ELEC2070 2023
Laboratory Worksheet for Weeks 8 and 9
AC circuits and AC power

***Abstract*— Frequency-domain analysis is used for finding the steady-state (AC) response of circuits to sinusoidal source functions. It requires simple complex algebra and it is suitable even for complicated circuits. In this practical session several ac circuits will be built, measured and analysed. Matlab software will be used for verifying the manual calculations of complex numbers and for plotting sinusoidal waveforms.**

I. INTRODUCTION

A periodic time signal can be represented as a linear combination of sinusoids in the frequency domain. Circuits are then analysed or designed in the frequency domain assuming a single sinusoidal source at a time. This is called steady-state AC analysis. The response to each frequency component is then converted back to the time domain to obtain the total steady-state response of the original periodic time signal.

In the frequency domain, a circuit can be analysed in a similar way to DC circuits using Kirchhoff's and Ohm's Laws but the circuit elements are represented by complex numbers called impedances. Matlab software is useful when calculating complex numbers. It can also be used for plotting sinusoidal waveforms in time and frequency domains.

The oscilloscope is the most convenient measurement tool for AC circuits. However, it measures the waveforms in the time domain and it requires some interpretation to express them in the frequency domain.

Please do up to the start of Section VII (Point 20) in Week 8.

II. PRELIMINARY WORK

Week 8: Study the lecture notes and the text book/s [1-2] to become familiar with the concepts of frequency domain, phasors, impedances and ac circuit analysis.

1. In your logbook, write the phasor of a voltage function given as:

$$v(t) = 10\cos(\omega t + 30°)$$

Show it in the complex plane. Calculate its real and imaginary parts and mark them on the complex plane.

2. Write the impedance, voltage and current relationships of a capacitor in the frequency domain.

3. Write the impedance, voltage and current relationships of an inductor in the frequency domain.

4. Calculate the equivalent impedance of the circuit in Fig. 1 at ~0 Hz, 200 Hz, and 100 kHz in magnitude and angle. Make a table for the magnitude and angle with respect to frequency.

5. If the circuit in Fig. 1 connected to an AC voltage source described as in question 1, calculate the total current in phasor form and add to the table.

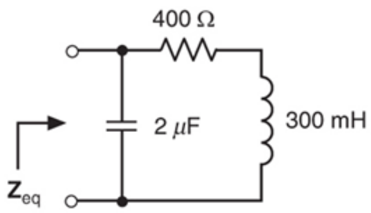

Fig. 1. Circuit of Example 10.5-5 in text book [1]

Week 9: Study the lecture notes and the text book/s on AC power.

6. Calculate the complex power generated by the voltage source in question 5 at 200 Hz.
7. Calculate the average power generated by the voltage source.
8. Calculate the average power to the 400Ω resistor in question 5 at 200 Hz.

III. TIME MANAGEMENT

Look through the whole worksheet before you start and plan your time so that you can complete the work in two weeks. Write your plan in your logbook. At the end of the two weeks compare your actual times to your initial estimates.

IV. LOGBOOKS AND PARTICIPATION MARKS

Participation marks are given to each student at each laboratory session following the marking rubric published on iLearn. The marks cover attendance, punctuality, positive engagement and logbook recording of each session. All students should have their logbooks signed and dated by their tutor before leaving each laboratory session.

V. COMPLEX ALGEBRA AND SINUSOIDAL FUNCTIONS WITH MATLAB

9. Start Matlab, refer to Appendix B in [1] for a brief introduction to complex numbers and plotting, also available in iLearn, (or Section 5.8 and Appendix A in [2]).

10. Plot a cosine voltage function, with 1 V amplitude and 1kHz frequency, with respect to time, and for a time

interval of 2-3 periods. Use a script file for easier debugging and for future use.

