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Course Code: EEE202

Section: 02

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Lab 3: Maximum Power Transfer

Software Implementation

Introduction:

The purpose of this experiment is designing at least two different passive linear circuits to transfer maximum power to 150Ω load resistor from a voltage source with output impedance 50Ω at a frequency between 10 and 15MHz.

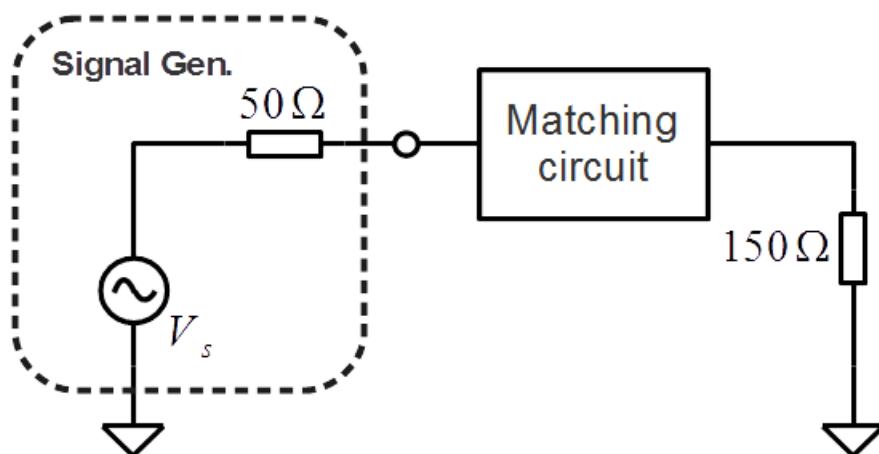


Figure 1: Desired Circuit

The primary purpose of a matching circuit is impedance matching of source and load in order to get maximum power transfer. There are various methods for obtaining maximum power transfer.

In this report, L-section and T-section methods are used in order to get maximum power at 150Ω load resistor.

Analysis:

In order to maximize the power at load resistor following equations can be used which includes a voltage source, source resistor, and load resistor.

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

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

Eqn. 1: Power formula at load resistor

To maximize the power transferred from source to load, the derivative of the power equation must be equal, from there, the value of the load resistance R_L could be find in terms of the source resistance R_S .

After some math, load resistance R_L turned out to be equal to the source resistance R_S .

$$R_L = R_S$$

Eqn. 2: Relation between R_L and R_S

Plugging in (Eqn. 2) to (Eqn. 1), we get,

$$P_L = \frac{|V|^2}{8(R_S)} = \frac{|V|^2}{8(R_L)}$$

Eqn. 3: Maximum power transfer formula

First Method: T-section matching circuit

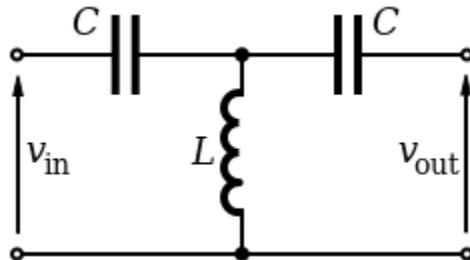


Figure 2: T-section matching circuit scheme

To find the inductor L_1 and capacitors C_1, C_2 , following calculations are made:

$$R_P = 150\Omega, R_S = 50\Omega, f = 10 \text{ Mhz}$$

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

$$X^2 = R_S \times R_L$$

$$X = \pm 86.6\Omega$$

Capacitors are chosen to be $-jX$ and inductor is chosen to be jX . Using this information, capacitor and inductor values are found with following equations.

$$jX = j\omega L, \quad jX = \frac{1}{j\omega C}$$

$$L = \frac{X}{2 \times \pi \times f}, \quad C = \frac{1}{2 \times \pi \times f \times X}$$

