Bilkent University Department of Electrical and Electronics Engineering EEE202 Circuit Theory Lab 4

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Section 3

Software Lab:

Introduction:

The aim of the Lab 4 is to design at least two passive linear circuits to transfer maximum power to the load 180 ohms with an output impedance of 50 ohms at a frequency between 5Mhz to 10 MHz. LTSpice is used to simulate these two circuits. And since the prerequisite is to use only passive tools, OPAMPS are not allowed to use in Lab 4.

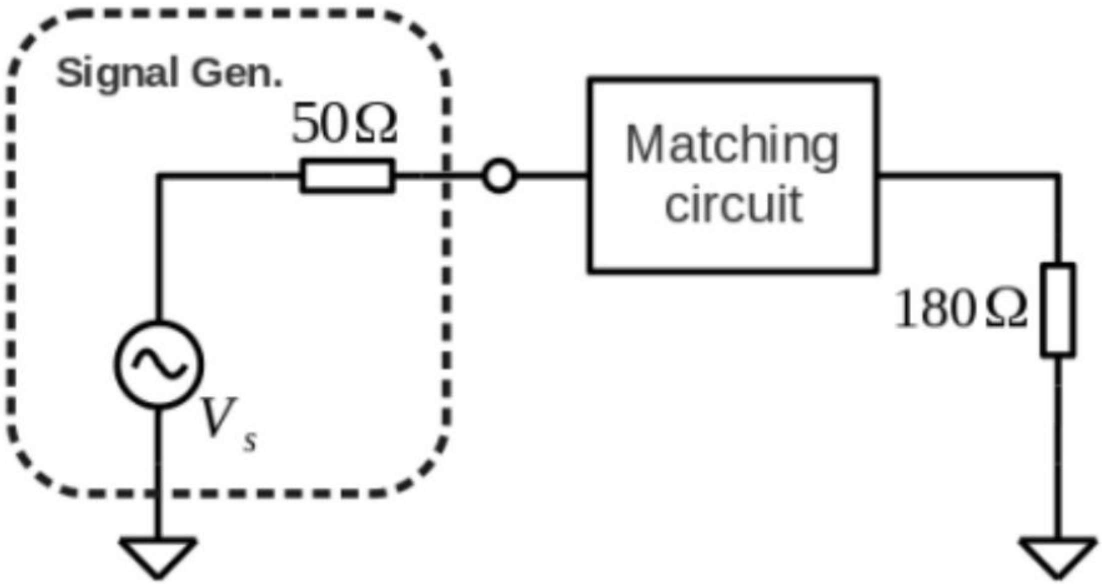

Figure 1: A Simple Example of the Desired Circuit

All of the design process will be explained later in this report including the equations, computations and LTSpice simulation results.

Analysis:

The analysis part will be conducted in three different parts. The first part will be explaining how the maximum power transfer is achieved. The second part will be explaining how the passive L-Section circuit is built and the third part will be explaining how the passive T-Section circuit is built.

Maximum Power Transfer:

The resistances of the source and the load must match and their reactance must cancel each other out in order to transfer the maximum amount of power to the load. Stated differently, the complex conjugate of the total impedance of one of the source should be equal to other source's total impedance. In other words, $Z_s = Z_l^*$ is required.

The equations of the average power on the load are known as:

$$P_{average} = \frac{1}{2} * (R_l) * I^2$$

Equation1

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

Equation 2

$$P_{average} = \frac{1}{2} * \frac{V^2}{(R_s + R_l)^2} * (R_l)$$

Equation 3

Since $Z_s = Z_l^*$, the real parts of the impedances are equal to each other. In other words, $R_s = R_l$.

With using $R_s = R_l$, Equation 3 becomes:

$$P_{average} = \frac{1}{8} * \frac{|V|^2}{R}$$

Equation 4

L-Section Method:

An easy example of L-Section can be seen in Figure 2.

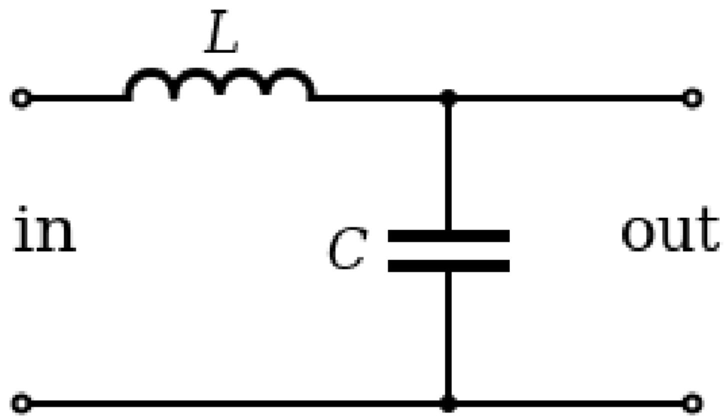

Figure 2: An Example of L-Section

The equations below shows how the values of capacitance and inductance is chosen when R_{load} = 180 ohms, Rs = 50 ohms , f = $8MHz$.

