LC Circuit and LC Oscillations

Objectives

After going through this module learner will be able to:

- Understand electrical networks using alternating voltages
- Analyze alternating current electrical circuit using resistances, inductor and capacitor
- Distinguish between reactance and impedance offered by resistance with inductor(RL)with resistance and capacitor(RC) in ac circuits
- Represent current and voltage using phasors for RL and RC circuits
- Understand LC Circuit and LC oscillations and obtain the condition for resonance

Content Outline

- Unit Syllabus
- Module Wise Distribution on Unit Syllabus
- Words You Must Know
- Introduction
- Circuit Containing Inductance and Resistance in Series
- Circuit Containing Capacitance and Resistance in Series
- LC circuit
- Summary

Unit Syllabus

Unit IV: Electromagnetic Induction and Alternating Currents

Chapter-6: Electromagnetic Induction

Electromagnetic induction; Faraday's laws, induced emf and current; Lenz's Law, Eddy currents; Self and mutual induction.

Chapter-7: Alternating Current

Alternating currents, peak and rms value of alternating current/voltage; reactance and impedance; LC oscillations (qualitative treatment only), LCR series circuit, resonance; power in AC circuits, wattless current; AC generator and transformer

Module Wise Distribution of Unit Syllabus

The above unit is divided into 9 modules for better understanding.

Module 1	● Electromagnetic induction ● Faraday's laws, induced emf and current; ● Change of flux ● Rate of change of flux
Module 2	● Lenz's Law, ● Conservation of energy ● Motional emf
Module 3	● Eddy currents. ● Self-induction ● Mutual induction. ● Unit ● Numerical
Module 4	● AC generator ● Alternating currents, ● Representing ac ● Formula ● Graph ● Phasor ● Frequency of ac and what does it depend upon ● peak and rms value of alternating current/voltage;
Module 5	● ac circuits ● Components in ac circuits ● Comparison of circuit component in ac circuit with that if used in dc circuit ● Reactance mathematically ● Pure R ● Pure L ● Pure C ● Phasor, graphs for each
Module 6	● AC circuits with RL, RC and LC components ● Using phasor diagram to understand current and voltage phase differences ● Impedance; LC oscillations (qualitative treatment only),

	• Resonance
Module 7	• Alternating voltage applied to series LCR circuit • Impedance in LCR circuit • Phasor diagram • Resonance • Quality Factor • Power in ac circuit • Power factor • Wattles current
Module 8	• Transformer
Module 9	• Advantages of ac over dc • Distribution of electricity to your home

Module 6

Words You Must Know

- **Magnetic Field:** The region around a magnet, a moving charge or a current carrying conductor within which its magnetic influence can be felt.
- **Electromotive Force:** The amount of work done by an external source, to take a unit positive charge once round the circuit.
- **Area Vector:** A vector perpendicular to a given area whose magnitude is equal to the given area.
- **Electromagnetic Induction:** The phenomenon in which electric current can be generated by varying magnetic fields is called electromagnetic induction (EMI).
- **Magnetic Flux:** Just like electric flux, magnetic flux $Ø_B$ through any surface of area A held perpendicularly in magnetic field B is given by the total number of magnetic lines of force crossing the area. Mathematically, it is equal to the dot product of B and A.

  $\Phi_B = B.\ A = BA\cos\theta$, where θ is the angle between B and A.
- **Induced emf and Induced Current:** The emf developed in a loop when the magnetic flux linked with it changes with time is called induced emf when the conductor is in the form of a closed loop, the current induced in the loop is called an induced current.

