T.C.

İSTANBUL UNIVERSITY

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

PHYSICS LABORATORY II
EXPERIMENT BOOK

ELECTRICITY AND MAGNETISM

2024

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1.1.1. MAGNETIC RESONANCE

MAIN PRINCIPLE

Investigation of electromagnetic resonance between two Thomson electrical vibration circuits.

EQUIPMENT

Electromagnetic transmitter and receiver circuit

Figure 2.1: Electromagnetic Resonance Experimental setup

THEORY

1. VIBRATION MOTION:

A physical system is said to be in equilibrium if it is not subject to any change over time. The system, which leaves the equilibrium state as a result of an excitation, performs a continuous vibrational motion around the equilibrium state under certain conditions. The duration of a single vibration (the time between two transitions in the same direction from the equilibrium position) is called a **period**, and the number of vibrations per unit time is called **frequency**. The relationship between τ period and frequency is as shown below.

$$f.\tau = 1 \qquad (2.1)$$

The largest value that the physical quantity indicating vibration will take at the moment of movement is called amplitude. If the amplitudes of successive vibrations decrease over time, we speak of **damped vibration**; if the amplitude remains constant, we speak of **undamped vibration**.

2. RESONANCE:

If the excitation that causes a system to vibrate is of short duration, the system vibrates at a frequency determined by its structure, which is called the self-vibration frequency of that system. If the system is subjected to a periodic excitation, then the system vibrates coercively with the frequency of the excitation. When the frequency of the exciter is equal to the self-vibration frequency of the system, in other words, when the system is forcibly vibrated with its self-vibration frequency, the amplitude reaches a maximum value, in which case the system is said to be in a state of resonance. **Error! Reference source not found.** shows a typical resonance curve. Here f_r is the resonance frequency at which the amplitude reaches its maximum. At this frequency value, the self-vibration frequency of the system takes the same value as the frequency of the stimulus. From the relation (**2.1**), the units of the period τ and the frequency f;

$$[\tau] = s\ ,\ [f] = s^{-1} = Hertz(Hz) \tag{2.2}$$

is obtained.

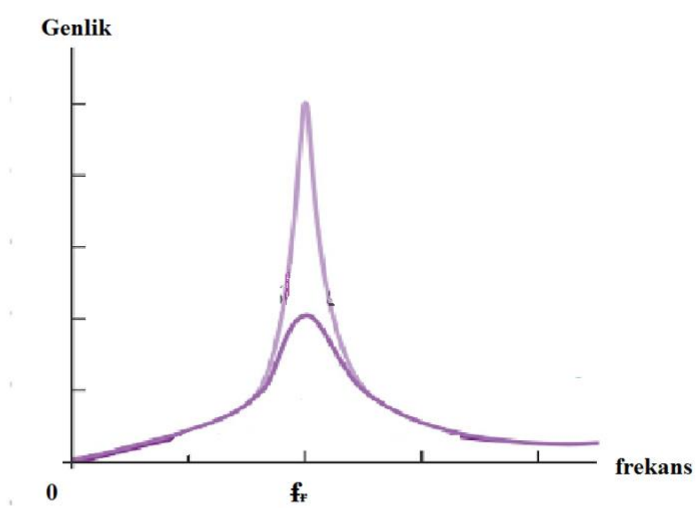

Figure 2.2

C) Thomson Vibration Circuit:

The circuit is obtained by connecting a capacitor with a capacity C and a coil with a self-induction coefficient L as shown in Figure 2.3 is called a **Thomson vibration circuit**.

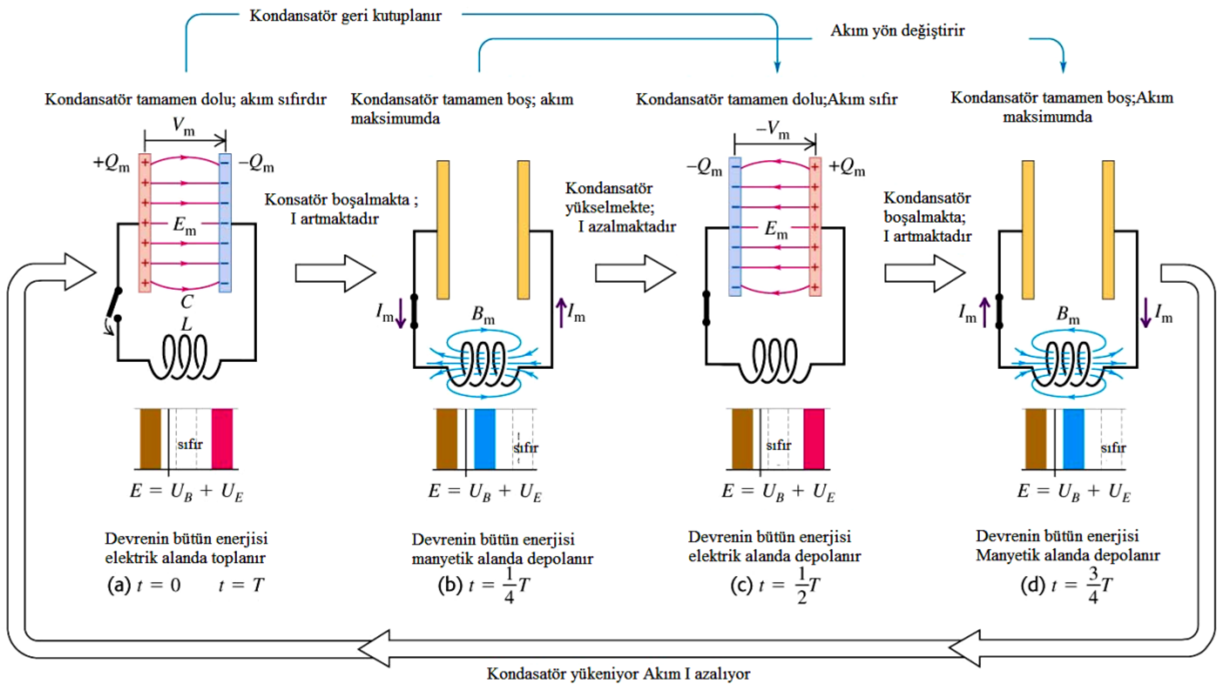

Figure 2.3

When the capacitor is charged with an electric charge q, the charge is discharged through the coil at an accelerating rate. When the charge on the capacitor is completely discharged, the current intensity reaches its maximum value (Figure 2.3b). After that, as the capacitor starts to charge again in the opposite direction, the current intensity starts to decrease and when the value of the current intensity is zero, the capacitor is again charged with q charge in the opposite direction (Figure 2.3). The capacitor starts to discharge again, this time in the opposite direction and the previous change is repeated in the opposite direction (Figure 2.3d). In this circuit, the smaller the internal resistance of the coil, the slower the damping. The period of this vibration;

$$\tau = 2\pi\sqrt{LC} \tag{2.3}$$

is obtained by the relation.

The units of the self-induction coefficient L and the capacity C of the capacitor are as follows.

$$[L] = Henry\ (H) = \frac{Vs}{A}, [C] = Farad\ (F) = \frac{Coulomb}{V} \tag{2.4}$$

D) Magnetic Coupling:

The magnetic field around a coil through which current flows changes in proportion to its intensity. On the other hand, an induction electromotive force ($iemf$) is generated at the ends of a coil in a variable magnetic field according to Faraday's law. This $iemf$ is proportional to the timedependent variation of the intensity of the magnetic field. In this case, if another coil is placed in the magnetic field of a coil, the two coils are in a state of **magnetic coupling**.

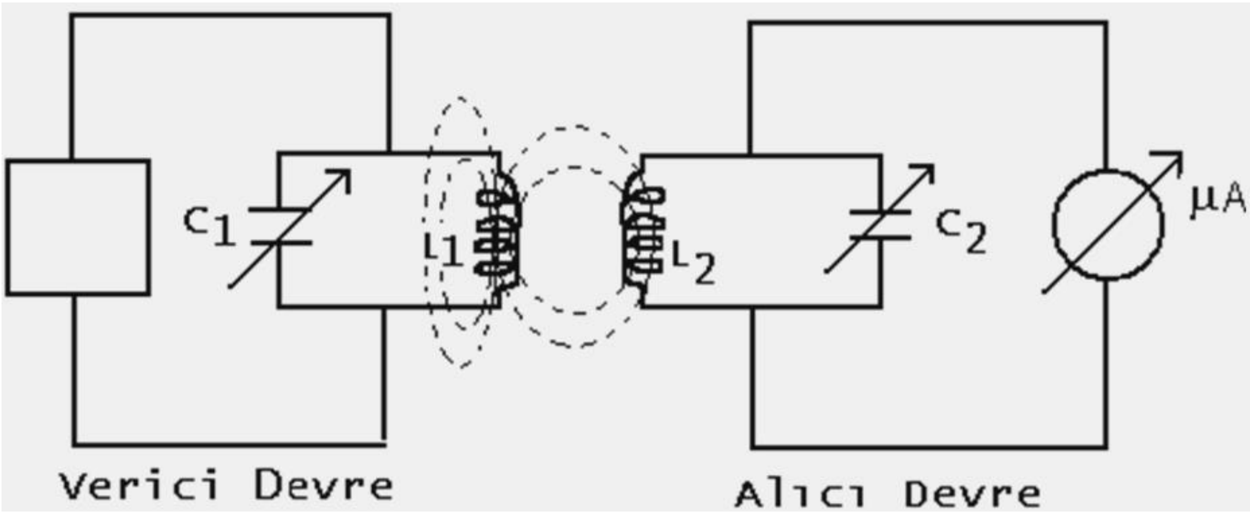

Figure 2.4

As shown in Figure 2.4, let us place a second Thomson oscillator circuit L_2C_2 near the oscillator circuit on the left side, which is electronically connected to the Thomson oscillator circuit L_1C_1 and vibrates undamped with the frequency in the Equation (**2.5**).

$$f_1 = \frac{1}{2\pi}\frac{1}{\sqrt{L_1C_1}} \tag{2.5}$$

At the end of the L_2 coil, which is magnetically coupled with the L_1 coil, an impulse of frequency f1 is generated, and the L_2C_2 circuit is forced to vibrate at the frequency f_1. However, the self-vibration frequency of the second circuit is given below.

$$f_2 = \frac{1}{2\pi}\frac{1}{\sqrt{L_2C_2}} \tag{2.6}$$

If the frequencies f_1 and f_2 are brought closer and closer to each other by changing the capacitance of the variable capacitors C_1 or C_2, the value of the current flow in the meter connected to the second circuit starts to increase. If exactly $f_1 = f_2$, the current flowing through the circuit will be maximum and the deviation on the meter will be maximum. In this case, the two circuits are resonant with each other. Hence, Equation (**2.7**) is written from relations (**2.5**) and (**2.6**).

$$L_1C_1 = L_2C_2 \tag{2.7}$$

In practice, the circuit on the left is called the transmitter, and the one on the right is the receiver.

SETUP AND PROCEDURE

Hartley oscillator circuit made with TIP 15A transistor is used as a transmitter. The resonance state is controlled by a micro ammeter connected to the receiving circuit.

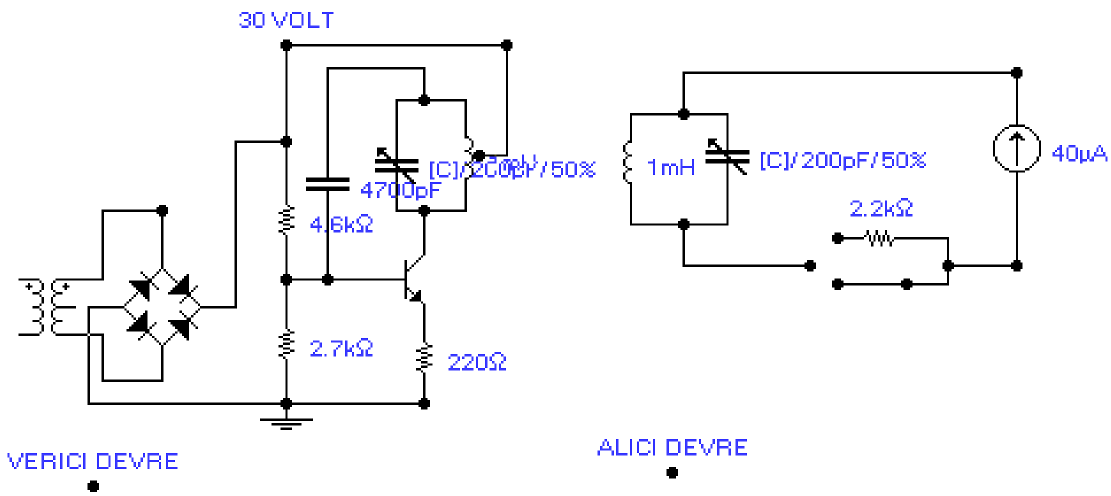

Figure 2.5: Experimental setup

1) The transmitter is switched on, and the switch in the receiver is set to the I position ($R = 0$) and placed near the transmitter in such a way as to ensure magnetic coupling (that is, the coils are perpendicular to each other and the distance between the coils is approximately 10 to 13 cm).
2) 2- The capacity C_2 is placed somewhere in the middle of the variation range (90).
3) 3- Starting from the smallest value of capacity C_1, the capacity C_1 is increased by observing the measuring instrument in the receiver. Meanwhile, the deviation of the meter starts to increase and after a maximum, it starts to decrease again. The maximum value of this deviation indicates resonance.
4) 4- If the coils are very close to each other, while approaching resonance, the needle of the meter tends to move out of the measurement area. In this case, the receiver is moved away from the transmitter. Conversely, when resonance is achieved, if the value measured from the measuring instrument is small compared to the maximum value that the instrument can measure, the receiver is brought closer to the transmitter.
5) 5- After the proper condition is achieved, the transmitter-receiver distance and C_1 capacity is kept constant. While the capacity C_2 is started and increased at appropriate intervals, both the

values of the divisions of the capacity C_2 and the currents flowing out of the circuit against them are read from the measuring instrument and recorded in Table 2.1.