$$R_s = \frac{R_{load}}{(Q^2+1)}$$

Equation 5

$$Q = \sqrt[2]{\frac{R_{load}}{R_s} - 1}$$

Equation 6

Since R_{load} = 180 ohms, Rs = 50 ohms:

$$Q = \sqrt[2]{\frac{180}{50} - 1} = 1.612$$

Equation 7

$$Q = 1.612 = \frac{f*L*2*pi}{R_s}$$

Equation 8

$$L = \frac{R_s*Q}{2*pi*f} = \frac{50*1.612}{2*pi*8*10^6}$$

Equation 9

<u>$Ls \sim 1.6\mu$H</u>

$$\omega = 2\pi f = \sqrt{\frac{1}{LC(1+\frac{1}{Q^2})}} \Rightarrow C = \frac{1}{4\pi^2 f^2 L(1+\frac{1}{Q^2})}$$

Equation 10

C ~ 179pF

T-Section Method:

An easy example of T-Section can be seen in Figure 3.

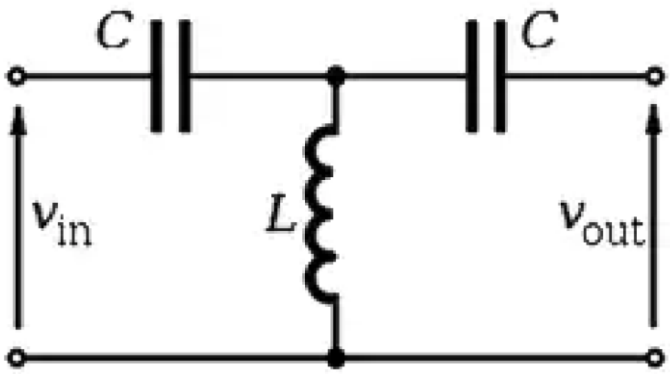

Figure 3: An Example of T-Section

The below equations are used to calculate the capacitance and inductance values of the T-Section circuit. When the values R_l= 180 ohms , Rs = 50 ohms , f = 8MHz:

$$X^2 = Z_{load} * Z_s$$

Equation 11

$$X^2 = R_{load} * R_s = 50*180$$

X = -94.86 ohms or X = +94.86 ohms

Equation 12

$$For\ inductor, jX = jwL, and\ for\ the\ capacitor, jX = \frac{1}{jwc}$$

Therefore,

$$L \sim 1.89\mu\text{H}$$

$$C \sim 210\text{pF}$$

Simulation:

As it is expected in the lab document, firstly the possible maximum transferred power to the load is calculated. The calculation is shown below in Equation 13 with using Equation 4.

$$P_{average} = \frac{1}{8} * \frac{|V|^2}{R} = \frac{1}{8} * \frac{100}{50} = \frac{1}{4}W = 250mW$$

Equation 13

The circuit in Figure 4 is used to determine the power delivered to the 180ohms load without the matching circuit. Peak voltage of the input is 10 V, and frequency is 8 MHz. The power delivered to the load is plotted in Figure 5.

