# Bilkent University Department Of Electrical and Electronics Engineering

# EEE212 Circuit Theory

# Lab 4

# Maximum Power Transfer

**Cankut Bora Tuncer 22001770 Section 1**

## Purpose:

Design at least two passive linear circuits to transfer maximum power to 220Ω load from a voltage source with output impedance 50Ω at a frequency between 10 and 15Mhz.

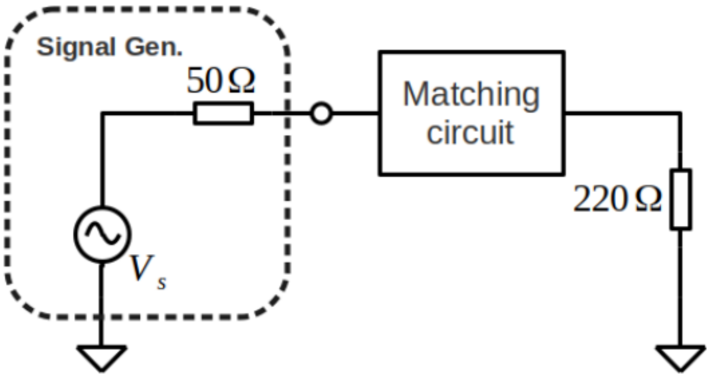


*Figure 1 – The Lab Task*

## Methodology:

To transfer the power available in the source to the desired source, the impedances of both sides must match. In other words, the impedances on both sides should have the relation: $Z_s = Z_l^*$.

Furthermore, the following calculations will be used to calculate and compare the power values.

$$P_{ave} = I^2 * \frac{R_s + R_l}{2}$$

$$I = \frac{V}{R_s + R_l}$$

$$P_{ave} = (\frac{V}{R_s + R_l})^2 * \frac{R_s + R_l}{2}$$

When $R_s = R_l^* = R$:

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

There are several ways to achieve this, but two possible methods will be proposed in this report. The calculations on each method are made referencing the prior class of EEE202, EEE 212 Analog Electronics. The component values were rounded in the simulation lab to make a viable comparison with the hardware lab.

**The L-Section Method**

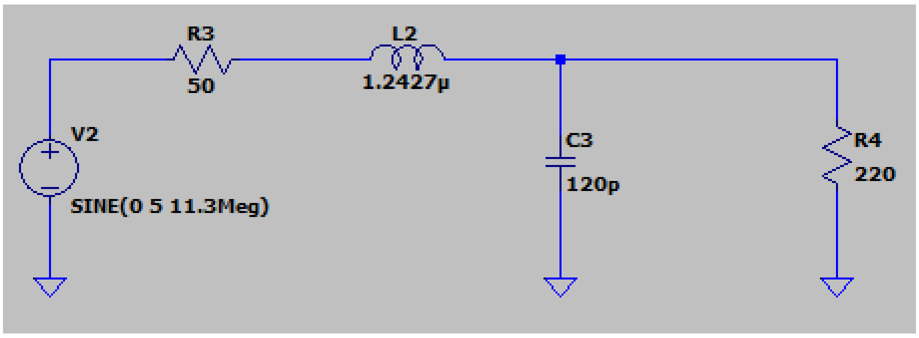


*Figure 2 – The L- Section*

To find the inductor and capacitor values, the following calculations are made:

$$\boldsymbol{R_p = 220, R_s = 50, f = 11.3MHz}$$

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

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

$$Q = 1.8439$$

$$Q = \frac{2 * \pi * f * L_s}{R_s}$$

$$\boldsymbol{L_s \sim 1.2427\mu}$$

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

$$\boldsymbol{C \sim 120p}$$

The frequency value is chosen precisely to fit applicable capacitor and inductor values.

## The T-Section Method

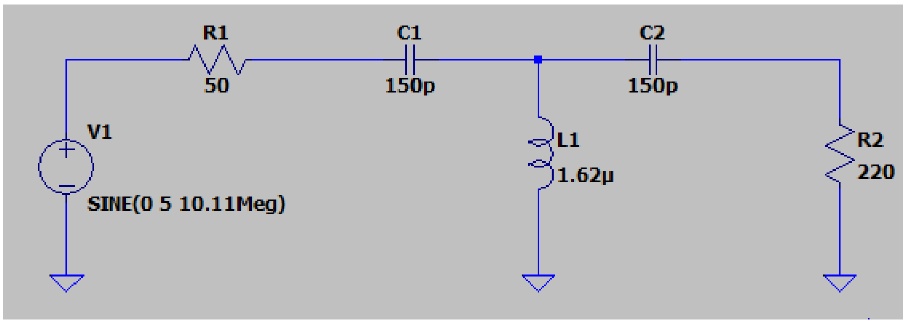


*Figure 3 – The T- Section*

To find the inductor and capacitor values, the following calculations are made:

$$\boldsymbol{R_p = 220, R_s = 50, f = 10.11MHz}$$

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

$$X^2 = R_l * R_s$$

$$X = -/+104.88\Omega$$

X is chosen as a minus as it is easy to use more capacitors than inductors in the hardware.

