PHYSICS LABWORK

For Electrics and Thermodynamics

PH1026

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Experiment 1

Measurement of Resistance, Capacitance, Inductance and Resonant Frequencies of RLC using Oscilloscope

Equipments

1. Dual trace oscilloscope 20 MHz – OS 5020C;
2. Function generator GF 8020H;
3. Changeable resistance box;
4. Electrical board and wires;
5. Devices including resistor, capacitor, and coil;

Purpose: This experiment helps the student understanding a typical circuit and the manner to use the equipments including oscilloscope and function generator in electronic engineering, namely measuring the physical parameters of the resistor, capacitor, and inductor as well as the resonant frequency of RLC circuit.

1. THEORETICAL BACKGROUND

1.1 RLC circuit

An RLC circuit (also known as a resonant circuit or a tuned circuit) is a typical one consisting of a resistor (R), an inductor (L), and a capacitor (C), connected in series or in parallel (figure 1).

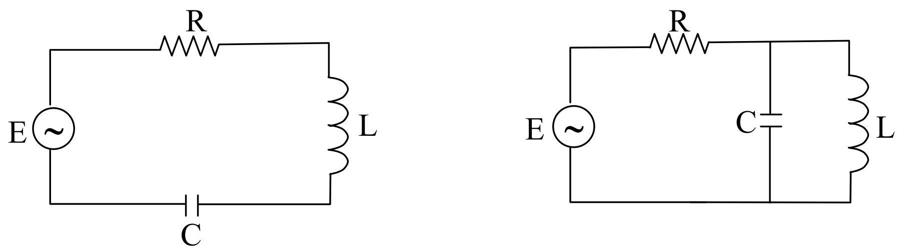


Figure 1: *Series (left) and parallel (right) RLC circuit*

RLC circuits have many applications particularly for oscillating circuits and in radio and communication engineering. Every *RLC* circuit consists of two components: a power source and resonator. Likewise, there are two types of resonators – series *LC* and parallel *LC*. The expressions for the bandwidth in the series and parallel configuration are inverses of each other. This is particularly useful for determining whether a series or parallel configuration is to be used for a particular circuit design. However, in circuit analysis, usually the reciprocal of the latter two variables is used to characterize the system instead. They are known as the resonant frequency and the damping factor (or the *Q* factor) respectively.

The undamped resonance or natural frequency of an *LC* circuit (in radians per second) is given by:

$$\omega_0 = \frac{1}{\sqrt{lC}} \tag{1}$$

In the more familiar unit hertz (or inverse seconds), the natural frequency becomes,

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{lC}} \tag{2}$$

Resonance occurs in *RLC* circuit when the complex impedance Z_{LC} of the *LC* resonator becomes zero,

$$Z_{LC} = Z_L + Z_C = 0 \tag{3}$$

Then ω_0 becomes exactly the resonant frequency of *RLC* circuit.
The damping factor of the circuit (in radians per second) for a series *RLC* circuit is,

$$\beta = \frac{R}{2L} \tag{4}$$

and for a parallel *RLC* circuit:

$$\beta = \frac{1}{2RC} \tag{5}$$

For applications in oscillator circuits, it is generally desirable to make the damping factor as small as possible, or equivalently, to increase the quality factor (Q) as much as possible. In practice, this requires decreasing the resistance *R* in the circuit to as small as physically possible for a series circuit, and increasing *R* to as large a value as possible for a parallel circuit. In this case, the *RLC* circuit becomes a good approximation to an ideal *LC* circuit.
In this experiment, the *RLC* circuit will be investigated by an oscilloscope. Using this equipment we can determine the resistance of a resistor, capacity of a capacitor, and inductivity of a coil as well as the resonant frequency of a series and a parallel *RLC* circuit.

1.2. Introduction to oscilloscope

1. 2.1 General description

An oscilloscope (abbreviated as OS) is a electronic test equipment that allows signal voltages to be viewed, usually as a two-dimensional graph of one or more electrical potential differences (horizontal axis) plotted as a function of time or of some other voltage (vertical axis).
The simplest type of OS consists of a cathode ray tube (CRT), a vertical amplifier, a time-base, a horizontal amplifier and a power supply as shown in figure 2.
CRT is a highly evacuated glass envelope (10^{-6} mmHg) with its flat face covered in a fluorescent material (phosphor). In the neck of the tube is an electron gun, which is a heated metal plate (FF) with a wire mesh (the grid G) in front of it. A small grid potential is used to block electrons from being accelerated when the electron beam needs to be turned off, as during sweep retrace or when no trigger events occur. A potential difference of about 1000 V is applied to make the heated plate (the cathode) negatively charged relative to the anodes A_1 and A_2. It increases the energy (speed) of the electrons that strike the fluorescent screen later. However, before striking the screen, the electron beam goes through two opposed pairs of metal plates called the deflection plates. The vertical amplifier generates a potential difference (U_y) across one pair of plates (Y_1Y_2), giving rise to a vertical electric field through which the electron beam passes. In general, the amplifier has a very high input impedance, typically one MΩ, so that it draws only a tiny current from the signal source. When the top plate is positive with respect to the bottom plate, the beam is deflected upwards; when the field is reversed, the beam is deflected downwards. The horizontal amplifier does a similar job with the other pair of deflection plates (X_1X_2), causing the beam to move left or right by potential difference U_x. The instantaneous position of the beam will depend upon the U_x and U_y voltages.
Let x as the horizontal deflection when U_x is applied to plates X_1X_2, and y the vertical one when U_y is applied to plates Y_1Y_2. By definition we have:

$$\alpha_x = \frac{x}{U_x} \text{ is the horizontal sensitivity of CRT} \tag{6}$$

$$\alpha_y = \frac{y}{U_y} \text{ is the vertical sensitivity of CRT}$$

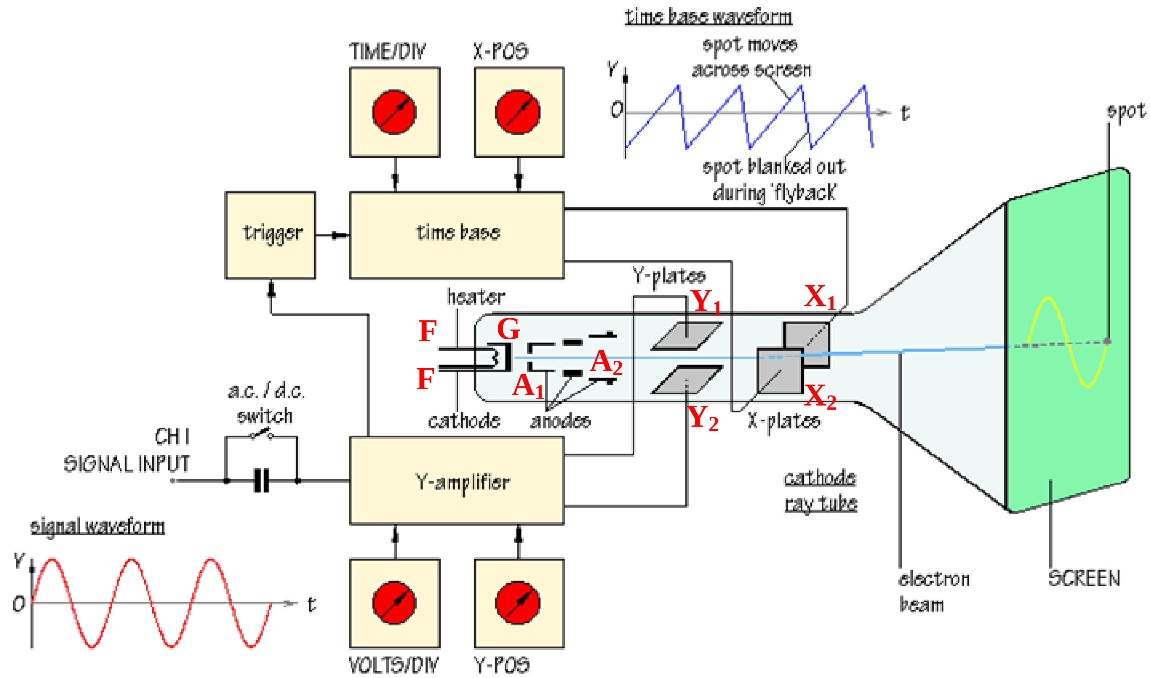


Figure 2: *Structure of an oscilloscope*

When hitting the screen, the kinetic energy of the electrons is converted by the phosphor into visible light at the point of impact. In general, when switched on, a CRT normally displays a single bright dot in the center of the screen.

Assuming that the input signal U_y is applied to the plates Y_1Y_2 (Y-channel):

$$U_y = U_{0y}.\cos \omega t \tag{7}$$

As a result, the bright dot in the screen will oscillate. Due to the image keeping of retina, a vertical light line can be observed on the screen. The length of this light line is proportional to amplitude U_{0y}:

$$y = K\alpha.2U_{0y} = K_y.2U_{0y} \tag{8}$$

where K is amplification factor of Y-amplifier and $K_y = K\alpha$ is the vertical sensitivity or Y-channel transmittance.

Similarly, when U_x is applied to the plates X_1X_2 (X-channel):

$$U_x = U_{0x}.\cos \omega t \tag{9}$$

Then a horizontal light line can be observed on the screen with the length:

$$x = K\alpha.2U_{0x} = K_x.2U_{0x} \tag{11}$$

where K_x is the horizontal sensitivity or X-channel transmittance.

If an alternative voltage in the form of U_y is applied to plates Y_1Y_2 and a voltage that changes continuously and linearly with time $U_x = a.t$ applied to plates X_1X_2 simultaneously, the bright line on the screen will represent the total motion of two oscillations which are perpendicular with each other.

$x = K_x.U_x = k_x.at$

$$y = K_y.U_y = K_y.U_{0y}.\cos\omega t = K_y.U_{0y}.\cos\frac{\omega x}{K_x a} \tag{12}$$

The electron beam draw on screen a signal $y = y(x)$ similarly to the investigated one.
The time-base component is an electronic circuit that generates a ramp voltage or saw-tooth waveform. This is a voltage that changes continuously and linearly with time,

$$U_x = a.t \tag{13}$$

until the maximum value U_{max} then decreases gradually to the initial voltage U_0.
When U_x is applied to X plates it sweeps the electron beam at constant speed from left to right across the screen and then quickly returns the beam to the left in time to begin the next sweep. The time-base can be adjusted to match the sweep time to the period of the signal T_S and sweep frequency f.

$$f = \frac{1}{T_s} \tag{14}$$

Let T is the period of the input signal then:

- If $T_s = T$: a total oscillation can be observed on the screen.
- If $T_s = nT$ (n is integer): n total oscillations can be observed on the screen.
- If $T_s \neq nT$: a complicated oscillation or oscillation in motion can be observed on the screen.

There is a knob on the front panel of the oscilloscope for adjusting the sweep frequency. This knob allows keeping the value of U_0 and U_{max} constant and changing the sweep speed, consequently the sweep frequency and the slope of graph $U_x(t)$. By adjusting this knob so that $T_s = nT$ n stable total oscillations can be observed on the screen.

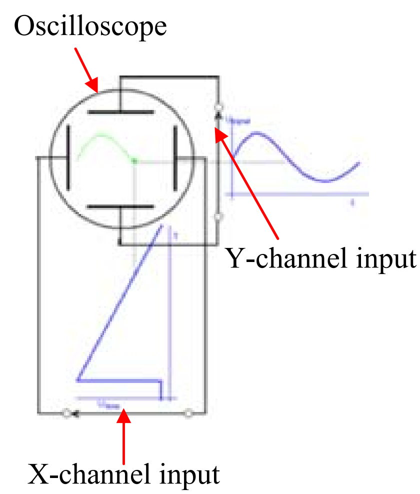


Figure 3: *Symbol of oscilloscope in electric circuit*

1.2.2. Symbol of oscilloscope in electric circuit

OS is symbolized in the diagram of a electric circuit by two pairs of parallel lines inside a circular (figure 3) characterizing two pairs of the deflection electrodes. In this case, X-channel consists of horizontal pair of which the left is symbolized as the positive plate and the right as the negative one (connected to the ground). Y-channel consists of vertical pair of which the upper is symbolized as the positive plate and the lower as the negative one (connected to the ground).
A typical OS is usually box shaped with a display screen, numerous input connectors, control knobs and buttons on the front panel. To aid measurement, a grid called the graticule is drawn on the face of the screen. ***Each square in the gratitude is known as a division***. In this experiment, a dual trace oscilloscope OS 5020 C is used for measurements. It is illustrated in figure 4.

