Lab 4 – AC Circuits and Filters

The purpose of this lab is to characterise RC and CR circuits and their behaviour as filters, i.e. circuits that block/attenuate some frequency components of the input signal but let pass other components. **The activities in this lab will contribute to the lab report that you will need to submit, hence be careful in taking notes and selecting data points you may need!**

Let us summarise some basic concepts about periodic time-dependent signals. Periodic time-dependent signals are known by the term *AC*, for *alternating current*. Examples include sine waves and square waves, as shown in Figures 4-1 and 4-2. The *period* **T** is the time taken for the signal to repeat itself, and the reciprocal of the period is the *frequency* ***f*** (*f = 1/T*). Frequency is the number of times the signal repeats per second, and is measured in Hertz, *Hz*.

Also given for the sine wave of Figure 4-1 are several important parameters involving the signal *amplitude*, either in current or voltage, which we will define and study in this course.

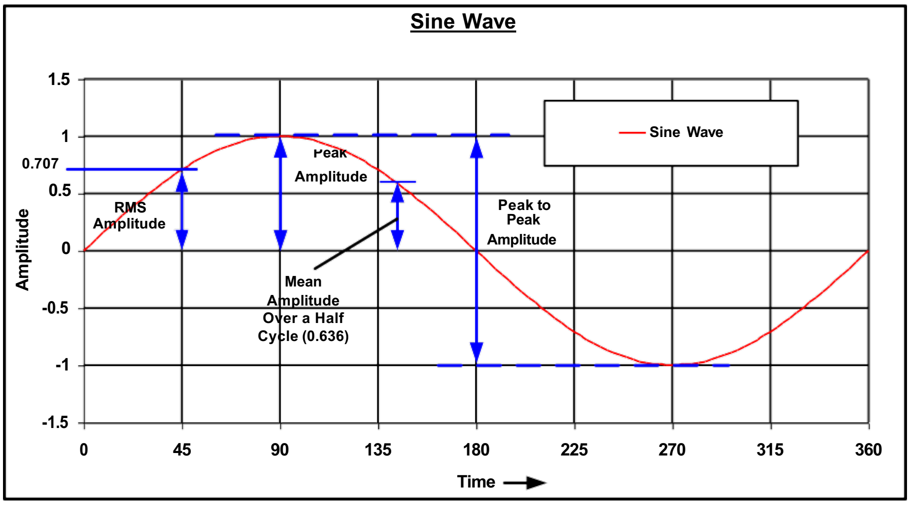

Figure 4-1 Sine wave

Figure 4-2 shows two identical sine waves (i.e. same amplitude and frequency) displaced in time. This time delay, t, can be represented as a *phase shift* ϕ. It is measured as a fraction of one complete waveform of period T and represented as an angular measurement in degrees or radians (1 radian = $360/2\pi$ degrees). In degrees, ϕ can vary in the range 0^0 - 360^0, and in radians, the range for ϕ is 0 to 2π). So: Phase shift $\emptyset = \frac{t}{T} \times 360°$.