$$jx = jwl, \qquad jx = \frac{1}{jwc}$$

$$L = \frac{x}{2 * \pi * f}, \qquad C = \frac{1}{x * 2 * \pi * f}$$

$$\boldsymbol{L{\sim}1.62\mu \quad C{\sim}150p}$$

The impedance and power matching can be achieved with the selected values.

# Results:

## Simulation Results:

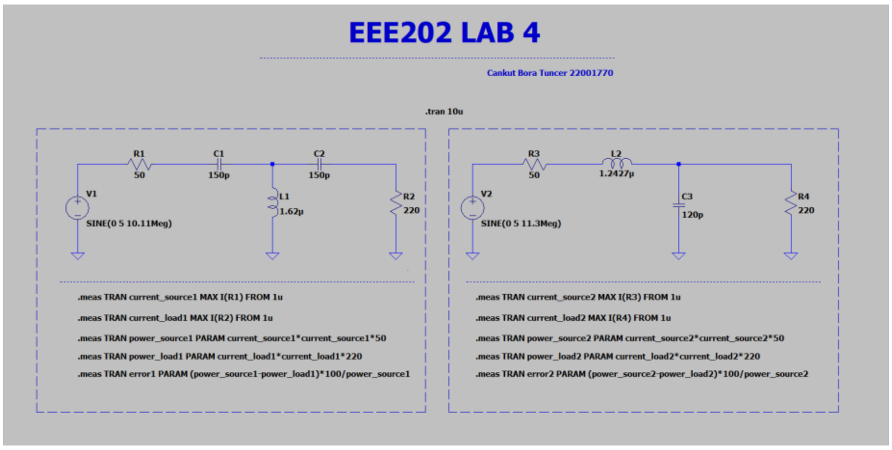


*Figure 4 – The Simulation Lab*

### L-Section:

After running the L-Section, the following results are obtained.

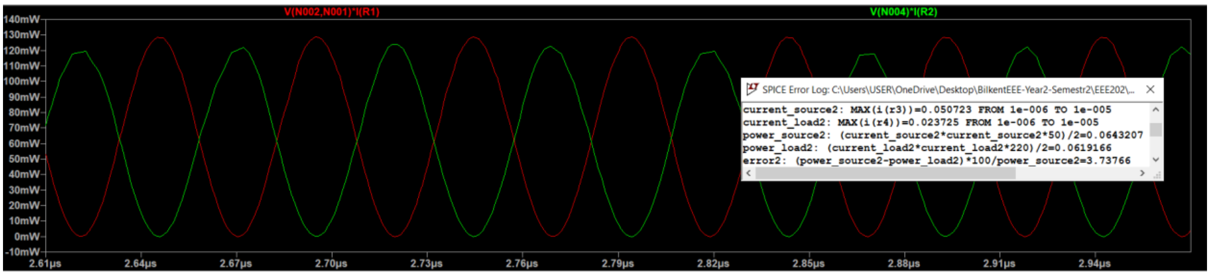


*Figure 5 – Power Graph of The L-Section*

As seen in Figure 5, the power available at the source and delivered to load is 64.3207mW and 61.9166mW, respectively. The error is %3.737, and the power deliver ratio is %96.26. Hence, in theory, this method is applicable as a power transfer circuitry.

### T-Section:

After running the T-Section, the following results are obtained.