- **Weber:** One weber is defined as the amount of magnetic flux, through an area of $1m^2$ held normal to a uniform magnetic field of one tesla. The SI unit of magnetic flux is weber (Wb) or tesla metre squared (Tm^2).
- **Faraday's Laws of Electromagnetic Induction:**
  - **First Law:** It states that whenever the amount of magnetic flux linked with the coil changes with time, an emf is induced in the coil. The induced emf lasts in the coil only as long as the change in the magnetic flux continues.
  - **Second Law:** It states that the magnitude of the emf induced in the coil is directly proportional to the time rate of change of the magnetic flux linked with the coil.
- **Lenz's Law:** The law states that the direction of induced emf is always such that it opposes the change in magnetic flux responsible for its production.
- **Fleming's Right Hand rule:** Fleming's right hand rule gives us the direction of induced emf/current in a conductor moving in a magnetic field.
- If we stretch the fore-finger, central finger and thumb of our right hand mutually perpendicular to each other such that the fore-finger is in the direction of the field, the thumb is in the direction of motion of the conductor, then the central finger would give the direction of the induced current.
- **Induced emf by Changing the Magnetic Field:** The movement of magnet or pressing the key of coil results in changing the magnetic field associated with the coil, this induces the emf.
- **Induced emf by Changing the Orientation of Coil and Magnetic Field:** When the coil rotates in a magnetic field the angle θ changes and magnetic flux linked with the coil changes and this induces the emf. This is the basis of ac generators.
- **Induced emf by Changing the Area A (MOTIONAL EMF):** Motional emf is a type of induced emf which occurs when a wire is pulled through the magnetic field. The magnitude of motional emf depends upon the velocity of the wire, strength of magnetic field and the length of the wire.
- **Electric Current:** An electric current equals the rate of flow of electric charge. In electric circuits this charge is often carried by moving electrons in a wire. It can also be carried by ions in an electrolyte, or by both ions and electrons such as in ionized gases or plasma.
- **Voltage:** the difference in electric potential energy between two points per unit electric charge, in an electric circuit.

- **Ohm's Law:** electric current through a conductor is directly proportional to the potential difference across the conductor provided the temperature and physical conditions of the conductor remain the same.
- **Ohmic Conductors:** conductors that follow ohm's law for a reasonable range of physical condition, conductor wires, conductor plates, strips.
- **Non-Ohmic Conductors:** conductors that do not follow Ohm's law e.g electrolytes, semiconductors.
- **Eddy Currents:** Eddy currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor, (as per Faraday's law of induction). Eddy currents flow in closed loops within conductors, in planes perpendicular to the magnetic field. They can be induced within (nearby) stationary conductors by a time-varying magnetic field.
- **Phasors:** InPhysics and Engineering, a phasor is a complex number representing a sinusoidal function whose amplitude (A), angular frequency (ω), and initial phase (θ) are time-invariant. Basically, Phasors are rotating vectors.
- **Alternating Voltage:** the electric mains supply in our homes and workplaces is a voltage that varies with time.eg Output from an ac generator.
- **Alternating Current:** current in a circuit driven by ac voltage is called alternating current.
- Alternating currents and voltages have **frequency f** and **angular frequency** $\omega = 2\pi f$ associated with it.
- Two currents, two voltages or currents and voltages may have a phase relation between them. This arises due to electromagnetic induction, self induction or time rate associated with charging and discharging of capacitors.
- Alternating currents and voltages have **instantaneous value** given by:
- $i = i_0 sin(\omega t + \Phi)$
- $V = V_0 sin(\omega t + \Phi)$
- Φ is the initial phase of the sinusoidal current or voltage.
- Alternating currents and voltages have **peak value I_0 and V_0**
- Alternating currents and voltages have **average value over half cycle:**

$$V_{avg(T/2)} = \frac{2V_0}{\pi} \cong 0.636\, V_0$$

- Alternating currents and voltages have **root mean square values:**

$V_{rms} = \frac{V_0}{\sqrt{2}}$

- **Self Inductance of a Coil(L) :** An electric current can be induced in a coil by flux changes produced by the changing current in it self

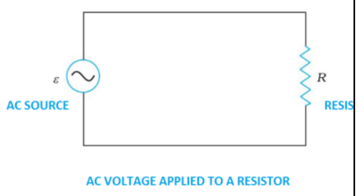
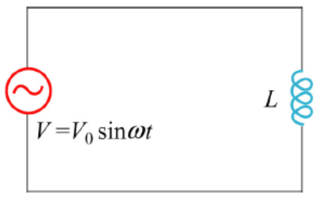
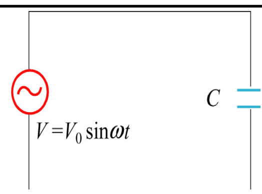
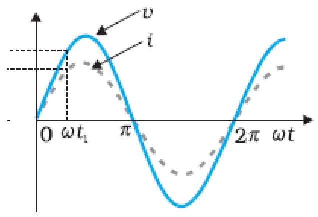
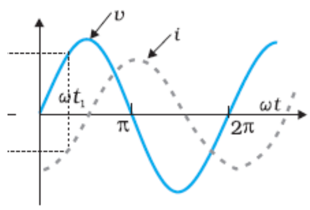
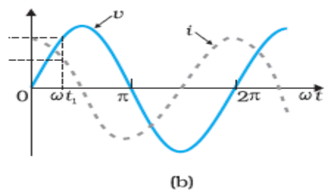
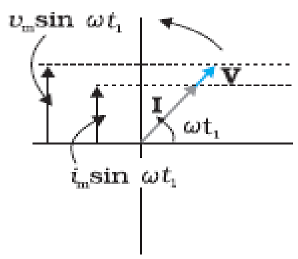
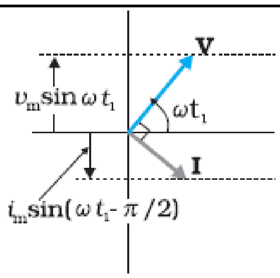
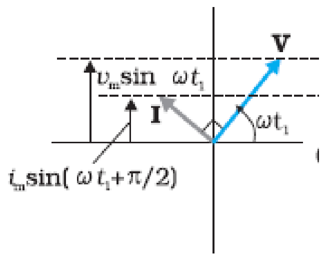
  $L = \mu_0 n^2 Al$

