Experiment 4

RC and RLC Circuits

Objectives:

In this experiment you will learn how to:

- Investigate the frequency response and time response of RC circuits.
- Investigate the frequency response of series RLC circuits.
- Use the oscilloscope to do frequency, time, and phase measurements.

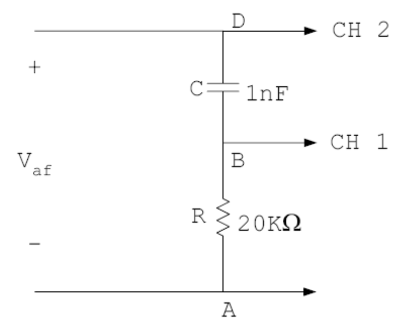


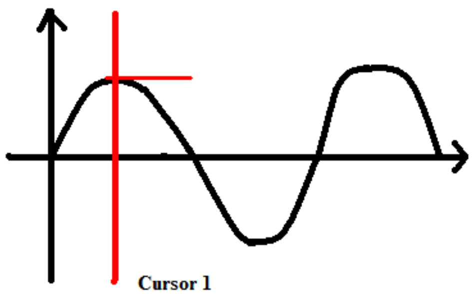
Fig. 1

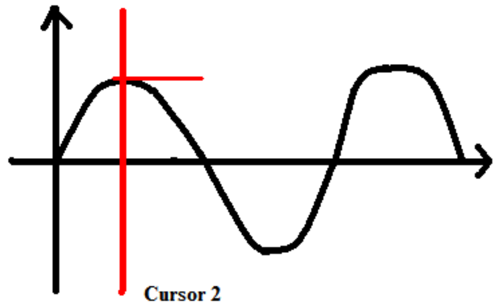
❶*W*hat are the different ways for measuring the phase shift?

Method 1:

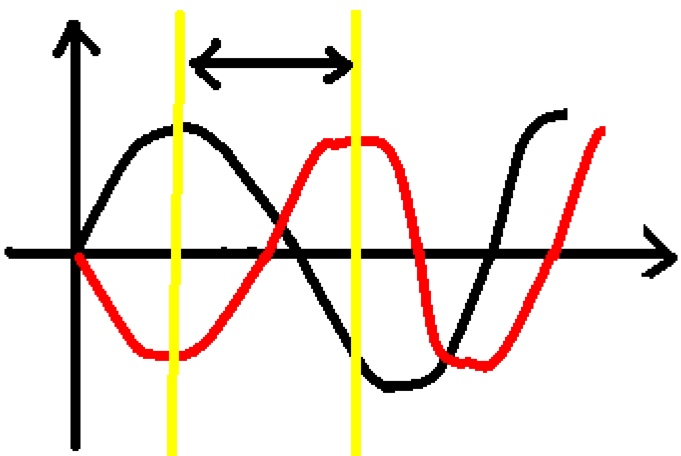
- **Using the function generator, apply a sinusoidal voltage (Vaf = 6 V peak-to peak) of frequency 5 KHz to the input of the circuit shown in Fig. 1**
- **By the use of the oscilloscope connect channels 1 and 2 across V_{BA} and V_{DA}**
- **Superpose the two traces of V_{BA} and V_{DA} *to have the same horizontal axis and adjust the VOLT/DIV and SEC/DIV settings to get stable traces.***
- **Place the two vertical cursors on each peak**
- **press the measure bottom and read ∆T and T(the period)**

- **Find** $\phi = \frac{\Delta T}{T} \times 360^{\circ}$





***Note**: The phase difference can be measured from the time instants at which the waveforms cross the time axis. Consider Vaf to be of the form* **3sinώ** *V and V_{BA} to be of the form V.*



Method 2:

We use the formula:

$$\tan\phi = \frac{X_C}{R} \text{ where } X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

Method 3- Lissajous method:

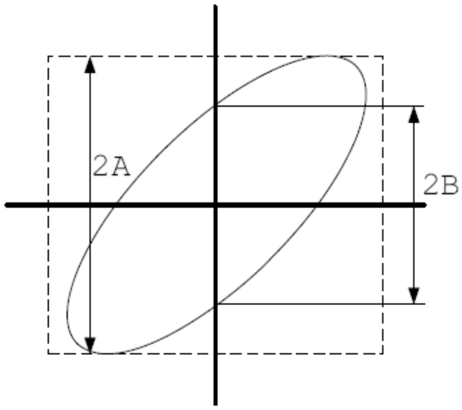


Fig. 2

Leaving the connections the same as in Part A.1., set the sweep rate to X-Y mode. V_{BA} and V_{DA} will be connected to the X and Y channels of the oscilloscope. An ellipse (called the Lissajous figure) will be observed on the oscilloscope screen resulting from the superposition of two perpendicular sinusoidal signals V_{BA} and V_{DA}. Adjust the VOLTS/DIV controls of X and Y and use the vertical and horizontal POSITION knobs to center the ellipse symmetrically as shown in Fig. 2.

