Experiment 11. Reactance

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Read the chapter "Alternating current circuits" – VERY IMPORTANT!! (AND TAKE NOTES!!!)

OBJECTIVE:

To study Ohm's law of AC circuits, and the frequency dependence of reactance.

APPARATUS:

Solenoid, capacitor, resistor, oscilloscope, signal generator.

THEORY:

Ohm's law plays a very important role in the theory of DC circuits. Does it work in AC circuits? Yes, it does, if the resistance R is replaced by the impedance, which is determined by both the resistance and the reactance of the inductors and the capacitors. What are the impedance and the reactance? We will study these concepts in the following two experiments.

The reason that Ohm's law takes more complicated form in AC circuits is that the current passing through a capacitor or inductor is not in phase with the AC voltage applied across them. Physically, it reflects the fact that capacitors and inductors are devices that store energy, not consuming it. Such storage function makes the current advance (in the case of capacitors) or lag (in the case of inductors) the voltage by one quarter of a period. To see this, let us consider the inductor circuit of Figure 1.

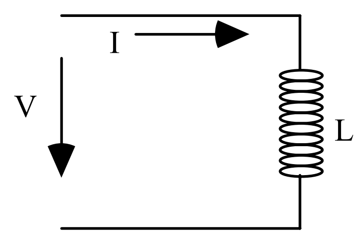

Figure 1. The voltage and current across an inductor

We assume the current passing through the inductor L to be

$$I = I_o \sin(\omega t) \qquad (1)$$

where $\omega = 2\pi f$, f being the frequency. According to Faraday's law, the voltage V across the inductor is given by

$$V_L = L\,(dI/dt) = I_o\,\omega L \cos(\omega t) = V_{Lo} \sin(\omega t + 90^o) \qquad (2)$$

With $V_{Lo} = I_o \omega L = I_o X_L$ (3)

where $X_L = \omega L$ (4)

X_L is called the inductive reactance. Similarly, for a capacitor we have

$$V_C = V_{Co} \sin(\omega t - 90^o) \quad (5)$$

With $V_{Co} = I_o / (\omega C) = I_o X_C$ (6)

where $X_C = 1/(\omega C)$ (7)

X_C is called the capacitive reactance. Eqs.(3) and (6) are the AC forms of the Ohm's law, because they show the linear relationship between the amplitudes (or rms values) of the voltage and the current. Eqs.(2) and (5) show that the voltage across an inductor advances the current by a phase angle of 90°, while the voltage across a capacitor lags the current by 90°.

In this experiment we will test the linear relationship of Eqs. (3) and (6), and the frequency dependence of the reactance, Eqs. (4) and (7).

PROCEDURE

1. Assemble the circuit shown in Fig. (2).

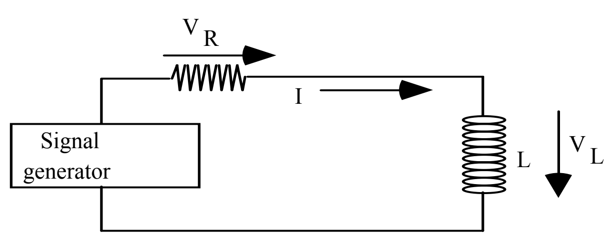

Figure 2

2. Record the values of L and R.
3. Turn on the signal generator and choose sine wave. Set the frequency at about a few tens of kHz. Measure the period T of the sinusoidal wave with the oscilloscope and calculate the frequency f. Keep this frequency unchanged through step 8. Use **Table 1** to record your data.
4. Set the amplitude of the output of the signal generator to maximum, and measure the amplitude of the voltage across the inductor, V_L. Record the value.
5. Measure the amplitude of the voltage across the resistor, V_R. Divide V_R by the resistance R to obtain the current I passing through the circuit. Record both V_R and I.
6. Reduce the amplitude by about 10% and repeat the steps 4 and 5 to get another set of data.
7. Repeat step 6 until the voltage becomes too low to obtain reasonably good data. You should be able to get more than 6 data points.

8. Now you are going to test Eq.(4), the dependence of the inductive reactance as a function of frequency. Use **Table 2** to record your data. The frequency is now a variable and must be changed in your data taking. Use the maximum amplitude all the time. For a certain frequency, measure the current I and the voltage across the inductor as described in steps 4 and 5, and measure the frequency (1/T) using the oscilloscope. This gives one data point. Then change the frequency and repeat the measurement to get another data point. You should get about ten data points in the frequency range between a few hundred Hz to a few hundred kHz.
9. Now replace the inductor with a capacitor and repeat the step 8. You will need to replace the equations with the ones appropriate to a capacitor, of course. Record your data in the **Table 3**.

DATA ANALYSIS

1. Plot the voltage across the inductor, V_L, versus the current I. Find the slope X_L. Calculate the inductance using the measured frequency measured in step 3. Compare the measured value of the inductance with the nominal value as read from the inductor. Calculate the percentage error.
2. Calculate the reactance $X_{L;}$ at all frequencies. Plot the reactance X_L as a function of frequency f. What is the slope? Theoretically, it is supposed to be 2π L. Calculate the percentage error in the measured slope as compared to the theoretical value 2π.
3. Calculate the reactance $X_{C;}$ at all frequencies. Plot the reactance X_C as a function of the period T. What is the slope? The theoretical slope should be $1/(2\pi C)$. Calculate the percentage error in the measured slope as compared to the theoretical value $1/(2\pi C)$.