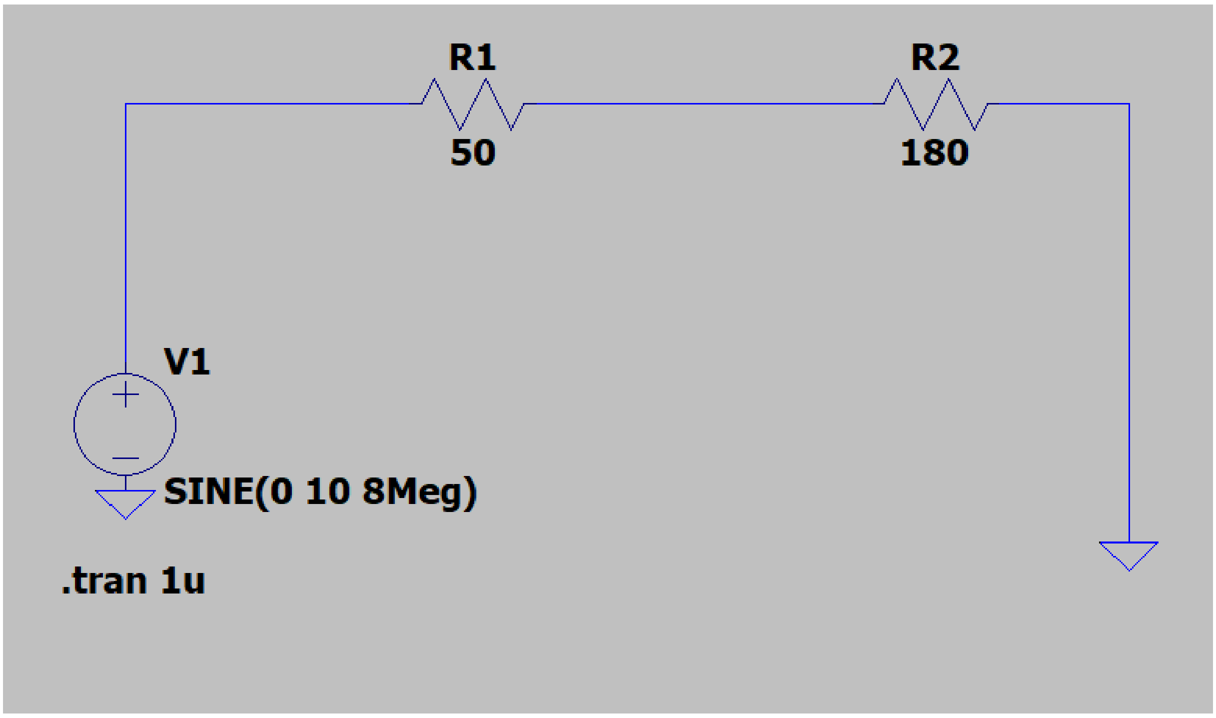

Figure 4: The Circuit without L and T-Sections

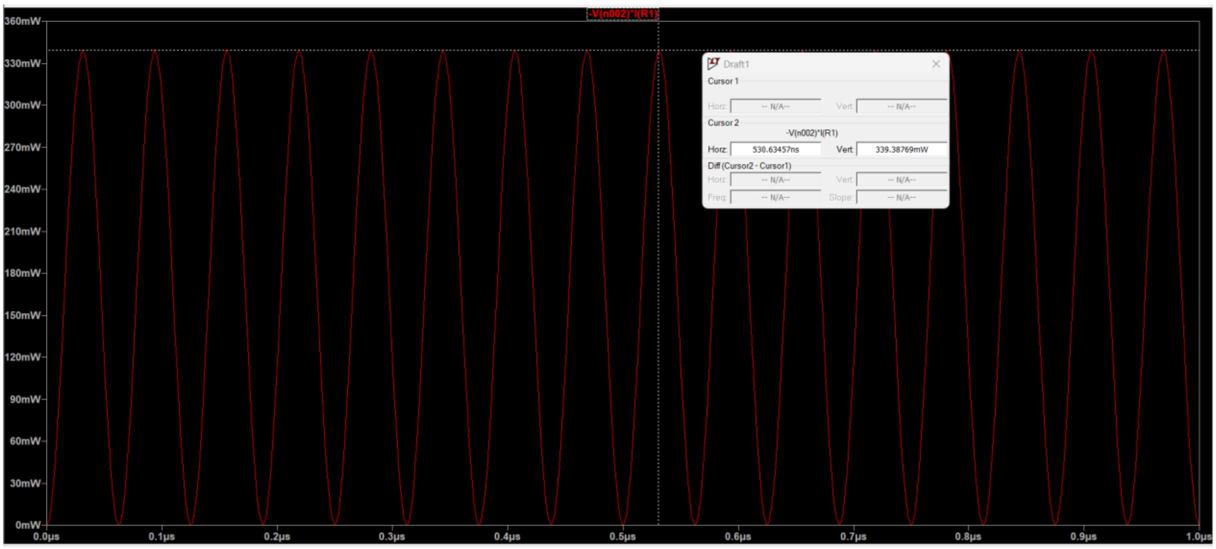

Figure 5: The Simulation Result of the Transferred Power to the Circuit without the Matching Parts

According to the simulation,

$$P_{average} = \frac{P_{maximum}}{2} = \frac{339.4}{2} = 169.7\ mW$$

Equation 14

The simulation result of the transferred power without the matching circuits (167.7 mW) is obviously less than the case with the theoretical result of the case with the matching circuits (250 mW). The ratio of the delivered power in this case is %67.08.

In Figure 6, the schematics of L-Section circuit can be seen.