- **Find 2B and 2A by placing the horizontal cursor with the same horizontal axis and adjust the VOLT/DIV and SEC/DIV settings to get stable traces and measure the divisions or simply count the divisions**
- **Apply the formula:**

$$\sin\phi = \frac{B}{A}$$

General Remarks on Lissajous:

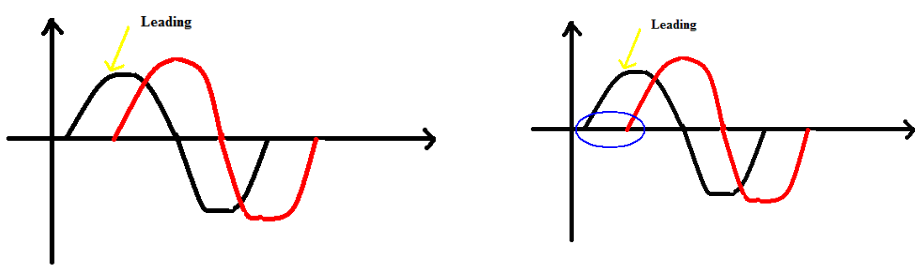
Our objective is to find whether V_{OUT} is lagging or leading V_{IN}
A well known and readily applied method of measurement of phase difference 8 between two sinusoidal signals with a single-trace oscilloscope is based on the elliptic display on the screen obtained by feeding the two signals as inputs to X and k' terminals of the CRO [I]. Here sin181 is deduced as the ratio of the intercept of the ellipse on the x- or y-axis to the distance

between the projections of the extreme points of the ellipse on the same axis.

One method for measuring phase shift is to use XY mode. This involves inputting one signal into the vertical system as usual and then another signal into the horizontal system. (This method only works if both signals are sine waves.) This set up is called an XY measurement because both the X and Y axis are tracing voltages. The waveform resulting from this arrangement is called a Lissajous pattern (named for French physicist Jules Antoine Lissajous and pronounced LEE-sa-zhoo). From the shape of the Lissajous pattern, you can tell the phase difference between the two signals. You can also tell their frequency ratio. Figure 6 shows Lissajous patterns for various frequency ratios and phase shifts.

❷ How do we know if the voltage leads or lags from the oscilloscope?

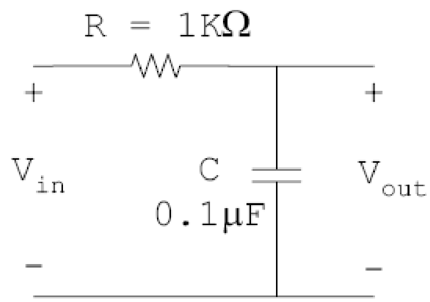
- **For either the lag or the lead networks we apply the output voltage to channel one of the oscilloscope and that of the input voltage to channel two.**
- **Superpose the two curves on the same horizontal axis and adjust the VOLT/DIV and SEC/DIV settings to get stable traces**
- **Decrease the V/div to zoom the figure**
- **Observe the leading and lagging waveforms**



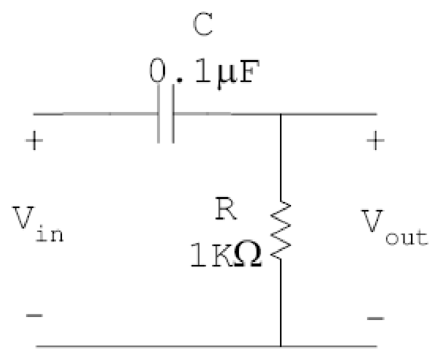
❸ ***Remark:*** **We can never measure the current using the oscilloscope. If we need the current waveform we measure the voltage and divide it by the resistance R.**

❹ ***Note:*** **The maximum frequency is the frequency at resonance.**

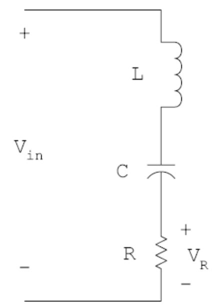
❺ ***Lag*** **networks: (Low-Pass Filter)**



Lead **networks: (High-Pass Filter)**



RLC **(Band pass filter):**



Explain the shape of the output waveforms of the lag and lead networks to square wave inputs of various frequencies, with particular reference to the fundamental property of a capacitor not changing its voltage instantaneously.

