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EE 202 Section 1

EEE 202 CIRCUIT THEORY

LAB 4

Software Implementation

In this lab experiment it is expected to design a circuit with passive circuit elements (such as resistors, inductors, capacitors) to have maximum power on the load (220Ω resistor) of the circuit. The sample of the circuit is shown below in Figure-1.

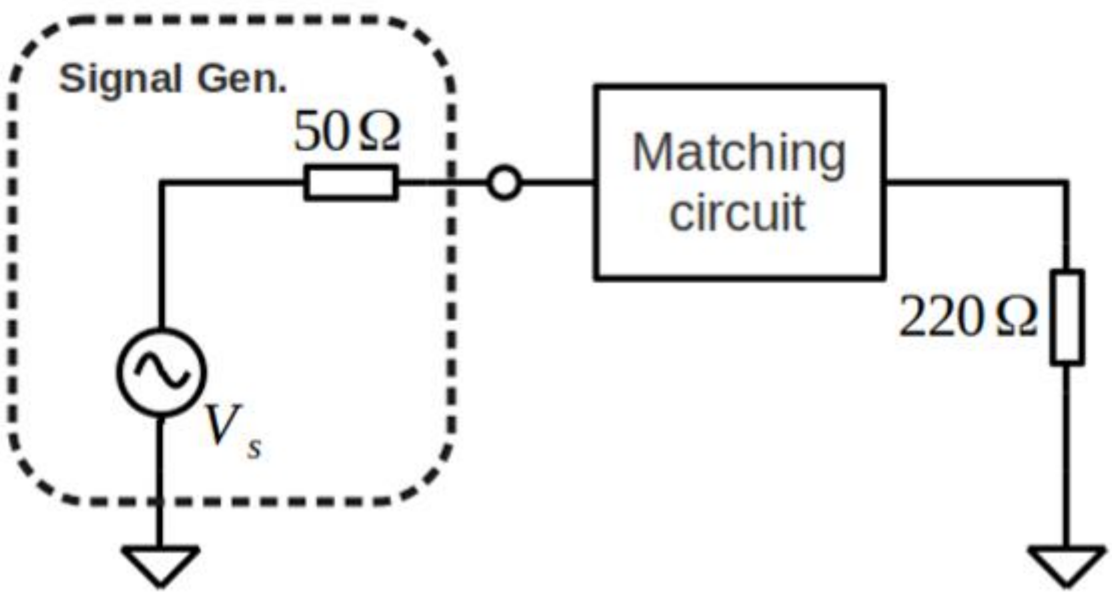

Figure 1: Sample Schematic

In this figure 50 Ω resistor represents the inner resistor of the signal generator. Therefore, throughout the software implementation part, this resistor will be added manually by us. In addition to that as seen in the figure 1, there is a matching circuit but what kind of matching circuit is unknown. First, the requirements for the maximum power transfer will be found. The sample circuit to be used is shown below in Figure 2.