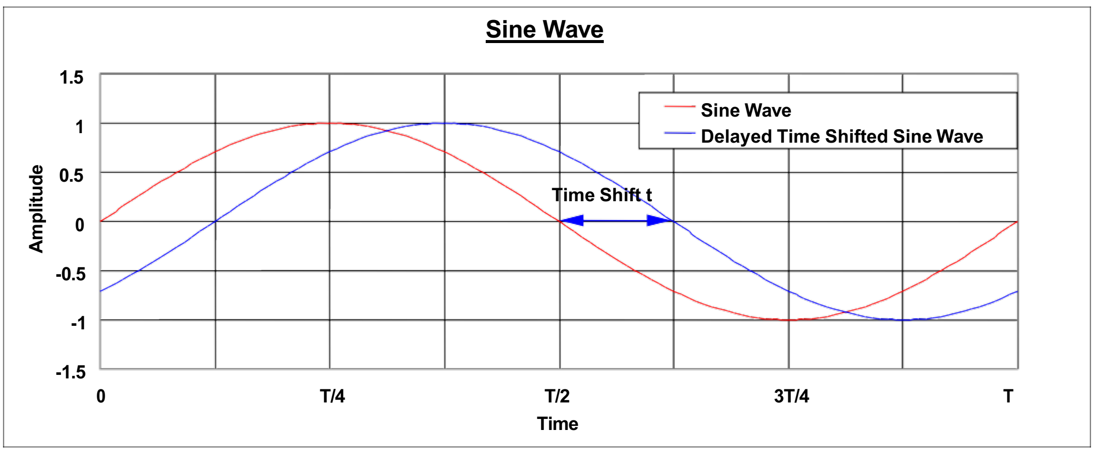

Figure 4-2 Phase-shifted sine waves

Let us recall first **some elements of theory** that we will study in detail during the course.

- $\omega = 2\pi f$, where f is the signal frequency in Hz and ω is the angular frequency, so f and ω <u>are not</u> the same parameter.
- A low-pass filter has the highest gains at lower frequencies.
- A high-pass filter has the highest gains at higher frequencies.
- A band-pass filter has the highest gains in a range of frequencies in the middle.
- A band-stop filter (or notch filter) has the highest gains outside a range of frequencies.
- Gain is often displayed in decibels, dB. This means taking 20 times the logarithm in base 10 of the gain -> $20\log_{10}(|V_{out}/V_{in}|)$
- The bandwidth of a filter, i.e. the range of frequencies that the filter lets pass without attenuating them, is often quoted in terms of the -3 dB from the maximum gain (i.e. the frequency at which the gain is -3 dB). In these circuits, this is given by the formula below and the frequency is generally called the cut-off frequency.

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

Let us begin with the **experimental work.**

Task 1: RC Circuit

1. Construct the RC circuit shown in Figure 4-3 (C = 10 nF, R = 1.2 kΩ), or a close value. The signal generator is an arbitrary waveform generator. The two channels of the oscilloscope will be connected to the two nodes shown in Figure 4-3 (do not forget to connect the ground!). Channel 1 is the input of the circuit (signal generator), and Channel 2 is the output.

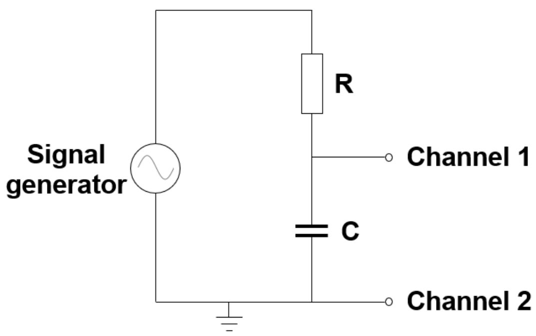

Figure 4-3. CR circuit schematic

2. Calculate the theoretical cutoff frequency of the RC circuit you built. Note it down here:

$f_{c\_theoretical}$ =____________________________________

3. Use PSpice simulation to obtain the simulated cutoff frequency. Write it down here.

$f_{c\_simulated}$ =____________________________________

4. Use PSpice simulation to obtain the gain and phase shift plots of the CR circuit. Record them here.

5. Implement the circuit on a breadboard. Set the arbitrary waveform generator to output a sine wave with a frequency range from 10 Hz to 20 kHz, and a peak-to-peak amplitude of 2 V. The step size between the minimum and maximum frequency is up to you, but ensure enough points (~10) to produce a smooth curve. For each frequency value, record the frequency, input and output signal peak-to-peak amplitudes, and the phase difference between input and output in the table. You may need to adjust the amplitude and time scales of the oscilloscope to view the waveforms properly.