Table 2.1: $R = 0$

$C_2\ (F)$	$I\ (\mu A)$

6) Without changing the transmitter-receiver distance and the capacity C_1, the switch on the transmitter is turned to position 2 ($R = 2.2k\Omega$) to see the effect of the resistance on the

resonance. C_2 2 is turned back to the initial position, the measurements are repeated, and the results are recorded in Table 2.2.

Table 2.2: $R = 2.2\ k\Omega$

$C_2\ (F)$	$I\ (\mu A)$

7) $I = F(C_2)$ curves in Figure 2.6 are drawn from Table 2.1 and Table 2.2. Although these curves are drawn according to the capacity, they are resonance curves since f_2 is proportional

to C_2 capacity according to Equation (**2.6**). You will see that the peaks of the resonance curves you find here are different. Why is there such a difference?

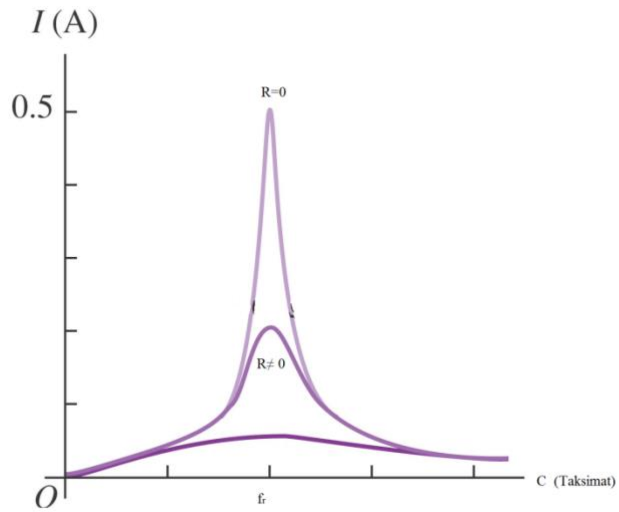

Figure 2.6

2. CHAPTER

2.1. BASIC INFORMATION ABOUT ALTERNATIVE CURRENT

2.1.1.1. PHASOR DIAGRAMS

Rotating vectors diagrams are used to represent sinusoidally varying voltages and currents. In these diagrams, the instantaneous value of a quantity that varies sinusoidally with time is given by the projection on the horizontal axis of a vector whose length is equal to the amplitude of that quantity. The vector rotates counterclockwise with constant angular velocity ω. These rotating vectors are called phasors. Figure 2.1 shows a phasor diagram for a sinusoidal current denoted by $i = I \sin \omega t$. The projection of the phasor on the horizontal axis at time t is $I \cos \omega t$.

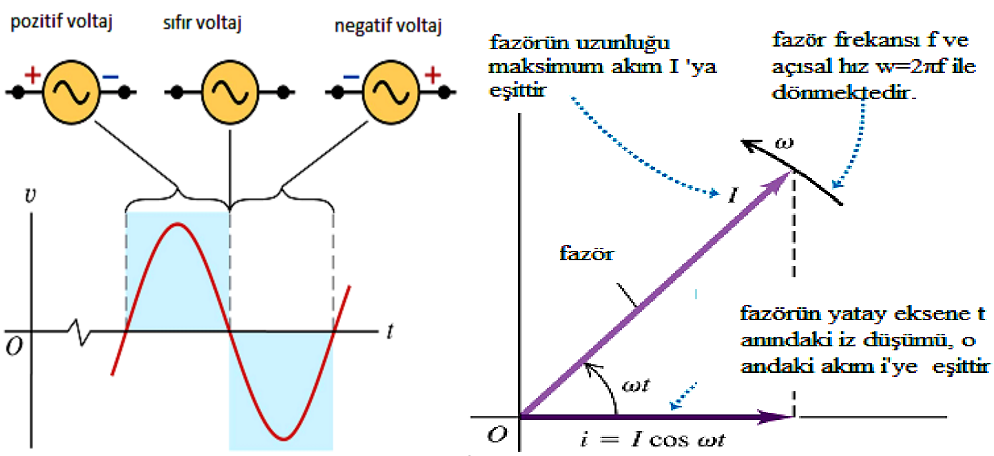

Figure 2.1: Alternative voltage (Left), Phasor Diagram (Right)

2.1.1.2. ROOT-MEAN-SQUARE ROOT VALUES

The simplest way to define quantities that take both positive and negative values is to take the root-mean-square root. We find the mean value of the sinusoidally varying current i, i^2, and then take the square root of the mean. This gives us the root-mean-square-root (effective) current, which we denote as i_{eff}. is always positive, even if it is negative. If i is not always zero, it is never zero. Figure 2.2 shows how i_{eff} is obtained for sinusoidal current. If it is given by the instantaneous current, it will be the square of this value, using the trigonometric half angle formula, it will be;

$$cos^2 A = \frac{1}{2}(1 + \cos 2A) \tag{2.1}$$

Here,

$$i^2 = I^2 \frac{1}{2}(1 + \cos 2\omega t) = \frac{1}{2} I^2 + \frac{1}{2} \cos 2\omega t \tag{2.2}$$

is found. The average of $\cos 2\omega t$ is zero, because it takes a positive value half the time and a negative value the other half. So the average of i^2 is only $I^2/_2$. The square root of this is I_{eff}.

$$I_{eff} = \frac{I}{\sqrt{2}} \tag{2.3}$$

If we took the i current as a sine function, we would find the same result.

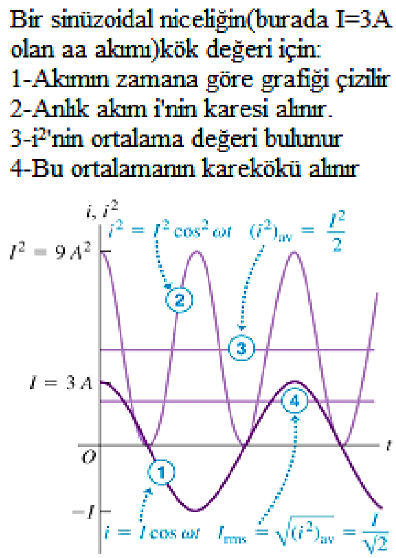

Figure 2.2: Calculating the root-mean-square value of an alternative current

2.1.1.3. RESISTANCE IN AN AC CIRCUIT

As shown in Figure 2.3, build an aa circuit with a resistor R through which a current $i = I \cos \omega t$ flows. The amplitude of the current (the maximum value it can take) is I. Using Ohm's law, the instantaneous potential v_R from point a to point b is given by $v_R = iR = (IR) \cos \omega t$. The maximum voltage V_R, that is, the amplitude of the voltage, is the coefficient of the cosine function: $V_R = IR$ and hence $v_R = V_R \cos \omega t$. As can be seen, the current i and the voltage v_R are both proportional to $\cos \omega t$. Then current and voltage are in the same phase. Figure 2.3b shows the plot of i and v_R as a function of time. The vertical scales used for current and voltage are different. Figure 2.3c shows the phasor diagrams of current and voltage. Since current and voltage are at the same frequency, the phasors of current and voltage rotate together and are parallel to each other at all times. Their projection onto the horizontal axis gives the instantaneous current and voltage respectively.

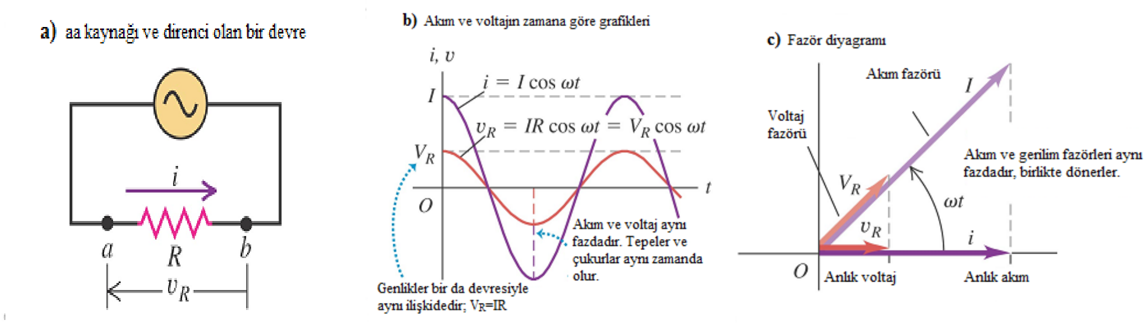

Figure 2.3: Resistance R connected to an AC source

2.1.1.4. COIL (INDUCTANCE) IN AC CIRCUIT

In Figure 2.4a, a coil is wired to an alternating current source. Although there is no resistance in a circuit with current $i = I\cos\omega t$ flowing through it, there is a potential difference v_L between the ends of the coil. This is because the time-varying current causes a self-induction emission. The induction emission is in the direction of the current i and is given by $\varepsilon = -L\, {di}/{dt}$, but the voltage v_L is not equal to ε. This is because if the current in the coil is positive and increasing from a to b, then it is important to note that the ${di}/{dt}$ is positive and the induction emf is to the left to counteract this increase in current. The potential at point a is higher than at point b and is given by $v_L = +L\, {di}/{dt}$, that is, the negative of the induction emf. i current is substituted into this equation,

$$v_L = L\frac{di}{dt} = L\frac{d(\cos\omega t)}{dt} = -I\omega L\sin\omega t \tag{2.4}$$

is found.

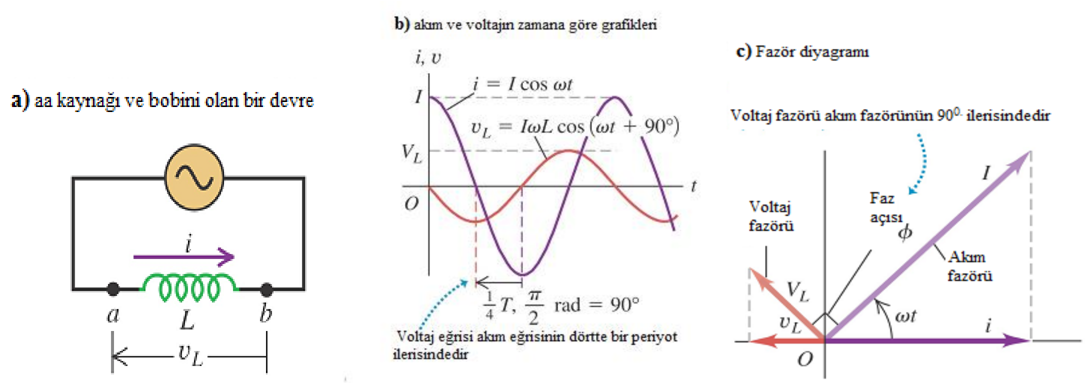

Figure 2.4: Coil with induction coefficient L connected to an AC source

The voltage v_L across the coil is proportional to the rate at which the current changes at any given moment. In Figure 2.4b, the maximum voltage points correspond to the points where the current curve is steepest.