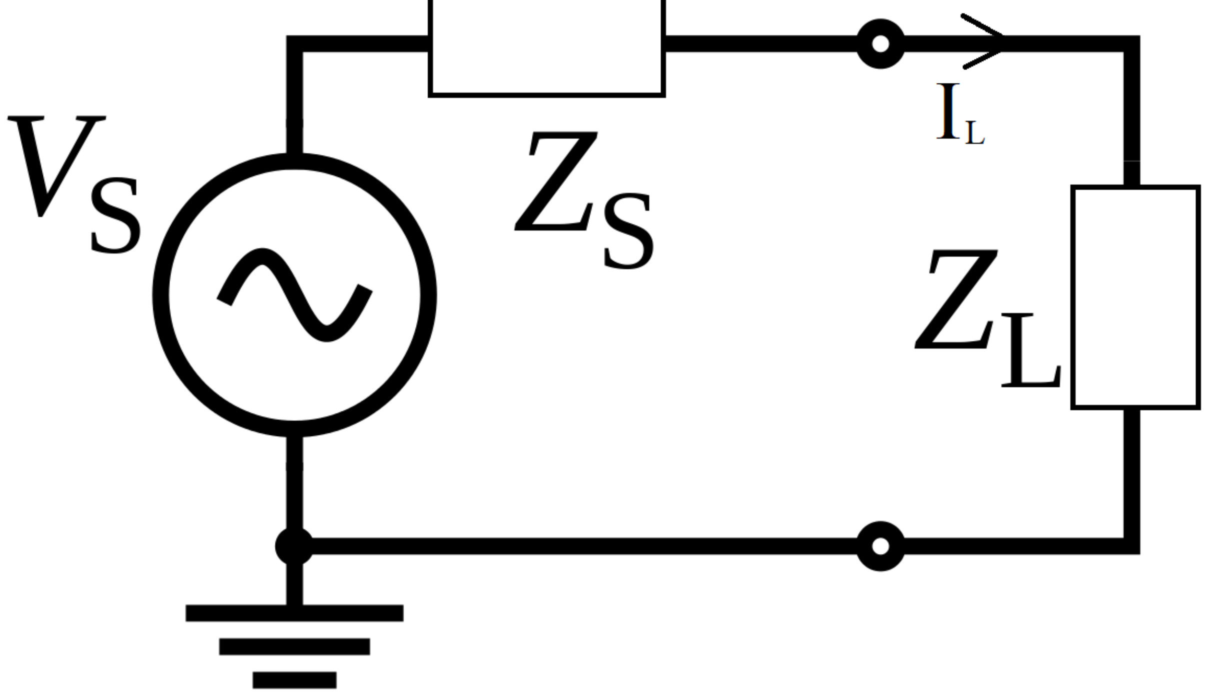

Figure 2: Sample circuit with source impedance and load impedance

Firstly, the average power delivered to power must be calculated and then it will be analyzed to make it maximum.

$$P_L = \frac{Z_L * I_L^2}{2}$$

Known that $I_L = \frac{V_S}{Z_L + Z_S}$, using this fact power equation becomes

$$P_L = \frac{Z_L * (\frac{V_S}{Z_L + Z_S})^2}{2}$$

To find the maximum point of the P_L, it will be differentiated with respect to $Z_L$since we need to design the circuit according to Z_L. After differentiation the equation below is obtained.

$$P_L' = \frac{V_S^2 * (Z_S^2 - Z_L^2)}{2 * (Z_L + Z_S)^4}$$

According to equation below $Z_S^2 = Z_L^2$must be satisfied to have maximum transfer. Since only passive elements are used in this experiment, we have $Z_L = Z_S$ to deliver maximum power transfer. Therefore, impedance matching will be required in this experiment.

Rewriting the power equation using $Z_L = Z_S$, the equation below is obtained.

$$P_L = \frac{V_S^2}{8 * Z_S}$$

The last equation gives us the maximum power transfer.

Impedance Matching

<u>Method 1: Pi section Impedance Matching</u>

The first method is impedance matching using pi section circuit. In this method, the circuit is in π shape. In this π shape there may be 2 capacitors and 1 inductor or 2 inductors and 1 capacitor. The sample circuit schematic is shown below in Figure 3. In the schematic -jX can be created using capacitors and jX can be created using inductors (while X is positive).

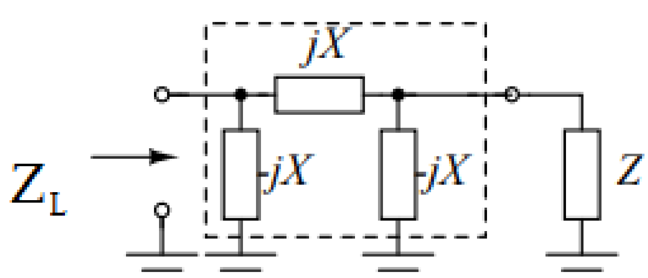

Figure 3: Pi section Circuit

In the circuit above the impedance (Z_L) is equal to $((Z//-jX) + jX)//(-jX)$

It is calculated as below.