$$L = 1.38\mu H, \quad C_1 = C_2 = 184pF$$

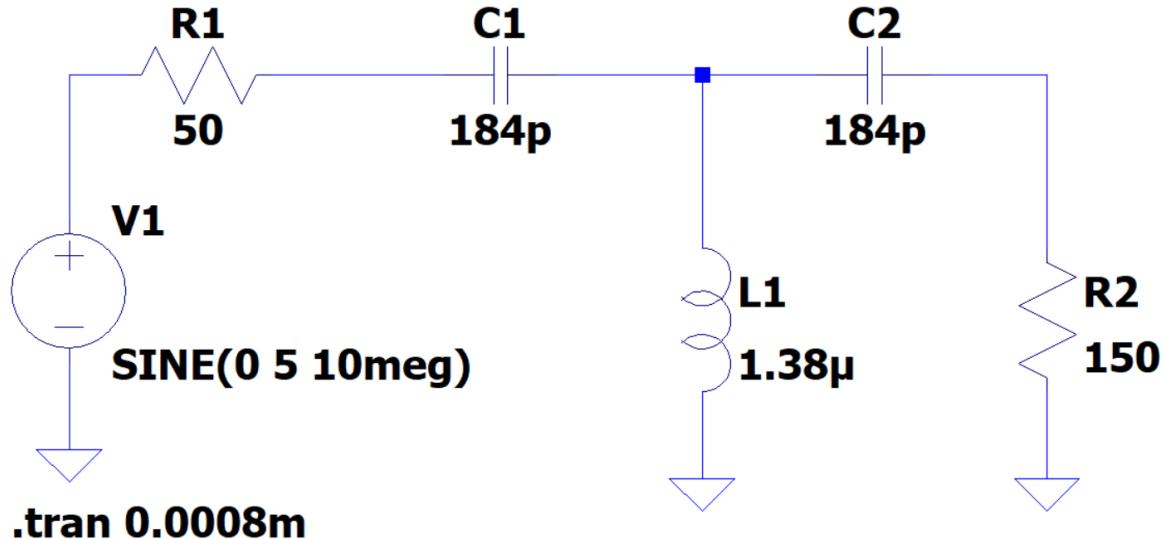


Figure 3: Designed T-section matching circuit

Second Method: L-section:

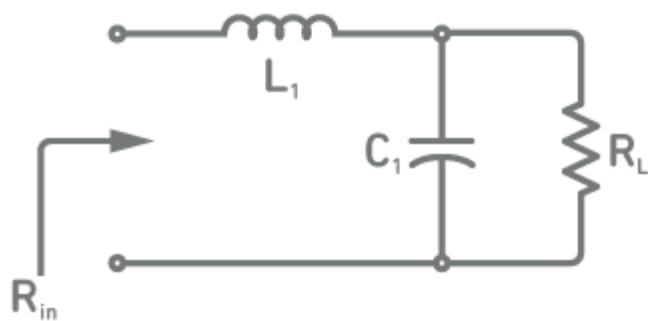


Figure 4: L-section matching circuit scheme

To find the inductor L_s and capacitor C values, following calculations are made.

$$R_P = 150\Omega, R_S = 50\Omega, f = 10 \text{ MHz}$$

$$R_L = (Q^2 + 1) \times R_S$$

$$150 = (Q^2 + 1) \times 50$$

$$Q = 1.41$$

$$Q = \frac{2 \times \pi \times f \times L_S}{R_S}$$

Using the equation for Q (quality factor), L_s can be find as,

$$L_S = 1.12\mu\text{H}$$

$$L_P = \left(1 + \frac{1}{Q^2}\right) L_S = 1.68\mu\text{H}$$

$$\omega = \frac{1}{\sqrt{C \times L_P}}$$

$$C = 150\text{pF}$$

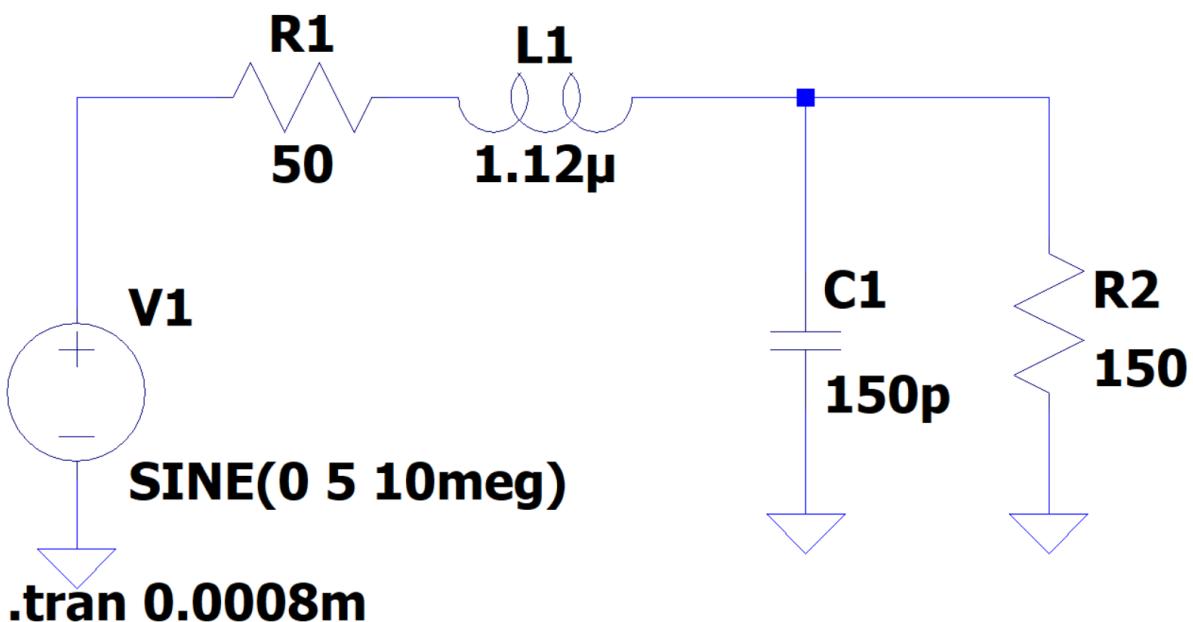


Figure 5: L-section matching circuit

$$P_{average} = \frac{|V|^2}{8(R_S)} = \frac{25}{8 \times 50} = 62.5mW$$

Eqn. 4: Average power formula

Simulation:

Figure below shows the power available at source resistor R_S for T-section method. (Figure 6)

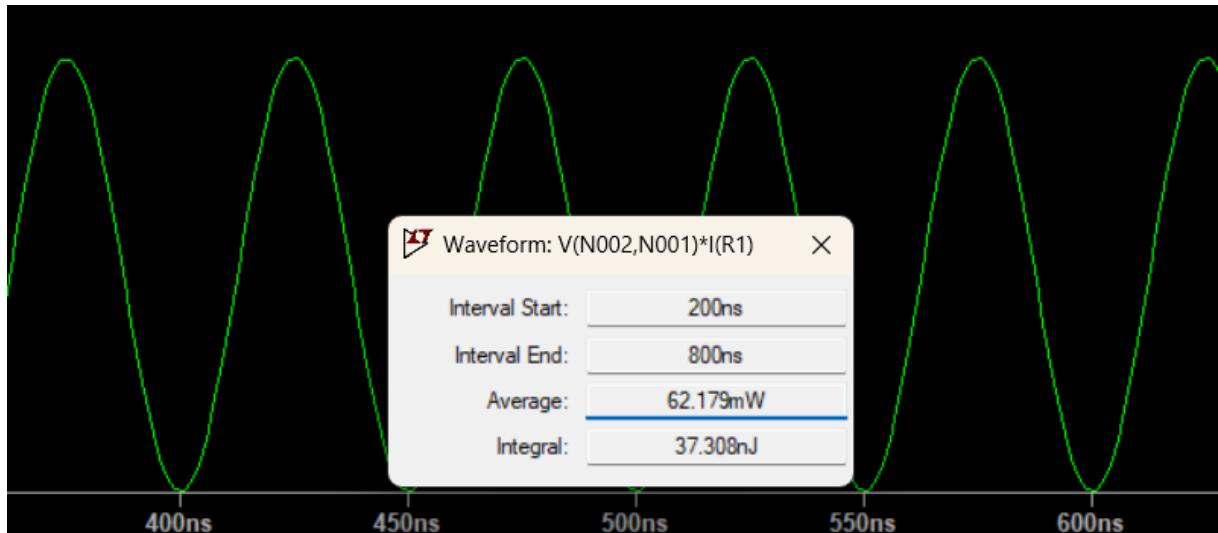


Figure 6: Maximum power available for T-section matching circuit

Power delivered to load resistor R_L is available at figure below. (Figure 7)

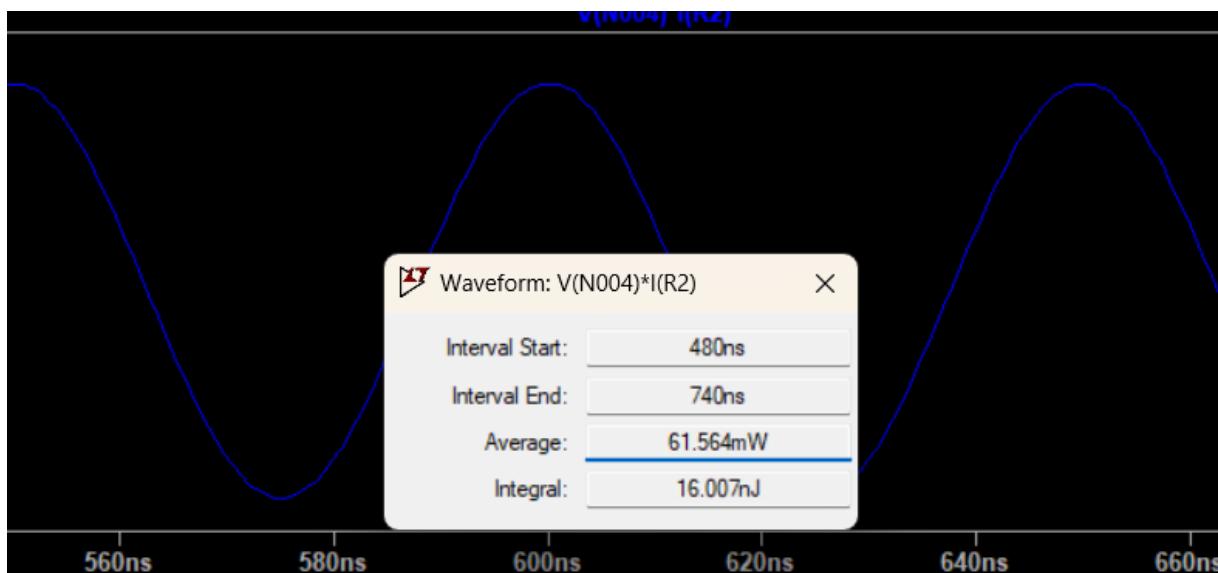


Figure 7: Power delivered to load resistor

From the simulation results, it is seen that power available at source resistance R_S is 62.18mW, power available in load resistor R_L is 61.56mW. The percentage error is 1%. Therefore, the theory of maximum power transfer is achieved in simulation results.