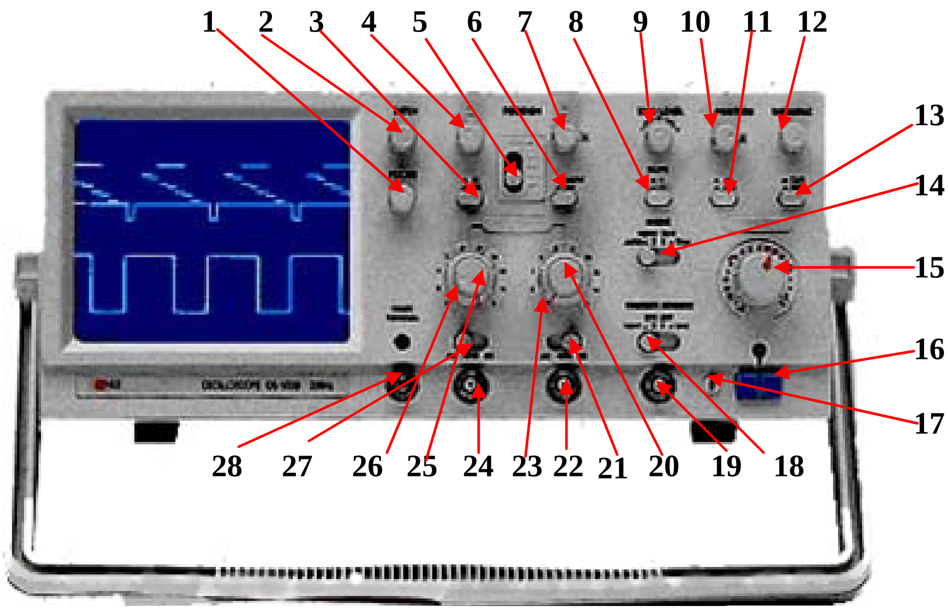


Figure 4. *Front panel of oscilloscope OS 5020C*

1. Adjustor of electron beam convergence
2. Adjustor of light intensity
3. Switch of X-channel scale (X1 or X10)
4. Adjustor for moving electron beam up and down
5. Switch of channel and measurement option
6. Switch of Y-channel scale (X1 or X10)
7. Adjustor for moving electron beam vertically
8. Signal slope switch
9. Adjustor for signal balance
10. Adjustor for moving electron beam horizontally
11. Switch of sweep magnification (X10)
12. Adjustor of calibrated signal time
13. On/off standard regime switch
14.
15. Individual/dual adjustor for signal time
16. On/off power switch
17. Polarity inversion switch
18.
19.
20. Amplitude adjustor for Y-channel
21. DC/AC/GROUND switch for Y-channel
22. Y-channel input
23. Adjustor for sensitivity in range of X5mV/div. to X20V/div. for Y-channel
24. X-channel input
25. Amplitude adjustor for X-channel
26. Adjustor for sensitivity in range of X5mV/div. to X20V/div. for X-channel
27. DC/AC/GROUND switch for X-channel
28. Ground

1.2.3. Resultant signal form produced by two perpendicular oscillations

If an alternative voltage $U_y = U_{0y}.\cos(\omega_y.t+\varphi)$ is applied to plates Y_1Y_2 and other voltage $U_x = U_{0x}.\cos(\omega_x t+\varphi)$ applied to plates X_1X_2 simultaneously, the bright line on the screen will represent the total motion of two oscillations which are perpendicular with each other.

$$x = K_x.U_x = x_0.\cos\omega_x t \tag{15}$$

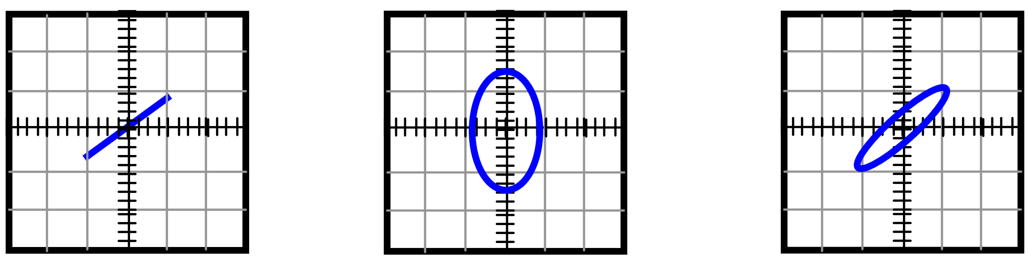
$$y = K_y.U_y = y_0.\cos(\omega y.t+\varphi) \tag{16}$$

When $\omega_x = \omega_y$ (in case of n = 1), the electron beam will produce an trace on the screen defined by the following equation:

$$\left(\frac{x}{x_0}\right)^2 + \left(\frac{y}{y_0}\right)^2 - 2\frac{xy}{x_0 y_0}\cos\varphi = \sin^2\varphi \qquad (17)$$

The trace may be either a line or oval depending on the value of the oscillation phase:

- If $\varphi = 0$ and $\varphi = \pi$, a diagonal line (figure 5a) is displayed. It is corresponding to resistance circuit.
- If $\varphi = \pm\,\pi/2$, a vertical oval trace is displayed (figure 5b). It is corresponding to either *RC* or *LR* circuit. If a suitable resistor is used so that $U_{0x} = U_{0y}$ a circular trace will be displayed.
- If φ gets an arbitrary value then the trace will be an oblique oval (figure 5c). It is corresponding to *RLC* circuit. In case of resonance that is the case of $Z_L = Z_C$ as mentioned above in part 1, a diagonal line is displayed as shown in figure 5a.

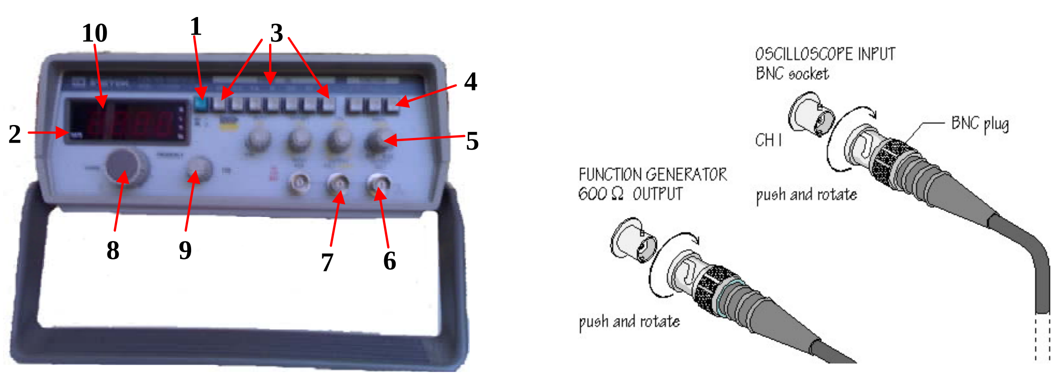


(a) (b) (c)

Figure 5. *Signal forms on oscilloscope screen produced by two perpendicular oscillations*

1.3. Introduction to function generator

A function generator (FG) is a device containing an electronic oscillator, a circuit that is capable of creating a repetitive waveform. The most common waveform is a sine wave, but saw-tooth, step (pulse), square, and triangular waveform. Function generators are typically used in simple electronics repair and design; where they are used to stimulate a circuit under test. The oscilloscope is then used to measure the circuit's output. Function generators vary in the number of outputs they feature, frequency range, frequency accuracy and stability, and several other parameters.



(a) (b)

Figure 6: *Front panel of function generator* GF8020F *(a) and BNC connector (b)*
(**1**. On/off power switch; **2&10**. LED display; **3**. Scale buttons of generated frequency range; **4**. Button for output option of sine waveform; **5**. Adjustor for output voltage amplitude; **8**. Adjustor for rough frequency; **9**. Adjustor for fine frequency)

The function generator GF8020F used in this experiment is shown in figure 6a. A typical FG can provide frequencies up to 20 MHz and uses a BNC connector, usually requiring a 50 or 75 ohm termination as shown in figure 6b. This connector is also used for OS in measurement.

2. EXPERMENTAL PROCEDURE

2.1. Materials for measurement

- Function Generator;
- Oscilloscope;
- Connection box, U-shape connectors, capacitor, resistor, and coil needed for measurement, resistance box, and connecting cords (Fig.7).

(*a*) (*b*) (*c*) (*d*) (*e*) (*f*) (*g*)

Figure 7: *Materials for measurement: (a) connection box, (b) resistor, (c) capacitor, (d) coil, (e) resistance box, (f) U-shape connecting plug, (g) connecting cords*

2.2. Measurement of resistance, capacitance, and inductance

2.2.1. Measurement of unknown resistance

- ***Step 1***: Plug the U-shape connectors, unknown resistor R_X and resistance box (denoted as R_0) on the connection box following the circuit layout shown in figure 8.
- ***Step 2***: See the description of FG in Fig. 6. Press the button 1 to switch on FG. Choose the frequency range of 1K (using button group 3) and sine waveform (using button 4). Adjust knobs 8 and 9 to set an initial measurement frequency of about 500 Hz (or 1000 Hz).
- ***Step 3***: See the description of OS in Fig. 4. Press the button 16 to switch on OS, a trace of vertical line would be appeared on the screen. Adjust the trace so that it should be on the center of screen by using small knobs 7 and 10.

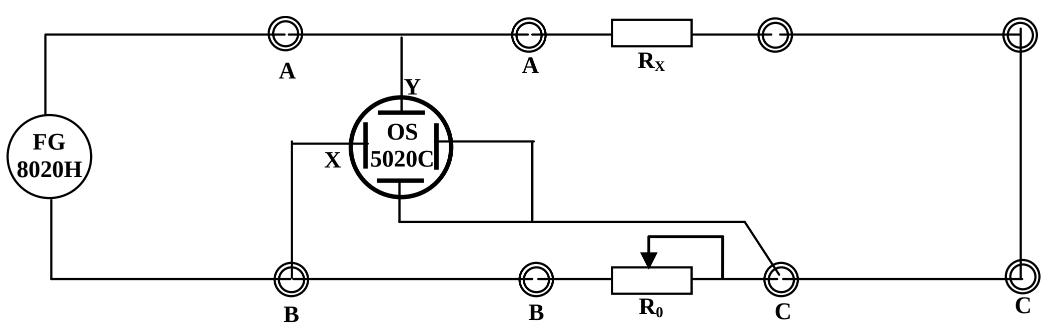


Figure 8: *Circuit layout for measurement of resistance, capacity, and inductivity*

- ***Step 4***: Regulate the resistance box R_0 so that the trace displayed on screen of OS becomes a diagonal line. Then, $U_X = U_Y = U_{R0}$ that is,

$$R_X = R_0 \tag{18}$$

Record the value of frequency *f* and the corresponding value of R_0 in data table 1.
<u>Note</u>: the resistance box R_0 are regulated by turning up its knobs with the order from greater range (~thousands ohm) to smaller one (~ohm or ~one tenths ohm), respectively.
- ***Step 5***: Turn down the knobs of the changeable resistor R_0 to zero positions.
- ***Step 6***: Repeat again the measurement step 4 and 5 for 2 different frequencies (may be either 1000, and 1500 Hz or 1500, and 2000 Hz).

2.2.2 Measurement of unknown capacitance

- ***Step 1***: Adjust knobs 8 and 9 to set an initial measurement frequency of 1000 Hz.
- ***Step 2***: Replace the resistor R_X by installing the unknown capacitor C_X, an upright oval would be appeared on the screen of OS. For convenient and exact observing, adjust knobs 7 and 10 to move the oval trace so that its center is coincided with the center of the coordinate axes of the screen.
- ***Step 3***: Regulate the resistance box R_0 so that the oval trace would become a circle.