The points where the voltage is zero are where the current curve flattens at maximum and minimum. There is a one-quarter phase difference between current and voltage. The phasor diagram in Figure 2.4c shows this relationship. Since the peaks of the voltage are a quarter period ahead of the peaks of the current, we say that the voltage is 90° in advance of the current. If we use the $\cos(A + 90°) = -\sin A$ equivalence in the above equation (**2.4**),

$$v_L = I\omega L\cos(\omega t + 90°) \tag{2.5}$$

is found. This shows that the voltage is a cosine function starting 90° in advance of the current. For $\phi = 90°$,

$$\begin{aligned} i &= I\cos\omega t \\ v &= V\cos(\omega t + \phi) \end{aligned} \tag{2.6}$$

ϕ is called the phase angle. Amplitude of the voltage at the terminals of the coil V_L is given by,

$$V_L = I\omega L \tag{2.7}$$

We also define the inductance of the coil as X_L,

$$X_L = \omega L \tag{2.8}$$

In fact, the definition of X_L is a definition of the self-induction emf that is opposite to any change in the current flowing through the coil. As the current or L increases, X_L will also increase. Since it is the ratio of voltage to current, the SI unit is the **ohm**.

2.1.1.5. CAPACITOR IN AN AC CIRCUIT

If we connect a capacitor to an AC source as shown in Figure 2.5a, the source generates a current $i = I\cos\omega t$ flowing through the capacitor. To find v_C, which is an instantaneous value of the voltage across the capacitor, if we denote the charge on the left side plate of the capacitor by q, the right side plate is charged with $-q$ charge. Current i depends on q with the relationship $i = {dq}/{dt}$. By this definition, a positive current corresponds to an increase in the charge on the left side plate.

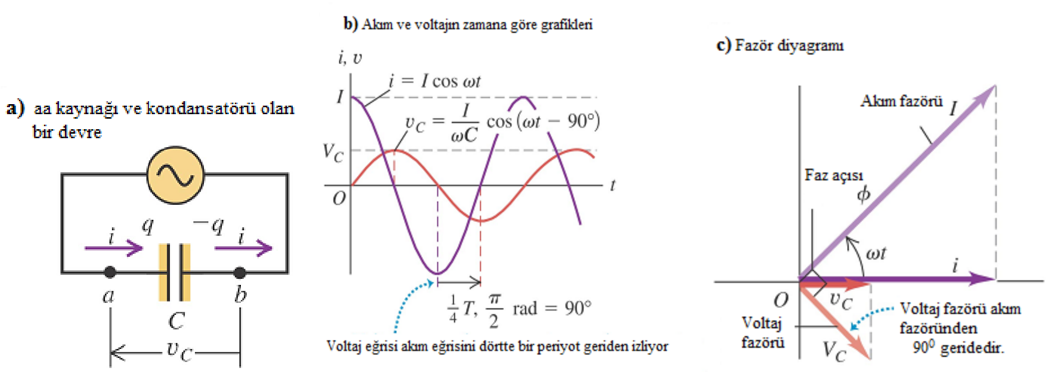

Figure 2.5: Capacitor connected to AC source

Then,

$$i = \frac{dq}{dt} = I\cos\omega t \tag{2.9}$$

If we take the integral,

$$q = \frac{I}{\omega}\sin\omega t \tag{2.10}$$

is found. Also, since the charge is $q = CV_C$, the equation becomes,

$$v_C = \frac{I}{C\omega}\sin\omega t \tag{2.11}$$

The instantaneous current i is equal to the rate of change of the charge q of the capacitor $i = {dq}/{dt}$. But since $q = CV$, i also depends on the rate of change of the voltage.

Figure 2.5b shows i and v_C as a function of time. The largest value of the current is where the v_C curve shows the steepest rise or fall, the current becomes zero when the v_C curve flattens for a moment at its maximum and minimum values. The capacitor's voltage and current are separated by a quarter of a cycle. The peaks of the voltage occur one-quarter cycle later than the corresponding peaks of the current. We say that the voltage is 90° behind the current. The phasor diagram in Figure 2.5c shows this relationship.

If we use the $\cos(A + 90°) = -\sin A$ equivalence in the above equation (**2.11**),

$$v_C = \frac{I}{\omega C}\cos(\omega t - 90°) \tag{2.12}$$

is found. The maximum voltage V_C is obtained as.

$$V_C = \frac{I}{\omega C} \tag{2.13}$$

If X_C, which we named capacitance (capacitive reactance), is defined as,

$$X_C = \frac{1}{\omega C} \tag{2.14}$$

V_C is obtained as,

$$V_C = IX_C \tag{2.15}$$

We find the amplitude of the voltage across a capacitor in an AC circuit. The capacitance of the capacitor is inversely proportional to both C and the angular frequency ω. As C increases, X_C becomes smaller. Capacitors tend to pass high currents and block low frequency currents. This is opposite to the behavior of the coil.

2.1.1.6. COMPARISON OF AC CIRCUIT ELEMENTS

Table I summarizes the relationship between voltage and current amplitudes for the three circuit elements we have discussed.

Table 2.1:

Component	Amplitude relationship	Circuit quantization	The phase of v
Resistance	$V_R = I_R R$	R	in the same phase with i
Coil	$V_L = IX_L$	$X_L = \omega L$	90° in advance of i
Capacitor	$V_C = IX_C$	$X_C = {}^1/_{\omega C}$	90° in behind of i

Figure 2.6 shows how a resistor, coil and capacitor change with angular frequency. As in a DC circuit, when $\omega = 0$, there is no current on the capacitor and no induction since $X_C \to \infty$. In the limit $\omega \to \infty$, X_L goes to infinity. And the current on the coil takes values close to zero. We must remember that the emf due to self-induction is opposite to the very fast changes in current. At the same limits X_C and the voltage across the capacitor both approach zero. Since the current changes direction very quickly, no charge accumulates on either of the plates.

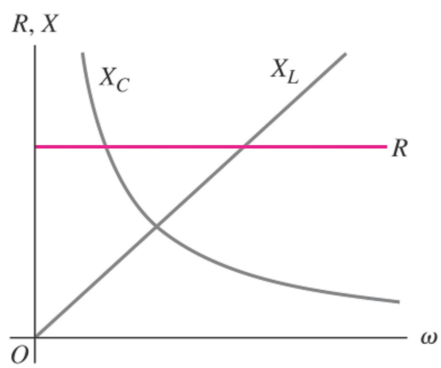

Figure 2.6: Variation of $\boldsymbol{R}$, $\boldsymbol{X_L}$ and $\boldsymbol{X_C}$ as a function of angular frequency $\boldsymbol{\omega}$

2.2. EXPERIMENTS

2.2.1. ALTERNATIVE CURRENT CIRCUITS

2.2.1.1. PART I: SERIAL RL CIRCUIT

Figure 2.7: $\boldsymbol{RL}$-$\boldsymbol{RC}$ Experimental Setup

MAIN PRINCIPLE

1) Investigation of an alternating current circuit consisting of a series resistor and a coil.
2) Determination of the self-induction coefficient of the coil.
3) Investigation of an alternating current circuit consisting of a series resistor and capacitor
4) Determination of capacitance of capacitor

EQUIPMENT

AC Voltage Source, Voltmeter, Ammeter, Coil, Rheostat, Capacitor, Ruler, Compass, Angle Meter, Connection Cable

THEORY

1. SELF-INDUCTION COEFFICIENT

A magnetic field is produced around a coil through which current flows Figure 2.8. The intensity B (magnetic flux density) of this field is proportional to the current flowing through the coil.

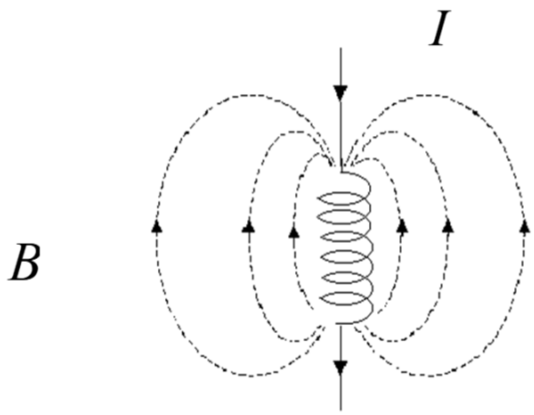

Figure 2.8:

$$B \sim I \tag{2.16}$$

or $B = KI$. Here, K (geometric factor) is a constant that depends on the given circuit. On the other hand, at the ends of a coil in a time-varying field B, an induction electromotive force (iemf) is generated, proportional to this change, given by the relation,

$$\varepsilon_i \approx \frac{dB}{dt} \tag{2.17}$$

This force causes a current I to flow through the coil. As shown in Figure 2.9, according to **Ampere's law**, the coil through which I current flows generates the magnetic field B_L, which is opposite to the B field that forms it. In this case, the coil remains under the influence of its own B_L magnetic field and if the current is variable, a self-induction electromotive force (siemf) appears at the ends of the coil.

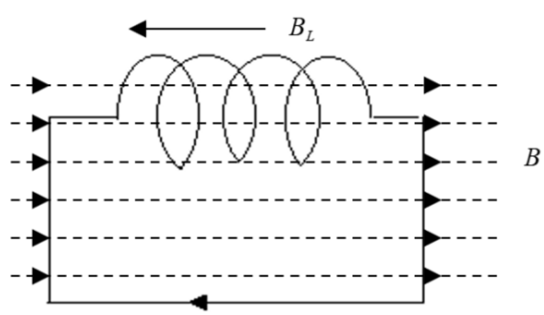

Figure 2.9:

The self-induction electromotive force ε_L is proportional to the time variation of the current flowing through the coil, according to relations (**2.16**) and (**2.17**). According to **Lenz's law**, the siemk is opposite to the self-inducing cause, taking into account that it is opposite to the direction of change of the current,

$$\varepsilon_L \approx -\frac{di}{dt} \text{ } or \text{ } \varepsilon_L \approx -L\frac{di}{dt} \tag{2.18}$$

relation can be written. The coefficient of proportionality L is called the self-induction coefficient and L,

$$L \equiv -\frac{\varepsilon}{\frac{di}{dt}} \tag{2.19}$$

is given by the relation Here, $[\varepsilon_L] = Volt$, $\left[\frac{di}{dt}\right] = \frac{A}{s}$ and $[L] = \frac{Volt \cdot s}{A} = Henry\ (H)$ is in units.

2. ALTERNATIVE CURRENT

A voltage source whose potential difference between its terminals changes periodically with time is called an **alternative voltage source**. This change is usually sinusoidal. The change of current intensity in the circuit connected to an alternating voltage source is also sine-shaped depending on time. Such currents are called **alternative currents**. **From now on, we will use lower case letters for time-varying quantities.** The time dependence of alternative current intensity and voltage is given by the relation below.

$$i = I_M \sin \omega t \tag{2.20}$$

$$v = V_M \sin(\omega t + \phi) \tag{2.21}$$

Where I_M and V_M are the maximum values (amplitudes) of current and voltage, ω is the frequency of change and is called **angular frequency**. The angular frequency depends on the frequency f and period τ with the relation $\omega = 2\pi f = {}^{2\pi}/_{\tau}$. The angle f indicates the “phase difference” between voltage and current intensity.

If $\phi > 0$, the voltage is in advance of the current,

If $\phi < 0$, the voltage is behind the current,

If $\phi = 0$, the voltage is in the same phase with the current.

Here, $[V] = Volt$, $[I] = Ampere$, $[\tau] = s$ and $[f] = [\omega] = s^{-1}\ (Hertz)$ is in units.

The impedance Z of an alternating current circuit with voltage V at its terminals and current I flowing through it is defined as the ratio of the amplitudes of the voltage and current magnitudes:

$$Z = \frac{V_M}{I_M} \tag{2.22}$$

As can be seen, this relation is the equivalent of Ohm's law in an alternating current circuit and impedance is the resistance of the circuit to alternative current. If the circuit element is only a resistor of value R, the impedance is

$$Z = R \tag{2.23}$$

and the phase difference is

$$\phi = 0 \tag{2.24}$$

If the circuit element is a coil with a self-induction coefficient L, the impedance is

$$Z = \omega L = X_L \tag{2.25}$$

and phase difference is,

$$\phi = \frac{\pi}{2} \tag{2.26}$$

The impedance of the coil is also called "inductance" or "inductive reactance" and is represented by X_L. Here it is $[Z] = [L] = [R] = Ohm\ (\Omega)$ in units.