Figure below (Figure 8) shows that the output voltage $V_{R_{pmax}} = 4.31V$.

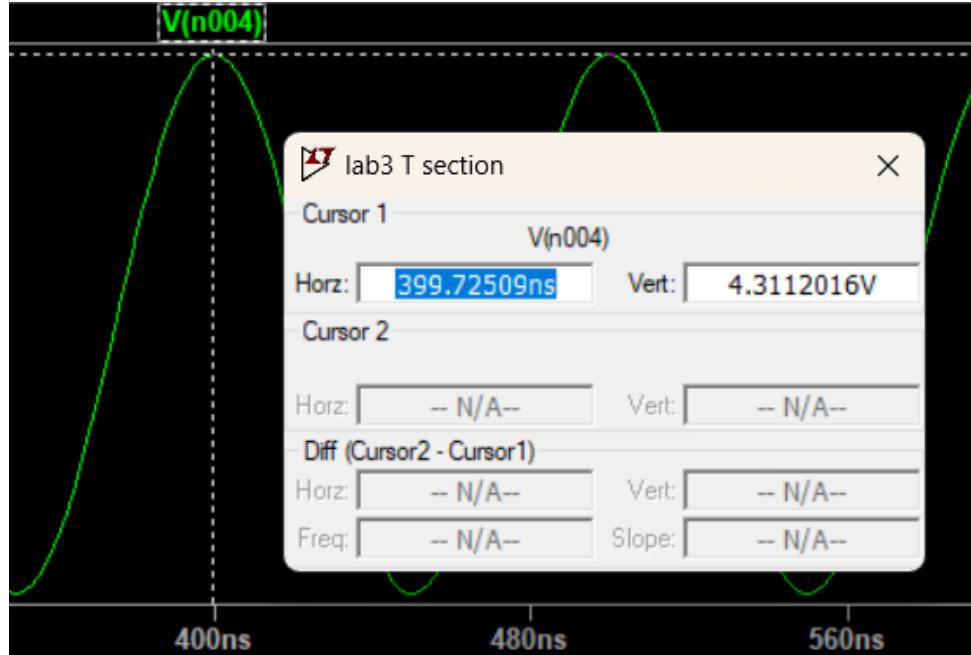


Figure 8: Output voltage of T-section matching circuit

Figure given below shows the maximum power available for L-section matching circuit. (Figure 9)

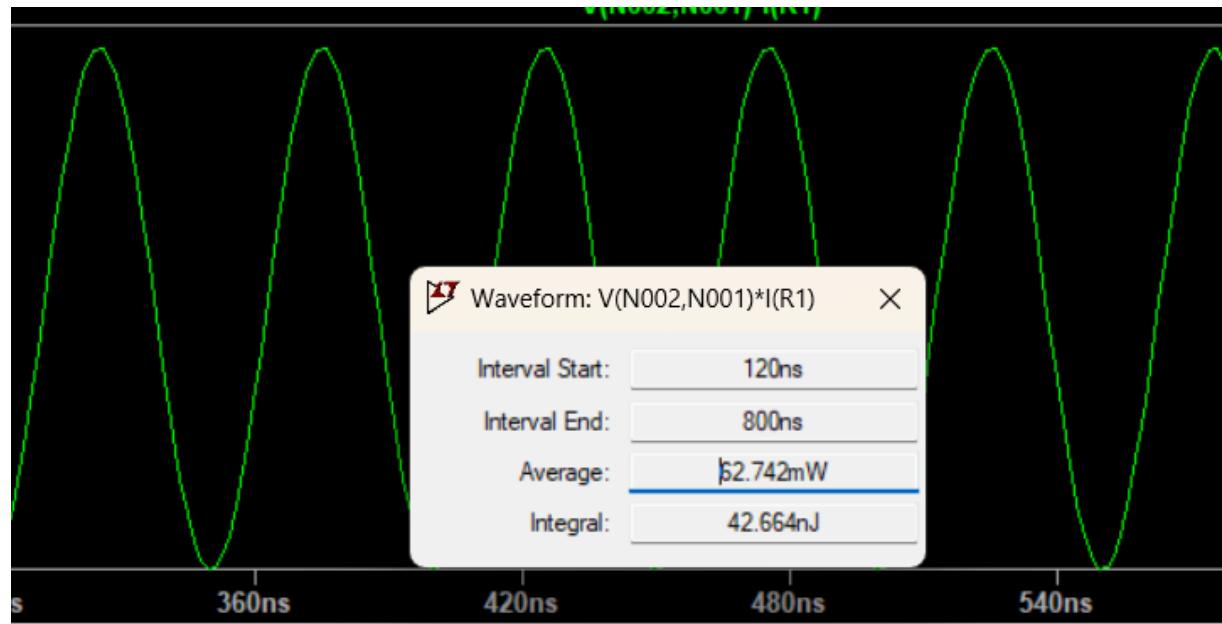


Figure 9: Maximum power available for L-section matching circuit

Power delivered to load resistor R_L can be observed in figure below. (Figure 10)