Then, $U_C = U_X = U_Y = U_{Ro}$ that is,

$$Z_X = \frac{1}{2\pi.f.C_X} = R_0 \tag{19}$$

Hence:

$$C_X = \frac{1}{2\pi.f.R_0} \tag{20}$$

Make a data table 2 and record the value of frequency *f* and the obtained value of R_0 in it.
<u>Note</u>: Regulating the resistance box R_0 by turning up its knobs with the order from greater range (~thousands ohm) to smaller one (~ohm or ~one tenths ohm), respectively.
- ***Step 4***: Turn down the knobs of the changeable resistor R_0 to zero positions.
- ***Step 5***: Repeat again the measurement step 3 and 4 for more 2 different frequencies (2000 and 3000 Hz).

2.2.3 Measurement of unknown inductance

- ***Step 1***: Adjust knobs 8 and 9 to set an initial measurement frequency of 10000 Hz.
- ***Step 2***: Replace the capacitor C_X by installing the unknown coil L_X, an upright oval trace would be appeared on the screen. Again adjust knobs 7 and 10 to move the oval trace so that its center is coincided with the center of the coordinate axes of the screen.
- ***Step 3***: Regulating the resistance box R_0 so that the oval trace becomes a circle.

Then, $U_C = U_X = U_Y = U_{Ro}$ that is,

$$Z_L = 2\pi.f.L_X = R_0 \tag{21}$$

Hence:

$$L_X = \frac{R_0}{2\pi.f} \tag{22}$$

Make a data table 3 and record the value of frequency *f* and the obtained value of R_0 in it.
<u>Note</u>: Regulating the resistance box R_0 by turning up its knobs with the order from greater range (~thousands ohm) to smaller one (~ohm or ~one tenths ohm), respectively.
- ***Step 4***: Turn down the knobs of the changeable resistor R_0 to zero positions.
- ***Step 5***: Repeat again the measurement step 3 and 4 for more 2 different frequencies (20000 and 30000 Hz).

2.3. Determination of resonant frequency of RLC circuit

2.3.1. Series RLC circuit

- ***Step 1***: Plug the U-shape connectors, resistor R_X, capacitor C_X and resistance box (denoted as R_0) on the connection box following the circuit layout shown in figure 9. Set a value of 1000 Ohm for R_0.
- ***Step 2***: Choose the frequency range of 100K by using button group 3, an inclined oval trace would be appeared on the screen of OS.
- ***Step 3***: Regulating the knobs 8 and 9 of FG to find the applied frequency matching with the specific one of circuit that the oval trace would become an inclined line. Make a data table 4 and record that value of frequency f_s in it.

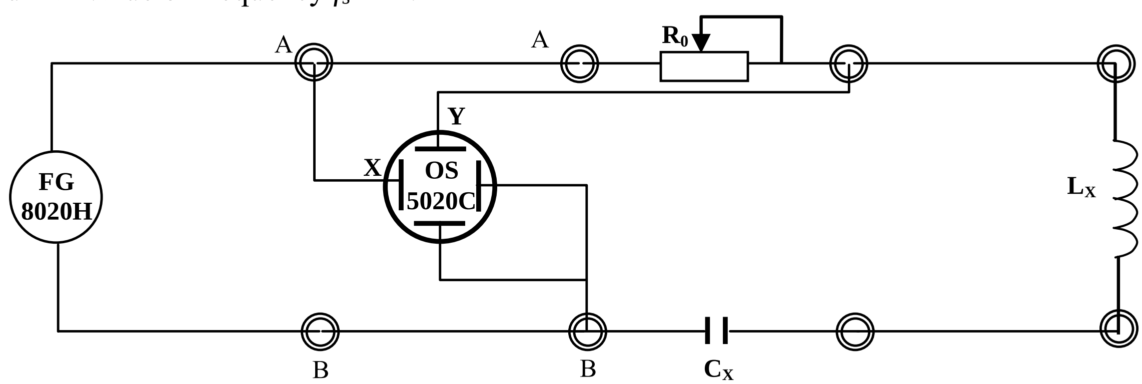


Figure 9: *Series RLC circuit layout for measurement of resonant frequency*

- ***Step 4***: Repeat step 3 for more 2 times and record the obtained results in data table 4.
- ***Step 5***: Turn off OS and FG in order to prepare for next measurement.

2.3.2 Parallel RLC circuit

- ***Step 1***: Plug the U-shape connectors, resistor R_X, capacitor C_X and resistance box (denoted as R_0) on the connection box following the circuit layout shown in figure 10. Set a value of 1000 Ohm for R_0.

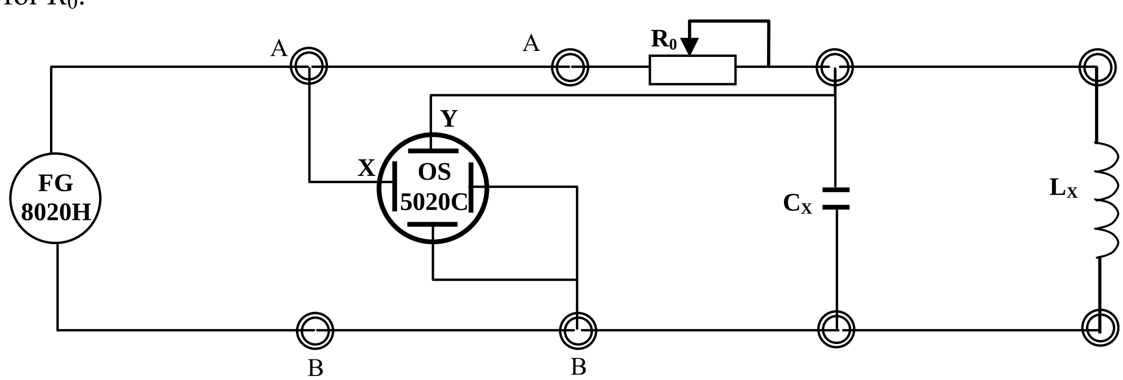


Figure 10: *Parallel RLC circuit layout for measurement of resonant frequency*

- ***Step 2***: Turn on FG and OS, an inclined oval trace would be appeared on the screen of OS.

- ***Step 3***: Regulating the knobs 8 and 9 of FG to find the applied frequency matching with the specific one of circuit that the oval trace would become an inclined line. Make a next column of the data table 4 for frequency f_s an record obtained value of f_s on it.
- ***Step 4***: Repeat step 3 for more 2 times and record the obtained results in data table 4.
- ***Step 5***: Turn off OS and FG.

3. REQUIREMENTS

3.1. Before doing the experiment

Learn the theoretical background to understand the following issues:
- What are the structure and operational principle of the oscilloscope?
- What type of the trace (a line or a curve) is on the oscilloscope's screen if a sine waveform signal is only applied to either Y_1Y_2 plates or X_1X_2 plates?
- How to observe the resultant trace produced by two perpendicular oscillations using oscilloscope?
- What is the resonant condition of RLC circuit? Explain why the signal trace on the oscilloscope's screen becomes a line for the resonant case of this circuit?

3.2. Lab report

Your lab report should include:
- four data sheets of measurement results for unknown resistance, capacitance, inductance, and parallel and serried resonant frequencies, respectively.
- calculation results of the average value of unknown resistance, capacitance, and inductance by using the eq. 18, 20, and 22 as well as their uncertainties.
- comparison the measured average value of series and parallel resonant frequency with that one calculated by using eq. (2) based on the determined values of unknown capacitance and inductance in part b.

Experiment 2

Measurement of magnetic field inside a solenoid with finite length

1. BACKGROUND

According to the Biot-Savard-Laplace's law, magnetic field $\vec{B}$ produced on the axis of a current-carrying loop (Fig. 1) is determined as follows:

$$B = \frac{\mu_0 \mu_r}{4\pi} \int_0^{2\pi R} \frac{I \sin \gamma dl}{r^2} = \frac{\mu_0 \mu_r}{4\pi} \int_0^{2\pi R} \frac{IR}{r^3} dl = \frac{\mu_0 \mu_r}{2} . \frac{IR^2}{r^3} \tag{1}$$

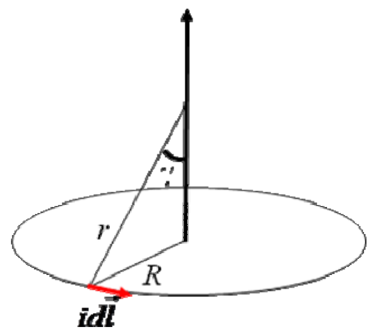
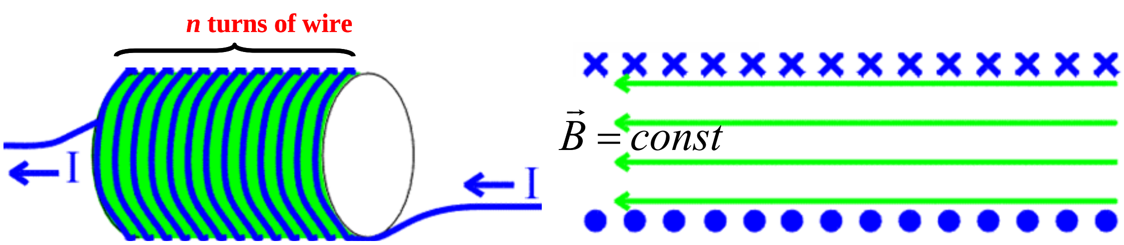


Fig.1. *Magnetic field produced on the axis of a current-carrying coil.*

A solenoid consists of a helical winding of wire on a cylinder, usually circular in cross section. There can be hundreds or thousands of closely spaced turns, each of which can be regarded as a circular loop (Fig.2a). Inside solenoid, the field lines are considered to be uniformly spaced as shown in Fig.2b.



(a) *(b)*

Fig.2. *Typical solenoid (a) and magnetic field lines produced by the currents in it (b)*

Exact calculations for a long, closely wound solenoid, half of these field lines emerge from the ends and half "leak out" through the windings between the center and the ends. Because all turns carry the same current *I*. then, the total *B* field at every point is the vector sum of the fields caused by the individual turns. For a unit of length of solenoid *ds* with *n* turns (Fig.3), we have:

$$dB = \frac{\mu_0 \mu_r}{2} \frac{R^2}{r^3} .I.n.ds \tag{2}$$

It can be seen that $s = R.cotg\gamma$ or $|ds| = +R\dfrac{d\gamma}{\sin^2\gamma}$ and $sin\gamma = R/r$

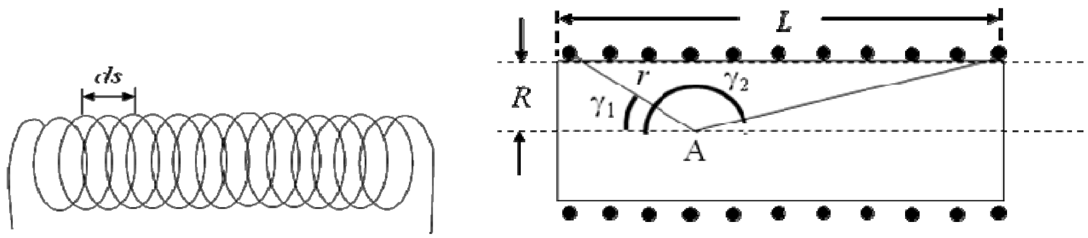


Fig.3. *The way to calculate the magnetic field at a point inside a finite solenoid*

Hence: $dB = +\dfrac{\mu_0\mu_r}{2}I.n.\sin\gamma d\gamma$

Using Ampere's law, the magnetic field B produced by a finite solenoid with length L at point A as shown in Fig.3 would be:

$$B = \frac{\mu_0\mu_r}{2}I.n._0\int_{\gamma_1}^{\gamma_2}\sin\gamma d\gamma = \frac{\mu_0\mu_r}{2}I.n_0(\cos\gamma_1 - \cos\gamma_2) \quad (3)$$

where $n_0 = \dfrac{n}{L_r}$ is number of turns per unit length.

For a solenoid with infinitely length, i.e., $\gamma_1 = 0$, $\gamma_2 = \pi$, the magnetic filed becomes:

$$B = \mu_0.\mu_r.I.n_0 \quad (4)$$

It can be seen that magnetic field produced by a finite coil is smaller than that by an infinite one. Clearly, the magnetic field inside is homogeneous and its strength does not depend on the distance from the axis. This last result, which holds strictly true only near the centre of the solenoid where the field lines are parallel to its length, is most important.

