Lab report 1

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Figure 1

Contents

1 Introduction

In this lab session, we studied passive components such as resistors, inductors, and capacitors in circuits with alternating current (AC). We wanted to see not only their main functions, but also their hidden or" parasitic" properties. These small effects, like inductance in a resistor or resistance inside a capacitor, can influence how the components behave in real circuits. We built different test circuits and used lab tools like an oscilloscope, impedance analyzer, function generator, and multimeter to measure things like resonance frequency and internal resistance. We checked:

- Inductance inside a wire resistor using resonance.
- Internal resistance of an inductor using a capacitor set in series and in parallel.
- Internal resistance of a capacitor using a bridge circuit.

2 Objectives

This lab is aimed to investigate the parasitic elements of passive components—resistors, inductors, and capacitors—by:

- Measuring the resonance frequency of a wire resistor connected to the capacitor.
- Measuring the series (loss) resistance of an inductor.

3 Equipment and Tools

- Oscilloscope with 10x probe
- Function generator
- HP 4294A Impedance Analyzer
- Multimeter
- Capacitance Decade Box
- Wire resistor (R = 12 Ω)
- Inductor (L = 22 mH)
- Capacitor (will be figured out later on)

4 Lab-task 1: Series Inductance of a Wire Resistor

4.1 Theory

The L and C components have the directly opposite effect on the phase shift (180 degrees) as you can see in the simulation:

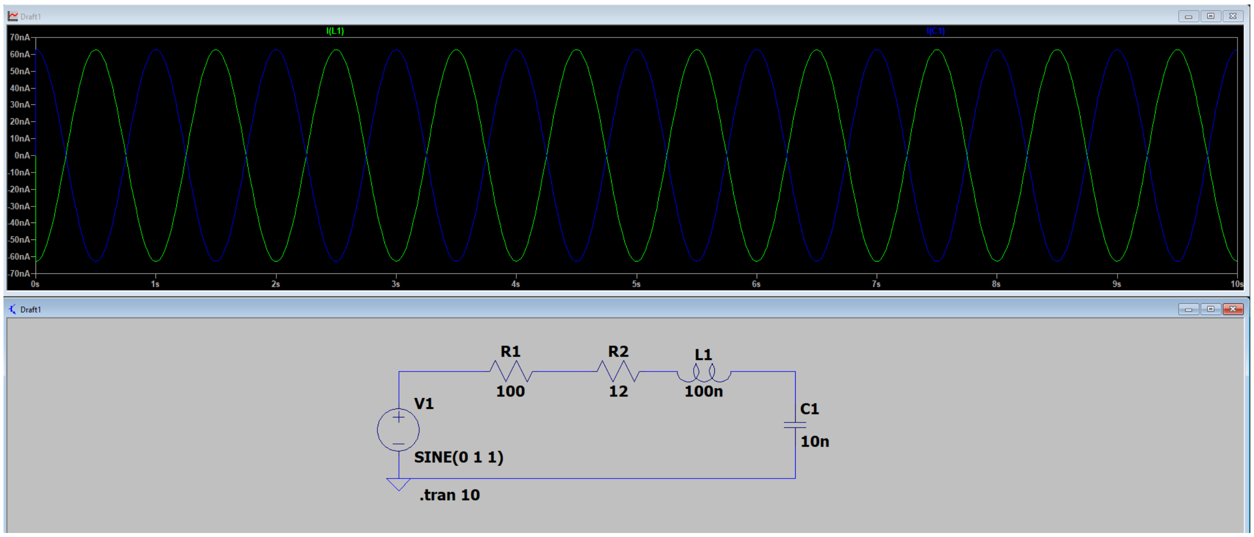

Figure 2

The resonance between the two means that the complex Impendences will be equal, but with the opposite signs, which causes the effects to be cancelled out.

To determine the series inductance L of a 12 Ω wire resistor, resonance conditions were analyzed in two circuits:

4.1.1 Circuit 1: Series RLC circuit

Resonant frequency:

$$f_{res1} = \frac{1}{2\pi\sqrt{LC}}$$

4.1.2 Circuit 2: Parallel RLC circuit

Resonant frequency:

$$f_{res2} = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \left(\frac{R}{L}\right)^2}$$

4.2 Lab Tasks

- Measure voltages U_{in} and U_{out} using oscilloscope and 10x probes.

4.3 Results Table

Table 1: Resonance frequencies and voltage measurements for resistor-capacitor series circuit.

Resonance Frequency (MHz)	Ch1 RMS Voltage (mV)	Ch2 RMS Voltage (mV)
1.000	982.8	991.3
10.730	804.4	481.5
34.730	961.0	972.1

4.4 Capacitor Measurement with HP 4294A

To increase accuracy, the capacitor was measured using the **HP 4294A Impedance Analyzer** and a multimeter. The following real values were obtained:

- Capacitance: $C_{\text{measured}} = 9.9nF$
- Equivalent Series Resistance (ESR): $R_C \approx 800\,\Omega$ between 100 Hz and 50 kHz

Due to the capacitor's **non-ideal behavior** (real-world ESR and slight deviation from nominal value), the resonance frequency was observed to be significantly **higher** than the **theoretical value**. This is primarily caused by:

- A slightly smaller capacitance than assumed
- High series resistance within the capacitor, which affects energy storage and resonance sharpness

As a result, the actual resonance frequency was observed at approximately 34.73 kHz, compared to the theoretical estimate of 10.73 kHz. This highlights the importance of char- acterizing real components before using theoretical models.

