

	Power Available	Power Transferred	Power Ratio
T-Section	66.4 mW	65.2 mW	%98.19277108
L-Section	51.4 mW	52.7 mW	% 97.41219963

Conclusion:

In this experiment, it is learnt how to match impedance using L-Section and T-Section and calculate maximum power. The goal of this experiment to prove the same power values for load and source resistance. It was used T-Section and L-section methods in order to achieve. We can also choose pi-Section to impedance matching. The simulation and hardware results are both promising. We can notice that there is a slight difference between the power values at the simulation and hardware part. There is an error ratio that varies between 0 to 20 percent. The main reasons for these errors may be that capacitors and inductors are used with their real values in hardware, the inductor is manually wound and there is a large number of fluctuations in its values at the smallest change, and we do not take the skin effect into account when making calculations in the simulation part. On the other hand, it can be observed that the power transferred ratio did not change between simulation and the hardware part, it varies between 97.4 to 98.9 percent. Moreover, when the voltages of load and sources are measured individually, we can see their values are almost the same. This shows that the calculations are made is very promising for impedance matching to obtain maximum power transfer. As a result, we learnt that it is possible to transfer power efficiently and we can achieve this with more than one method.