2. EXPERIMENT

2.1 Experimental apparatus

The equipments used for the measurement are shown in Fig.4. The current from the DC power supply flows through a rheostat then through the solenoid. The rheostat is used to monitor the magnitude of current, which is read out with an ammeter. The axial magnetic-induction probe inside solenoid measures the component of the magnetic field along the solenoid symmetry axis. The axial probe can be moved easily along the solenoid. The position of the probe is determined using a linear rule attached with the probe. The magnetic field is read out with the Teslameter.

Fig.4. *Experimental apparatus*

2.2 Preparation

- Using wires to connect the solenoid, rheostat and ammeter together in series following the circuit shown in figure 5.
- Check if the axial probe had connected with Teslameter.

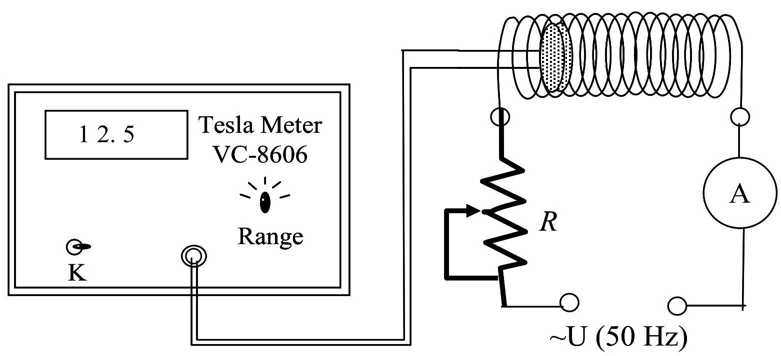


Fig.5. *Layout of measurement circuit*

2.3 Measurement Procedure

a) Investigation of the magnetic field at the positions along the axis of solenoid - B(x)

-***Step 1*:** Place the axial probe so that one end of solenoid is corresponding to the position 0 of the linear rule attached with the probe, Set the voltage of power supply to 3 V and Turn on the solenoid power supply and Teslameter. Record the initial value of current shown on ammeter and magnetic field shown on Teslameter.

- ***Step 2***: pull out slowly the probe with the displacement of every 1 cm then stop and record the value of magnetic field ($B(x)$) inside the solenoid shown on Teslameter up to its position at 30cm. In this case, please make a data table (denoted table 1) showing the corresponding values of magnetic field $B(x)$ at every position x of the probe.

b) Measurement of the relationship between the magnetic field and the current through the solenoid - B(I)

- ***Step 1*:**.Place and fix the axial probe at the center of the coil (that is x = 15 cm).
- ***Step 2***: Set the value of output voltage of power supply as 3V then record the corresponding of magnetic field $B(x)$. Continue to repeat the procedure with other values of 6, 9, and 12 V respectively. Please make a data table (denoted table 2) showing the corresponding values of magnetic field $B(x)$ at every value of output voltage

c) Comparison of experimental and theoretical magnetic field

- ***Step 1*:**. Vary the rheostat so that the value of current shown on ammeter is 0.4 A, then fix this value of the current.
- ***Step 2***: Place the axial probe so that one end of solenoid is corresponding to the position 0 of the linear rule attached with the probe, Record the initial value of current shown on ammeter and magnetic field shown on Teslameter Repeat the measurement procedure at two other positions of the probe x as 15 cm and 30 cm. Make a data table (denoted table 3) showing the corresponding values of magnetic field $B(x)$ at every position x of the probe.

3. LAB REPORT

Your lab report should include:
- three data tables of measurement results as required in part 2.3;
- a graph showing the relationship $B(x)$ between the magnetic field and the position of the probe x inside the solenoid relying on the data table 1 as well as a graph showing the relationship between the magnetic field $B(x)$ and the applied voltage V relying on the data table 2. You can use Excel software or other ones to plot those graphs. The graphs should be demonstrated by the measured points and the fitting lines together in each plot.
- calculation of the magnetic field $B(x)$ using the eq.3 relying on the experimental condition required for the third measurement of part 2.3 then make a comparison the obtained results with those you got directly from the experiment in data table 3.

EXPERIMENT 3

INDUCTOR AND FREE OSCILLATIONS IN RLC CIRCUIT

Equipment and Materials

1 Science Workshop 750 1 Power Amplifier 1 AC/DC electronic board

1. INTRODUCTION

1.1 Inductor and RL circuit

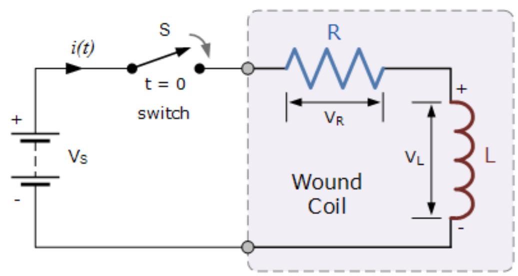
An inductor is a 2-terminal circuit element that stores energy in its magnetic field. Inductors are usually constructed by winding a coil with wire. To increase the magnetic field inductors used for low frequencies often have the inside of the coil filled with magnetic material (at high frequencies such coils can be too lossy). If a current $i(t)$ is owing through an inductor, the voltage V_L across the inductor is proportional to the time rate of change of i or di/dt, that is

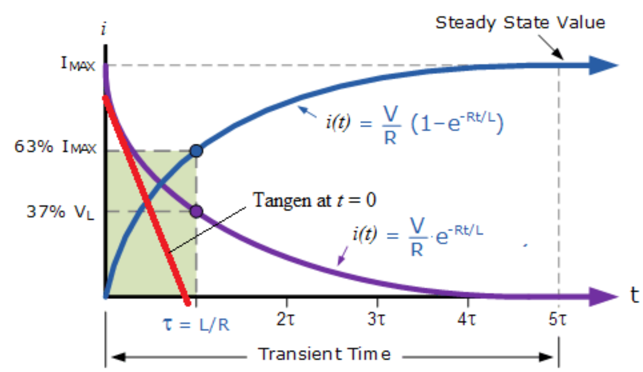
$$V_L = L\frac{di(t)}{dt} \tag{1}$$

where L is the inductance in henries (H). The inductance depends on the number of turns of the coil, the configuration of the coil, and the material that fills the coil. Generally, a henry is a large unit of inductance. More common units are the mH and the μH.

Inductors are the least perfect of the basic circuit elements due to the resistance of the wire they are made from. Often this resistance is not negligible, which will become apparent when the voltages and currents in an actual circuit are measured. It means that when a wound coil is connected with a voltage source V_S we can consider it a series RL circuit as shown in Fig. 1a. In this circumstance, the voltage across the resistor and inductor are designated by V_R and V_L, and the current around the loop by $i(t)$. We can use Kirchoff's voltage law which says that sum of the voltage changes around the loop is zero, that is

$$V_S = V_L + V_R = L\frac{di}{dt} + iR = 0 \tag{2}$$





(*a*) (*b*)

Figure 1: *Principal RL circuit (a) and signal form of currents flow through the circuit (b)*

Due to the presence of the self induced emf within the inductor as a result of the growth of magnetic flux (Lenz's Law), when the switch, S is open until it is closed at a time $t = 0$, and then remains permanently closed the circuit produces a "step response" type voltage input. The current (i) begins to flow through the circuit but does not rise rapidly to its maximum value of I_{max} as determined by the ratio of V_S/R (Ohms Law). After a time the voltage source neutralizes the effect of the self induced emf, the current flow becomes constant and the induced current and field are reduced to zero. In fact, the voltage across R will have moved about 63% of the way from its level at $t > 0$ toward its final value and the voltage across L will have dropped to about 37% and essentially to zero (0.7%) after certain time. Kirchhoff's voltage law implies that the voltage across the resistor will rise at the same rate. When the voltage source is then replaced with a short-circuit the voltage across R drops exponentially with t from V towards 0. R will be discharged to about 37% and essentially fully discharged (0.7%) after about certain time as shown in Fig.1b. For this situations, the current in circuit decays exponentially with time constant τ as

$$i(t) = I_0 e^{-\frac{t}{\tau}} \tag{3}$$

where time constant $\tau = \frac{L}{R}$ and I_0 is the current through the circuit at time $t = 0$.

Here, R is just pure resistance of coil that can be easy to calculate for a given V_S

$$R = \frac{V_S}{I_0} \tag{4}$$

The inductance L can be determined by taking the natural logarithm of both side of eq.3

$$\ln i(t) = -\frac{R}{L} t + \ln I_0 \tag{5}$$

Eq. (5) is linear function of time t of which the graph has the slop as tangent $S = R/L$ (Fig.1b). Therefore if the slope was known the inductance L can be calculated as

$$L = \frac{R}{S} = \frac{V_S}{I_0 . S} \tag{6}$$

1.2 Oscillation in LC and RLC circuit

For series LC circuit where the internal resistance of the inductor is non-negligible as mentioned above then it can be consider a RLC one. Applying Kirchhoff's voltage rule, the equation for the circuit without any external voltage is

$$L\frac{d^2 i}{dt^2} + R\frac{di}{dt} + \frac{q}{C} = 0 \tag{7}$$

The solution of eq.7 is $i(t) = I_0 e^{-\gamma t}\cos(\omega t)$ showing the current is exponential decay with t.
Here, the exponential decay coefficient $\gamma = R/2L$, and the specific frequency or natural angular frequency of the LC oscillator $\omega^2 \equiv 1/LC$.
A plot demonstrating exponential decay *of* $i(t)$ for a typical underdamped circuit is presented in Fig.2.

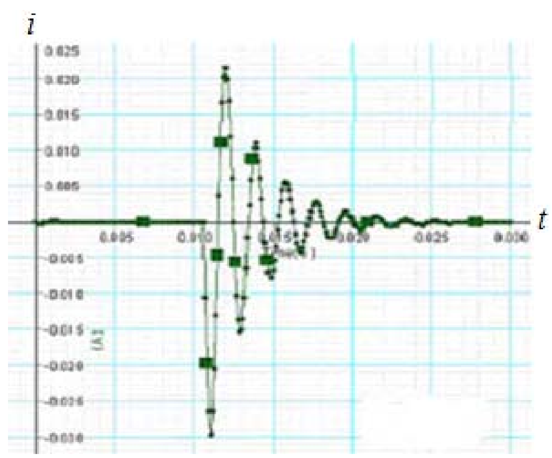


Figure 2: *Signal form of current in RLC circuit*

Since the coefficient of exponential decay γ is proportional to the resistance we see that the current will fall off more rapidly as the resistance increases.

1.3 Energy relationships in RLC circuit

As the current sloshes back and forth in such circuits, energy may be stored in both the magnetic field of the inductor

$$U_B = \frac{1}{2}Li^2 \quad (8)$$

and in the electric field of the capacitor

$$U_E = \frac{1}{2}CV^2 \quad (9)$$

The energy stored in the electric and magnetic fields is simply the sum:

$$U = U_B + U_E = \frac{1}{2}Li^2 + \frac{1}{2}CV^2 \quad (10)$$

This energy is gradually being lost as heat in the resistor at the rate I^2R. It means that the energy in the circuit dies out faster for larger R because it disappears more rapidly into ohmic heating (sometimes called Joule heating) as can be seen in Fig.3.

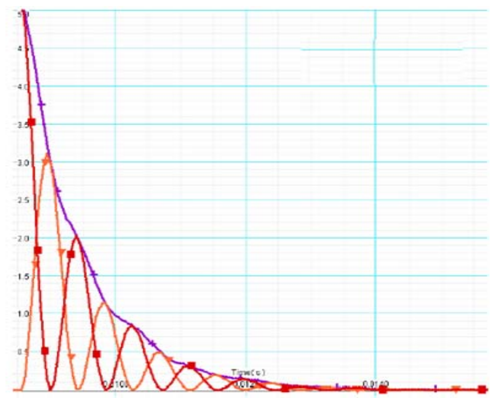


***Figure 3**: Energy in RLC circuit also exponential decays*

2. INTRODUCTION TO DEVICES AND TOOL FOR MEASUREMENT

2.1 Devices for measurement

2.1.1 Science-workshop 750 interface

The Science-workshop 750 Interface is used as an intermediary connected with computer transferring the analog into digital information for data acquisition system. The device has four digital channels, three analog channels and a pair of output jacks. The Analog Channels allow three analog sensors to be plugged into the 750 interface as shown in Fig.4a. The Output Jacks allow using the 750 interface as power supply with ±5 volts AC or DC.