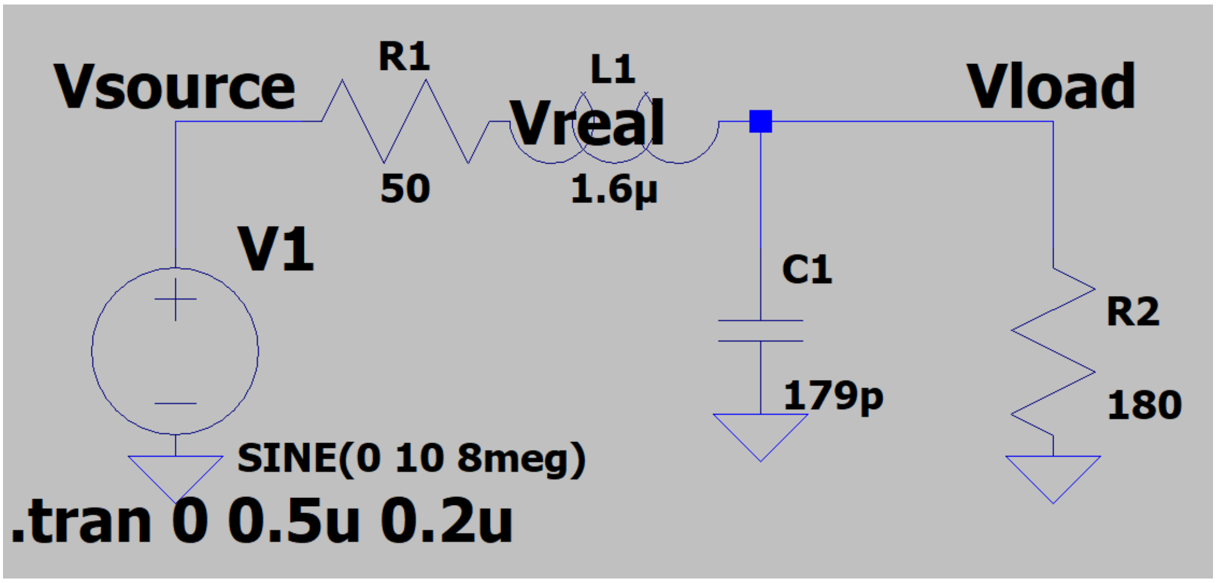

Figure 6: Schematics of L-Section Circuit

In Figure 7, the simulation result of L-Section circuit can be seen.

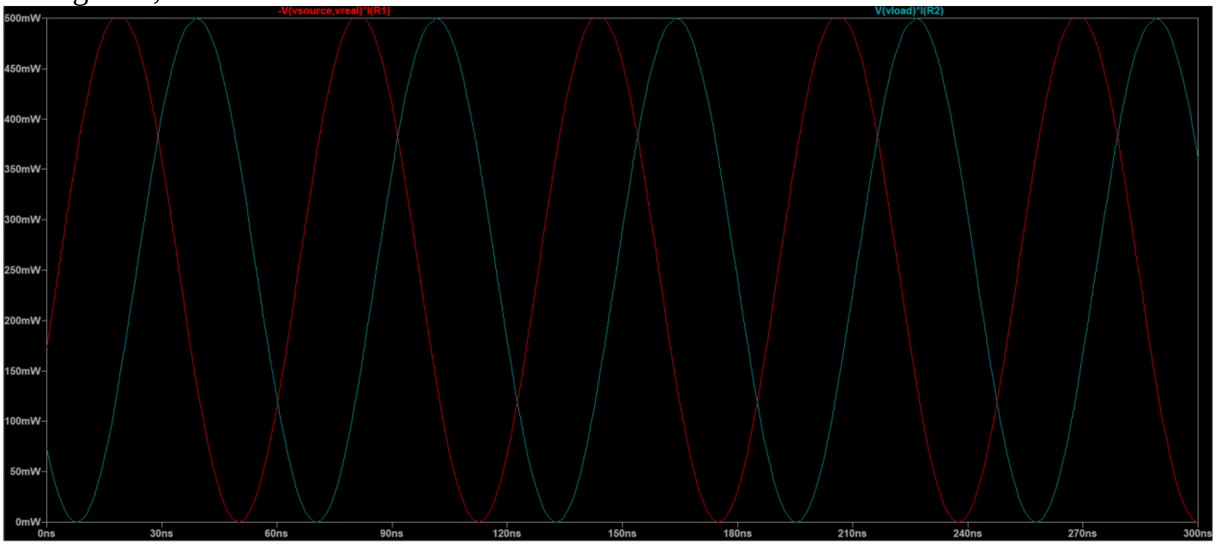

Figure 7: Simulation Result of Power Deliver in L-Section Circuit

In figure 8, a more detailed result of the power deliver is shown.