The lag and the lead networks differ in the output voltage. In the lag network, as the frequency increases, the shape of V_{out} tends to deviate more from the square shape. In the lead network, as the frequency decreases, the shape of V_{out} tends to deviate more from the square shape. Since the fundamental property of a capacitor states that the voltage can't change instantaneously, it changes exponentially $V_c = V_0 * e^{(-t/RC)}$ with a time constant parameter ô = RC.

The relationship between the RC time constant and the frequency of the square wave so that:

If 1/F >>RC (RC is small):

- **The lag network does not appreciably distort the square wave.**
- **The lead network is a differentiator.**

If 1/F <<RC(RC is large):

- **The lead network does not appreciably distort the square wave.**
- **The lag network is an integrator.**

What should be the relationship between the RC time constant and the frequency of the sinusoidal input so that:

- **The lag network does not introduce appreciable attenuation: RC and F should be both small**
- **The lead network does not introduce appreciable attenuation: RC and F should be both large**

These relationships are the same for the sinusoidal and square wave input functions.

Fourier theorem states that any periodic function can be expressed as the sum of a series of sine and cosine terms, each of which has specific amplitude and phase coefficients.

Note: The cutoff frequency is defined as the frequency at which the output amplitude is 1/√2 times its maximum value.

A low-pass filter is a filter that passes low frequency signals but attenuates signals with frequencies higher than the cutoff frequency.
Cutoff frequency= 1/ (2π x R x C)

A high-pass filter is a filter that passes high frequencies well, but attenuates frequencies lower than the cutoff frequency. Cutoff frequency= 1/ (2π x R x C)

→ The cut-off frequency for the series RC circuit has the value 1/ (2π x R x C) whether the circuit is configured as a low-pass filter or a high pass filter.

❻ Considering one of the RC elements to be source impedance, and the other to be load impedance, explain the integrating and differentiating action of these networks on the basis of the relationship between source and load impedances in the *s* domain.

The integrating and differentiating action could be explained using the S-domain.

In Integrator we consider only high frequencies, so that the capacitor has insufficient time to charge up, so the input voltage approximately equals the voltage across the resistor.
The formula of the integrating low pass lag filter where R is the source impedance and C is the load impedance is H(s)=wc/(wc+s)=(1/RC)/[s+(1/RC)]

In Differentiator, we consider only low frequencies, so that the capacitor has time to charge up until its voltage almost equals that of the source.
The formula of the differentiating high pass lead filter where C is the source impedance and R is the load impedance is:
H(s)=s/(wc+s)=s/[s+(1/RC)]

❼ The sum of the average voltages across the capacitor and that across the resistor will be equal to the average value of the input voltage:
$V_{DC} = VC_{DC} + VR_{DC}$

❽ How do we calculate the cutoff frequency F in lead or lag networks?

- **Measure the output voltage and get the peak value (or maximum value)**
- **Find $V_{max}/\sqrt{2}$**
- **Vary the frequency up and down until we get the same output voltage**
- **We will get two values of the cutoff frequency (up and down movements).**

Note: Bandwidth is defined as $f_2 - f_1$, where f_2 and f_1 ($f_2 > f_1$) are the frequencies where the magnitude of the transfer function is times its maximum value.

❾ How do we calculate the bandwidth in the RLC circuit?

- **Measure the output voltage and get the peak value (or maximum value)**
- **Find $V_{max}/\sqrt{2}$**
- **Vary the frequency up and down until we get the same output voltage**
- **We will get two values of the cutoff frequency (up and down movements).**

- **SIMILAR TO THE ABOVE (SO FAR)**
- **With the two calculated values of the cutoff frequencies f_1 and f_2, find $f_2 - f_1$ and find the bandwidth.**

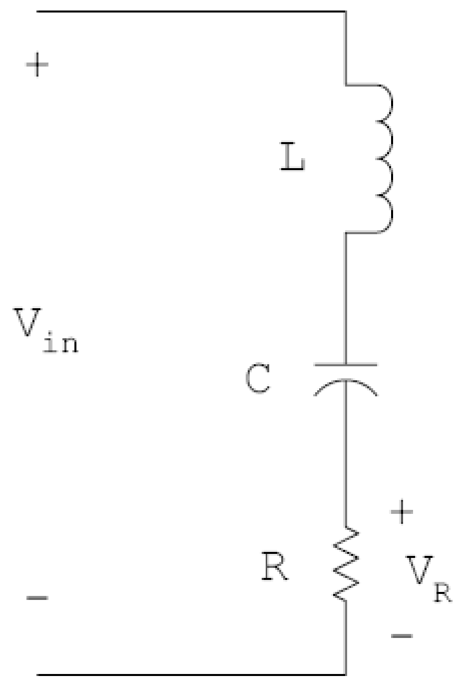


Fig. 5