Attention: The interface must be turned on before powering up the computer.

(*a*)

(*b*)

***Figure 4:** Science-workshop interface (a) and Power amplifier (b)*

2.1.2 Power amplifier

It is a device that can produce ±10 volts at up to 1 amp through its 'SIGNAL OUTPUT' terminals (Fig. 4b). As a power supply, the Power Amplifier can provide up to 10 watts. The device can also be used as a function generator. The device can be connected to one of three analog channels (mostly C channel) of the Science-workshop interface with DIN plug.

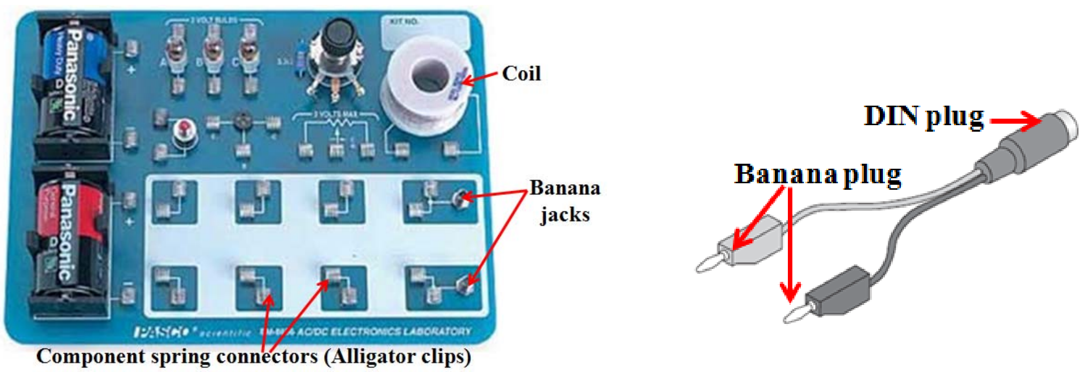
2.1.3 AC/DC electronic board

The AC/DC Electronic tray is a kit of AC/DC circuits that can be used with a ScienceWorkshop Computer Interface and Power Amplifier. The board allows users to install all components such as capacitors, resistors, diodes and transistors. In addition, the experiments can be powered by the 750 Interface w/Power Amplifier. Using the AC/DC

Electronics Laboratory with 750 ScienceWorkshop Interface users can collect/analyze voltage and current data.

2.1.4 Voltage sensor

The Voltage Sensor is a device that can measure voltages from –10 volts to +10 volts. In fact, the physical Sensor's DIN plug is usually connected into Analog Channel A or B on the interface and two probe ends are stackable banana plugs which are installed on two terminals of AC.DC electronic board to be measured.



(*a*) (*b*)

Figure 5: *AC/DC electronic board (a) and physic voltage sensor (b)*

2.2 DATA STUDIO software

Data Studio is a data acquisition, display and analysis program during experiment. The software works with Science-workshop interfaces and sensors to collect and analyze data. Setting up an experiment is a simple matter of plugging sensors into the interface and configuring the software. Data Studio has many ways to view data, including a digit display, meter, graph, and an oscilloscope. Once the program was launched, the interface of software will appear on desktop as shown in Fig.6.

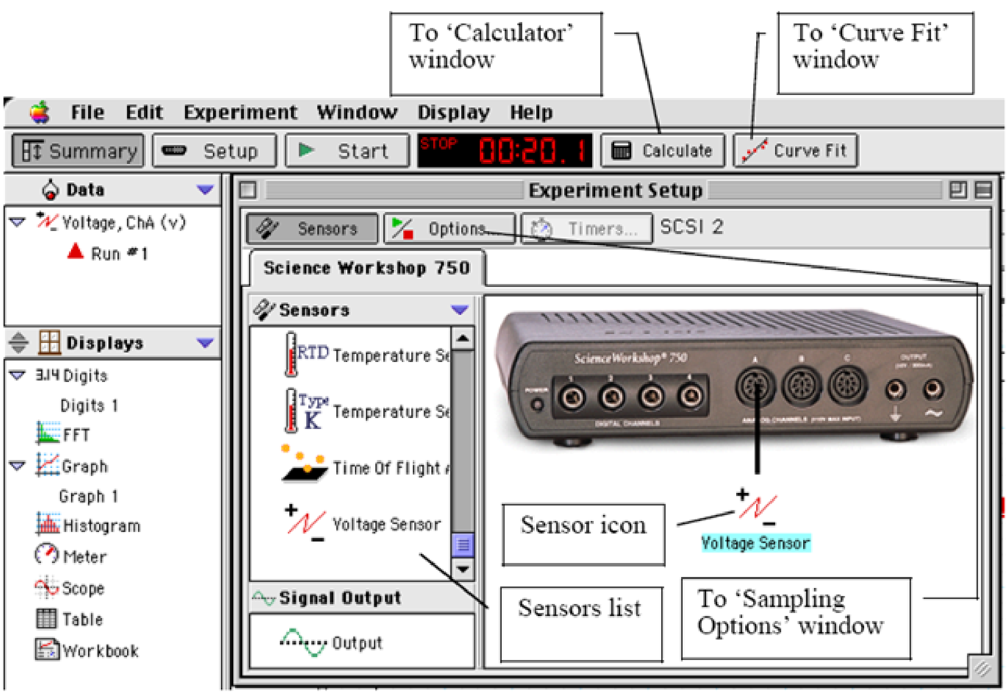


Figure 6: *Illustration of Data studio software's interface*

At this interface, the "**Setup**" button is used to activate the **Experiment Setup** window. Usually, it is used this window to select sensors and set experimental conditions. The Sensors panel lists all possible sensors. Scroll through the list to find the senor(s) for the experiment. To select a sensor, double-click the icon in the "**Sensors**" panel. The software will automatically choose the correct available port.

After completing the experimental set up, click the "**Start**" button to begin collecting data. Data Studio has a variety of tools to assist with configuring experiments. Using the "**Summary**" panel and associated functions helps further define the parameters of the experiment. The displays available provide a powerful method of data visualization. The graph display which plots a sensor's data vs. time is one of displaying ways of Data Studio software. In order to create a graph of measurement result you can click and drag the data from the data summary to the "**Graph**" icon in the "**Displays"** panel below the "**Summary**" panel.

Data Studio incorporates a calculator feature that is capable of not only calculating mathematical expressions, but also manipulating data measurements from sensors. Similar to displays, calculations can be created or deleted at any time. The measurement data can processed by using "**Calculate**" button. The calculator may be used to graph equations, as well as perform calculations on data sets. Click the "**Calculate**" button to activate the calculator window. Enter functions in the form of y = f (x) where y = the name of the function and x = variable. Prompt Data Studio to evaluate the expression by clicking the "**Accept**" button. The software will highlight any undefined terms, which need to be defined before calculation can proceed. **Variables** can be defined as **Data Measurement** which associates a data measurement with a variable. This will perform a calculation on an entire data set to convert the data into another desired quantity (e.g. calculate momentum using velocity data). Simply click, hold and drag a measurement into the calculator window and release on the variable to be defined.

3. MEASUREMENT

3.1 Investigation of the current in RL circuit and measurement of the resistance and inductance of the coil

- ***Step 1***: Set up the physics circuit shown in Fig.7 by connecting the wire leads between a component springs next to the top banana jack with the component springs next to the inductor coil considered as output voltage and connecting banana plug patch cords from the 'OUTPUT"' ports of the interface to the banana jacks on the AC/DC Electronics Lab circuit board that considered as input voltage.

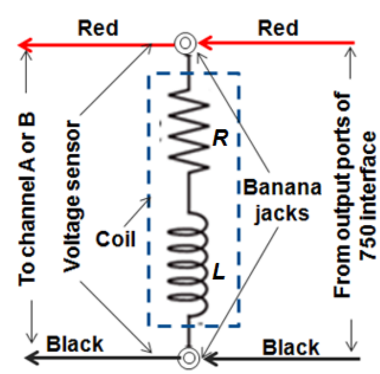


Figure 7: *RL circuit diagram for measuring resistance and inductance of a coil*

- ***Step 2***: Double-click the Data Studio icon on your desktop to launch the Data Studio software. Once the program was launched a window similar to the picture illustrated in Fig.6 will appear. Click "**Connect**" button an image of the 750 interface will appear in the window.

- ***Step 3***: Implement a virtual connecting by performing the drag and drop manipulate to bring the voltage Sensor to channel A/or B and then the power amplifier to the channel C. Immediately, the "**Signal Generator**" window will appear. Set the measurement regime by choosing ***Positive Square Wave*** with ***frequency*** of ***20 Hz*** and ***Amplitude*** of ***1 V*** and the ***Sample rate*** as ***10.000 Hz***. Simultaneously, set the measurement time smaller than 1 s.

- ***Step 4*****:** Perform the measurement by clicking "**Start**" button then the measurement results Data recording will end automatically corresponding to the setting time and the measurement files (▲Run#1) correspond to the voltage acquired by the Voltage Chanel A/or B will appear at the result panel on the left of the interface window. Use the manipulation "drag and drop" to bring the file ▲Run#1 acquired by the Voltage Chanel A/or B to "**Graph**" function. A graph showing the output voltage will be displayed at the graph window. The graph appears will have the form similar to the example shown in Fig. 8.

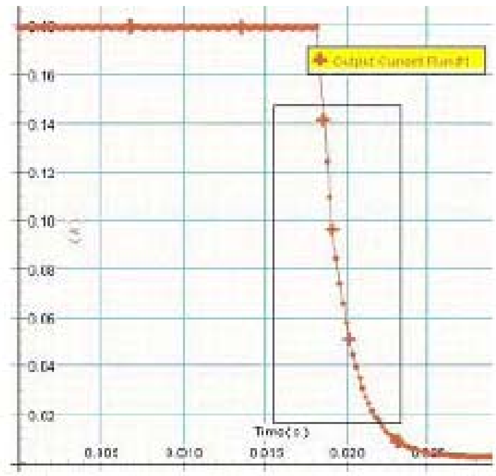


Figure 8: *Exponential decay of current in RL circuit*

- ***Step 5*****:** Click the "**Calculate**" button in main toolbar to open the "**Calculator**" window. Click the "▼"symbol to choose the *ln* function. Move the cursor to the "Define the variable as" then click the "▼"symbol to choose the "measurement data". Select the corresponding measurement file, click OK and click the "Accept" button to finish the procedure. Close the "**Calculator**" window. The calculation result (also another file (▲Run#1) will appear in the Data list in the Experiment Setup window.
- ***Step 6***: Use the manipulation "drag and drop" to bring the file ▲Run#1 of calculation result to the graph of output current above. . In the Graph display area, click-and-draw a rectangle around the linear region of the plot. Select "Curve Fit/Linear Fit". A fitting plot appears and a fitting result will be automatically displayed showing the value of the slope of the fitting plot. Finally, click the "Display" to store the graphs with file name as demonstrated in Fig.8.
- ***Step 7***: Delete all the measurement results and place a metal core inside the coil. Repeat all the measurement procedure from ***Step 4*** to ***Step 6*** to get the measurement data foe this case, then click the "**Display**" button to store the graphs.

3.2 Investigation of the oscillation of current in RLC circuit

Note**:** The measurement regime established in part 3.1 will be kept for this part.
- ***Step 1*****:** Replace a short wire lead connecting a component spring next to the top banana jack and the component spring next to the inductor coil by a 10 μC capacitor in series with the coil. Connect the voltage sensor across the terminals of the capacitor. as circuit diagram shown in Fig.9.