3. SERIAL R-L CIRCUITS

In the circuit in Figure 2.10, which is formed by connecting a resistor R and a coil L in series, the total voltage V is given by $v = V_m \sin(\omega t + \phi)$ according to relation (**2.21**). The voltage at the resistance terminals can be written using equation (**2.24**),

$$v_R = V_{RM} \sin \omega t \tag{2.27}$$

is obtained. The voltage at the coil terminals is according to relation (**2.26**),

$$v_L = V_{LM} \sin\left(\omega t + \frac{\pi}{2}\right) \tag{2.28}$$

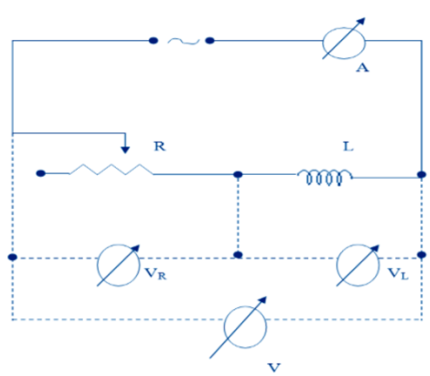

Figure 2.10:

When the quantities in alternating current circuits are vectorial, $\vec{v} = \overrightarrow{v_R} + \overrightarrow{v_L}$ and these three quantities can be represented by the vector diagram in Figure 2.11-Left. If both sides of the equations (**2.20**), (**2.27**), (**2.28**) are divided by I, the vector diagram in Figure 2.11-Left is reduced to the vector diagram in Figure 2.11-Right.

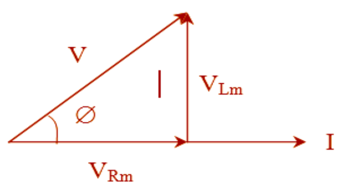

Figure 2.11: Vector diagram (Left), reduced vector diagram (Right)

The impedance of the circuit given by the relation (**2.22**) in these diagrams can be written more precisely in the form

$$Z_L = \sqrt{R^2 + \omega^2 L} \tag{2.29}$$

The phase angle of the circuit is given by relation,

$$\tan\phi \equiv \frac{V_{LM}}{V_{RM}} \equiv \frac{\omega L}{R} \Rightarrow \phi \equiv \tan^{-1}\frac{V_{LM}}{V_{RM}} \equiv \tan^{-1}\frac{\omega L}{R} v_L \tag{2.30}$$

Since the resistance of the winding wires of the coil cannot be ignored, the coil itself can be treated as a series $R - L$ circuit as shown in Figure 2.6.

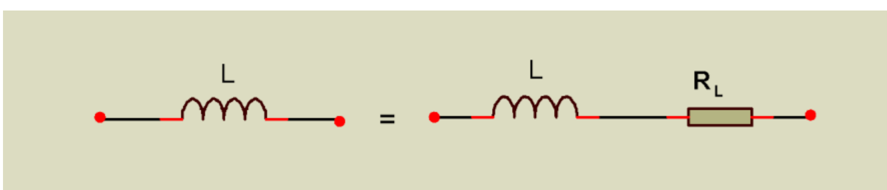

Figure 2.12

If the internal resistance of the coil is represented by R_L, if an R resistor is connected in serial to such a coil, the vector diagrams in Figure 2.11-Left and Figure-11-Right would be transformed into the diagrams in Figure 2.13-Left and Figure 2.13-Right.

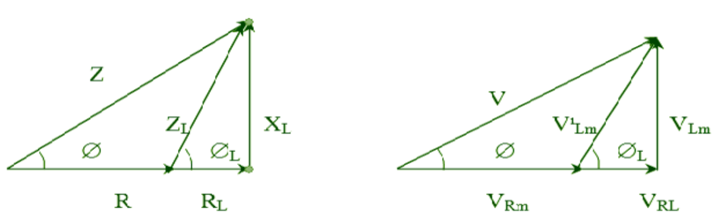

Figure 2.13: Coil (Left), Coil with internal resistance (Right)

Here, the total impedance of the coil is the maximum value of the voltage measured at the terminals of the coil. In this case, relations (**2.29**), (**2.30**) become,

$$Z_L = \sqrt{(R^2 + R_L) + {X_L}^2} \tag{2.31}$$

$$\phi \equiv \tan^{-1}\frac{v_{LM}}{v_{RM} + v_{R_LM}} \tag{2.32}$$

The phase difference ϕ_L between the voltage on the coil and the current flowing through the circuit is obtained as from Figure 2.13-Left and Figure 2.13-Right as,

$$\tan\phi_L = \frac{v_{LM}}{V_{R_LM}} = \frac{\omega L}{R_L} \Rightarrow \phi_L = \tan^{-1}\frac{v_{LM}}{V_{R_LM}} = \tan^{-1}\frac{\omega L}{R_L} \tag{2.33}$$

4. EFFECTIVE VALUES

In addition to the instantaneous value and maximum value in alternating currents, there are also effective values or effective values for both potential difference and current intensity. Like direct current, when alternating current passes through a resistance, it causes that resistance to heat up. The amount of heat generated by an alternating current passing through a certain resistance in a certain time interval is called the effective intensity and effective potential difference of that alternating current. Suppose that an alternating current whose change with time is $i = I_M \sin \omega t$ passes through a resistance such as R. The amount of heat released during a period will be

$$Q = \int_0^T i^2 R\,dt = I_M^2 R \int_0^T \sin^2 \omega t\,dt \tag{2.34}$$

$$Q = \frac{1}{2} I_M^2\ (Joule) \tag{2.35}$$

The amount of heat that a direct current of intensity i will generate in the same resistance at the same time,

$$Q = i^2 RT\ (Joule) \tag{2.36}$$

According to the definition, since these two amounts of heat will be equal, the effective intensity of the alternative current,

$$i = \frac{I_M}{\sqrt{2}} \tag{2.37}$$

is found. Similarly, the effective potential difference is

$$v = \frac{V_M}{\sqrt{2}} \tag{2.38}$$

is obtained. Such as, the effective value of the alternative voltage in the city electricity network is $220\ volts$. For the maximum value, $220\ x\ =\ 311\ volts$ is obtained.

Accordingly, effective values can be written instead of the maxima of voltages and currents in equations (**2**.**22**), (**2**.**30**), (**2**.**33**). Therefore, the vector diagrams in Figure 2.11 and Figure 2.13 can also be drawn with effective values.

SETUP AND PROCEDURE

1. Set up the circuit in Figure 2.10 and let current flow through the circuit. Set the current strength to a suitable value with the help of variable resistor R (rheostat) and record this value.

$i =$.....................

2. Measure v_R across the resistor, v'_L across the coil and the total voltage v. Disconnect the current and from these three values draw the vector diagram in Figure-14 to scale (this diagram is called the three-voltmeter method).

$v_R =$..................... $v'_L =$..................... $v =$.....................

3. A vector diagram is completed to include v_{RL} and V'_L. Measure the values of v_{R_L} and v_L on the diagram.

$v_{R_L} =$..................... $v_L =$.....................

4. Taking $f = 50\ s^{-1}$, calculate the angular frequency ω from the relation $\omega = 2\pi f = {}^{2\pi}/_{\tau}$.

$\omega =$.....................

5. Determine the self-induction coefficient L of the coil.

$v_L = i\omega L \Rightarrow L = \frac{v_L}{I\omega} =$.....................

6. Calculate the total impedance Z of the circuit from the relation (**2.25**).

$Z =$.....................

7. Calculate the internal resistance R_L of the coil.

$R_L = \frac{v_{R_L}}{i} =$.....................

8. Calculate the value of the resistor R.

$R = \frac{v_R}{i} =$.....................

9. Recalculate the self-induction coefficient L of the coil by using the relation (**2.31**).

$L = \frac{1}{\omega}\sqrt{Z^2 - (R + R_L)^2} =$.....................

10. Calculate the phase angle ϕ using the relation (**2.32**).

$\phi =$.....................

11. Calculate the phase angle ϕ_L using the relation (**2.33**).

$$\phi_L = \tan^{-1}\frac{\omega L}{R_L} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

12. Record the quantities calculated and found from the figure in Table-II.

13. Interpret the results of the experiment. Briefly explain the information you gained from the experiment.

Table 2.2:

Physical Quantities	Calculated	Figure
$\boldsymbol{i\ (A)}$		
$\boldsymbol{v_R\ (V)}$		
$\boldsymbol{v'_L\ (V)}$		
$\boldsymbol{v\ (V)}$		
$\boldsymbol{v_{R_L}\ (V)}$		
$\boldsymbol{v_L\ (V)}$		
$\boldsymbol{L\ (H)}$		
$\boldsymbol{Z\ (\Omega)}$		
$\boldsymbol{R_L\ (\Omega)}$		
$\boldsymbol{R\ (\Omega)}$		
$\boldsymbol{\omega\ (s^{-1})}$		
$\boldsymbol{\phi\ (deg)}$		
$\boldsymbol{\phi_L\ (deg)}$		

2.2.1.2. PART II: SERIAL RC CIRCUIT

MAIN PRINCIBLE

Consider an alternative current generator (generator) connected to a series circuit containing R and C elements. If the voltage amplitude and frequency of the generator are given together with the values of R and C, the current flowing through the circuit can be found in terms of amplitude and phase constant. To simplify our work when analyzing more complex circuits involving two or more elements, we will use graphical structures called phasor diagrams. In these structures, alternating quantities such as current and voltage are represented by phasors. The projection of the phasor on the vertical axis shows the instantaneous value of the quantity in question, and its length shows the amplitude (maximum value) of the quantity. The phasor rotates counterclockwise. As we will see later, the method of summing various currents and voltages of different sinusoidally varying phases is considerably simplified by this procedure.

Capacitors are widely used in various electrical circuits. For example, they are used to adjust the frequency of radio receivers, as filters in power supplies, to eliminate sparks in automobile ignition systems, and as an energy storage device in electronic flash units. A capacitor is essentially an insulator placed between two conductors.

EQUIPMENT

AC Voltage Source, Voltmeter, Ammeter, Coil, Rheostat, Capacitor, Ruler, Compass, Angle Meter, Connection Cable

THEORY

1. DEFINITION OF CAPACITANCE:

Take two conductors with a potential difference of V between them and assume that they have equal and opposite charges. This can be achieved by connecting two uncharged conductors to the poles of a battery. Such a combination of two conductors is called a capacitor. The magnitude of the charge on the capacitor is found to be proportional to the potential difference V. The capacitance C of a capacitor is defined as the ratio of the magnitude of the charge on one of the conductors to the magnitude of the potential difference between these conductors.

$$C = \frac{Q}{V} \tag{2.39}$$

Note that, according to the definition, the capacitance will always be a positive quantity. Moreover, since the potential difference increases as the accumulated charge increases, the $Q/_V$ ratio for a given capacitor is constant. It is easy to see from the equation that in SI units the capacitance is coulombs per volt. The name of the capacitance in **SI** units is farad. In short $[Capacitance\ ] = 1F\ =\ C/_V$. Farad is a very large unit of capacitance. In practice, the capacitance of many devices ranges from milli-farads ($1\ mF\ =\ 10^{-3}\ F$) to pico-farads ($1pF\ =\ 10^{-12}\ F$).

2. SERIAL RC CIRCUIT:

In the previous sections we have investigated the effects of placing capacitors and resistors separately between the terminals of a voltage source. Now we will examine what happens when these elements are used together. As before, we will assume that the applied voltage varies sinusoidally with time.

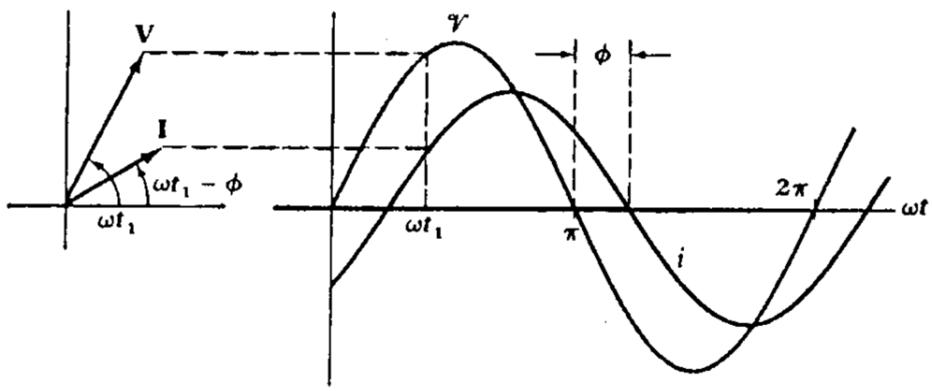

Figure 2.14: a) Left b) Right

It is reasonable to think of the voltage as

$$v = V_M \sin \omega t \tag{2.40}$$

and the current as

$$i = I_M \sin(\omega t - \phi) \tag{2.41}$$

The ϕ quantity is called the phase angle between the current and the applied voltage. Our goal is to determine ϕ and I_M. Recall that since the elements are in series, the current everywhere in the circuit must be the same at any given moment. That is, the alternating current at each point of an alternating current series circuit has the same amplitude and phase. Therefore, as we found in the previous section, the voltage between the terminals of each element will have different amplitude and different phases. In particular, the voltage between the terminals of the resistor is in phase with the current Figure 2.15a. The voltage between the terminals of the capacitor is 90° behind the current Figure 2.15b.