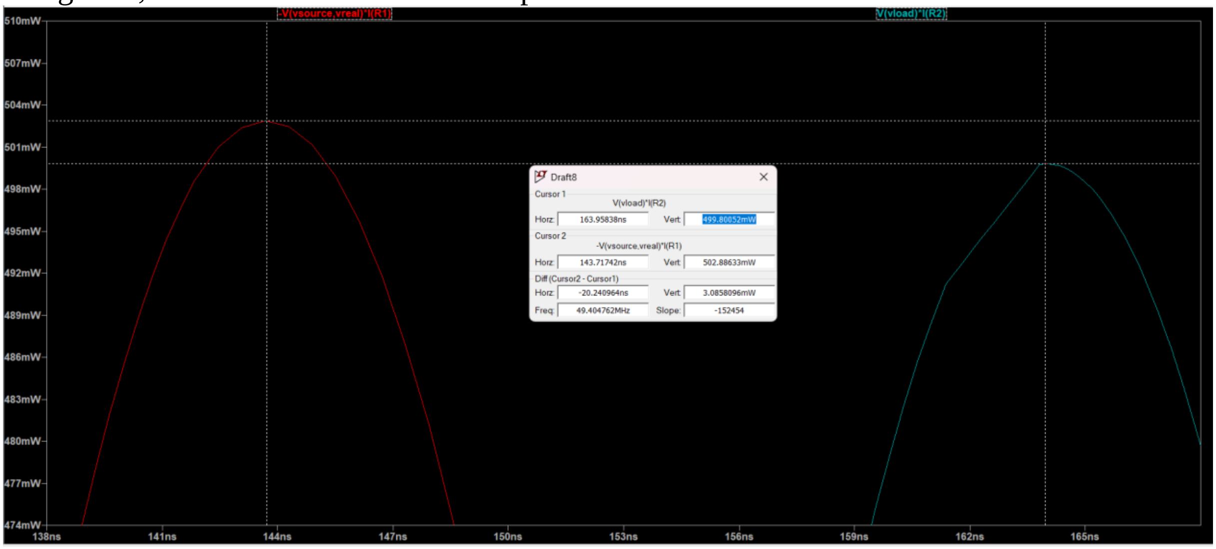

Figure 8: Simulation Result of Power Deliver in L-Section

By Equation 14, delivered average power to the load is (499.8/2)mW= 249.9mW.
By Equation 14, average power available in the source is (502,8/2)mW= 251.4mW.

In Figure 9, the schematics of T-Section circuit can be seen.

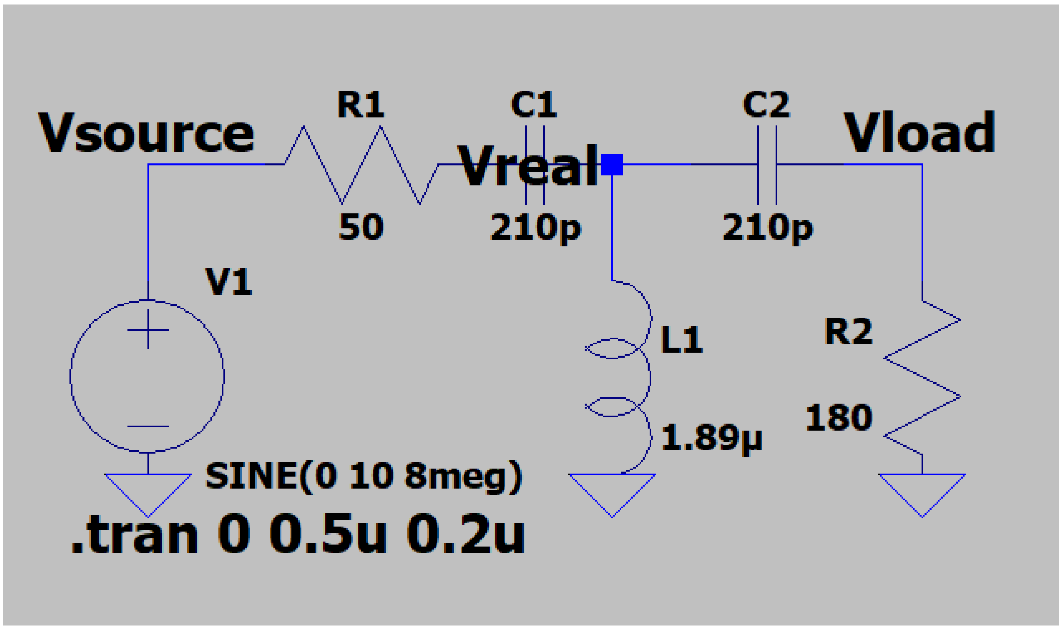

Figure 9: The Schematics of T-Section Circuit

In Figure 10, T-Section circuit results can be seen.

