Report: Circuit Theory Lab 3

Bilkent University Electrical and Electronics Department
EE202-03 Lab 3

Mahmut Semih Akkoç - 22103132

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Purpose

In this lab work, two different passive linear circuits are designed to transfer maximum power to a 180Ω load from a voltage source with output impedance 50Ω at a frequency between 5 and 10 MHz. LTSpice tool has been used for the design process and analysis of the circuit.

Software Implementation

Introduction

Perform time-domain analyses in LTSpice in the proposed circuit in this lab. The lab consists of the following parts:

- Design two passive linear circuits to transfer maximum power to 180Ω load from a voltage source with an output impedance of 50Ω at a frequency between 5 and 10MHz.
- Calculate the maximum power the signal generator can transfer for the chosen sinusoidal signal and compare it to the power delivered to the 180Ω resistor without and with the matching circuit.
- Verify by simulation results that maximum power is transferred using the matching circuit.
- Build the circuit by using linear, passive components.
- Connect the designed circuit to the signal generator and calculate the power dissipated by the 180Ω resistor.

Analysis

For the analysis section, since it has been asked to design two circuits, these circuits will be investigated and analyzed individually.

The First Proposed Circuit

For this circuit impedance inverter with a "T" form will be used. Like the following figure from the "Analog Electronics" book by H. Koymen and A. Atalar.

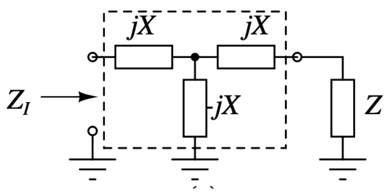


Figure 1: The impedance inverter circuit with a T form.

To find the X value in this circuit one can use the following equation.

$$Z_1 = jX + \frac{1}{1/(-jX) + 1/(jX + Z)} = \frac{X^2}{Z}$$

Therefore with the given values of $Z_1 = 50\Omega$ and $Z = 180\Omega$, this will yield $X^2 = ZZ_1 = 180 * 50 \Rightarrow X = \sqrt{180 * 50} = 94.86\Omega$ using these numbers and f= 10MHz, the capacitor value and inductor value can be determined as follows.

$$jX = j\omega L \Rightarrow L = \frac{X}{\omega} \Rightarrow L = \frac{94.86}{2\pi 10^7} \Rightarrow L = 1.5\mu H$$

$$-jX = \frac{1}{j\omega C} \Rightarrow C = \frac{1}{X\omega} \Rightarrow C = \frac{1}{2\pi 10^7 * 94.86} \Rightarrow C = 168pF$$

Therefore, the impedance matching circuit will yield two series 50Ω impedance to find the maximum power delivered to the load with the following equation.

$$P_{load} = \frac{|V|^2}{4Z_1} = \frac{10^2}{4 * 50} = 500mW$$

The Second Proposed Circuit

For the second circuit, it has been proposed to use a matching by resonant circuit. The mentioned circuit's figure can be found below.

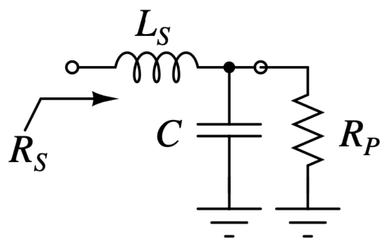


Figure 2: The matching by resonant circuit.

One can carry the following equations to find the L_S and C values.

$$R_S = \frac{R_P}{(Q^2+1)} \text{ with } \omega_o = \frac{1}{\sqrt{L_P C}} \text{ and } Q = \frac{R_P}{\omega L_P}$$

Thus one can calculate the inductance and capacitance values as follows with $R_S = 50\Omega$, $R_P = 180\Omega$ $f = 10\text{MHz}$,

$$Q^2 + 1 = \frac{R_P}{R_S} = \frac{180}{50} = 3.6 \Rightarrow Q = 1.61$$

$$L_S = \frac{QR_S}{\omega_o} \Rightarrow L_S = \frac{1.61 * 50}{2\pi 10^7} = 1.28\mu H$$

$$C = \frac{1}{\omega_o{}^2(1+\frac{1}{Q^2})L_S} \Rightarrow C = \frac{1}{(2\pi 10^7)^2(1+\frac{1}{1.61^2})1.28 * 10^{-6}} = 143pF$$

With the calculated values of the matching by resonant circuit, one can find the power dissipated by the load as,

$$P_{load} = \frac{|V|^2}{4Z_1} = \frac{10^2}{4 * 50} = 500mW$$

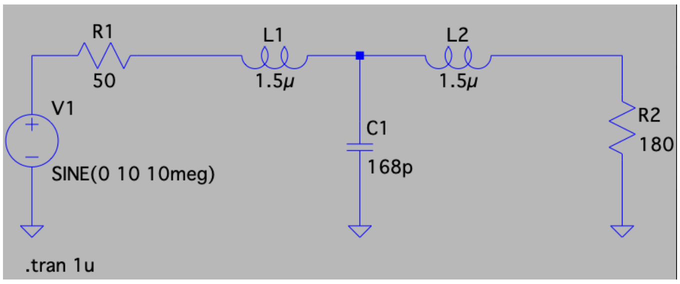
Simulation

As done in the analysis section in the simulation part, a similar approach will be followed to investigate and discuss each part. The following figures include the implementation of the LTSpice tool from the previously explained analysis part.