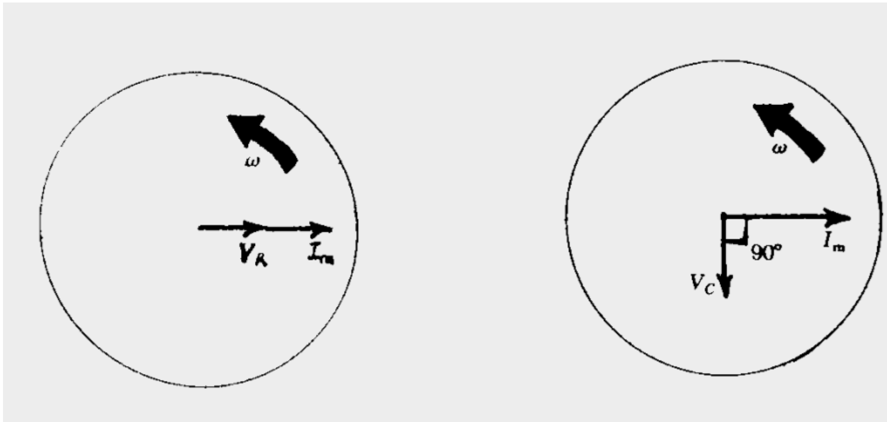

Figure 2.15: Phase of the current with the potential difference between the terminals of a) the resistor and b) the capacitor

Using these phase relationships, we can express the voltage drops between the terminals of both elements as follows:

$$v_R = I_M \sin \omega t = V_{RM} \sin \omega t \tag{2.42}$$

$$v_C = I_M X_C \sin\left(\omega t - \frac{\pi}{2}\right) = -V_{CM} \cos \omega t \tag{2.43}$$

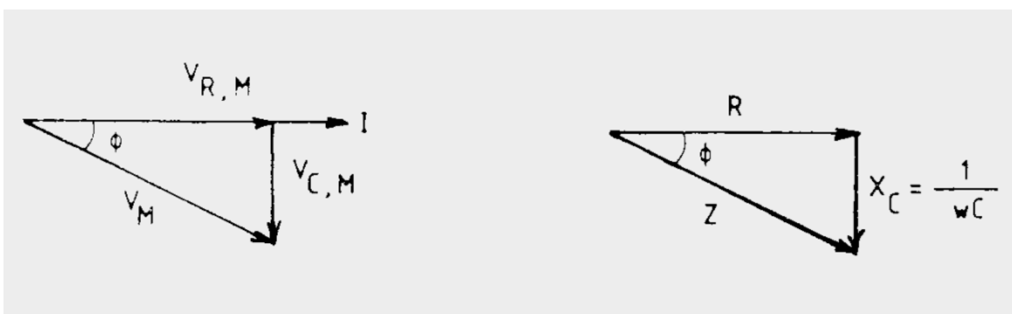

Figure 2.16

Since quantities in alternative current circuits can be expressed in phasors,

$$\vec{v} = \overrightarrow{v_R} + \overrightarrow{v_C} \tag{2.44}$$

and these three quantities can be represented by a phasor diagram. From the diagram,

$$V = \sqrt{V_{RM}^2 + V_{CM}^2} \tag{2.45}$$

relation can be written. The impedance of the circuit can be written in the form,

$$Z = \sqrt{R^2 + \frac{1}{\omega^2 C^2}} \tag{2.46}$$

The phase angle of the circuit is,

$$\tan\phi = -\frac{V_{CM}}{V_{RM}} = -\frac{1/_{\omega C}}{R} \tag{2.47}$$

$$\phi = \tan^{-1} - \frac{V_{CM}}{V_{RM}} = \tan^{-1} - \frac{1/_{\omega C}}{R} \tag{2.48}$$

SETUP AND PROCEDURE

1. The circuit in the Figure 2.17 is established. Measure v_R across the resistor, v_C across the capacitor and the total voltage v.

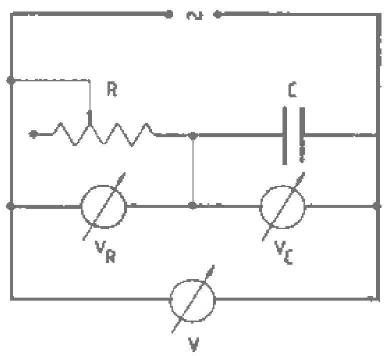

Figure 2.17

$v_R =$..................... $v_C =$..................... $v =$.....................

2. Using the voltages v, v_R and v_C,

$v = \sqrt{V_R^2 + V_C^2} =$.....................

is calculated.

3. Phase difference ϕ,

$\phi = \tan^{-1} - \frac{V_C}{R} =$.....................

4. The intensity of the current i in the circuit, if the resistance R is known,

$i = \frac{v_R}{R} =$.....................

5. The angular frequency ω is calculated by taking the frequency $f = 50\ s^{-1}$.

$\omega = 2\pi f =$.....................

6. The capacitance of the capacitor is

$C = \frac{1}{\omega}\frac{i}{v_C} =$.....................

7. A vector diagram is drawn to scale with the measured v_R, v_C, v values. From this drawn diagram, the phase angle ϕ is found with an angle meter.

Table 2.3:

Physical Quantities	Calculated	Figure
$v_R\ (V)$		
$v_C\ (V)$		
$v\ (V)$		
$\phi\ (deg)$		
$R\ (\Omega)$		
$i\ (A)$		
$\omega\ (s^{-1})$		
$C\ (F)$		

2.2.2. ALTERNATIVE CURRENT BRIDGES

MAIN PRINCIBLE

1) Comparison of two coils by Maxwell's method.

2) Comparison of two capacities by De Sauty method.

EQUIPMENT

Variable Coil, Variable Resistor, Variable Capacitor, Ammeter, AC Power Supply (Function Generator), Connection Cables

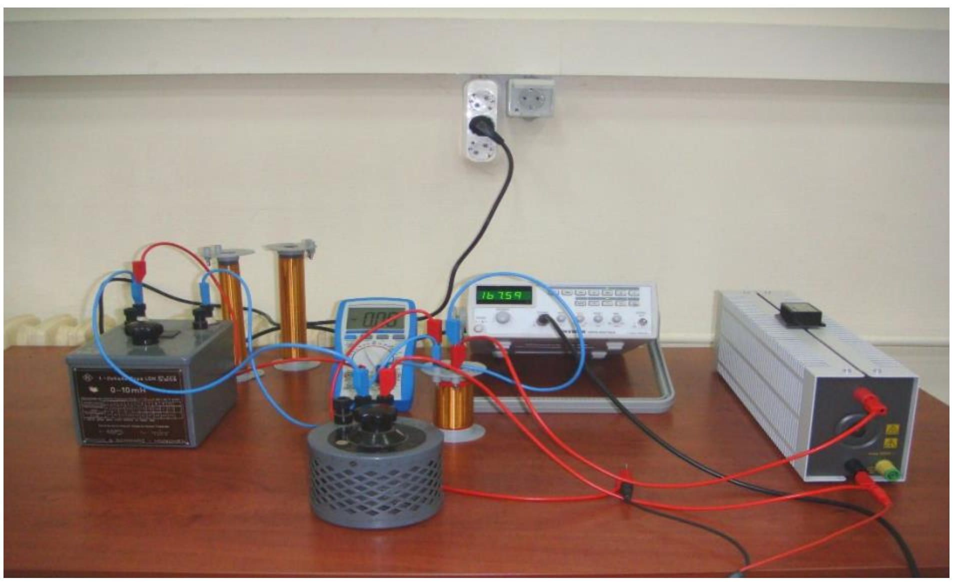

Figure 2.18: Maxwell Bridge experimental setup

THEORY

1. MAXWELL'S METHOD

In this method, two coils are connected in the form of a bridge as shown in Figure 2.19. The impedances in the arms are $Z_1 = r_1 + j\omega L_1$, $Z_2 = r_2 + j\omega L_2$, $Z_3 = R_3$, $Z_4 = R_4$. When the circuit elements are brought to the appropriate values, no current passes through the galvanometer G. ($I_G = 0$) and the bridge are said to be in equilibrium. Since there will be a potential difference between the CD points in equilibrium;

$$I_1 Z_1 - I_2 Z_2 = 0,\ I_1 Z_3 - I_2 Z_4 = 0 \tag{2.49}$$

$$Z_1 Z_4 = Z_2 Z_3 \tag{2.50}$$

can be written. When impedances are replaced,

$$(r_1 + j\omega L_1) R_4 = (r_2 + j\omega L_2) R_3 \tag{2.51}$$

equation is obtained. For this equality to be realized, the real and imaginary coefficients must be equal among themselves. From the equality of the imaginary coefficients;

$$j\omega L_1 R_4 = +j\omega L_2 R_3 \Rightarrow L_1 R_4 = L_2 R_3 \Rightarrow \frac{L_1}{L_2} = \frac{R_3}{R_4} \tag{2.52}$$

the equilibrium condition of the bridge is found.

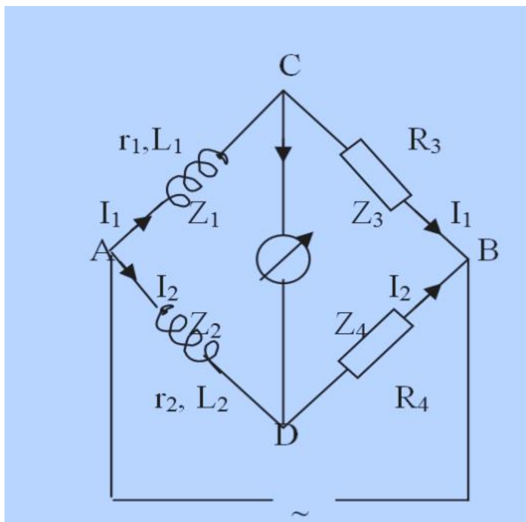

Figure 2.19

2. DE SAUTY'S METHOD

Here, the bridge is formed by installing two resistors and two capacitors as shown in Figure 2.20. Impedances of the arms;

$$Z_1 = \frac{1}{j\omega C_1}, Z_2 = \frac{1}{j\omega C_2}, Z_3 = R_3 \; and \; Z_4 = R_4 \tag{2.53}$$

When $I_G = 0$, the bridge is in equilibrium and in the equilibrium state;

$$Z_1 Z_4 = Z_2 Z_3 \tag{2.54}$$

can be written. When impedances are replaced by their equivalents,

$$\frac{1}{j\omega C_1} R_4 = \frac{1}{j\omega C_2} R_3 \Rightarrow \frac{C_1}{C_2} = \frac{R_4}{R_3} \tag{2.55}$$

the equilibrium condition of the bridge is found.

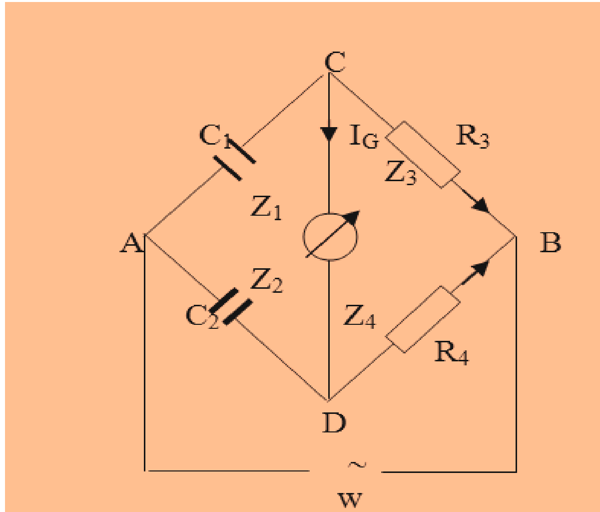

Figure 2.20

SETUP AND PROCEDURE

The experimental setup consists of variable resistors (rheostats), variable coil (etalon self), variable capacitance box and AC galvanometer to perform the circuits in Figure 2.19 and Figure 2.20. The alternating voltage supplying the bridge (function generator) is provided by a variable transformer (variac) from the city network.

1- First build the Maxwell bridge in Figure 2.19. Etalon variable self is used for L_1 and rheostats are used for R_3 and R_4. Apply voltage to the circuit with the help of a variac.
2- Balance the bridge for five different values of L_2 etalon coil. For this, measure the resistance values of R_3 and R_4 and record them in Table-I.
3- Calculate the value of coil L_1 five times from equation (**2.52**) and record them in Table-I.