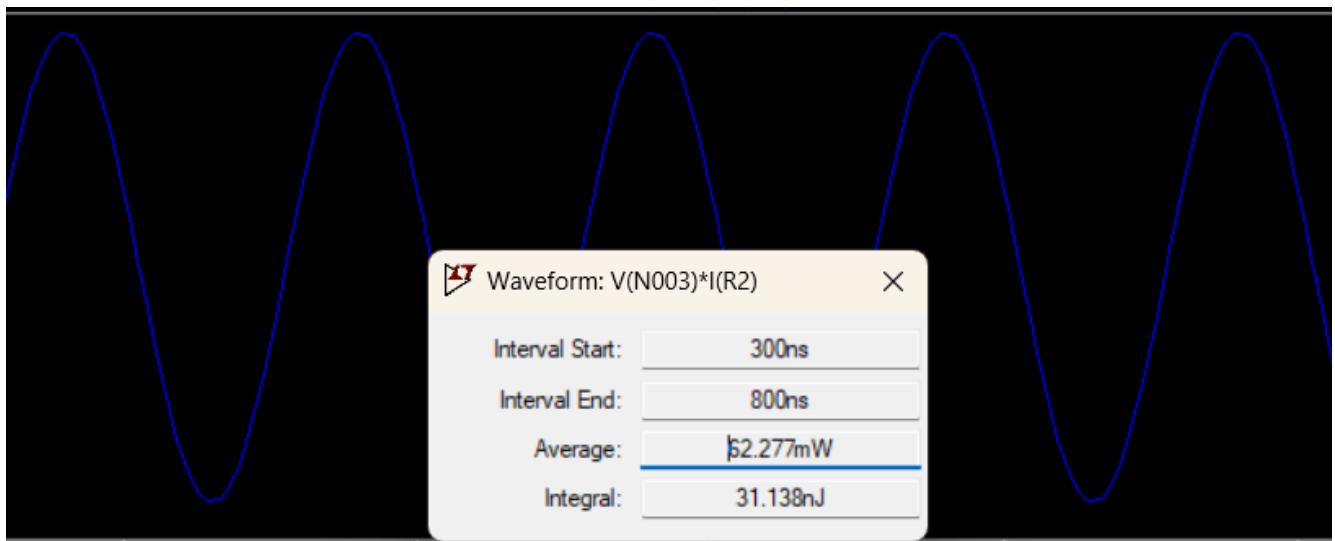


Figure 10: Power delivered to load resistor

From the simulation results, it is seen that power available at source resistance R_S is 62.74mW, power available in load resistor R_L is 62.27mW. The percentage error is 0.75%. Therefore, the theory of maximum power transfer is achieved in simulation results.

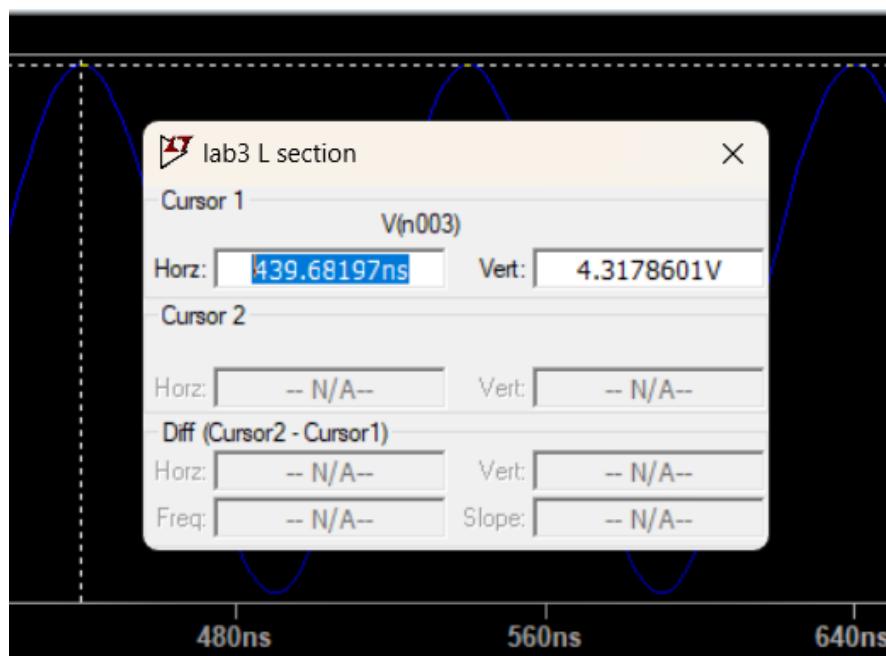


Figure 11: Output voltage of L-section matching circuit

As seen in (Figure 11), $V_{R_{pmax}} = 4.317V$.