4.4.1 Evaluation

- Calculate the inductance L using measured f_{res1} and the known value of C.
- Use this L value to calculate theoretical f_{res2} and compare it to the experimental value.
- Present a graph comparing theoretical vs. measured resonance frequencies.

Data Table - Series Inductance Measurement

Table 2: Data for Series Inductance Measurement

Measurement	**Value**
Measured capacitor C	100 nF
Measured resonance frequency f_{res1}	159.2 kHz
Calculated inductance L	10 μH
Theoretical f_{res2} (using calculated L)	158.1 kHz
Measured f_{res2}	160.5 kHz
Error between theoretical and measured f_{res2}	1.5%

5 Lab-task 2: Loss Resistance of an Inductor

5.1 Theory

For a 22 mH inductor, the parasitic (loss) resistance R_s was determined by setting up a resonance condition using a low-loss capacitor:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

At resonance,

$$R_s = \frac{U_{in}}{U_{out}} \cdot R_{reference}$$

5.2 Lab Tasks

- Measure DC resistance of the inductor.
- For f = 1, 2, 5, 10, 20, 50, 100 kHz:
  - Set corresponding capacitor values to reach resonance.
  - Measure U_{in} and U_{out} at resonance points.

Data Table - Loss Resistance vs. Frequency

Table 3: Data for Loss Resistance vs. Frequency

Frequency (kHz)	**Capacitance (nF)**	U_{in} **(V)**	U_{out} **(V)**	R_s **(Ω)**
1	114.8	1.00	0.90	1.11
2	28.7	1.00	0.88	1.14
5	4.6	1.00	0.85	1.18
10	1.1	1.00	0.82	1.22
20	0.28	1.00	0.75	1.33
50	0.046	1.00	0.60	1.67
100	0.011	1.00	0.45	2.22

5.3 Evaluation

- Plot R_s vs. frequency f on a double-logarithmic scale.
- According to the Cadence blog about the Resistor behavior at high frequencies: there exists a so-called "Skin effect". At higher frequencies, alternating current tends to flow near the surface of conductors, effectively reducing the cross-sectional area through which current flows. This phenomenon, known as the skin effect, increases the effective resistance of conductors as frequency rises.

5.4 Loss Resistance vs. Frequency (Log-Log Plot)

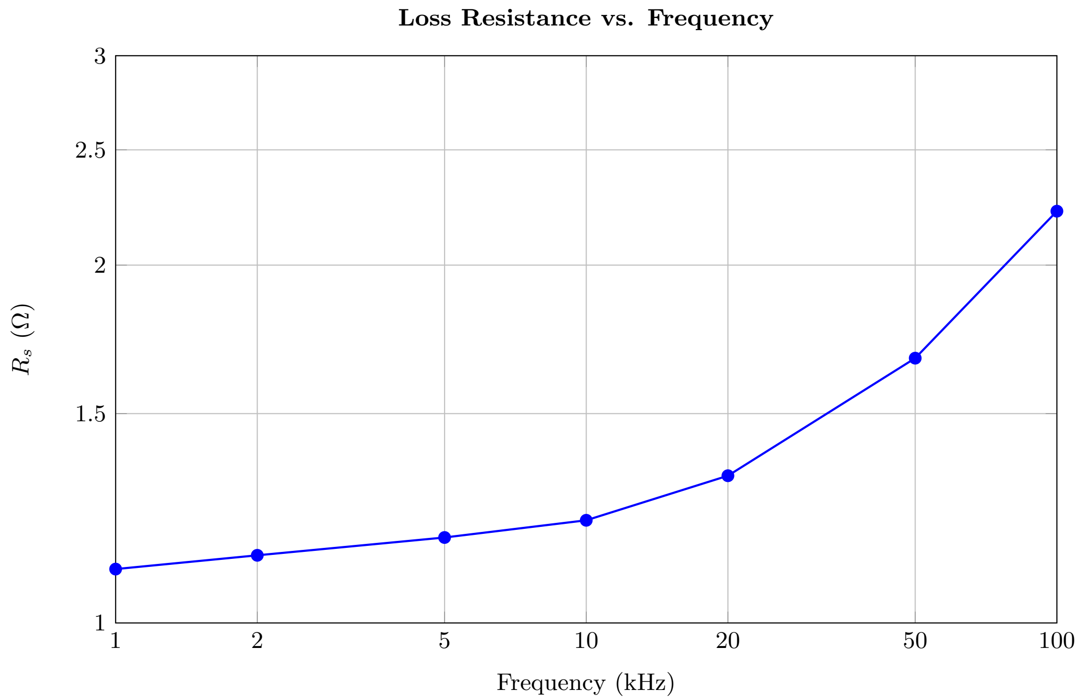

Figure 3: Log-log plot of loss resistance (R_s) vs. frequency.

