

Experimental Methods

PY2108

Practical Session 2: *RC Circuits and Frequency Response*

M.P. Vaughan

Contents

1	Learning objectives	2
2	Pre-lab preparation	2
2.1	Theory	2
2.2	Plotting the transfer functions	3
2.3	Preparing for experimental data	3
3	Methods	4
3.1	Constructing the <i>RC</i> circuit	4
3.2	Setting up the function generator and oscilloscope	4
3.3	Voltage and phase shift measurements	4
4	Post-lab	5
4.1	Error analysis	5
4.2	Report requirements	5

1 Learning objectives

The objectives of this practical section are to

1. Understand the dynamics of RC circuits and appreciate their use as low/high-pass filters.
2. Consolidate experience using breadboard, function generators and analogue oscilloscopes
3. Gain experience measuring the frequency response of a system
4. Perform an error analysis on measured data
5. Gain experience of professional report writing

2 Pre-lab preparation

2.1 Theory

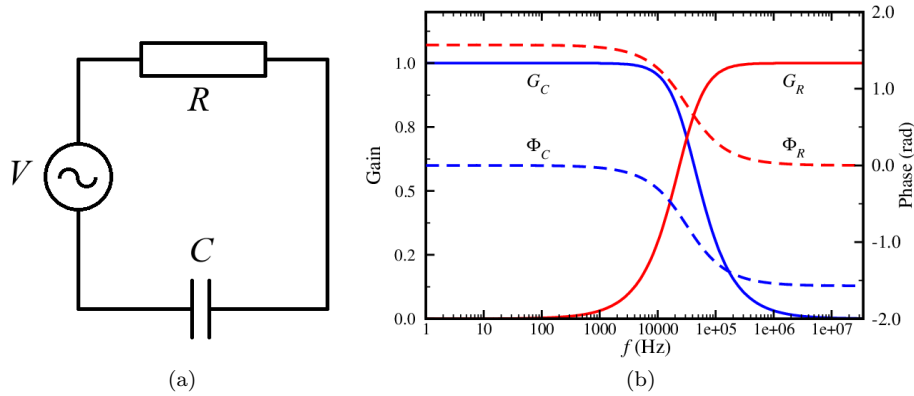


Figure 1: (a) Series RC circuit diagram. (b) The frequency response of an RC circuit with $R = 50\ \Omega$ and $C = 100\ \text{nF}$.

For the series RC circuit shown in Fig. 1 driven by an AC supply, the voltages across R and C are

$$V_R = \frac{i\omega RC}{1 + i\omega RC} V \quad (1)$$

and

$$V_C = \frac{1}{1 + i\omega RC} V, \quad (2)$$

where V is the input voltage and Z_C is the complex capacitive impedance

$$Z_C = \frac{1}{i\omega C}. \quad (3)$$

The *transfer functions* for the resistive and capacitive elements, H_R and H_C respectively, are given by

$$G_R = |H_R| = \frac{\omega RC}{[1 + (\omega RC)^2]^{1/2}} \quad (4)$$

and

$$G_C = |H_C| = \frac{1}{[1 + (\omega RC)^2]^{1/2}}, \quad (5)$$

for the gains and

$$\phi_R = \tan^{-1} \left(\frac{1}{\omega RC} \right) \quad (6)$$

and

$$\phi_C = \tan^{-1} (-\omega RC). \quad (7)$$

for the phase shifts.

2.2 Plotting the transfer functions

In a spreadsheet package, plot the transfer functions H_R and H_C . It will be best at this stage to plot the gains G_R and G_C on one graph and the phase shifts ϕ_R and ϕ_C on another. Ensure that it is easy to adjust the values of R and C on your graph. Note also that the frequency axis should be logarithmic (use base 10), so set frequency points that will be evenly spaced on the final graph.

It is important that you bring this spreadsheet to the lab with you.

2.3 Preparing for experimental data

It will be advantageous to have your spreadsheet set up ready to accept data. You should pick a realistic number of frequency points to take your data over (about 10 points would be good). It will be useful to have your spreadsheet set up so that you can easily change the minimum and maximum frequencies and that the data points will be evenly spread between them on a logarithmic scale.