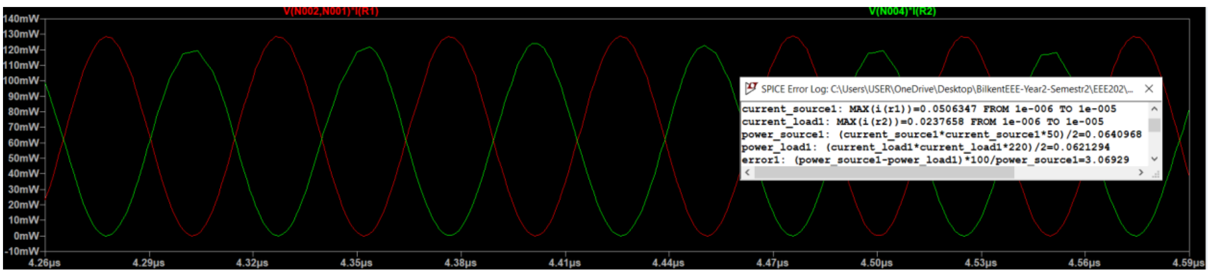


*Figure 6 – Power Graph of The T-Section*

As seen in Figure 6, the power available at the source and delivered to load is 64.0968mW and 62.1294mW, respectively. The error is %3.06929, and the power deliver ratio is %96.93. Hence, in theory, this method is applicable as a power transfer circuitry.

*Table 1 – Overall Simulation Results*

| | **Power Available(mW)** | **Power Delivered(mW)** | **Error(%)** | **Power Transfer Ratio(%)** |
|---|---|---|---|---|
| **L-Section** | 64.0968 | 62.1294 | 3.06929 | 96.93 |
| **T-Section** | 64.3207 | 61.9166 | 3.737 | 96.26 |

**Hardware Results:**

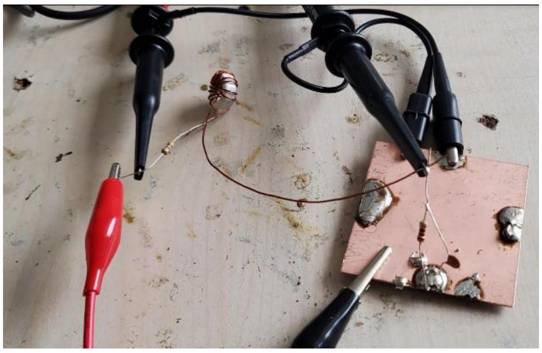

*Figure 7 – L-Section*

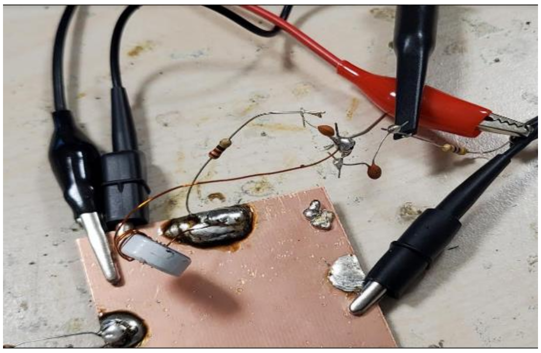

*Figure 8 – T-Section*

For the hardware implementation, the inductor core is chosen as T50 with Al = 4.3nH/t^2.

The signal generator configurations for both methods are given in Figures 9 and 10 separately.

As the guideline indicates, the source resistor is changed from 50ohms to 47ohms.

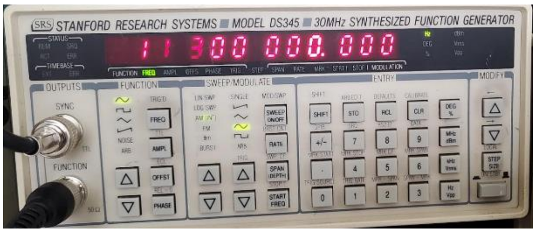


*Figure 9 – Signal Generator for L-Section*

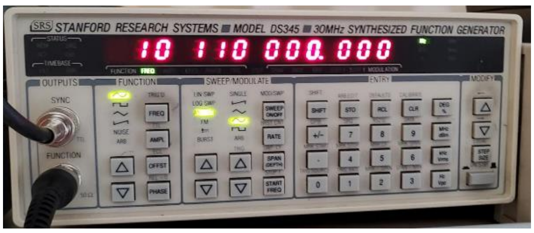


*Figure 10 – Signal Generator for T-Section*

In LTSpice, we can easily measure the power with the given software tools. However, it is not quite possible to directly measure the power in the hardware lab. Hence the power will be calculated after three steps.

1- Measuring the voltage difference at the source resistance.
2- Measuring the voltage of the load resistance.
3- Calculation using the formula $P_{ave} = \frac{V^2}{2R}$.

**L-Section:**

The inductor is winded 17 times to obtain 1.2427uH. The results are as follows.