Sample script file for plotting a sinusoidal current:

```
clear all
close all
t=0:.001:15;
i=83*sin(0.866*t+0.1);
plot(t,i,'r','LineWidth',2)
ylabel ('Current (mA)')
xlabel ('Time (s)')
grid on
```

11. Add a cosine function to the plot with the same amplitude and frequency but with a 30° phase shift. (you can use “hold on” command after the first plot). Convert 30° into rad/s before using as the argument of the cosine function.
12. Plot an AC voltage waveform with 1 V amplitude and 1kHz frequency.
13. In the laboratory, what setting do you need to use on the signal generator to generate a sinusoidal voltage with 1 V amplitude and 1kHz frequency. Measure the signal generator output with the oscilloscope and confirm your setting by comparing it to the Matlab plot.

VI. RC CIRCUIT

14. Use a resistor in the range of 500 Ω to 5 kΩ, available in the laboratory, and a capacitor in the range of 1-10 nF to design a circuit as in Fig. 2. Use the signal generator as the voltage source v_I. Output voltage v_O is to be measured with the oscilloscope.
15. Remember the signal generator has an internal resistor, which is not shown in Fig. 2, and the oscilloscope has an internal resistor and capacitor. These may or may not affect your measurement. You will need to comment on this later.

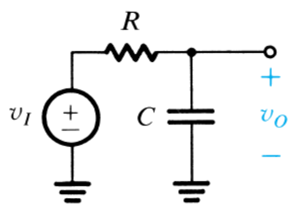

Fig. 2. Simple RC circuit with low-pass frequency response

16. If the signal generator is set to generate a sinusoidal voltage with 1 V amplitude and 100 kHz frequency, calculate the impedance and the expected v_O. What do you expect to measure at very low frequencies (close to 0 Hz) and at very high frequencies (say at 1 GHz)? Why this circuit is called a low-pass circuit?
17. Calculate the corner frequency f_c of your circuit using the following formula. Notice that it relates to the natural time constant you have already learned.

$$f_c = \frac{1}{2\pi RC}$$

18. Connect the circuit and measure the amplitude of v_I and v_O and the phase shift of v_O compared to v_I at 100 kHz (or at a frequency close to the corner frequency of your circuit). Use two channels of the oscilloscope to measure both v_I and v_O at the same time.
19. Check your calculations with Matlab.
20. Calculate the input impedance of your oscilloscope at your measurement frequency and compare to the impedances you were measuring. Did the oscilloscope impedance change the voltage you were measuring?

VII. RL CIRCUIT

21. Use a resistor in the range of 50 to 100 Ω and an inductor in the range of 20-300 µH to design a circuit as in Fig. 3. Repeat the calculations and measurements of Section VI for the inductor circuit. This time use a higher frequency such as 200 kHz for your calculations and the measurement. Note the corner frequency of the inductor circuit is calculated as

$$f_c = \frac{R}{2\pi L}$$

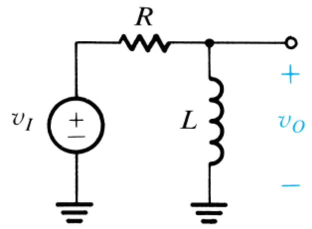

Fig. 3. Simple RL circuit with high-pass frequency response

VIII. AC POWER

22. Pick one of your circuits in Sections VI and VII and assume it is connected to a load resistance of 100 Ω (at the terminals of v_O). Calculate the complex and average powers delivered to the 100 Ω load at the frequency of your previous calculation and measurement.
23. Check your calculations with Matlab.
24. Connect the circuit, measure v_O (and its phase relative to v_I) and verify your power calculations.

IX. MAXIMUM AVAILABLE AVERAGE POWER

25. Calculate the Thévenin equivalent circuit seen by the 100 Ω load in Section VIII.
26. What is the value of the load impedance that would totally absorb the maximum available average power from the Thévenin equivalent?
27. Calculate the maximum average power available.
28. Can you make a load in the laboratory that would totally absorb the maximum available power at this frequency?

REFERENCES

[1] J. A. Svoboda, R. C. Dorf, “Introduction to Electric Circuits 9th edition,” Wiley, 2014.

[2] A. R. Hambley, “Electrical Engineering, Principles and Applications, International Sixth Edition,” Pearson, 2014.