$L_1 = L_2 \frac{R_3}{R_4} \Rightarrow L_1 =$.....................H

Table 2.4:

$L_2\ (H)$	$L_1\ (H)$	$R_3\ (\Omega)$	R_4
1			
2			
3			
4			
5			

4- Calculate the standard deviation for coil L_1 and express the result in the form;

$L_1 = L_{average} \mp \Delta L_{average}$ =.....................H

$L_{average} = \frac{\sum L}{n} =$

$\Delta L_1 = (L_1 - L_{average}) \Rightarrow \Delta L_1 =$ ....H

$\Delta L_2 = (L_2 - L_{average}) \Rightarrow \Delta L_2 =$ ....H

$\Delta L_3 = (L_3 - L_{average}) \Rightarrow \Delta L_3 =$ ....H

$\Delta L_4 = (L_4 - L_{average}) \Rightarrow \Delta L_4 =$ ....H

$\Delta L_5 = (L_5 - L_{average}) \Rightarrow \Delta L_5 =$ ....H

$\Delta L_n = (L_n - L_{average})$

$$L_{average} = \sqrt{\frac{(\Delta L_1)^2+(\Delta L_2)^2+(\Delta L_3)^2+\cdots+(\Delta L_n)^2}{n(n-1)}} = \sqrt{\frac{(......)^2+(.....)^2+(.....)^2+ ....}{20}}$$

$L_1 = L_{average} \mp \Delta L_{average}$ =.....................H

2.2.3. TRANSFORMERS

MAIN PRINCIBLE

1) Examining the current and voltage relationship between the primary and secondary windings of the transformer.

2) Calculating the efficiency of the transformers.

EQUIPMENT

Transformer, ammeter, voltmeter, rheostat, variac, connecting cords.

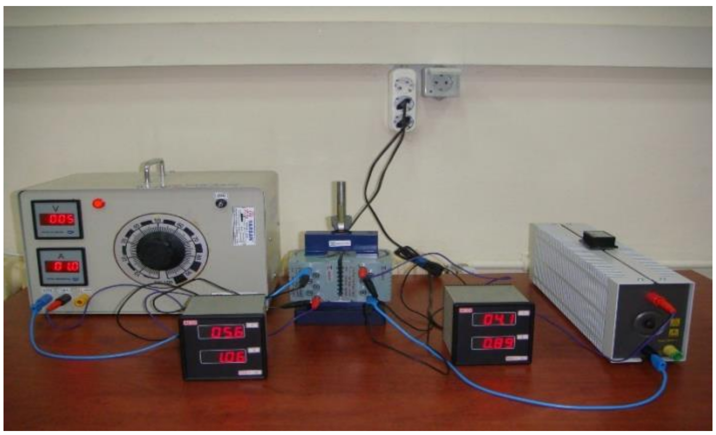

Figure 2.21: Experimental Setup

THEORY

A transformer is a circuit element that converts an alternating voltage to an alternating voltage of another value. This conversion can be done by increasing a few volts of alternating voltage to a few tens of thousands of volts, or by decreasing a few tens of thousands of volts of alternating voltage to a few volts. For example, in a typical television receiver a transformer steps up the $220\ volts$ alternating input voltage to the approximately $15{,}000\ volts$ required to operate the picture tube. For another example, a doorbell operates on $9\ volts$, and so $220\ volts$ of mains voltage is stepped down to $9\ volts$ by using a transformer.

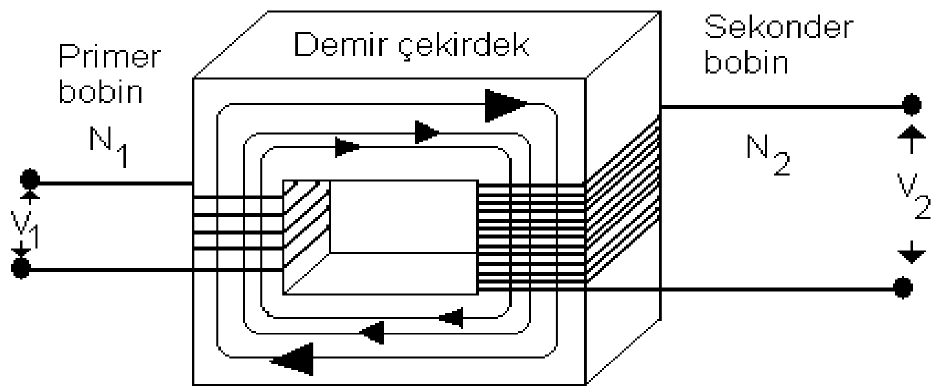

Figure 2.22:

Transformers consist of two coils with different winding numbers (N_1 and N_2) wrapped around the arms of an iron core (Figure 2.22). Power is given to one of the coils; it is taken from the other. The coil that is given power is called the **primary**, and the coil that power is taken from is called the **secondary**. The primary coil is connected to an alternating power source, and the alternating current in this coil creates a variable magnetic field in the iron core. The magnetic flux lines, which change direction and intensity, tend to follow the iron core and pass through the secondary coil. Accordingly, the magnetic flux in the primary and secondary coils will be the same. The change in magnetic flux in the secondary coil causes an induced emf (V_2) in that coil.

$$V_2 = -N_2 \frac{\Delta \phi}{\Delta t} \tag{2.56}$$

Since the same flux change is also valid in the primary coil, the emf of V_1 at the primary coil ends is given by;

$$V_1 = -N_1 \frac{\Delta \phi}{\Delta t} \tag{2.57}$$

From the ratios of expressions (**2.56**) and (**2.57**) we will have;

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \tag{2.58}$$

Here N_1 and N_2 are the number of turns in the primary and secondary coils respectively. This equation is known as the ‘transformer equation’. This equation shows us how the secondary electromotive force is related to the primary electromotive force. If $N_2 > N_1$, such a transformer is called a **step-up transformer** because it increases the voltage difference; if $N_1 > N_2$, it is called a **step-down transformer** because it decreases the voltage difference. If there is no load connected to the ends of the secondary coil, the current in it will be zero. Therefore, no power is consumed in the secondary coil. Again, in this case, the input current in the secondary coil will have a 90° phase difference with the input voltage, so the average power in this coil is zero.

If a current is drawn from the secondary coil, since some of the power will be taken by the output, an amount of energy equal to this power must be given to the input. In an ideal transformer, the primary and secondary powers are equal so that there is no energy loss. However, due to the Foucault currents occurring in the iron core and the small amount of energy lost in the wires as heat according to Joule's law, the output power of a transformer is inevitably smaller than the input power. In order to reduce the Foucault currents occurring in the core, the core is made of sheet metal plates insulated from each other. Despite these losses, the efficiency of transformers is over 90 %.

If we assume that there are no losses (for 100% efficiency), the power given to the primary coil (P_1) will be equal to the power taken from the secondary coil;

$$P_1 = P_2 = I_1 V_1 = I_2 V_2 \tag{2.59}$$

The efficiency (η) of a transformer is defined as the ratio of the power taken from the secondary coil (P_2) to the power delivered to the primary coil (P_1).

$$\eta = \frac{P_2}{P_1} \tag{2.60}$$

SETUP AND PROCEDURE

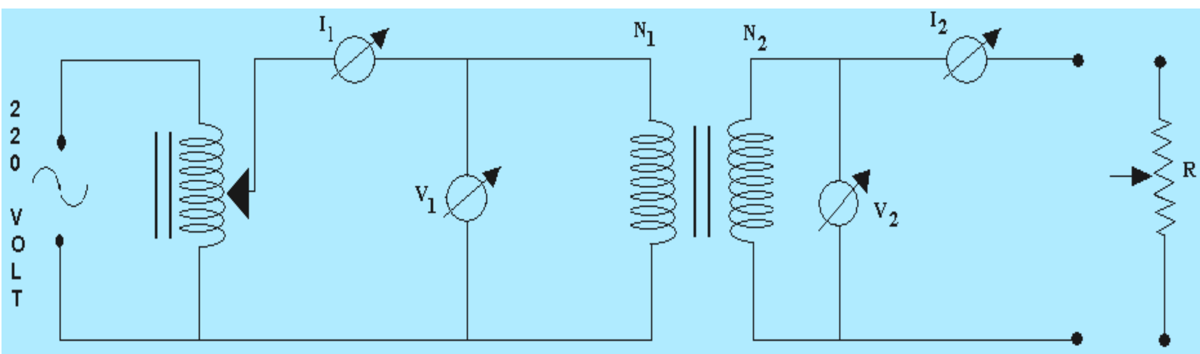

Figure 2.23

The experimental setup, as seen in Figure 2.23, consists of an iron core and a transformer that can be made up of coils with different number of windings, as well as the necessary measuring instruments and rheostat to measure currents and voltages. There is also a variable transformer (variac) to provide different input voltages.

1) Set up the circuit in Figure 2.23 so that the ends of the secondary coil are open (unloaded transformer). Select the $^{N_1}/_{N_2}$ ratio as 0.5, 1 and 2, respectively.
2) Read the V_2 output voltage values corresponding to the input voltage of V_1 at different values from the variable transformer (variac) and mark them in Table 2.5. Then, draw the $V_2 = f(V_1)$ graph for each fixed $^{N_1}/_{N_2}$ value as in Figure 2.24.

Table 2.5: Output voltage values corresponding to different input voltages.

$\boldsymbol{N_1/N_2 = 0.5}$		$\boldsymbol{N_1/N_2 = 1}$		$\boldsymbol{N_1/N_2 = 2}$	
$V_1(V)$	$V_2(V)$	$V_1(V)$	$V_2(V)$	$V_1(V)$	$V_2(V)$

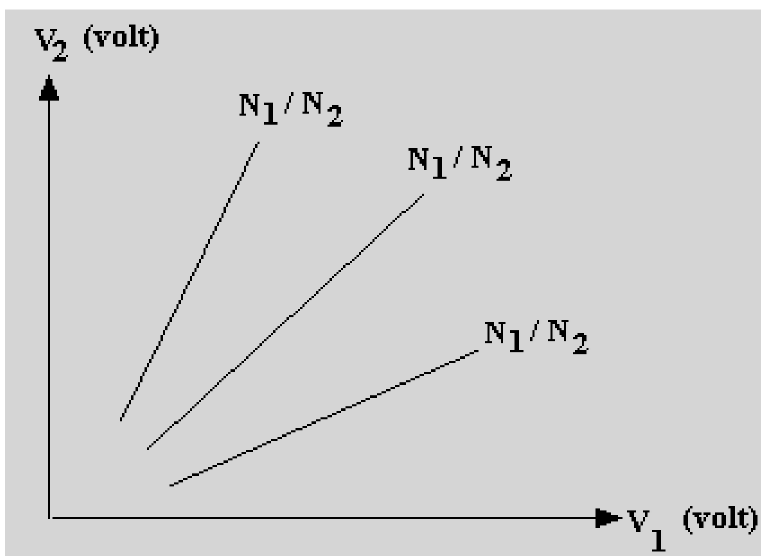

Figure 2.24: Graph of $\boldsymbol{V_2 = f(V_1)}$ for fixed ratios of $\boldsymbol{N_1/N_2}$

3) Connect the rheostat (R) to the secondary ends of the circuit in Figure 2.23 and adjust the resistance of the rheostat to a certain value between $20 - 80$, keeping the $N_1/N_2 = 1$ constant.
4) Read the I_1, I_2, and V_2 values for different V_1 primary circuit voltages and enter them in Table 2.6. Calculate the primary circuit power (P_1) from equation (**2.58**). Find the transformer efficiency (η) from the expression (**2.60**).

Table 2.6: Calculating the efficiency of the transformer ($R_L = \dots\dots\dots\dots \Omega$)

$V_1(V)$	$I_2(A)$	$V_2(V)$	$I_2(A)$	$P_1(W)$	$P_2(W)$	$\eta = {P_2}/{P_1}$

5) Using Table 2.6, draw $\eta = f(P_1)$ curve as in Figure 2.25.

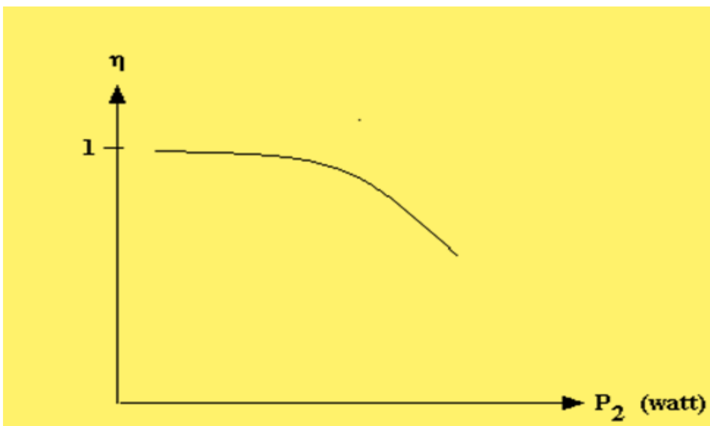

Figure 2.25: $\eta = f(P_1)$ efficiency graph

6) Comment on the experimental results you found. Briefly explain the information you obtained from the experiment.