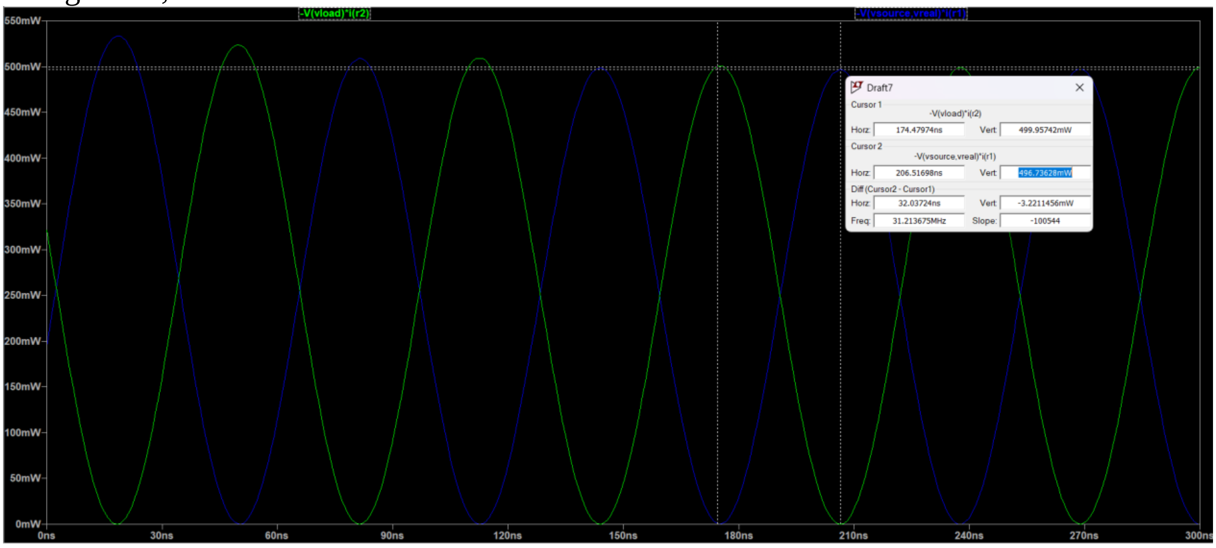

Figure 10: Simulation Result of Power Deliver in T-Section

By Equation 14, delivered average power to the load is (496.7/2)mW= 248.4mW.
By Equation 14, average power available in the source is (499,9/2)mW= 249.5mW.

The results from L-Section and T-Section so far are shown in Table 1.

	Theoretical Maximum Average Power	Available Maximum Average Power in Source	Delivered Maximum Average Power to Load	Error Percentage with using Theoretical and Delivered Values
L-Section	250mW	251.4mW	249.9mW	%0.04
T-Section	250mW	249.5mW	248.4mW	%0.64

Table 1: Overall Results of Software Lab

Hardware Lab:

The objective of the hardware setup is to ensure the accurate execution of the software's outcomes. Furthermore, we need to incorporate a 47Ω resistor into the signal generator to enable the computation of the power it receives. Additionally, after the feedbacks from lab TAs, the input voltage was chosen as 10 V peak to peak.

Figure 11: Resistor with 47 Ohms

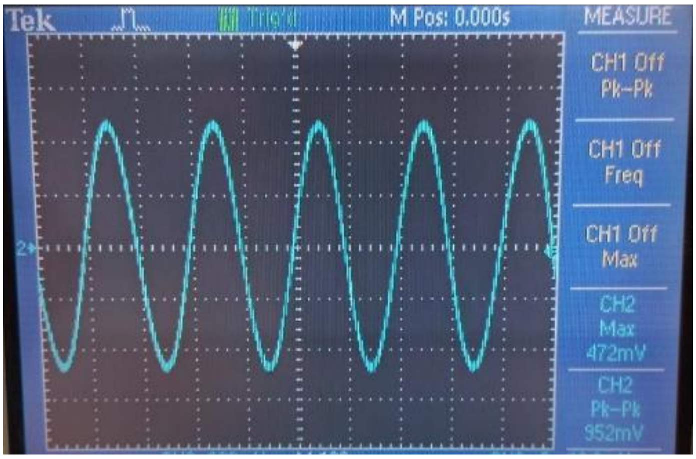

Figure 12: Voltage Across Resistor

When input voltage is 10Vmax and 20V peak to peak, with using Vmax = 472mW and R = 47 ohms.

The average power is found as 237mW by using Equation 13 and Equation 14.

Implementing T-Section:

While building the T-Section circuit, 220pF capacitors are used for 210 pF capacitors. And 2uH inductors are used for 1.89uH inductors. The input voltage value is decided as 5 V max, 10 V peak to peak after discussing with Tas.