  Where nl = N total number of turns of the coil, A area of the face of the coil, μ_0 is the permeability of free space.
- SI unit henry
- Self inductance is also called **back emf.** It depends upon the geometry of the coil and permeability of the medium inside the coil
- **Energy Required to Build up Current I:** in a coil of inductance $L = \frac{1}{2}LI^2$
- **Capacitor:** A system of two conductors separated by an insulator .Parallel plate capacitors, spherical capacitors are used in circuits. Capacity of parallel plate capacitor is given by
  - $c = \frac{\mu_0 A}{d}$ 'A' area of the plate,'d' separation between the plates. , 'μ_0' is the permeability of free space
  - Capacitors block dc but ac continues as charging and discharging of the capacitor maintains a continuous flow of current.
- **Capacitance :** $C = \frac{Q}{V}$ S I unit farad
- **Dielectric Constant of a Material K:** is the factor by which the capacitance increases from its vacuum value when the dielectric (material) is inserted fully between the plates of a capacitor.
- **Combination of Capacitors:** capacitors may be combined in ways to obtain a value of effective capacitance.
- **Series Combination:** capacitances are said to be in series if the effective combined capacitance C is given by

  $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots\ldots + \frac{1}{C_n}$
- **Parallel Combination of Capacitors:** capacitances are said to be in series if the effective combined capacitance C is given by

  $C = C_1 + C_2 + \ldots\ldots + C_n$

- **Choke Coil:** In electronics, a choke is an inductor used to block higher-frequency alternating current (AC) in an electrical circuit, while passing lower-frequency currents or direct current (DC).
- **Wattless Current:** Wattless current is that AC component of AC current, whereby the power consumed by the circuit is zero.

	Pure resistance circuit	Pure inductive circuit	Pure capacitive circuit
Circuit diagram			
Input voltage	V=$V_0 sin\omega t$	V=$V_0 sin\omega t$	V=$V_0 sin\omega t$
Current	○ I=$\frac{V_0}{R} sin\omega t$ ○ I=$I_0 sin\omega t$	$I = I_0 sin(\omega t - \frac{\pi}{2})$	$I = I_0 sin(\omega t + \frac{\pi}{2})$
reactance	○ **R**	○ **X_L=2πfL**	○ **X_C=1/2π fC**
Current voltage graph	 **Current and voltage are in the same phase**	 **Voltage leads the current by π/2**	 **Voltage leads the current leads voltage by π/2**
Current voltage phasor			

Introduction

The fundamental circuit elements are the resistances (R), capacitors (C) and coils Inductance (L). These circuit elements can be combined to form an alternating current circuit in four distinct ways:

- **The R C series circuit**
- **The R L series circuit,**
- **The L C circuit**
- **The L C and R circuit**

These circuits exhibit important types of behavior.**Why would such circuits be important to us?** the answer lies in the fact that inductor or capacitor in an alternating current circuit set up a phase difference between voltage and current which means if the voltage across them is increasing the current need not, this phase lead or lag causes the **reactance** meaning an **obstruction like resistance in dc circuits**.

Then why do we not call it resistance? The reason is that if a resistance wire is connected in a dc or ac circuit, it decides the value of current but does not vary the phase of current wrt voltage.

We have learnt that **an inductor** offers no resistance to current in dc circuit but in ac circuit offers a resistance called inductive reactance $X_L = \omega L$ depending upon

-inductance L

-frequency of ac source f or angular frequency $\omega = 2\pi f$

The value X_L is **called inductive reactance** and has a unit of ohm.