QUESTIONS:

1) What is a variac and how does it work?
2) If there is no load on the secondary coil of the transformer, what will be the current value in the primary coil?
3) What causes the decrease in transformer efficiency?
4) What happens if we connect the ammeter in series with the circuit?
5) What do you think the internal resistance of the voltmeter is?

6) A What will be the equivalent resistance if the ammeter and voltmeter are connected in parallel?

2.2.4. RLC SERIAL-PARALLEL CIRCUITS

2.2.4.1. PART I: SERIAL RLC CIRCUITS

MAIN PRINCIBLE

Investigation of frequency performance of a series tuned circuit for the following cases:

1) voltage resonance without damping resistor
2) current resonance without damping resistor
3) current resonance with damping resistor

EQUIPMENT

Resistance, Capacitor, Coil, Computer, Combo3 Software Program, AC Power Source, Connecting cords

Figure 2.26: Experimental setup

THEORY

1. SERIAL RLC CIRCUIT

If an alternating voltage source with a voltage of

$$U(t) = U_0 \cos \omega t \tag{2.61}$$

or its equivalent

$$U(t) = U_0 e^{j\omega t} \tag{2.62}$$

is connected to a series circuit consisting of a coil with inductance L, a capacitor with capacitance C and a resistance R, (see Figure 2.27).

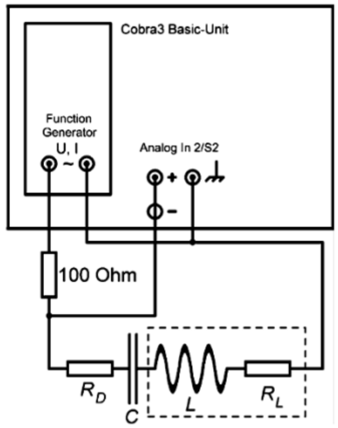

Figure 2.27:

According to the Kirchhoff loop rule:

$$U(t) = I(t)R + L\frac{dI(t)}{dt} + \frac{Q}{C} \tag{2.63}$$

Here; I is the current and Q is the charge on the capacitor. We can write the current as:

$$I(t) = \frac{dQ}{dt} \tag{2.64}$$

If we take the derivative of equation (**2.63**) with respect to time:

$$\frac{dU(t)}{dt} = R\frac{dl(t)}{dt} + L\frac{d^2I(t)}{dt^2} + \frac{I(t)}{C} \tag{2.65}$$

In alternating current circuits we expressed the current as $I(t) = I_0 \cos \omega t = I_0 e^{j\omega t}$. We know that there is a phase difference of ϕ between the current and voltage in RL and RC circuits operating with AC. Taking this phase difference into account, if the current expression above is replaced by

$$I(t) = I_0 e^{j\omega t} e^{-j\phi} \tag{2.66}$$

and placed in equation (**2.65**) together with equation (**2.61**):

$$j\omega U_0 = I_0 e^{-j\phi}\left(\frac{1}{C} + j\omega R - \omega^2 L\right) \tag{2.67}$$

If we write impedance as $Z = {}^{U_0}/_{I_0}$ equation (**2.67**) becomes:

$$j\omega Z = e^{-j\phi}\left(\frac{1}{C} + j\omega R - \omega^2 L\right) \tag{2.68}$$

The magnitude of the equation (**2.68**) whose right and left sides are complex numbers is found as:

$$|Z| = \sqrt{R^2 + \left(\frac{1}{C} + j\omega R - \omega^2 L\right)^2} \tag{2.69}$$

Equation (**2.69**) expresses that "at low frequencies the impedance of the circuit will be infinite, and the capacitor will be active in the circuit". A ω_0 value can be found in Equation (**2.69**) that will minimize the impedance (Z) of the circuit:

$$\left(\omega_0 L - \frac{1}{\omega_0 C}\right) \tag{2.70}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{2.71}$$

Such a value of ω_0 is called the angular resonance frequency, and f_0 is called the resonance frequency. The frequency f_0 gives the value at which the current is maximum. In this case, the voltage across the resistor is equal to the voltage of the source. The circuit behaves as if only the resistor were present.

At values below the resonant frequency, capacitive reactance is dominant in the circuit, the voltage lags behind the current and the phase angle ϕ is between zero and $-90°$.

Above the resonance frequency, inductive reactance dominates; voltage leads current and the phase angle ϕ is between zero and $+180°$.

On the other hand, we can insert the identity $e^{-j\phi} = \cos\phi - j\sin\phi$ into equation (**2.68**) and write the real and imaginary parts separately. The imaginary part can be found as:

$$j\left(\omega L - \frac{1}{\omega C}\right)\cos\phi - jR\sin\phi = 0 \tag{2.72}$$

Here we can obtain:

$$\tan\phi = \frac{\omega L - \frac{1}{\omega C}}{R} \tag{2.73}$$

Expression (**2.73**) tells us that at low frequencies the current leads the voltage, while at high frequencies the current lags the voltage.

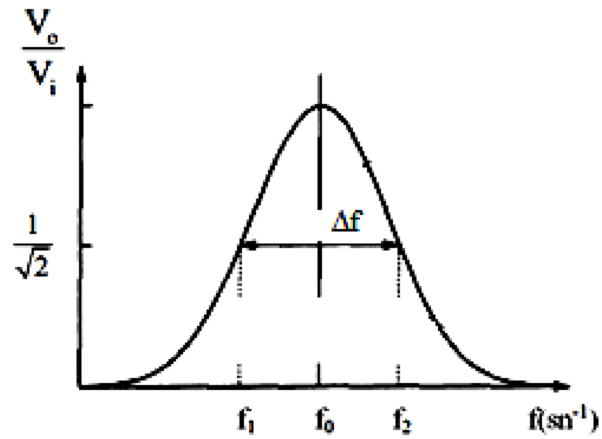

Figure 2.28:

f_1 and f_2 are called the half power frequencies of the circuit. In series RLC circuits the quality factor Q_s is defined:

$$Q_s = \frac{1}{R}\sqrt{\frac{L}{C}} \tag{2.74}$$

The quality factor defines the bandwidth of the circuit.

$$Q_s = \frac{f_0}{\Delta f} = \frac{f_0}{f_2 - f_1} = \sqrt{2}R \tag{2.75}$$

is also the geometric mean of the resonance frequencies ω_1 and ω_2.

$$\omega_0 = \sqrt{\omega_1 \omega_2} = \frac{1}{\sqrt{LC}} \tag{2.76}$$

The bandwidth of a circuit is the region between the frequency values where the voltage taken from the output of the circuit falls below $1/\sqrt{2}$ times its maximum value (Figure 2.28). These frequencies are called half-power frequencies.

SETUP AND PROCEDURE

1) Set up the circuit as in Figure 2.27.
2) Connect the COBRA3 Basic Unit to the computer port **COM1**, **COM2** or to **USB** port.
3) Start the **"measure"** program and select **"Gauge"** → **"Cobra3 PowerGraph"**.
4) Click the **"Analog In2/S2"** and select the **"Module /Sensor"** → **"Burst measurement"** with the parameters seen in Figure 2.29.
5) Click on the **"Function Generator"** symbol and create the parameters in Figure 2.30.
6) Add a **"Virtual device"** by clicking the white triangle in the upper left of the **"PowerGraph"** window or by right-clicking the **"Cobra3 Basic-Unit"** symbol. Turn off all channels but the first and configure this one as seen in Figure 2.31.

7) The **“Settings”** chart of **“PowerGraph”** should look like Figure 2.32.
8) Configure a diagram to be seen during the measurement on the **“Displays”** chart of **“PowerGraph”** as in Figure 2.33 and turn on some Displays for the frequency, the voltages and the current.

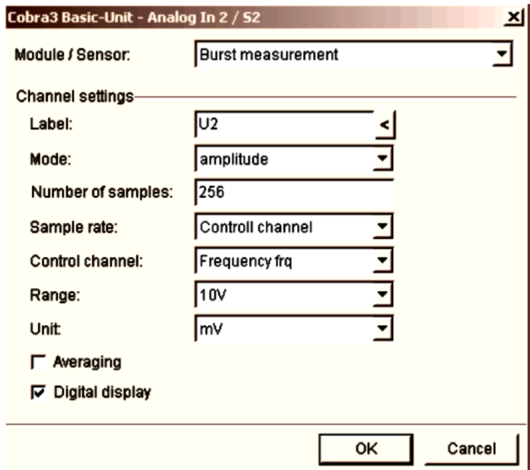

Figure 2.29:

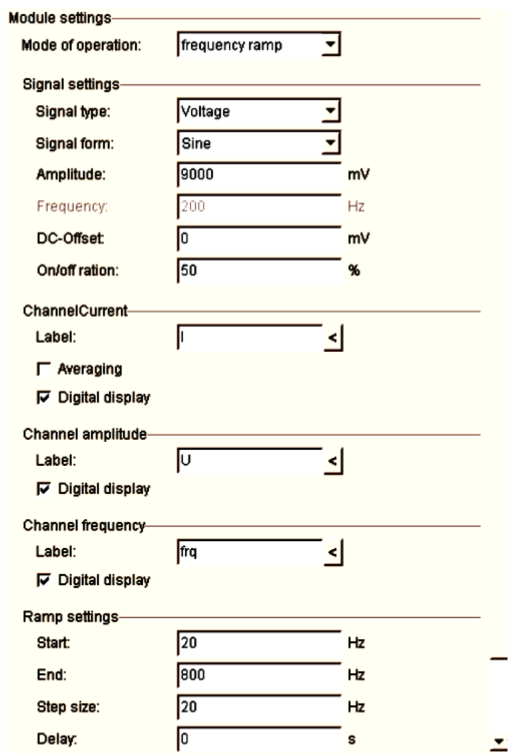

Figure 2.30:

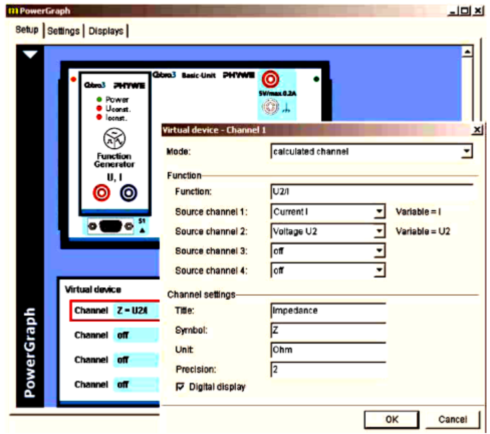

Figure 2.31:

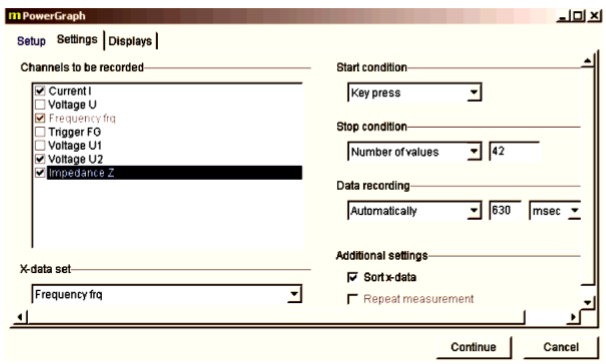

Figure 2.32:

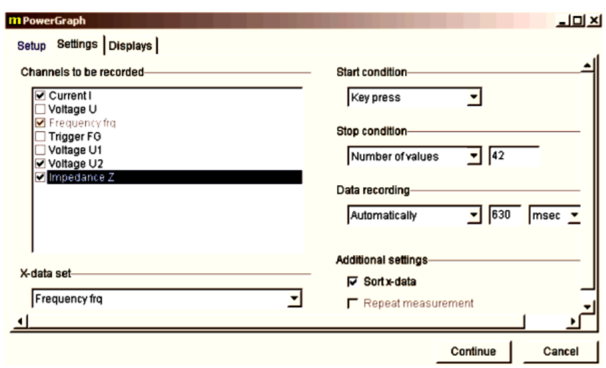

Figure 2.33:

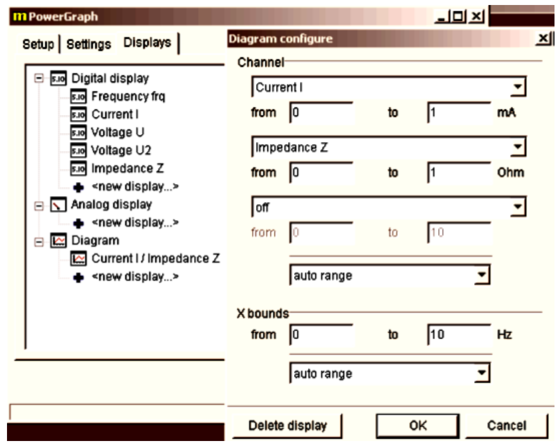

Figure 2.34:

9) Set up a series tuned circuit as seen in Figure 2.27. Start a measurement with the **"Continue"** button. After the measurement has stopped, the recorded curves are visible in the **"measure"** program main menu.