$$\left(\frac{1}{(\frac{1}{Z} + \frac{1}{-jX})^{-1} + jX} + \frac{1}{-jX}\right)^{-1} = Z_L$$

When the expression above is simplified the equation below is obtained.

$$\frac{X^2}{Z} = Z_L$$

<u>Method 2: T section Impedance Matching</u>

The second method is impedance matching using T section circuit. In this method, the circuit is in T shape. In this T shape there may be 2 capacitors and 1 inductor or 2 inductors and 1 capacitor. The sample circuit schematic is shown below in Figure 4. In the schematic -jX can be created using capacitors and jX can be created using inductors (while X is positive).

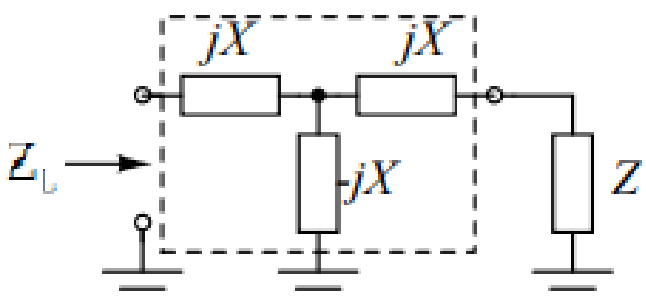

Figure 4: T section Circuit

In the circuit above the impedance (Z_L) is equal to $((Z + jX)//(-jX)) + (jX)$

It is calculated as below.

$$\left(\frac{1}{Z + jX} + \frac{1}{-jX}\right)^{-1} + jX = Z_L$$

When the expression above is simplified the equation below is obtained.

$$\frac{X^2}{Z} = Z_L$$

The same results are obtained from both of the methods. Therefore, the same values can be used for both methods.

Since I want to have impedance matching for certain frequency (resonance frequency), X must be equal to ωL or $\frac{1}{\omega C}$. Since we need resonance frequency, known that $\omega^2 = LC$

Now we have the finalized version of equation. It is known that by theory $Z_L = 50\Omega$, Z=220Ω.

From the equation X is found as 104.88. Now L, and C values must be chosen. Using the equations below.

$$X = \omega L = \frac{1}{\omega C}, \omega^2 = LC$$

To convenience for the hardware part, L is chosen as 1.3μH so ω becomes 2* π*12.84 and C becomes 118pF.

Using the decided values, the designed circuits and their simulation reports are given below.