	Power at R_s	Power at R_L	Percentage Error	Power Transfer Ratio
T-section	62.179 mW	61.564 mW	1%	99%
L-section	62.742 mW	62.277 mW	0.75%	99.25%

Table 1: Measured power values

From (Eqn. 4), calculated average power values is 62,5mW. The measured values (Table 1) are slightly different from the calculated value 62,5mW. Which shows that the measurements are correct with a slight error included.

Hardware Implementation

Before designing the circuits that are created in LTSpice, I measured the power at the terminals of the signal generator. (Figure 12)



Figure 12: Designed circuit to measure the power available at the terminals of signal generator

Then I connected a 47Ω resistor accross the terminals of the signal generator and an oscilloscope probe to it. The measured oscilloscope values can be seen in the figure below.

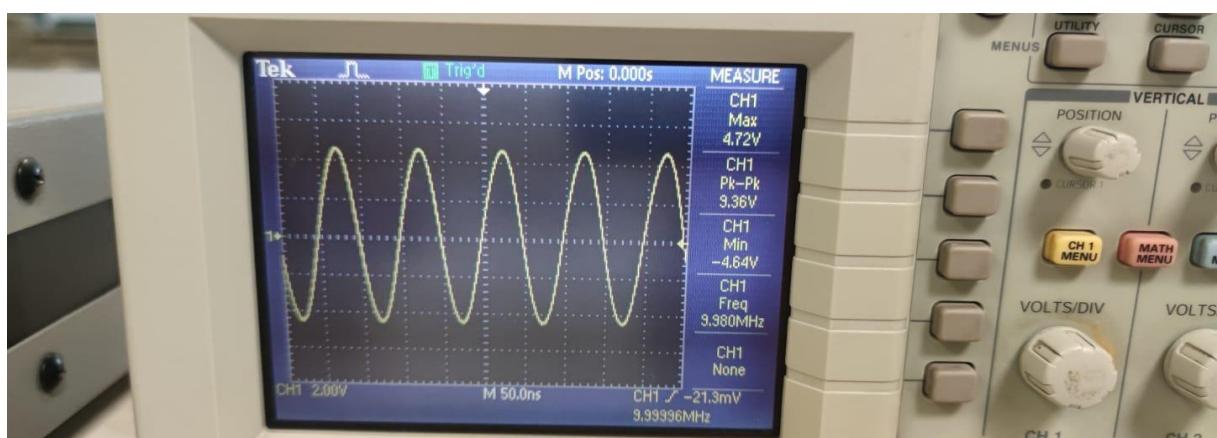


Figure 13: Input voltage

In the simulation, the input voltage was measured to be 10V peak-to-peak at 10MHz, in hardware implementation, the result obtained is 9.36V peak-to-peak at 10MHz. The results are slightly similar to each other as expected. The difference between the results may occur due to the instability of the signal generator.

T-SECTION METHOD

For hardware implementation, both T-section and L-section matching circuits are created on a breadboard with desired inductor, capacitor, and resistor values.