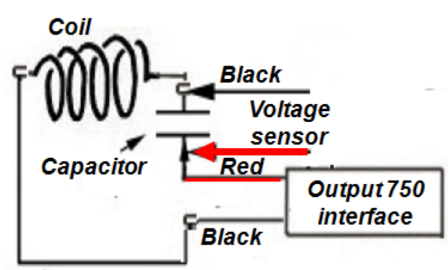


Figure 9: *RLC circuit diagram for investigation of its oscillation*

- ***Step 2:*** Perform the measurement by clicking "**Start**" button. Data recording will end automatically corresponding to the setting time and the measurement files (▲Run#1) correspond to the voltage acquired by the Voltage Chanel A/or B will appear at the result panel on the left of the interface window. Use the manipulation "drag and drop" to bring the file ▲Run#1 acquired by the Voltage Chanel A/or B to "**Graph**" function. A graph showing the output voltage will be displayed at the graph window. The graph appears will have the form similar to the example shown in Fig. 2. Click the "**Display**" button to store the graph.
- ***Step 3*:** Click the "**Calculate**" button to open the "**Calculator**" window. Set the calculation of the ***eq.8*** in function window. Move the cursor to the "Define the variable as" then click the "▼"symbol to choose the "measurement data". Select the corresponding measurement file as ***Current***, click OK and click the "Accept" button. The calculation result (also another file (▲Run#1) will appear in the Data list in the Experiment Setup window as ***y***. Click "**New**" button in the "**Calculator**" window. Set the calculation of ***eq. 9*** in function window. After that move the cursor to the "Define the variable as" then click the "▼"symbol to choose the "measurement data", select the corresponding measurement file as ***Voltage,*** click OK and click the "Accept" button. The calculation result (also another file (▲Run#1) will appear in the Data list in the Experiment Setup window as ***y2***. Click "**New**" button once more again in the "**Calculator**" window. Set the calculation as y3 = y + y2 as shown in ***eq.10*** and select the corresponding measurement files of y and y2 in the box of "Define the variable as". Click OK and click the "Accept" button then close the "**Calculator**" window to finish the procedure.
- ***Step 4***: Use the manipulation "drag and drop" to bring the files ▲Run#1 of calculation results to display the graph of the energy stored in capacitor, coil as well as the total energy of the RLC circuit. The graph should be similar to the example shown in Fig. 3. Finally click the "**Display**" button to store the graphs and finish the measurement.
- ***Step 5*:** Get all the measurement results by transfer them to your own data storage (USB).

4. LAB REPORT

Your lab report should include the following contents

Part 1: Resistance and Inductance of the Coil

- Calculate the resistance R_L of the coil.
- Calculate the inductance of the coil with and without the iron core based on the value of slope obtained by Data studio software.
- Coil inductance without core: *Lw/o* = mH
- Coil inductance with core: *Lw* = mH
- Briefly explain the difference of this quantity of the coil.
- Print out the graphs obtained by measurement and attach them to the lab report.

Part 2: Free Oscillations of the *RLC* circuit

- Calculate the frequency, $f_{measured} = 1/T$ *(Hz)* based on the period of oscillation determined by tools of Data studio software.
- Compute the expected value of $f_{prediction} = \dfrac{1}{2\pi\sqrt{LC}}$ (Hz) and compare it to the obtained result of measurement. Do you expect your result to be greater, equal, or less than the measured value then calculate $\Delta f = p_{\text{rediction}} - f_{measured}$? Make comments and conclusions.
- Print out the graphs obtained by measurement and attach them to the lab report.
- Make the comment and discussions of obtained result of energy in RLC circuit. It can be seen that the circuit is losing energy most rapidly at times when the graph of total energy is steepest; these times occur at about the same times that the magnetic energy reaches a local maximum. Briefly explain why.

Experiment 4

Verification of Faraday's Law of Electromagnetic Induction

Equipment and Materials Part Number

- 1 Science Workshop 750
- 1 Set of two bar magnets
- 1 Large Base and Support Rod
- One 1200-turn and one 150-turn Coil (or equivalent).

Purpose

This experiment is to measure the voltage across a coil of wire when a bar magnet moves through it according to Faraday's law.

1. BACKGROUND

Michael Faraday was one of the first scientists to show that electricity can be produced from magnetism. He discovered that when a magnet is moving relative to a coil consisting of a number of turns of conductive wire there will be a voltage across the coil of wire as a result. The essence of his discovery is described in the following statement,

A voltage is induced in a circuit whenever relative motion exists between a conductor and a magnetic field and that the magnitude of this voltage is proportional to the rate of change of the flux

$$V_{induced} = -N\frac{\Delta\Phi}{\Delta t} = -N\frac{\Delta(BA)}{\Delta t} \quad (1)$$

where N is number of wire's turns and A is the cross-section area of the coil, $\Delta\Phi$ is changing magnetic flux, and ΔB is changing magnetic field.

Because electricity is induced by a changing magnetic field, this process is called *electromagnetic induction*.

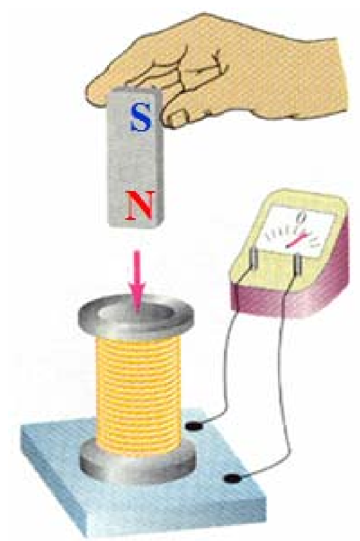


Figure 1: *Experiment presenting Faraday's law*

It's the concept behind the electric generator (and countless other electrical devices). Faraday also realized several factors that determine how much voltage is induced. One is the *strength* of the magnetic field. A second is how *fast* the magnetic field changes. Another factor is the *number of turns* (loops) of wire that are in the coil.

2. EXPERIMENT

2.1 Preparation

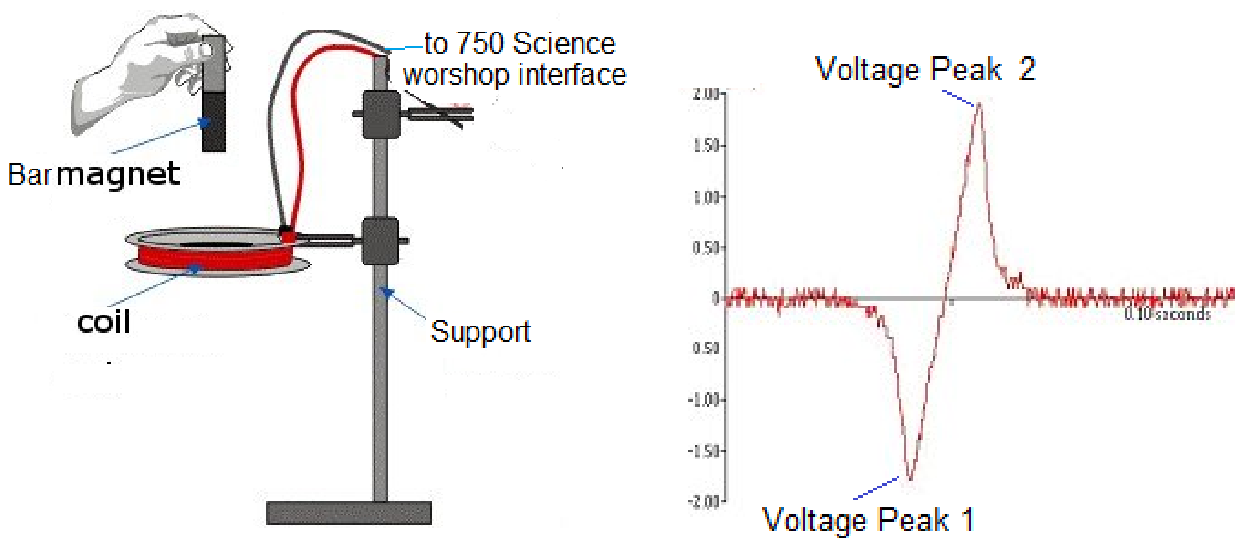
- Turn on the 750 Science Workshop interface and then the computer;
- Plug a Voltage sensor into channel A/or B of Science Workshop 750 and connect itr to the coil terminals.
- Click to launch the Data Studio program. Set to measure voltage 100 times per second (100 Hz).

- Place a protective pad or cushion underneath the coil to catch the bar magnet after it falls through the coil (be careful to leave enough room under the coil so the magnet can fall completely through the coil before it reaches the pad or cushion).

2.2. Measurement

2.2.1 1200 turn coil

- ***Step 1:*** Hold the bar magnet above the 1200 turn coil so that the 'North' end of the magnet is at the bottom as illustrated in Fig.2a;
- ***Step 2:***. Press "**Start**" button on the Data Studio interface to start recording data.
- ***Step 3:*** Release the bar magnet to drop freely throughout the center of the coil. When the bar magnet is out of coil, press "**Stop**" button to stop data recording.
- ***Step 4:*** Data recording will appear at the result panel as ▲Run#1 on the left of the interface window. Use the manipulation "drag and drop" to bring the file ▲Run#1 to "**Graph**" function. A graph showing a pulse of induced voltage will be displayed at the graph window that may be similar an example shown in Fig.2b.



(*a*) (*b*)

Figure 2*: Arrangement of measurement (a) and form of induction voltage (b)*

- ***Step 5***: Use the "Point" tool of data Studio interface to determine the value of peaks of the graph. Record the voltage Peak 1 and voltage Peak 2 in two separated columns of data table then click the "**Display**" button to store the graph. The graph may be small and it may be necessary to zoom in to see it clearly.
- ***Step 6***: Reverse the bar magnet so that the South end of the magnet will fall through the coil first and repeat the experimental procedure from ***Step 2*** to ***Step 5***. Record the values of voltage peak 1 and peak 2 in the same data table.
- ***Step 7*****:** Tape two bar magnets together so that each end has a 'north' and 'south' pole together. Repeat the experimental procedure from ***Step 2*** to ***Step 5***. Record the values of voltage peak 1 and peak 2 in the same data table.
- ***Step 8*****:** Rearrange the two bar magnets so one end is 'north-north' and the other end is 'south-south'. Repeat the experimental procedure from ***Step 2*** to ***Step 5***. Record the values of voltage peak 1 and peak 2 in the same data table.

2.2.2 150 turn coil

- Repeat the measurement procedure similarly to part 2.2.1 for single and double bar magnet and record the measurement results in the second data table.
- After finish the measurement you have to transfer the files of induced voltage of two coils you performed the measurements.

3. LAB REPORT

Your Lab report must include
- graphs you got during experiment of the induced voltage:;
- comments and explanations of the following issues relying on the Faraday's discovery and the mathematical presentation of the effect shown by eq.1,
    - How does the voltage of the *second* peak compare to the voltage of the *first* peak?
    - How does the *magnitude* (amount) of the voltage of the second peak compare to the *magnitude* of the voltage of the first peak for each run,? why you think this happens?
    - How does the shape of the voltage versus time graph when the north pole of the magnet is dropped first compare to the overall shape of the graph when the south pole is dropped first?
    - How does the maximum voltage for the coil with more turns compare to the maximum voltage for the coil with fewer turns?

Experiment 5
Investigation of transmission of electromagnetic wave (microwave)

Objective

Evaluation of both qualitative and quantitative results of transmitting and receiving microwave.

1. INTRODUCTION TO THE EXPERIMENT AND INSTRUMENTS

Microwaves are radio waves belonging to electro-magnetic (EM) ones whose wavelengths are conveniently measured in small numbers of centimeters corresponding to the radio spectrum ranges across frequencies of roughly 1.0 gigahertz (GHz) to 30 GHz. The small wavelength of microwaves allows conveniently-sized antennas to direct them in narrow beams, which can be pointed directly at the receiving antenna.
Microwave radio transmission is commonly used:
- in point-to-point communication systems on the surface of the Earth, in satellite communications, and in deep space radio communications;
- for radars, radio navigation systems, sensor systems, and radio astronomy.