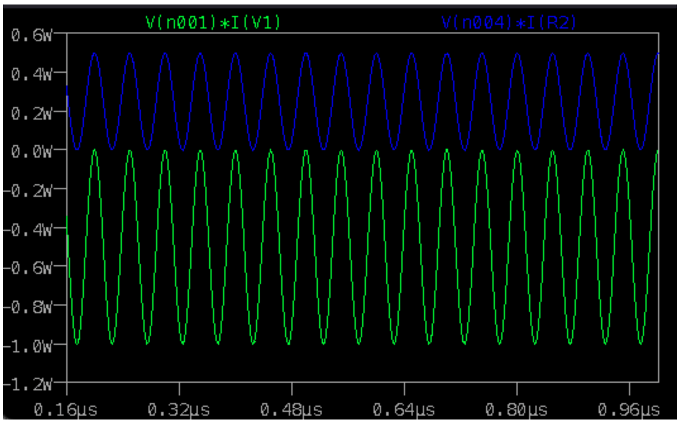
Note that the figures below may seem little, but since they are high quality, the reader may zoom in as much as they wish. The size of the figures is as they are because of aesthetic concerns. If plots are not as visible as required, please kindly zoom in.

The First Proposed Circuit

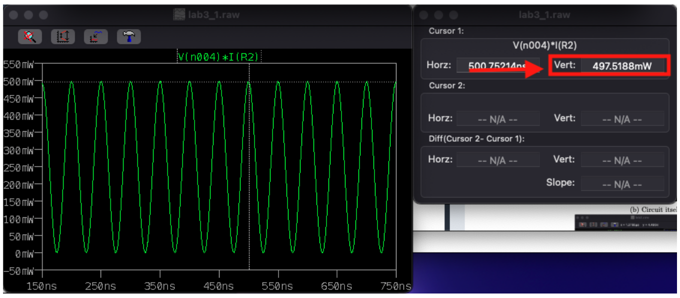
The below figures include the simulations on the LTSpice,



(a) The circuit itself.



(b) Both input power and power delivered to the load.



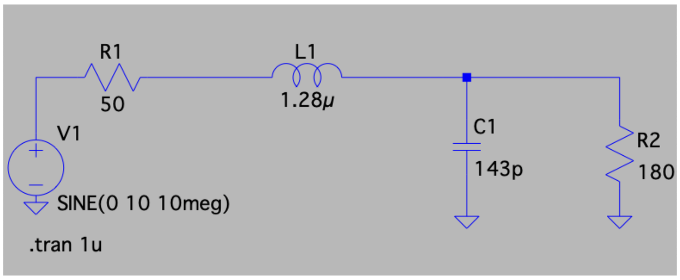
(c) Power delivered to the load.

Figure 3: Impedance matching circuit in the T form.

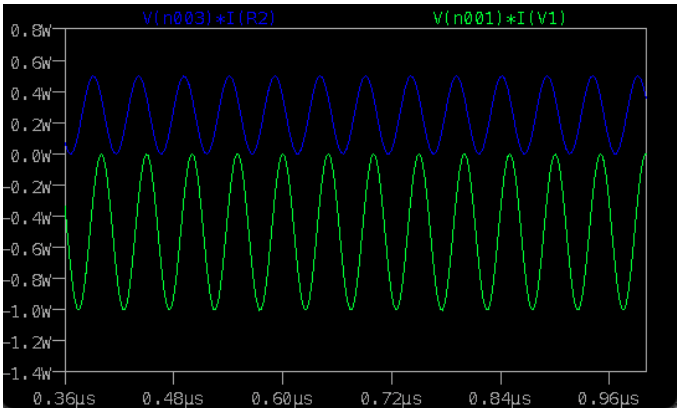
The figures confirm that the maximum power delivered to the load is 0.5W, which is as calculated, but the small difference may be caused due to the rounding error in the values.

The Second Proposed Circuit

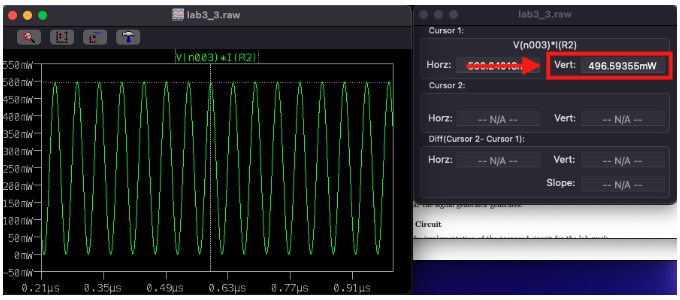
The below figures include the simulations for the transformer idea on the LTSpice tool.