<u>First Method</u>

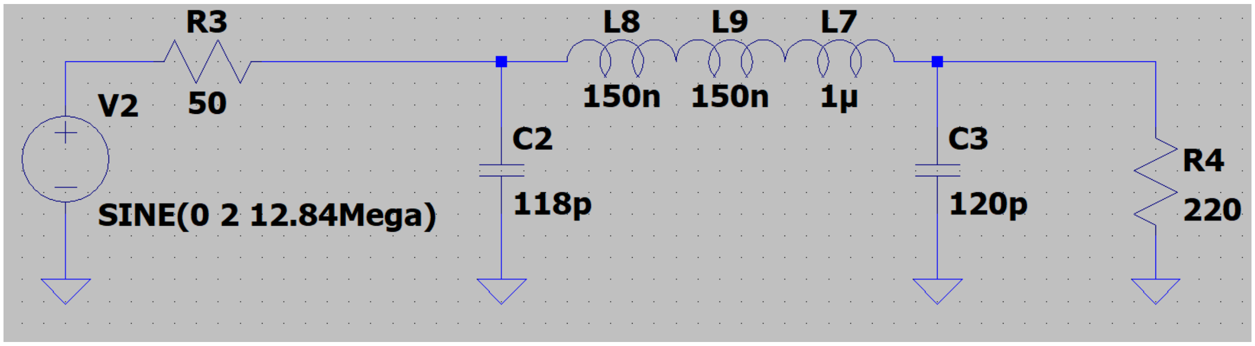

Figure 5: Designed Pi circuit for maximum power transfer

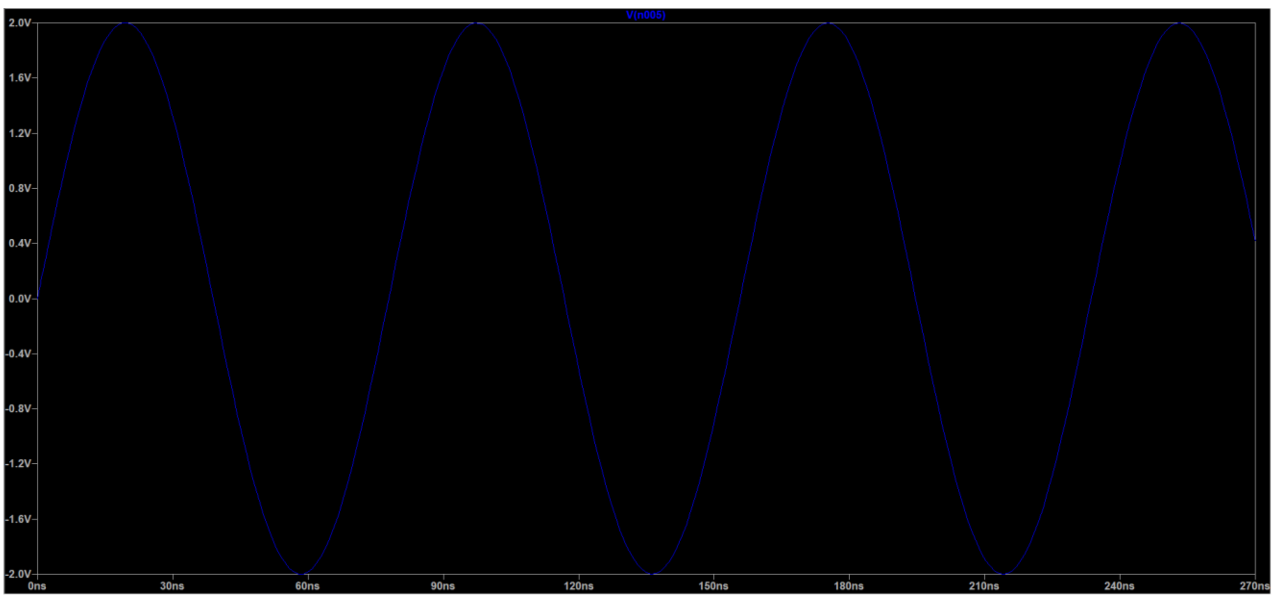

Figure 6: Input signal (source)