Frequency (Hz)	**Peak-to-peak (V)**	**Phase difference(°/rad)**

Draw two plots in the space below: one representing experimental gain (in dB) and the other representing phase shift, both as functions of frequency for the circuit. Set the X-axis to a logarithmic scale (this can be easily achieved in Excel with the appropriate chart option). Plot both gain and phase shift for the CR circuit below and compare them with PSpice simulation results. Show the plots to the GTA or instructor before proceeding.

6. Comment on the gain plot: which frequency ranges can pass through this filter, and which cannot?

7. What type of filter is this?

8. From your data, what is the experimental cutoff frequency?

Task 2: CR Circuit

2. Construct the CR filter circuit as shown in Figure 4-4 (C = 10 nF, R = 12 kΩ).

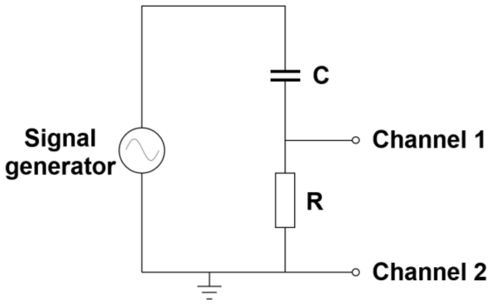

Figure 4-4 RC circuit schematic

3. Observe the gain and phase shift diagrams in PSpice and plot them below.

4. Implement the circuit on a breadboard. For each frequency value, record the frequency, input and output signal peak-to-peak amplitudes, and the phase difference between input and output using the oscilloscope.
5. Plot the experimental gain (in dB) and phase shift, both as functions of frequency, and show it to the GTA.

Frequency (Hz)	Peak-to-peak (V)	Phase difference(°/rad)

6. Comment on the gain plot: which frequency ranges can pass through this filter, and which cannot?

7. What type of filter is this?

8. From your data, what is the experimental cutoff frequency?

<u>Task 3: Cascaded RC and CR Circuits</u>

Now we will study how combining the RC and CR circuits, which were analysed separately during the earlier tasks, can form a new circuit with an overall **band-pass characteristic**. This means that only a certain range of frequencies can pass through the filter, while frequencies above and below this range will be attenuated.

1. First, try to think about how you would combine the CR circuit and the RC circuit you have analysed to obtain a band-pass filter. Try to sketch the circuit below (Remember that you want to eliminate at your output both the highest frequencies (what filter can do that?) and the lowest frequencies (what other filter will you then need?)

2. Sketch the gain plot in logarithmic scale that you would expect from a band-pass system. Highlight in the plot the cut-off frequencies (you will have two, one related to the RC circuit and one related to the CR circuit).

3. Discuss these sketches with the GTA to see if your approach is correct.

4. Build the circuit in PSpice using C1 = 10 nF, R1 = 1.2 kΩ, C2 = 10 nF, R2 = 12 kΩ. Plot the gain and phase shift diagrams as observed on PSpice below.

5. Implement the circuit on a breadboard and note down the input and output signal peak-to-peak amplitudes, and the phase difference between input and output for each frequency.

Frequency (Hz)	Peak-to-peak (V)	Phase difference(°/rad)

6. Plot the experimental gain (in dB) and phase shift, both as functions of frequency, and show it to the GTA.

7. Comment on the gain plot: Is this a valid band-pass filter?

8. Now, swap the positions of R and C components in the circuit and do the PSpice simulation again. Plot the gain and phase shift diagrams as observed on PSpice.

9. Implement the modified circuit on a breadboard and note down the input and output signal peak-to-peak amplitudes, and the phase difference between input and output for each frequency.

Frequency (Hz)	**Peak-to-peak (V)**	**Phase difference(°/rad)**

10. Plot the experimental gain (in dB) and phase shift for the modified circuit below, both as functions of frequency, and show it to the GTA.

11. Comment on the gain plot: Is this a valid band-pass filter?

12. Why are the results of Task 3 and Task 4 different?

13. How does the loading effect in cascading affect the results?

14. How can a flat passband be achieved?