You will be taking data for both gain and phase shift, although, because of time constraints, you will only be taking measurements for H_C . For the gain measurements, you will need columns to record

1. The peak-to-peak input signal voltage in divisions (this may change as you change the frequency)
2. The number of volts per division for the input signal (to calculate actual voltage)
3. The actual input voltage in volts (or convenient unit)
4. The peak-to-peak voltage over the capacitor in divisions

5. The number of volts per division for the measurement of V_C (this may be different to that used for the input signal)
6. The actual value of V_C (ensure that this is in the same units as for the actual input voltage)
7. The calculated gain

For the phase shift measurements, you will need columns to record

1. The time difference between traces in divisions
2. The number of seconds per division
3. The time division in seconds (or convenient unit)
4. The calculated phase shift (you should explain how you calculate this in your final report)

These data should be plotted on the same graphs as you theoretical calculations. It is highly recommended that you plot the data points as you take them (this gives a way of checking your method as you go).

3 Methods

3.1 Constructing the RC circuit

For this experiment, you will be using a $56\ \Omega$ resistor and a $0.1\ \mu\text{F}$ capacitor. On a breadboard, construct the circuit shown in Fig. 1 (a). The AC voltage source will be supplied by a function generator, connections to appropriate terminals should be made at this point in the circuit. Terminals should also be connected across the capacitor to record V_C .

3.2 Setting up the function generator and oscilloscope

The function generator should be set to produce a sinusoidal output. You will need to attach a ‘T’ connector to the output of the generator to allow two coaxial cables to be connected to it. One of these will drive the RC circuit, the other should be connected to channel 1 of the oscilloscope. A second coaxial cable should be connected between the terminals over the capacitor and channel 2 of the scope. Ensure that AC coupling and the dual trace mode have been selected.

3.3 Voltage and phase shift measurements

The frequency points chosen for these measurements should span a reasonable window around the range where G_C goes from 1 to zero. However, bear in mind that the function generator will not go all the way up to 10 MHz (you should check the maximum frequency that it can output). The output of the generator should be adjusted high enough not to be distorted too much by noise, although it is always advisable to keep voltages fairly low. A peak-to-peak voltage of 1 V is suggested.

Note that you may find that you need to adjust the vertical and horizontal offsets at each new frequency to align the signals to the screen grid. For the phase shift measurements, it is recommended that you record the time differences between the peaks of each signal.

4 Post-lab

4.1 Error analysis

Using the analytical tools in the supplementary manual ‘Error Analysis’ (available on blackboard), perform an error analysis on your data and calculated values. You should show the working of this in your report. Hence, add error bars to your data points (or argue that the errors would be too small to be noticed if this is the case).

4.2 Report requirements

You should type up your report. Preferably, equations should be typeset using suitable software (e.g. Equation Editor in Word, using Scientific Word or Latex). The report should have the following structure:

Title This should have the main heading ‘PY2108 Experimental Methods: Session (2)’ and then an appropriate sub-heading of your choice.

Author Your name and student number.

Abstract A very brief description of the report.

Introduction A short introduction. Possible applications of the methods employed could be included here.

5 %

Theory This should include any theory that you actually use to either make testable predictions (e.g. plot theoretical graphs) or analyse the data. Try to keep this as brief as possible when describing experimental work.

10 %

Method A description of the experimental setup and how you took the data. You should also include your error analysis in this section.

35 %

Results / Discussion Presentation of the results. For this experiment, this should be graphs of the transfer functions with the data plotted over the top of the theoretical curves. Ensure that you clearly label all axes (with units where appropriate) and data sets. Also ensure that there is a figure caption. You may include discussion of any points of especial interest encountered in the lab in this section.

35 %

Discussion / Conclusions Brief conclusions summarising the report. You may also include some discussion of the experiment and possible applications in this section.

5 %

A further 10 % will be given for presentation, including the correct structure and grammar.