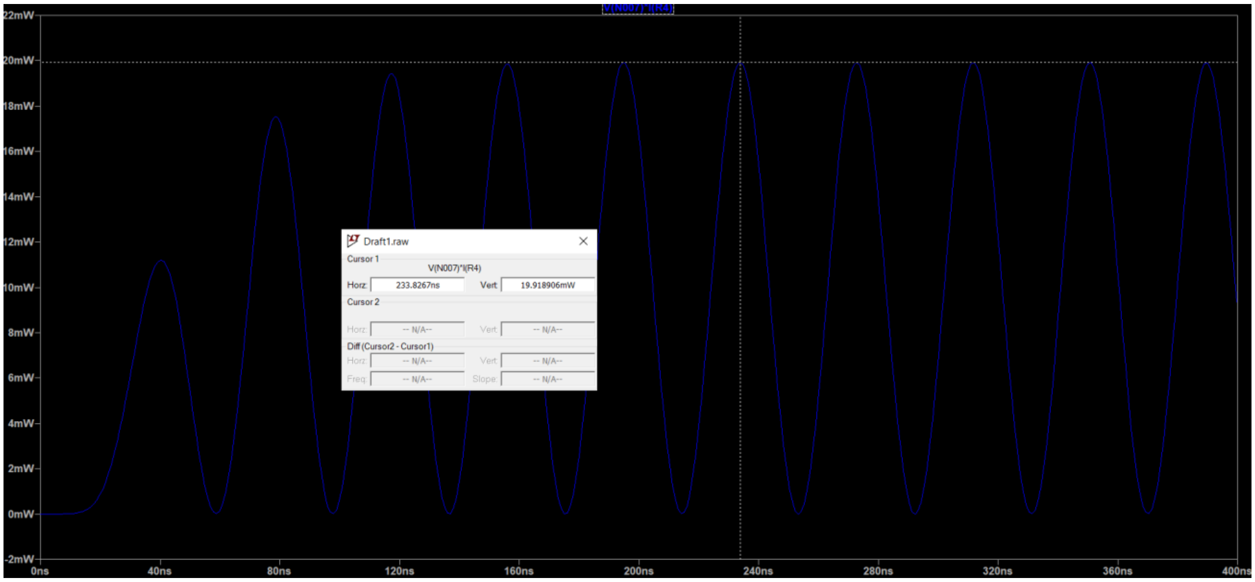

Figure 7: Delivered power to load (220 Ω)

According to simulation result $P_{max} = 20mW\,(with\ small\ error)$, so $P_{rms} = \frac{20mW}{2} = 10mW$.

According to formula found for max power transfer $P = \frac{V_S^2}{8*Z_S} = \frac{2^2}{8*50} = \frac{1}{10}W = 10mW$

As seen above the formula and simulation report are consistent with each other for the π section method.