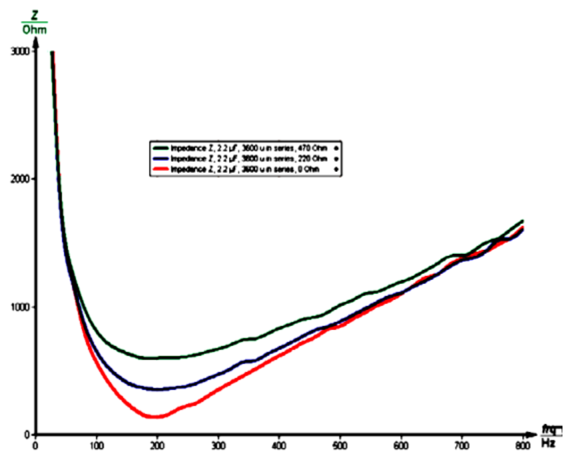

Figure 2.35:

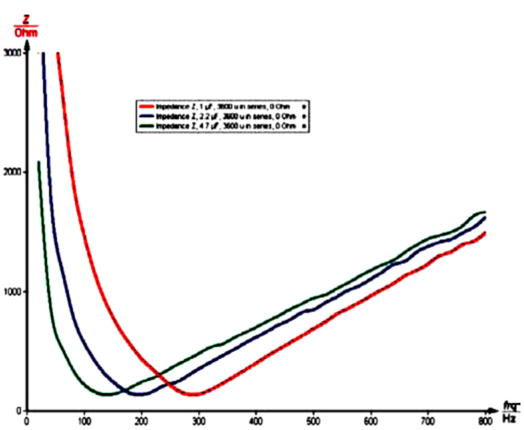

Figure 2.36

10) Record curves for $R_D = 0\ \Omega, 220\ \Omega$ and $470\ \Omega$ with the $2.2\ \mu F$ capacitor.
11) Record curves for $R_D = 0\ \Omega$ with the $1\ \mu F$ capacitor and the $4.7\ \mu F$ capacitor.
12) Use **"Measurement"** → **"Assume channel..."** and **"Measurement"** → **"Channel manager..."** to display the three impedance curves with the damping resistor values $R_D = 0\ \Omega, 220\ \Omega$ and $470\ \Omega$ for the $2.2\ \mu F$ capacitor in a single plot. Scale the impedance curves to the same value either using the **"Scale curves"** tool with the option **"set to values"** or using **"Measurement"** → **"Display options..."** filling appropriate values into the field **"Displayed area"** on the **"Channels"** chart. The result may look like Figure 2.35.
13) In a similar way produce a plot of the impedance over the frequency for the series tuned circuit with no additional damping resistor and the three capacitance values $C = 1\ \mu F, 2.2\ \mu F$ and $4.7\ \mu F$. Figure 2.36 shows a possible result.

2.2.4.2. PART II: PARALLEL RLC CIRCUITS

THEORY

1. PARALLEL RLC CIRCUITS

When making calculations in the circuit in Figure 2.37, the process is more complicated because the R_L internal resistance, which is in series with the coil, and the R_D resistance are parallel to each other. The equivalent resistance is:

$$R = \frac{R_D R_L}{R_D + R_L} \tag{2.77}$$

The total impedance of the circuit is:

$$\frac{1}{Z} = \frac{1}{j\omega L} + j\omega C + \frac{1}{R} \tag{2.78}$$

$$\frac{1}{Z} = j\left(\omega C - \frac{1}{\omega L}\right) + \frac{1}{R} \tag{2.79}$$

The resonance equation for the parallel RLC circuit is:

$$\left(\omega C - \frac{1}{\omega L}\right) = 0 \tag{2.80}$$

For small values of Q_P the resonant frequency is:

$$Q_P = R_D \sqrt{\frac{C}{L}} \tag{2.81}$$

Again, the following equations are also valid in parallel circuits:

$$Q_P = \frac{f_0}{\Delta f} = \frac{f_0}{f_2 - f_1} \tag{2.82}$$

$$\omega_0 = \sqrt{\omega_1 \omega_2} = \frac{1}{\sqrt{LC}} \tag{2.83}$$

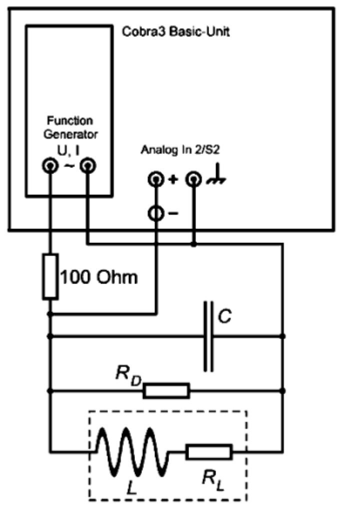

Figure 2.37:

SETUP AND PROCEDURE

1) Set up a parallel tuned circuit as in Figure 2.37.
2) Record curves with the 2.2 μF capacitor and different damping resistors $R_D = \infty\ \Omega, 220\ \Omega$ and $470\ \Omega$.
3) Record curves with the damping resistor $R_D = \infty\ \Omega$ (i.e. no resistor) and $C = 1\ \mu F$ and 4.7 μF. Plot the impedance in dependence on the frequency for $C = 2.2\ \mu F$ and $R_D = \infty\ \Omega, 220\ \Omega$ and $470\ \Omega$ (Figure 2.38).
4) Plot the impedance in dependence on the frequency for $C = 1\ \mu F, 2.2\ \mu F$ and 4.7 μF and $R_D = \infty\ \Omega$ (Figure 2.39).
5) Set up a series tuned circuit with $R_D = \infty\ \Omega$ and $C = 2.2\ \mu F$.
6) Select **"Gauge"** → **"Cobra3 Universal Writer"** and select the parameters as seen in Figure 2.40.
7) Record current and voltage curves in dependence on time for different frequencies between $80\ Hz$ and $360\ Hz$. For frequencies over $200\ Hz$ it is necessary to switch the frequency range under **"Configure FG module"** to **"High frequencies"**.

8) Note which of the curves, current or voltage, was ahead of the other.
9) Use **“Analysis” → “Smooth...”** with the options **“left axis”** and **“add new”** on both current and voltage curves. The curve that was clicked on before will be processed.
10) Use **“Measurement” → “Channel manager...”** to select the **“Current FG' ”** values as x-axis and the **“Analog in 2' ”** voltage values as y-axis (Figure 2.41). The Lissajous-figure to be produced now is no function but a relation so selects in the **“Convert relation to function”** window the option **“Keep measurement in relation mode”**.

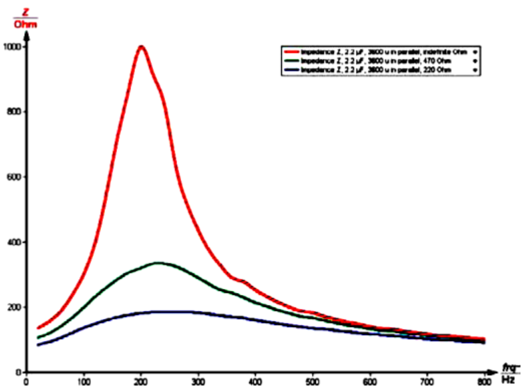

Figure 2.38:

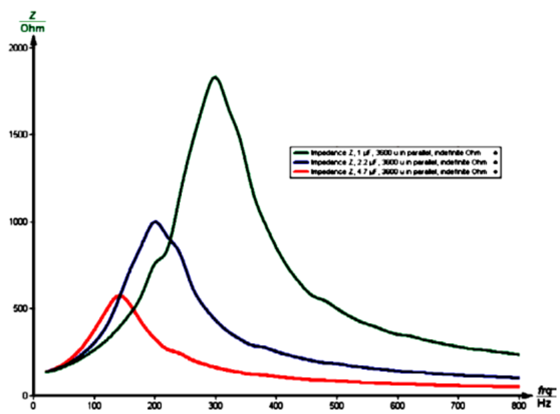

Figure 2.39:

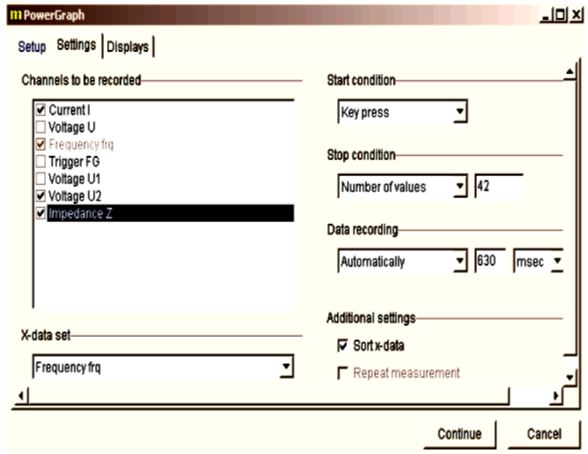

Figure 2.40:

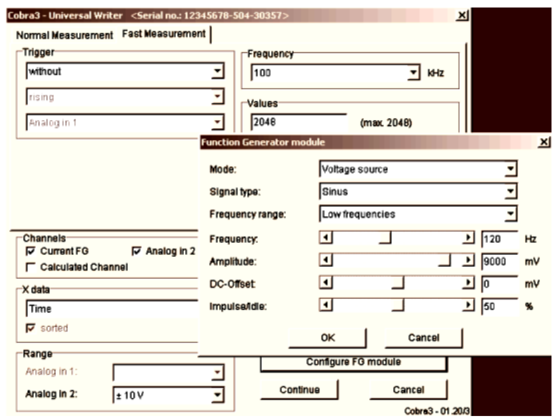

Figure 2.41:

11) Use the **"Survey"** tool to determine the maximal extension of the Lissajous-figure in x-direction ΔI_{max} (Figure 2.42) and the extension of the figure on the $y = 0$ line (ΔI_0) (Figure 2.43).

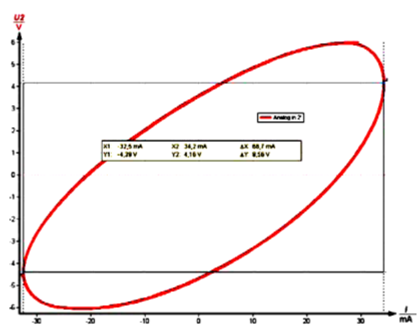

Figure 2.42:

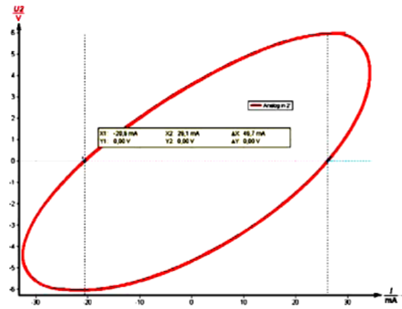

Figure 2.43:

12) The ratio ${}^{\Delta I_0}/_{\Delta I_{max}}$ equals the sine of the phase shift angle $\sin \omega$ between current and voltage.
13) Calculate ω and $\tan \omega$ for the used frequencies and plot them over the frequency using **"Measurement" → "Enter data manually..."** (Figure 2.44).
14) You can use **"Measurement" → "Function generator..."** to compare calculated theoretical values with the measured values. Figure 2.44 shows the equation for coil with $L = 0.3\ mH$ and d.c. resistance $R_L = 150\ \Omega$ in series with a $2.2\ \mu F$ capacitor with no additional damping resistor.

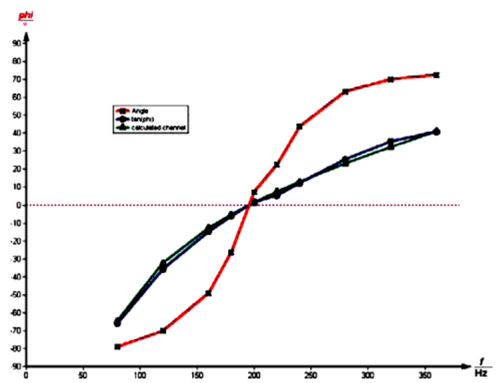

Figure 2.44

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