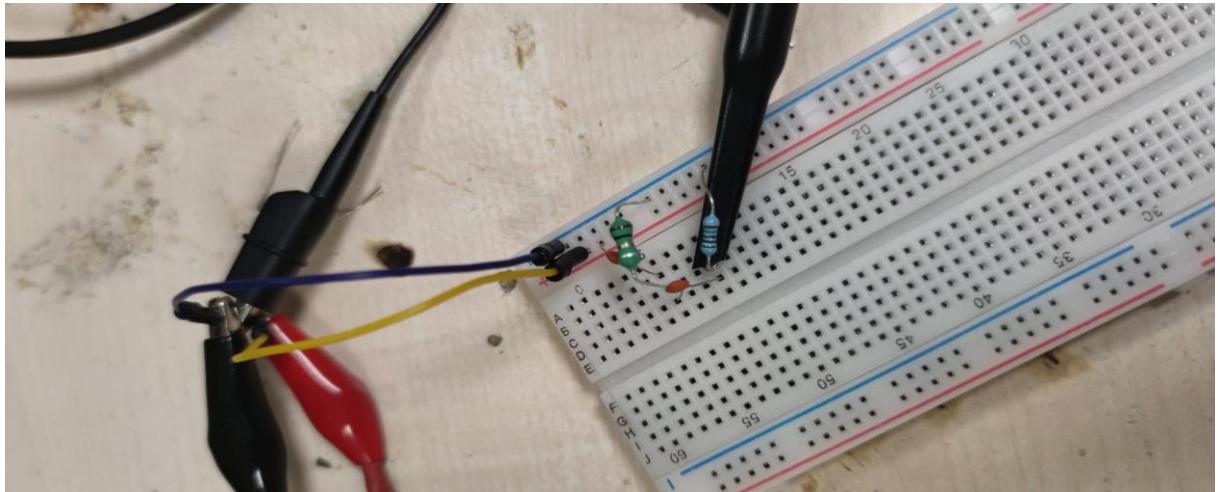


Figure 14: T-section matching circuit

After creating the T-section circuit, I made the correct connections in order to observe the output voltage and power. Figure below shows the result of output voltage.

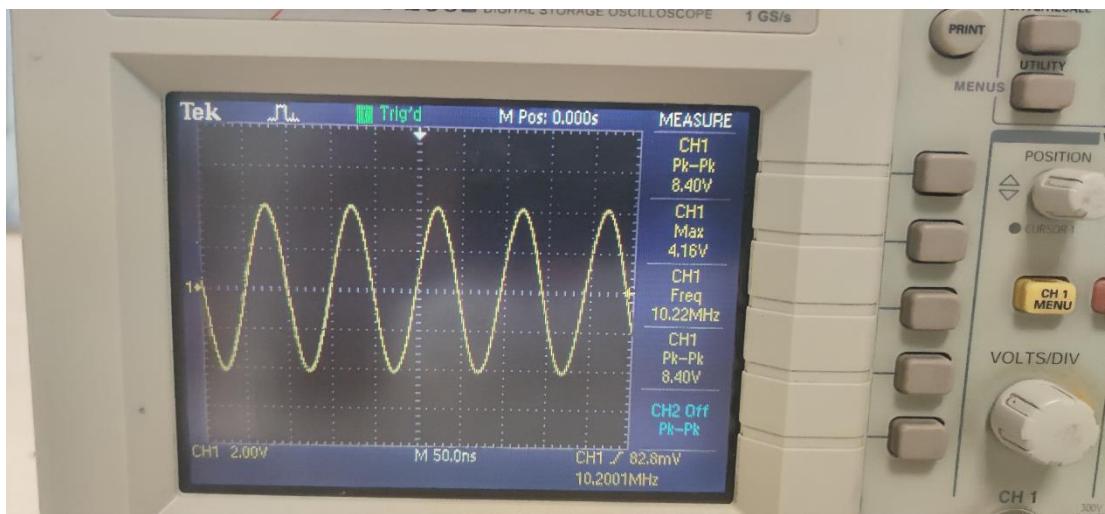


Figure 15: Output voltage value for T-section matching circuit

Here, I get 8.40V peak-to-peak. Slightly similar with the result in LTSpice which is 8.62V peak-to-peak. The only difference in hardware implementation is results are obtained around 10.2MHz instead of 10MHz.

$$P_{ave} = 58.8 \text{mW}$$

The error between measured and calculated results are given in Eqn. 5.

$$\text{Error} = \frac{61.5 - 58.8}{58.8} \times 100 = 4.59\%$$

Eqn. 5: Error calculation

Theoretical output power (V)	8.62V
Measured output power (V)	8.40V
Theoretical output power (mW)	61.5mW
Measured output power (mW)	58.8mW
Error	4.59%

Table 2: Error for T-section matching circuit

The error turned out to be under 10% which is acceptable.

L-SECTION METHOD

Figure below shows the designed L-section matching circuit on a breadboard with desired inductor, capacitor, and resistor values.