Second Method

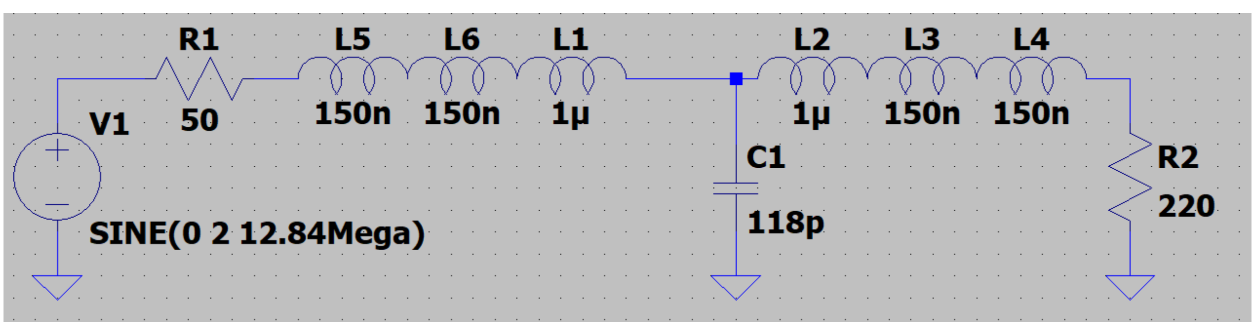

Figure 8: Designed T circuit for maximum power transfer

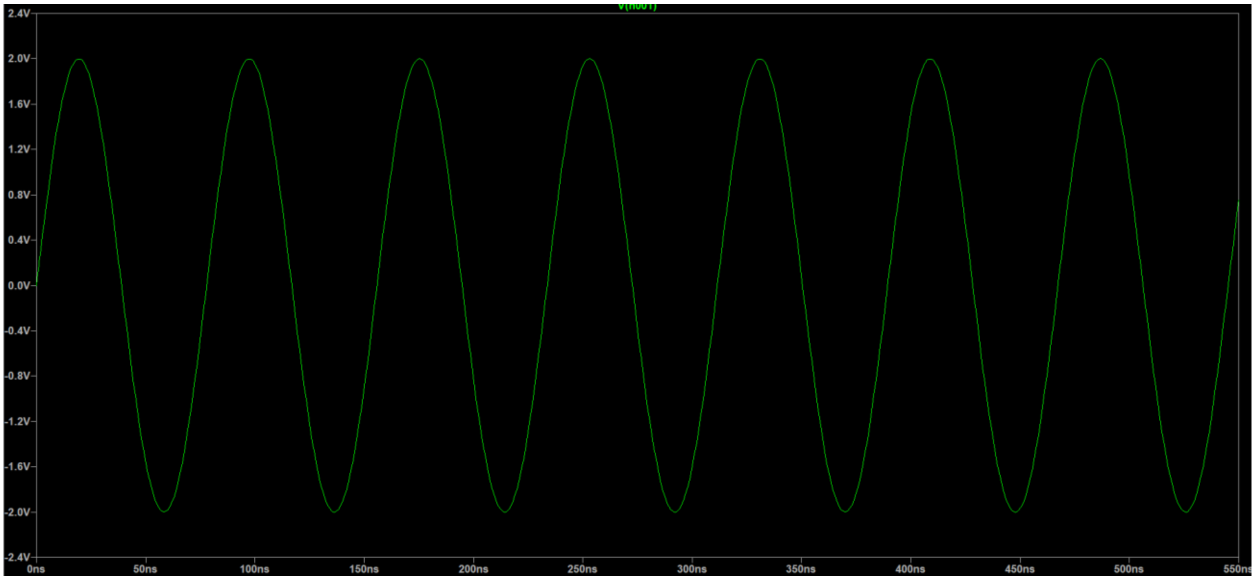

Figure 9: Input signal (source)

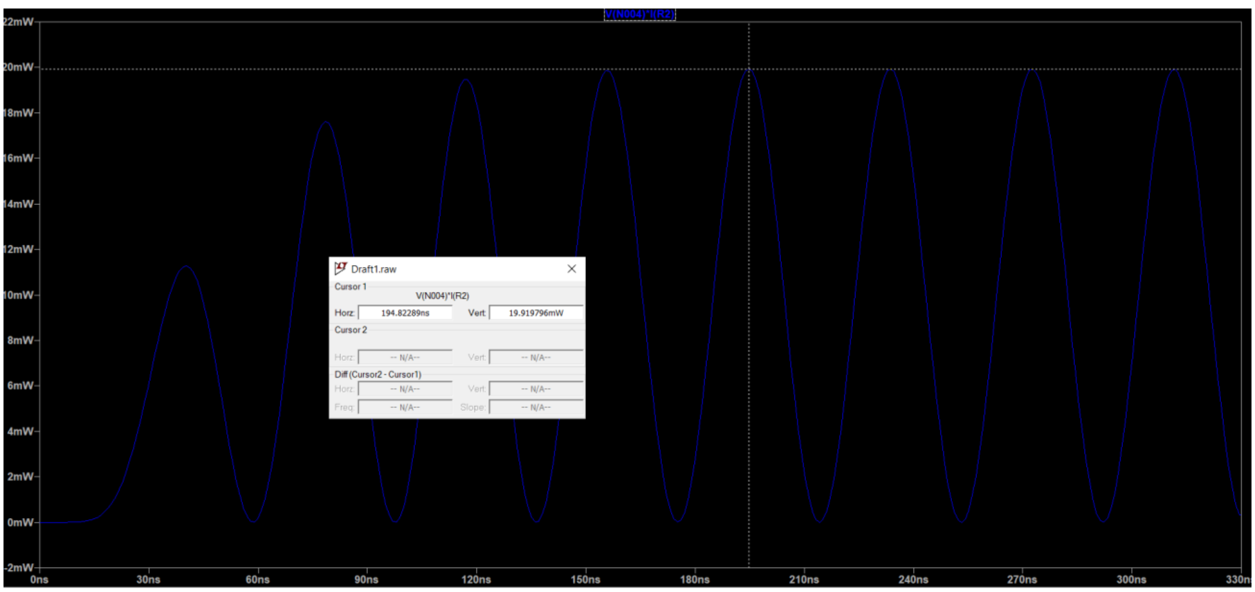

Figure 10: Delivered power to load (220 Ω)

According to simulation result $P_{max} = 20mW\,(with\ small\ error)$, so $P_{rms} = \frac{20mW}{2} = 10mW$.