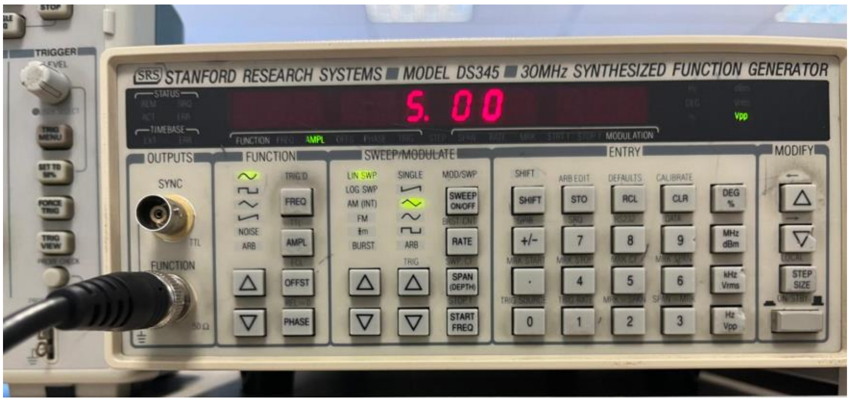

Figure 13: 5V Max Input Source

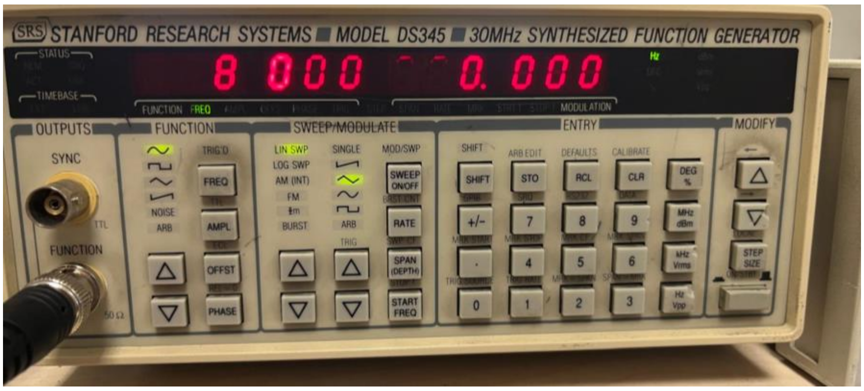

Figure 14: 8Mhz Frequency

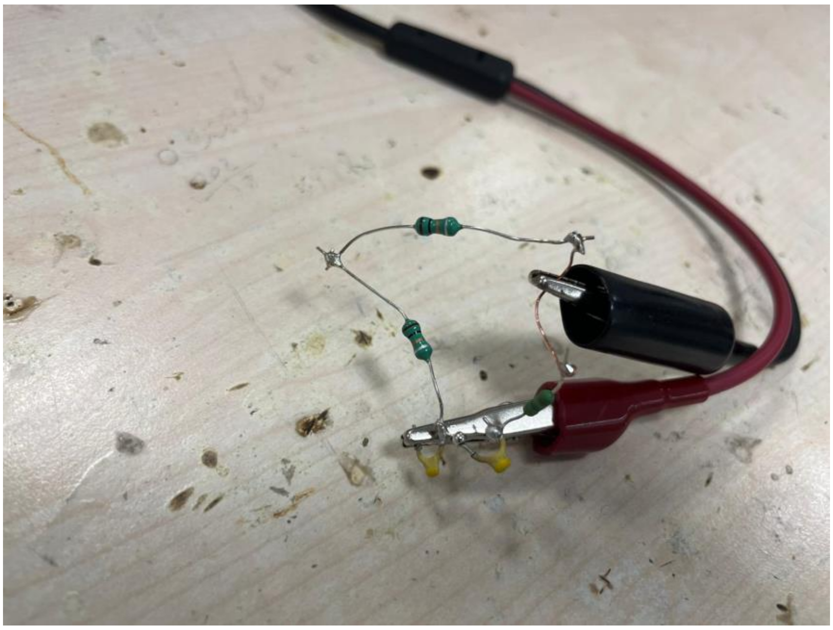

Figure 15: Hardware Implementation of T-Section

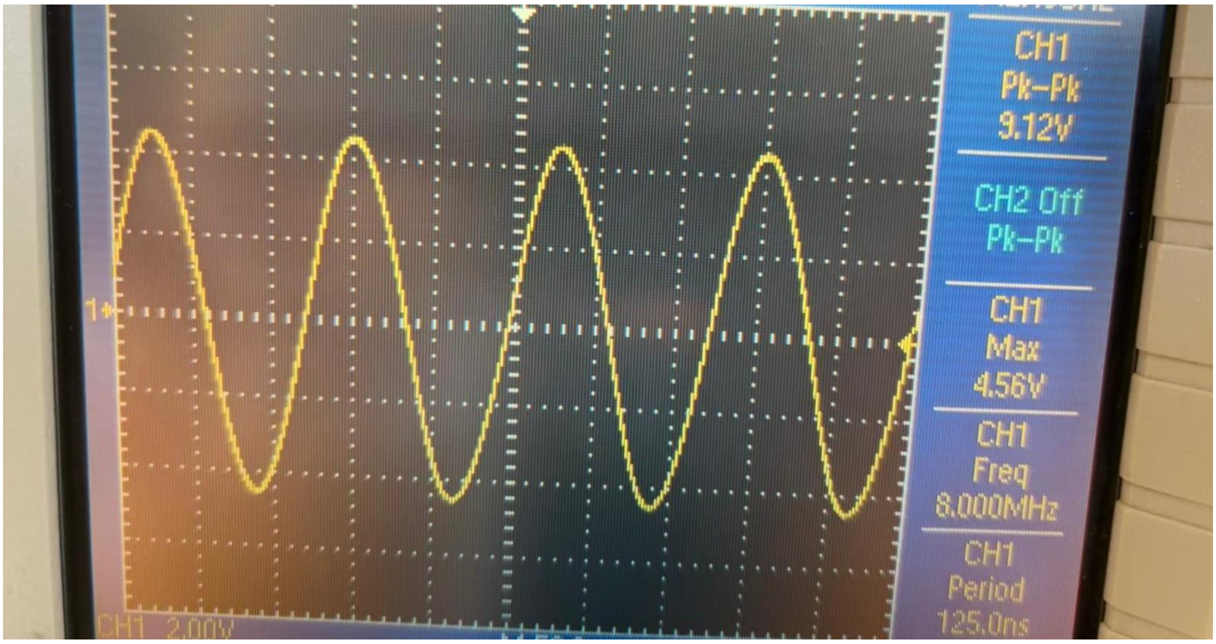

Figure 16: Hardware Result of T-Section, Vmax=4.56V

The average power is found as 55.8 W when R=180ohms and Vmax=4.56V. With the input voltage is 5V, the theoretical average power value is 69mW.