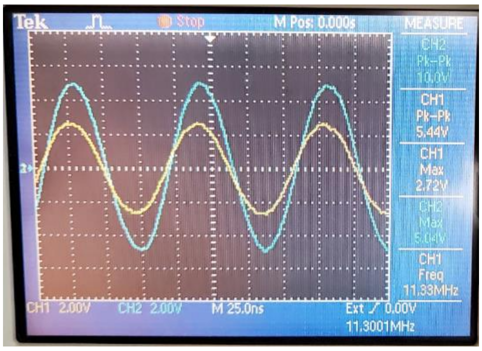


Figure 11 – Voltage difference at the source resistor

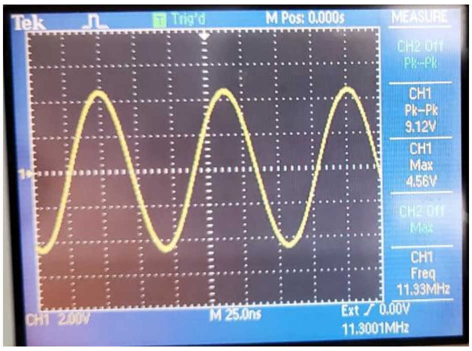


Figure 12 – Voltage of the load resistor

The input voltage is 5.04V, and the voltage difference of the source resistor is 2.72V. The voltage at the load resistor is 4.56V. Hence the power available is 57.259mW, and the power delivered is 47.2581mW. There is a 17.46% error, and the power transfer ratio is 82.53%.

**T-Section:**

The inductor is winded 19 times to obtain 1.62uH. The results are as follows.

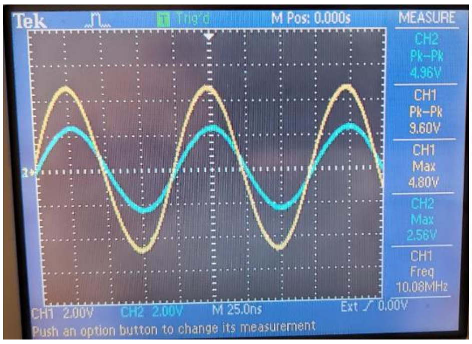


*Figure 13 – Voltage difference at the source resistor*

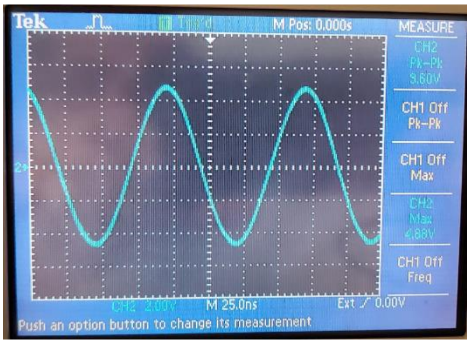


*Figure 14 – Voltage of the load resistor*

The input voltage is 4.8V, and the voltage difference of the source resistor is 2.56V. The voltage at the load resistor is 4.8V. Hence the power available is 53.3787mW, and the power delivered is 52.3636mW. There is an 8.55% error, and the power transfer ratio is 91.45%.

*Table 2 – Overall Hardware Results*

| | **Power Available(mW)** | **Power Delivered(mW)** | **Error(%)** | **Power Transfer Ratio(%)** |
|---|---|---|---|---|
| **L-Section** | 57.259 | 47.2581 | 17.46 | 82.53 |
| **T-Section** | 53.3787 | 52.3636 | 1.901 | 98.09 |

As it can be seen from the Table 2, the T- Section is much more efficient than the L-section I have implemented.

## Conclusion:

In this experiment, the purpose was to implement a power matching circuit to deliver the power from a source with 50ohm resistance to a load with 220ohm resistance. The two proposed method was the L-Section and T-Section. In the simulation part, the component values are chosen to simplify the hardware part. The simulation results were promising regarding the power ratios of the source and the load, and there were no significant differences between the methods. The results were still applicable in the hardware lab except for the L-Section method which was not as promising as the simulation results. The L-Section had 82.5%, and the T-Section had a 98% power transfer ratio. There is a noticeable difference between the software and the hardware lab for the L-Section. One main reason is due to the fact that the inductor is hand winded, even the touch changed the output values. Furthermore, in the software lab, the copper loss and skin effect are discarded and the inductor is considered ideal. Another reason is the resistance and capacitor values are considered as same with the given label and I have calculated the power accordingly. But in reality, they have 5-10% tolerance values. In a realistic case, the T-Section is much more reliable and more applicable in a commercial product than the L-Section. If the efficiency of the L-Section needs to be improved, the inductor can be winded more carefully or even used as a manufactured one. Moreover, the actual values of the capacitors and the resistors can be used in the measurements. To sum up, I learned how to analyze power on the LTSpice Software and design an impedance matching circuit.