According to formula found for max power transfer $P = \frac{V_S^2}{8*Z_S} = \frac{2^2}{8*50} = \frac{1}{10}W = 10mW$

As seen above the formula and simulation report are consistent with each other for the T section method.

Hardware Implementation

In the hardware implementation part same circuits with same component values are used for convenience but instead of 118pF capacitor 120pF capacitor is used. The circuits and corresponding signal forms are given below.

Since delivered power cannot be calculated directly using oscilloscope, I measured the voltage on the load resistor to check maximum power and calculated power using the voltage on the load using the formula below.

$$P = \frac{\left(\frac{V_{max}}{\sqrt{2}}\right)^2}{R}$$

First Method- Pi Section Circuit

Figure 11: Real Life Implementation of the Pi Circuit

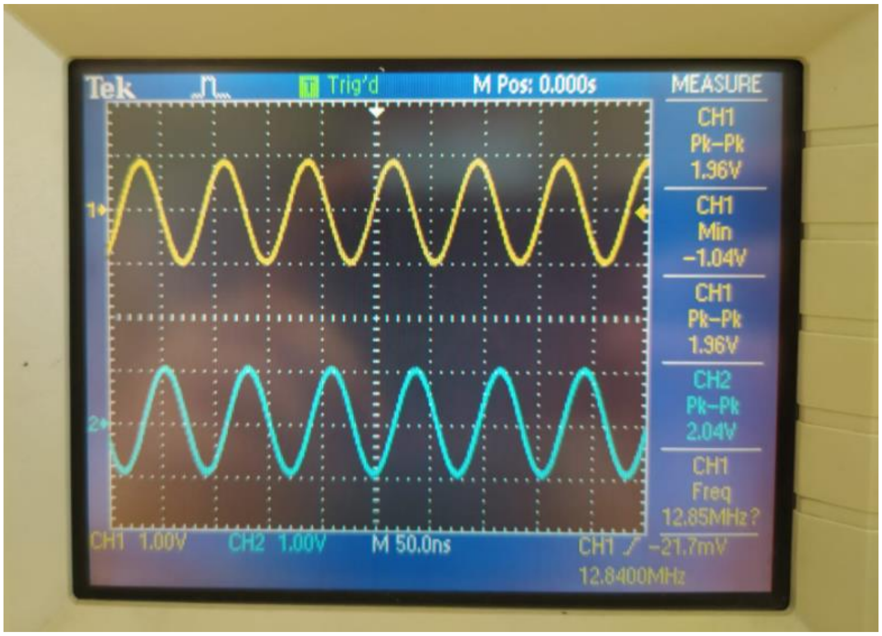

Figure 12: Yellow signal is input source and blue signal is voltage on the load

By the power formula we have $P = \frac{(\frac{Vmax}{\sqrt{2}})^2}{R} = \frac{(\frac{2.04}{\sqrt{2}})^2}{220} = 9.46mW$