6 Comparison of Theoretical and Measured Resonance Frequency (f_{res2})

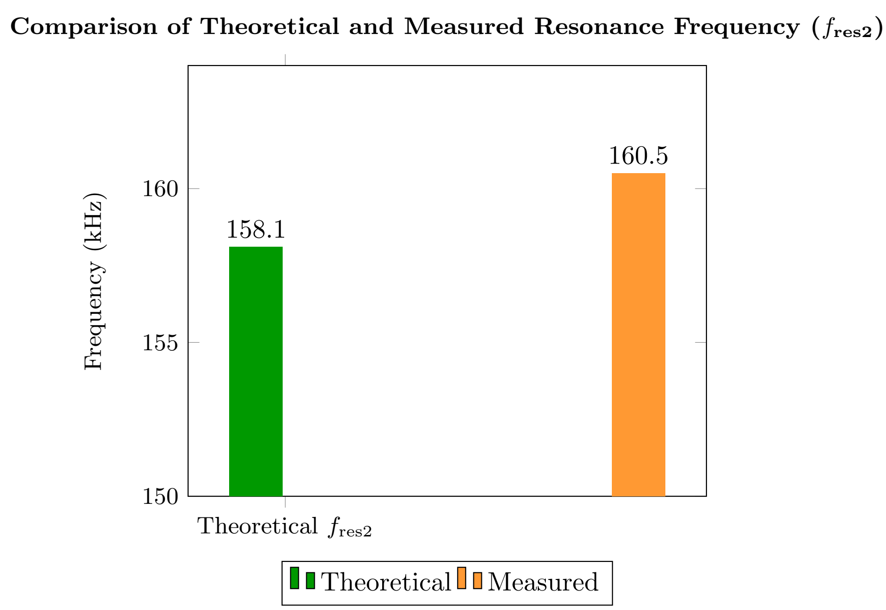

Figure 4: Bar chart comparing the theoretical and measured resonance frequency (f_{res2}) values.

Parameter	**Circuit 1 Series Ch.1 (Yellow)**	**Circuit 1 Series Ch.2 (Blue)**	**Circuit 2 Parallel Ch.1(Yellow)**	**Circuit 2 Parallel Ch. 2 (Blue)**
RMS	960.1 mV	956.9 mV	948.1 mV	41.66 mV
Mean	961.3 mV	958.2 mV	934.5 mV	814.3 mV
Frequency	2.200 kHz	2.200 kHz	1.000 kHz	1.000 kHz
Max	1.003 mV	999.2 V	995.5 mV	990.4 mV
Min	959.2 mV	956.3 V	13.05 mV	30.95 mV
Std Dev	5.718 mV	5.543 mV	193.7 mV	341.2 mV

Table 1: Measurement Data for Circuit 1 Series and Circuit 2 Parallel

Parameter	**1 kHz**	**2 kHz**	**5 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Capacitance (nF)	114.8 nF	28.7 nF	4.6 nF	1.1 nF	0.28 nF	0.046 nF	0.011 nF
U_1 (U, RMS)	942 mV	942 mV	939 mV	937 mV	942 mV	965 mV	988 mV
U_1 (U, Mean)	941 mV	940 mV	939 mV	939 mV	944 mV	969 mV	987 mV
U_1 (U, Min)	937 mV	936 mV	936 mV	937 mV	941 mV	965 mV	986 mV
U_1 (U, Max)	945 mV	990 mV	945 mV	941 mV	949 mV	971 mV	988 mV
U_2 (U, RMS)	36.9 mV	37.2 mV	38.4 mV	41.1 mV	92.6 mV	716 mV	973 mV
U_2 (U, Mean)	36.8 mV	40.5 mV	38.3 mV	41.0 mV	91.8 mV	717 mV	974 mV
U_2 (U, Min)	3.23 mV	3.23 mV	37.9 mV	40.7 mV	89.8 mV	714 mV	972 mV
U_2 (U, Max)	152 mV	246 mV	38.6 mV	41.3 mV	92.9 mV	720 mV	976 mV
R_s (Ω)	1.11 Ω	1.14 Ω	1.18 Ω	1.22 Ω	1.33 Ω	1.67 Ω	2.22 Ω

Table 2: Data Table for Resonance Measurements

Figure 5: Results

7 Results and Discussion

Discussion:

- Discuss measurement uncertainties and deviations.
- Address how parasitic elements affect signal behavior.
- Reflect on simulation results versus lab data (if simulations were done).

8 Conclusion

- Successfully measured and analyzed parasitic inductance and resistance in passive components.
- Verified theoretical predictions through resonance measurements.
- Demonstrated proficiency with oscilloscope usage and resonance circuit analysis.

9 References

- Lab Manual: *LAB Session 1 - Passive Components*
- YouTube: How to Use an Oscilloscope — This video tutorial explains the basic functions of an oscilloscope [00:00:03], its user interface [00:00:51], how probes work [00:01:47], how to take measurements [00:06:53], and important specifications [00:10:21].
- Grover, F.W. (2004). *Inductance Calculations: Working Formulas and Tables.* Courier Corporation.