(a) The circuit itself.



(b) Both input power and power delivered to the load.



(c) Both input power and power delivered to the load.

Figure 4: The second proposed circuit in LTSpice.

The figures confirm that the maximum power delivered to the load is 500mW, which is as calculated, but the small difference may be caused due to the rounding error in the values.

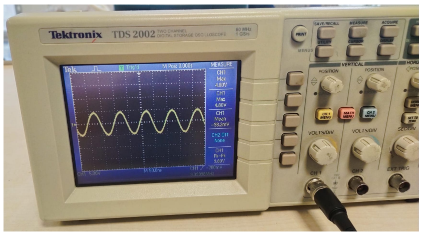
Hardware Implementation

The hardware implementation consists of the above-described software results' application. Additionally, the lab required an extra step to analyze the power delivered to the 47Ω resistor.

47Ω Resistor Power Delivery

The following figure shows the voltage across the 47Ω resistor connected to the signal generator with 10MHz frequency and $V_{pp} = 20V$.

(a) Circuit itself for analyzing the power delivery.



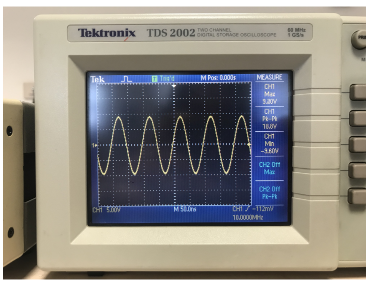
(b) Voltage across the 47Ω resistor.

Figure 5: 47Ω resistor circuit.

With the experimental measurement, one can see that $V_{max} = 4.8V$ which yields the power delivery on the load resistor of 47Ω as $P_{load} = V^2/R = 4.8^2/47 = 490mW$. Compared to the $V_{theo} = 500mW$ there is 2% error.

The First Proposed Circuit

This part is the implementation of the first proposed circuit for the lab work.



(a) The voltage across the load resistor.

(b) Circuit itself.

Figure 6: The first proposed circuit implementation.

Comparison between theoretical and practical values will be shown in the following table,

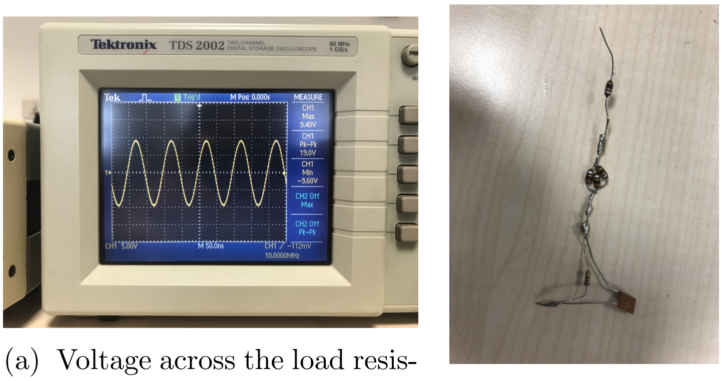
	Experimental Value	Theoretical Value
Voltage Across the Load	9.46V	9.2V
Power Delivered to the Load	497mW	470mW

Table 1: Table of the expected and measured data for the first circuit.

According to the obtained data, one can find the error regarding power delivery as 5%.

The Second Proposed Circuit

This part is the implementation of the second proposed circuit for the lab work.



(a) Voltage across the load resistor.

(b) Voltage output.

Figure 7: The second proposed circuit implementation.

Comparison between theoretical and practical values will be shown in the following table,

	Experimental Value	Theoretical Value
Voltage Across the Load	9.47V	9.4V
Power Delivered to the Load	498mW	490mW

Table 2: Table of the expected and measured data for the second circuit.

According to the obtained data, one can find the error regarding power delivery as 2%.

Conclusion

In conclusion, the aim of the lab experiment was to design a circuit that transfers maximum power to the load resistor of 180Ω. This task has been achieved by two different matching circuits. One is impedance matching other is matching by impedance circuit. The concept of impedance matching is based on equating the real parts of input and output impedances.
However, errors have been encountered in the course of the lab work due to certain reasons, such as the oscilloscope was not in an ideal condition and the errors in the values of the components as well as soldering might have caused some errors due to lack of connectivity. As a result, the measured values were not as expected, as in the first circuit, the error was 5%, and in the second circuit, the error was 2%. To reduce these errors, one could also use less stressed components and solder the components better.
To summarize, the experiment demonstrated how matching circuits can deliver maximum power to the load and how different matching circuits can be done.

References

- Analog Electronics, H. Koymen and A. Atalar, Accessed from Moodle.