Error= $\frac{|10-9.46|}{10} * 100 = \%5.4$

<u>Second Method- T Section Circuit</u>

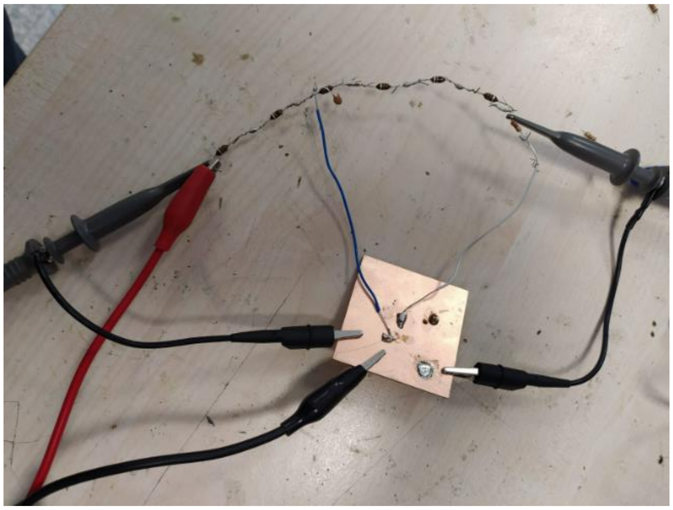

Figure 13: Real Life Implementation of the T Circuit

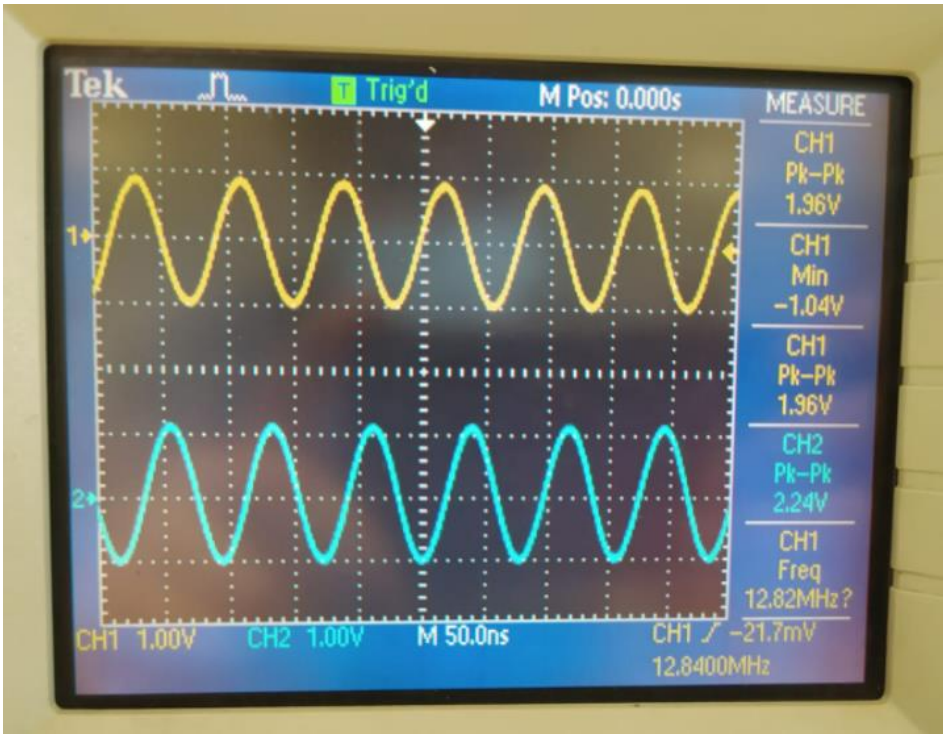

Figure 14: Yellow signal is input source and blue signal is voltage on the load

By the power formula we have $P = \frac{(\frac{Vmax}{\sqrt{2}})^2}{R} = \frac{(\frac{2.24}{\sqrt{2}})^2}{220} = 11.4mW$

Error= $\frac{|10-11.4|}{10} * 100 = \%14$

Conclusion

In this lab experiment we have investigated how to deliver the maximum power to load. After investigation it is found that to deliver the maximum power to load, impedance matching is required. To impedance matching there were lots of method such as L section circuit, transformer circuit, pi section or T section circuits. In this experiment I have chosen T and pi section circuits to realize impedance matching. For both methods I had to use resonant circuits and chose the required components according to this frequency. For both methods it is investigated that same valued components can be used. Using same valued components simulation results are checked and same results have obtained. The power delivered to power is checked both using the formula and simulation result in the software simulation part. In the hardware implementation part I couldn’t get same results and both of the results have some errors. It can have several reasons. Frequency was not stable I have observed on the oscilloscope screen even if it is stable on the signal generator, it can be one of the reasons. The second reason can be raised from the components and inner resistances. Since there is no suitable capacitor in the lab, I have chosen a capacitor with close value to required one, and I have used some cables for convenience their resistances could be effective on the results. Fortunately, the errors were not high and in this way impedance matching, power transfer concepts are observed in real life.