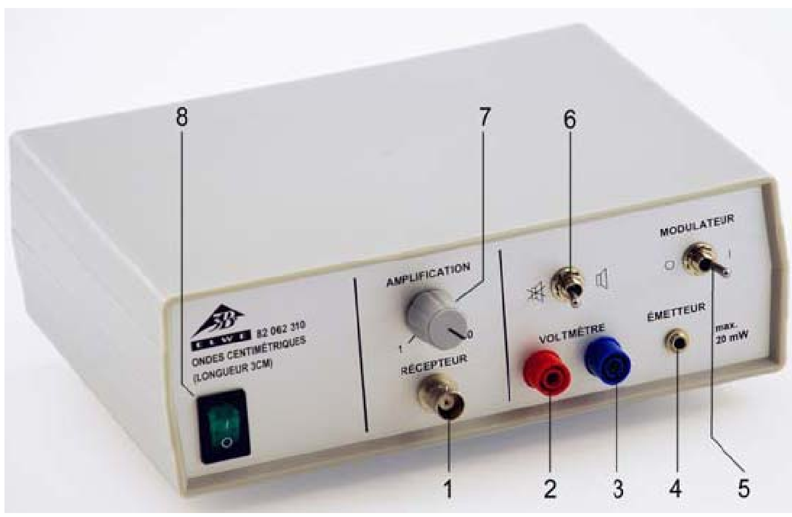


Fig.1. *Control unit, (1) receiver terminal, (2) amplifier output, (3) amplifier output (ground); (4) transmitter terminal, (5) modulator switch, (6) speaker switch, (7) amplifier gain (amplification), (8) mains switch*

In this experiment, the transmission and receive of electro-magnetic (EM) waves, actually microwave will be investigated qualitatively and quantitatively. The components and equipment included allow for various experiments to be performed. A narrow beam of electro-magnetic waves with wavelength in the cm range (microwaves) in the form of square signal is generated by the control unit (Fig.1) that can be output by a transmitter and picked up using the accessories such as horn antenna or the sensor probe as shown in Fig.2. The modulation of the receiver signal can be rendered audible by means of an internal speaker and the intensity of the signal can also be controlled.

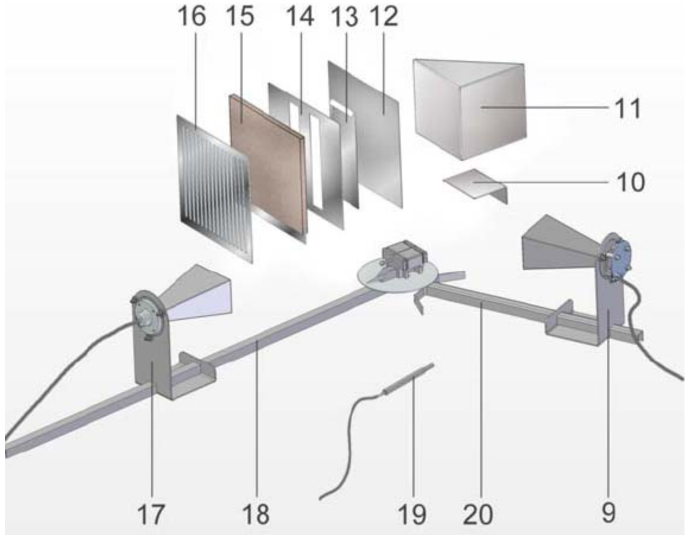


Fig.2. *Accessories: (9) transmitter with horn antenna, (10) stand for prism, (11) paraffin prism;*
(12) reflection plate. (13) cover plate for double slit, (14) plate with double slit. (15) absorption plate, (16) polarization grating, (17) receiver with horn antenna, (18) microwave bench,
(19) microwave probe, (20) folding microwave bench with plate holder.

2. EXPERIMENTAL PROCEDURE

2.1 Investigation of straight-line propagation of microwaves

- Set up the transmitter (9) and receiver (17) facing one another with the receiver off the rail, as shown in Fig. 3.

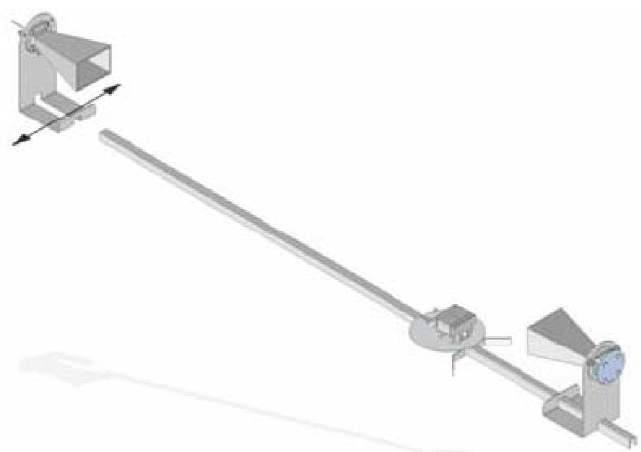


Fig.3. *Experimental setup for investigation 2.1*

- Move the receiver in a plane perpendicular to the rail. Observe and make a conclusion of the optimum position of the horns as the reception.

2.2 Investigation of penetration of microwaves

- Set up the transmitter (9) and receiver (17) facing one another.
- Attach the dry absorption plate (15) (electrical insulator) to the plate holder and place it between the transmitter and receiver, as shown in Fig. 4.

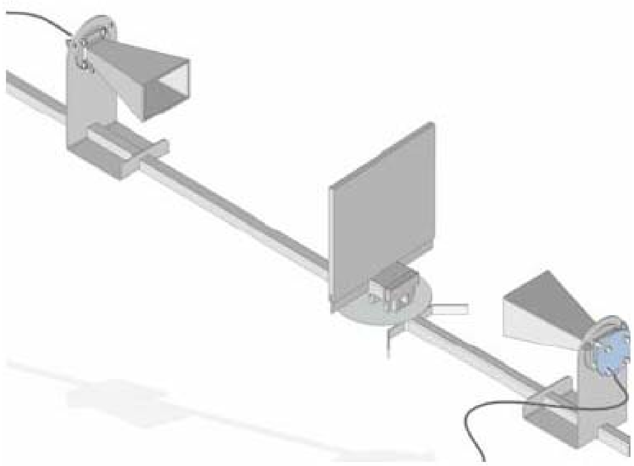


Fig.4. *Experimental setup for investigation 2.2*

- Set the amplification (7) to a medium level. Observe and make a conclusion of the reception of a signal.

2.3 Investigation of screening and absorption of microwaves

- Set up the transmitter (9) and receiver (17) facing one another.
- Place the reflection plate (12) (electrical conductor) between the transmitter and receiver as shown in Fig. 5.

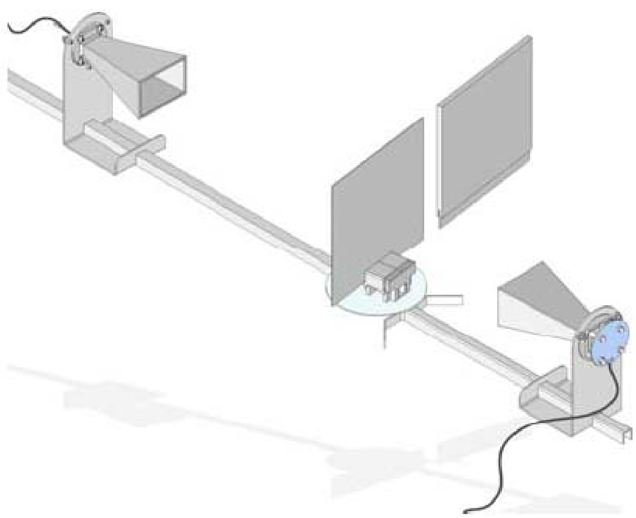


Fig.5. *Experimental setup for investigation 2.3*

- Set the amplification (7) to a medium level. Observe and make a conclusion of the reception of a signal.
- Replace the reflection plate with the absorption one (15). Observe and make a conclusion of the reception of a signal.

2.4 Investigation of reflection of microwaves

- Set up the transmitter (9) and receiver (17) at an angle of incidence to be read off.
- Line up the reflector plate at angle of approximately 30° with the help of the pointer for the rails, which points in the direction of the normal (a line perpendicular to the mirror's surface).as shown in Fig. 6.

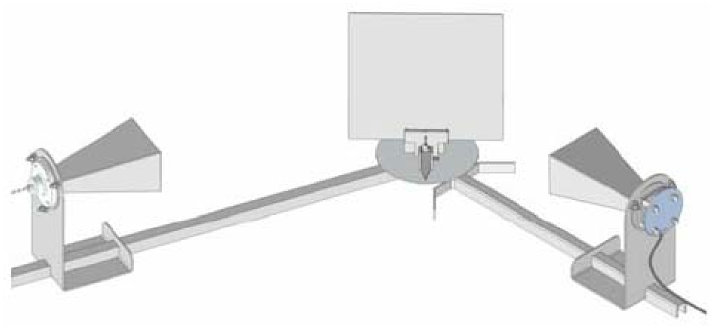


Fig.6. *Experimental setup for investigation 2.4*

- Change the angle of the long rail until the maximum reception is attained. Measure angles of incidence from the normal (arrow) and make conclusion.
- Repeat the procedure with other angles of reflector, that is, 40°, 50° and 60°.

2.5 Investigation of refraction of microwaves

- Set up the accessories including transmitter (9), receiver (17), and the prism (10) into the side facing away from the arrow as shown in Fig. 7.

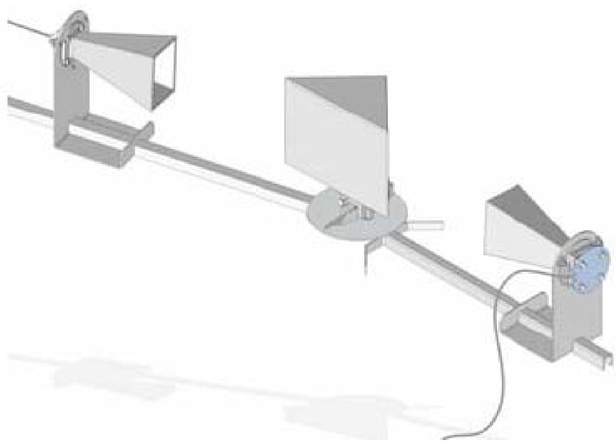
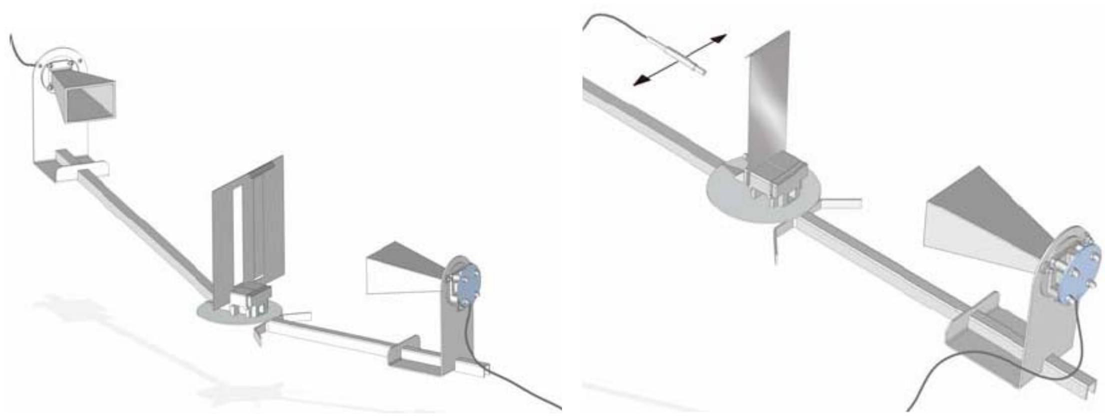


Fig.7. *Experimental setup for investigation 2.5*

- Turn the long rail until the maximum reception is attained. Observe and make a conclusion of the reception of a signal.

2.6 Investigation of diffraction of microwaves

- Set up the accessories including transmitter (9) and receiver (17) directly facing each other about 80 cm apart as shown in Fig. 8a. Turn the receiver around on its rail so that it is out of the bundled microwave beam and the signal is clearly weakened.
- Place single-slit plate (14) (width of slit is smaller than the wavelength) so that it is vertically aligned about 20 cm in front of the transmitter in such a way that the receiver once more detects a signal.
- Observe and make a conclusion of the reception of a signal if microwaves were diffracted by the slit that wavelets could be detected in the shadow of the aperture.
- Clamp the cover plate (13) in the holder on the hinge plate and set up the transmitter about 20 cm in front of the plate as shown Fig. 8b.
- Move the probe (19) in a horizontal plane behind the plate. Observe and record the corresponding signal on multimeter. Conclude the experimental results especially when the probe is in the shadow of the plate.



(*a*) (*b*)

Fig.8. *Experimental setup for investigation 2.6*

2.7 Investigation of interference of microwaves

- Clamp the plate with the double slit (14) centrally in the holder on the plate over the hinge. Position the transmitter about 12 cm in front of the plate. Place the receiver probe which is connected to a multimeter, about 6 cm behind the double slit plate as shown in Fig. 9.