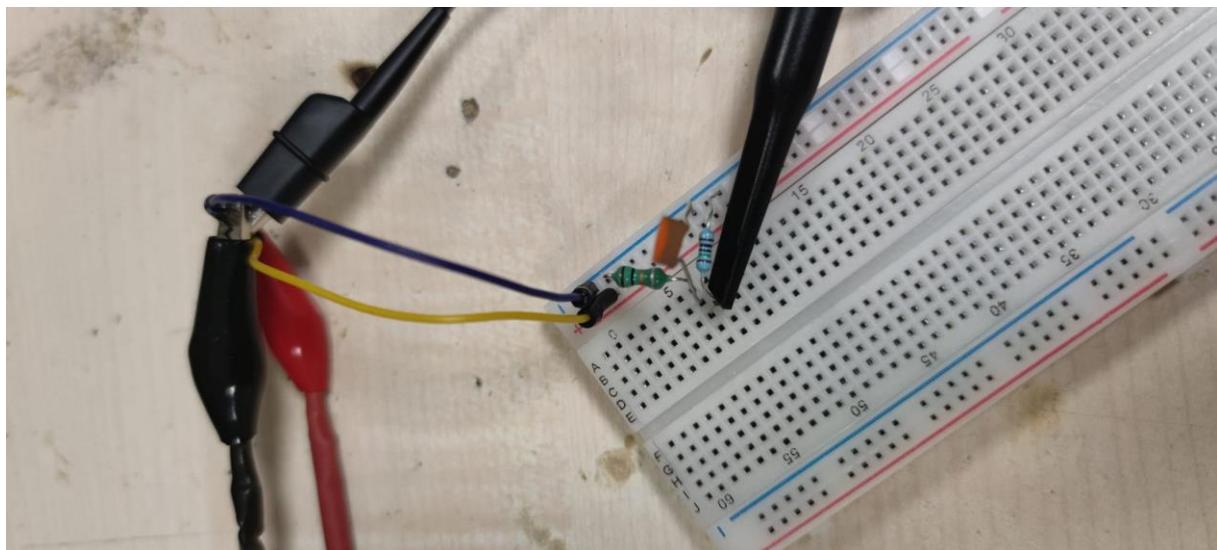


Figure 16: Designed L-section circuit

The output voltage in load resistor R_p can be observed on the oscilloscope in the figure below.

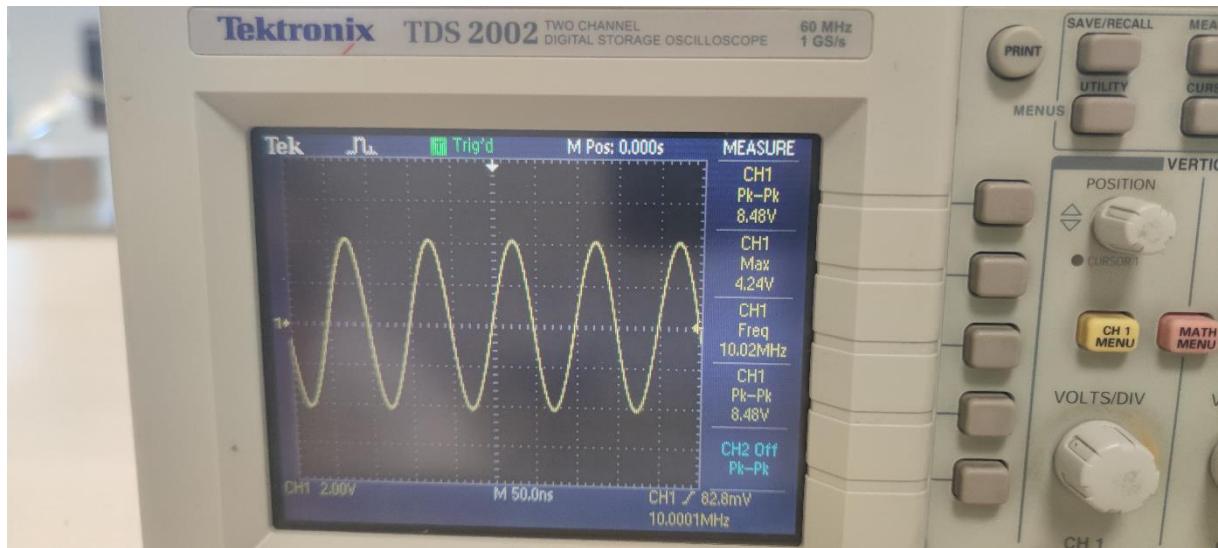


Figure 17: Output voltage of L-section matching circuit

From the simulation results, output voltage value at load resistor came 8.64V peak-to-peak at 10MHz. Looking at (Figure 17), output voltage at load resistor for designed circuit turns out to be 8.48V peak-to-peak around 10Mhz. Calculating the power, we get,

$$P_{ave} = 59.9 \text{mW}$$

$$\text{Error} = \frac{62.3 - 59.9}{59.9} \times 100 = 4.00\%$$

Theoretical output power (V)	8.64V
Measured output power (V)	8.48V
Theoretical output power (mW)	62.3mW
Measured output power (mW)	59.9mW
Error	4.00%

Table 3: Error for T-section matching circuit

The error turned out to be under 10% which is acceptable.

Conclusion:

The main purpose of this experiment is designing at least two different matching circuits in order to obtain maximum power transferred from source resistance with a value of 50Ω to load resistance with a value of 150Ω . I designed a T-section and a L-section matching circuit to fulfil the requirements of the lab. The frequency is chosen as 10MHz, however, in the hardware part of the lab, the values of the frequency was modified a bit in order to obtain the maximum results. The software implementation of the lab resulted in slight error with the results calculated theoretically. As software implementation, hardware implementation values have slight errors compared to the theoretically calculated values. These errors occurred because of the instability of the signal generator, lack of sensitivity of the experimenter, lack of sensitivity of oscilloscope, and inductors not being ideal. Also, in the lab, not all of the desired values of resistors and inductors are available, therefore I used the closest values I can find at the software implementation part of the lab.