Implementing L-Section:

While building the L-Section circuit, 180 pF capacitors are used for 179 pF capacitors. And by paralleling and trying arbitrary number of inductors, 1.6uH is achieved. Since the inductance value of the inductors were different on breadboard then the multimeter, the right value was achieved after some trying. The input frequency and voltage values are the same as in the T-Section. 8Mhz = f and Vin = 5Vmax

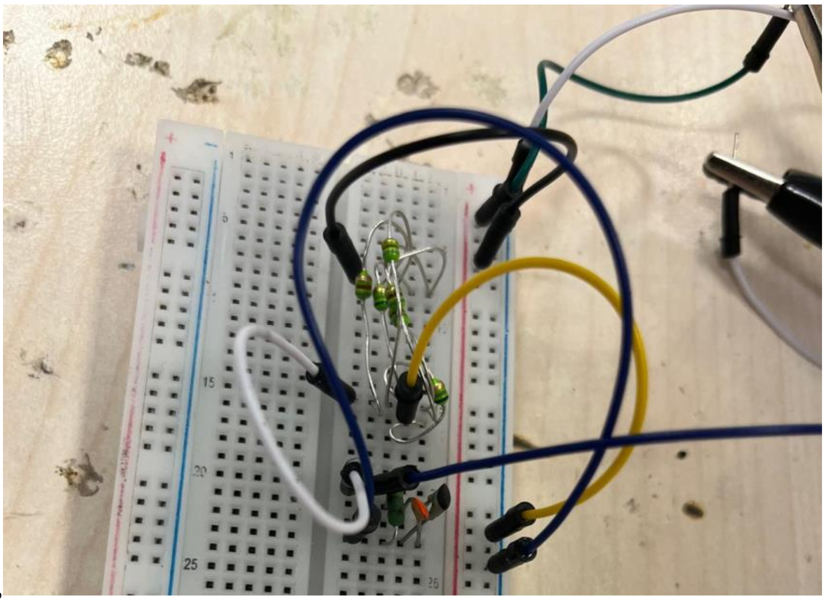

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Figure 17: Hardware Implementation of L-Section

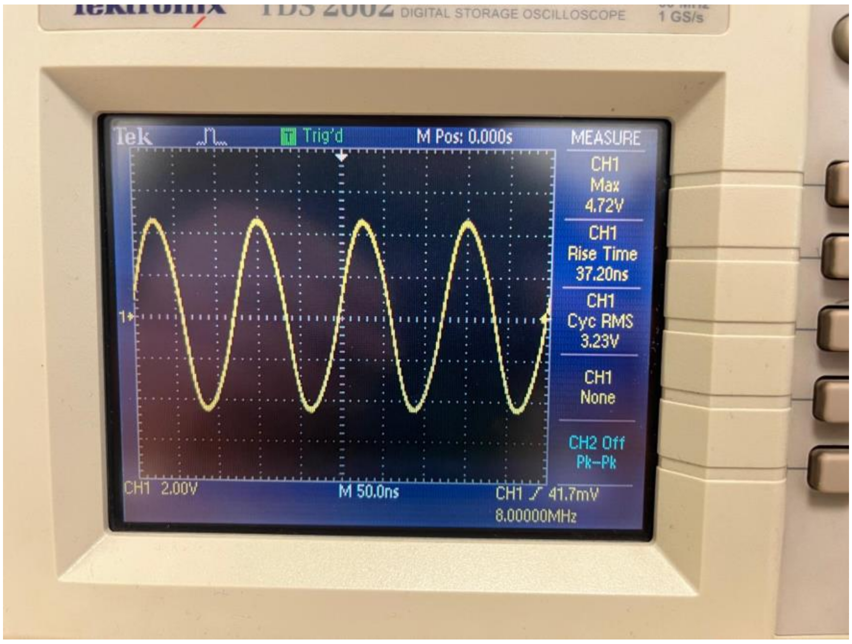

Figure 18: Hardware Result of L-Section, Vmax=4.72V

The average power is found as 62mW when R=180ohms and Vmax=4.72 V. With the input voltage is 5V, the theoretical average power value is 69mW. The overall results of the hardware is shown in Table 3:

	Theoretical Average Power with 5Vmax input	Hardware Result of Average Power with 5Vmax input	Error Percentage
L-Section	69mW	62mW	%10.1
T-Section	69mW	57.8mW	%16.2

Conclusion:

The experiment highlighted the success and adaptability of matching circuits in efficiently delivering maximum power to the load across various setups, including L and T sections. It concluded successfully with minimal errors, as detailed in Table 1 and Table 2. The error values were less than the boundary value which is %20. This is the reason why this experiment is successfully done. Errors might have occurred due to rounding component values in the software lab, while differences in hardware lab results could be attributed to simultaneous use of capacitors and inductors to achieve specific component values, potentially leading to discrepancies.