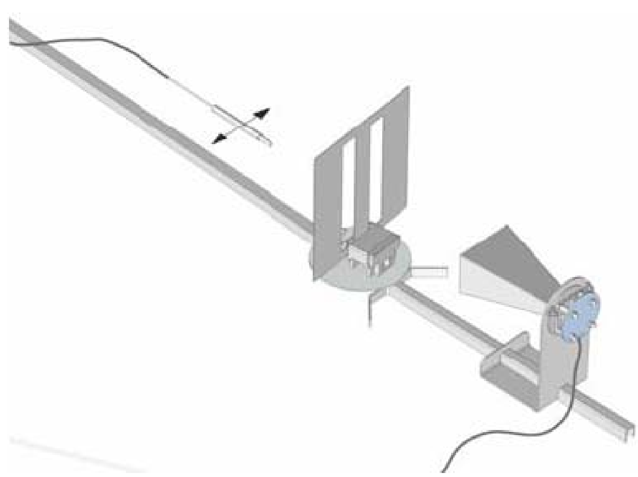
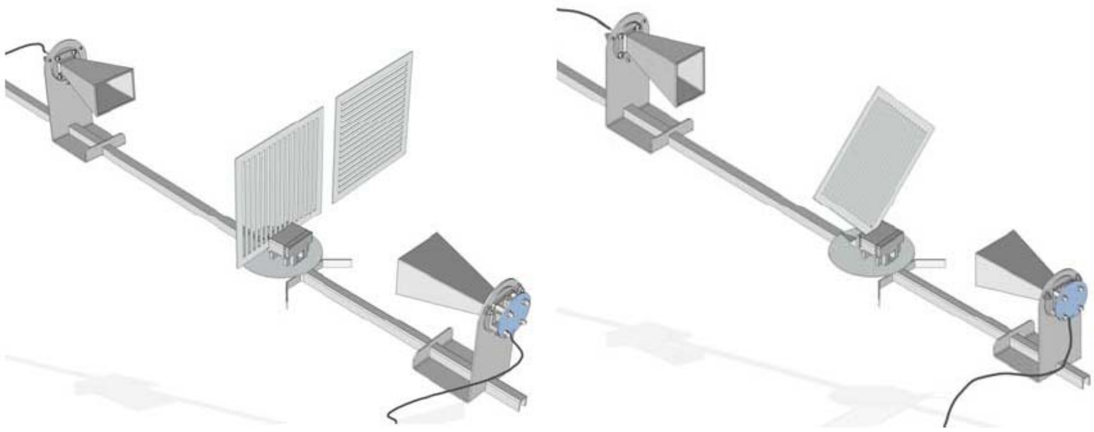


Fig.9. *Experimental setup for investigation 2.7*

- Move the receiver probe parallel to the double slit plate as illustrated in Fig. 9. Observe and record the number of interference maxima corresponding to the signal on the digital multimeter. Conclude the experimental results.

2.8 Investigation of polarization of microwaves

- Set up the polarisation grating (16) in the screen holder.
- Check the reception when the polarization grating is aligned horizontally and vertically as illustrated in Fig.10a. Make the conclusions of receiver’s signal and explanations of experimental results in two cases.
- Check the reception when the polarization grating is introduced into the beam and tilted by 45° as shown in Fig.10b. Make the conclusions of receiver’s signal and explanations of experimental results.



(a) (b)

Fig.10. *Experimental setup for investigation 2.8*

2.9 Determining wavelength of standing waves

- Set up the transmitter and reflector plate facing each other about 50 cm apart (in this case the angle of incidence 0°) as shown in Fig. 11. The transmitted and reflected waves are superimposed, resulting in a standing wave such that the wavelength corresponds to two time the distance between two adjacent minima (or maxima), i.e., $\lambda = 2a$.

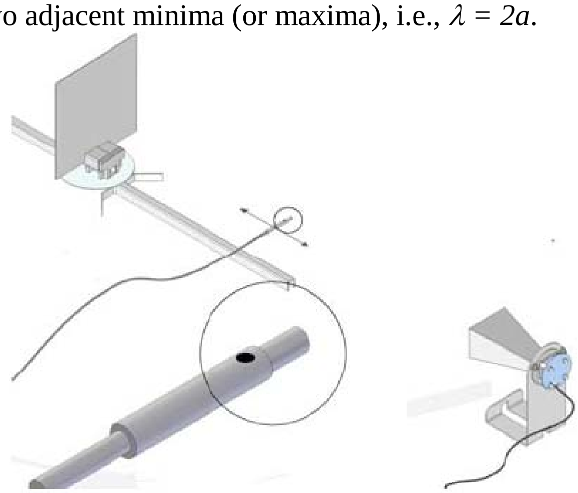


Fig.11. *Experimental setup for investigation 2.9*

- ***Step 1:*** roughly investigate the maxima and minima interference of the transmitted and reflected wave by moving the microwave probe (19) on the surface of and along the long bench as illustrated in Fig.11.
- ***Step 2***: Placing the probe at the position corresponding to the interference maxima (or may be minima) by observing the display on the voltmeter and record that position as $\boldsymbol{x_1}$. After that continue to move the probe to the adjacent position of interference maxima (or minima) and record that position as $\boldsymbol{x_2}$. Consequently, determine the difference between two these position as $\boldsymbol{d}$.
- Step 3: Repeat Step 2 for more two times and record the measurement results by making a data table with 4 columns as Trial, $\boldsymbol{x_1}$, $\mathbf{x_2}$, and $\boldsymbol{d}$, respectively.

3. LAB REPORT

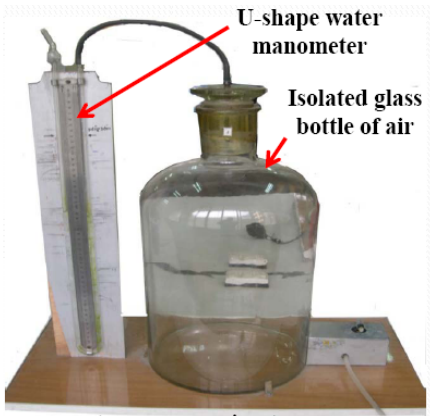
Your Lab report must include

- investigation results of part 2.1 to 2.8 together with illustrated pictures and conclusions;
- calculate the wavelength $\boldsymbol{\lambda = 2d}$. and frequency of the microwaves and their uncertainty using the formula $\boldsymbol{c = \lambda f}$., where $\boldsymbol{c}$ = 3x10^8 m/s.

Experiment 6
Determination of specific heat ratio of air based on Clement Desorme's method

Equipment and Materials:

1. Large glass bottle or flask;
2. U-shape water manometer;
3. Rubber-air-ball blower;
4. Gas valves;
5. Support stand.



Objective
To determine the specific heat ratio γ = Cp/Cv for air.

1. BACKROUND

A method of determining gamma, the ratio of the specific heat capacities at constant pressure and constant volume of an ideal gas was proposed by Clement Desormes. The method consists of a large flask A and an U-shape water manometer as shown in Fig.1. In this case air is considered to be the ideal gas that would undergo a quasi-static adiabatic expansion from state 1 to state 2, followed by a constant volume process from state 2 to state 3 as illustrated in Fig.2.

Indeed, when the flask is closed, a mass of dry air of volume V_o at atmospheric pressure P_o (as indicated a zero height difference on the manometer) is enclosed. When air is slowly pumped into the flask by squeezing the **rubber-air-ball blower B,** an additional volume which had been outside the flask is now compressed inside the flask. The pressure in the flask is increased to P_1 and the volume the gas occupied is reduced to V_1.

The manometer now indicates a height difference which is related to the pressure change:

$$P_1 = P_o + \rho g H \qquad (1)$$

ρ is the density of the liquid in the manometer. When the lid K_2 of the flask is quickly opened and closed, the extra air is allowed to escape and the pressure returns momentarily to atmospheric. The ideal gas is allowed to expand adiabatically

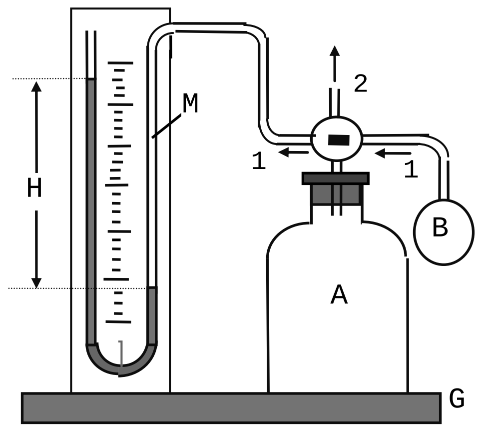


Fig.1. Clement Desorme's experiment

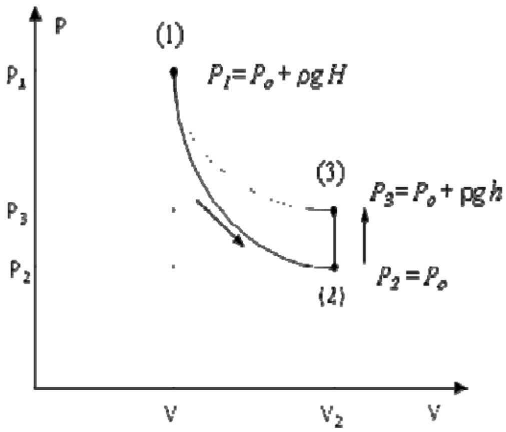


***Fig.2**. P-V diagram of thermodynamic processes occurred in Clement Desorme's experiment*

then at this moment the pressure $P_2 = P_o$, T_2 is less than T_o and the volume is V_2. Since $PV^\gamma = const$ along an adiabatic process, then

$$P_1 V_1^\gamma = P_2 V_2^\gamma \tag{2}$$

After just some minutes, gas is warmed up slowly at constant volume, that is $T_3 = T_o$, $V_3 = V_2$, and the pressure has increased to P_3.

The new pressure P_3 is given by:

$$P_3 = P_o + \rho g h \tag{3}$$

Since $PV = consst$ along an isotherm:

$$P_o V_o = P_1 V_1 = P_3 V_3 \tag{4}$$

Where $V_2 = V_3$, the volume of the flask Combining equations (2) and (4) and taking the natural log of both sides we obtain: (Hint: divide (2) by P_2 which equals P_o and find the ratio of pressures to volumes from equation (4).)

$$ln(P_1/Po) = \gamma\, ln(P_1/P_3) \tag{5}$$

In terms of the variables measure in lab, then we have:

$$ln[1 + (\rho g H/P_o)] = \gamma \{ln[1 + (\rho g H/P_o)] - ln[1 + (\rho g h/P_o)]\} \tag{6}$$

If $\rho g h/P_o$ is small compared to one, then we can make an approximation. When $x << 1$, we have $ln(1+x) \sim x$. Then equation (6) becomes:

$$H \sim \gamma (H - h) \tag{7}$$

Or γ can be simply determined by equation:

$$\gamma = \frac{H}{H - h}. \tag{8}$$

2. Measurement Procedure

- ***Step 1***: Open a valve to the rubber-air-ball blower then performing pump on it to the flask A. Close that valve and wait for the stability of the water columns of the U-shape manometer.
- ***Step 2***: Adjust the height difference of the two water column of the U-shape manometer ***H*** so that its value is between 240 to 250 mmH_2O.
- ***Step 3***: Open anther valve to let the air out of the flask. In this step please observe carefully the level of two water columns. When they have the same height then must close the valve at once.
- ***Step 4***: Waite a while (about 5 min) for the stability of the two water column. In this situation, it means that the temperature inside and outside of the flask is equal. Record the positions of water levels in pipes as l_1 and l_2 in the U shape manometer and consequently the value ***h*** showing their difference.
- ***Step 5***: Repeat the measurement procedure from ***step 1*** to ***step 4*** again for more 9 times and record all the experimental results in a data table which consists of 4 columns as Trial, $\boldsymbol{l_1}$, $\boldsymbol{l_2}$, and ***h***, respectively. Note that the value of ***H*** must be kept constant for all trials of measurement.

3. LAB REPORT

Your lab report must consist of

- a data table showing the measurement results;
- calculation of the value of gamma using the eq.8 and its uncertainty;
- comparison of the obtained value from experimental results with that one calculated by using the equation $\gamma = \frac{i+2}{i}$ where $i = 5$ is the Degree of Freedom (DOF) of ideal gas (in this case it is air). Make the comments and discussions on the results.