Similarly a capacitor in dc circuit would block the current after the capacitor is charged, but in ac circuit continuous charging and discharging will cause a resistance which we call **capacitive reactance** $X_C = \frac{1}{\omega C}$

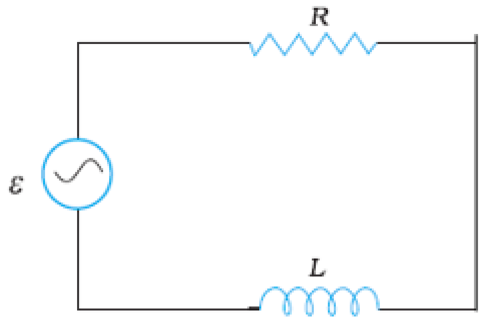
X_C depends upon

- Capacitance C
- Frequency of ac source for angular frequency $\omega = 2\pi f$

In this module we will study the RL, RC, LC circuits

Circuit Containing Inductance and Resistance in Series

A RL circuit is composed of one resistor and one inductor and is the simplest type of RL circuit.

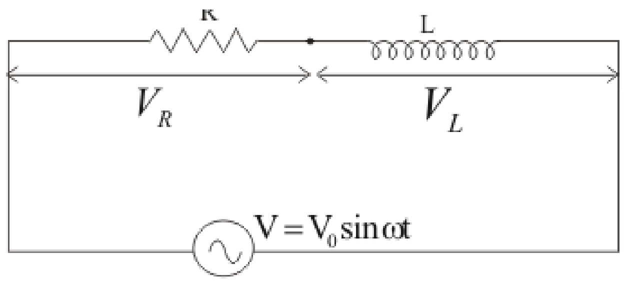


RL circuit composed of one resistor and one inductor

A RL circuit is one of the simplest circuit. It consists of a resistor and L an inductor, in series driven by an alternating voltage source ε.

Figure below shows pure inductor of inductance L (which means a coil of negligible resistance) connected in series with a resistor of resistance R through sinusoidal voltage:

$$V = V_0 sin\,(\omega t)$$



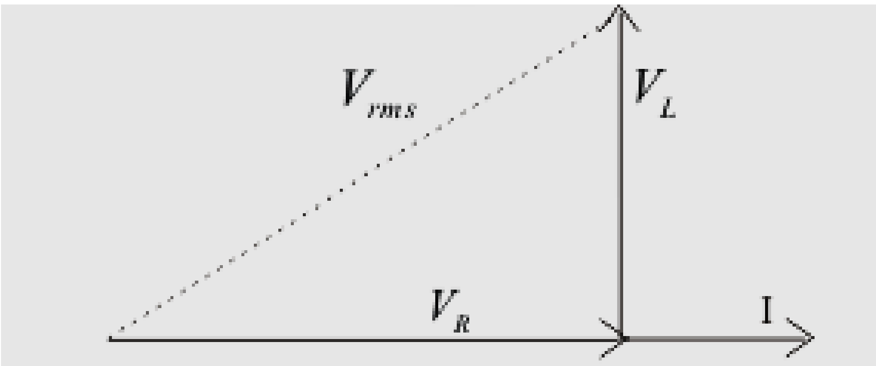
AC circuit with R and L

An alternating current I flowing in the circuit give rise to voltage drop V_R across the resistor and voltage drop V_L across the coil. The Voltage drop V_R across R would be in phase with current but voltage drop across the inductor will lead the current by a phase angle π/2.

Now voltage drop across the resistor R is:

$V_R = I R$, and across inductor $V_L = I\,(\omega\, L)$

Where I is the value of current in the circuit at a given instant of time. Hence, the voltage phasor diagram for LR circuit is as shown:



In the figure we have taken current as a reference quantity because the same amount of current flows through both the components. Thus from phasors diagram we have:

$$V = \sqrt{V_R^2 + V_L^2}$$

$$= I\sqrt{R^2 + \omega^2 L^2}$$

$$= IZ$$

Here notice $Z = \sqrt{R^2 + \omega^2 L^2}$

Z gives the **impedance** of the circuit and therefore the **Current** in steady state will be:

$$I = \frac{V_0 sin(\omega t - \Phi)}{Z}$$

The current it lags behind the applied voltage by an angle φ such that tan φ =ωL/R

What is Φ?

When an alternating voltage source is connected to a circuit containing L and R from our previous study the voltage and current for resistor can be given by

$$V = V_0 sin\, \omega t$$

And current I will be

$$I = I_0 sin\, \omega t$$

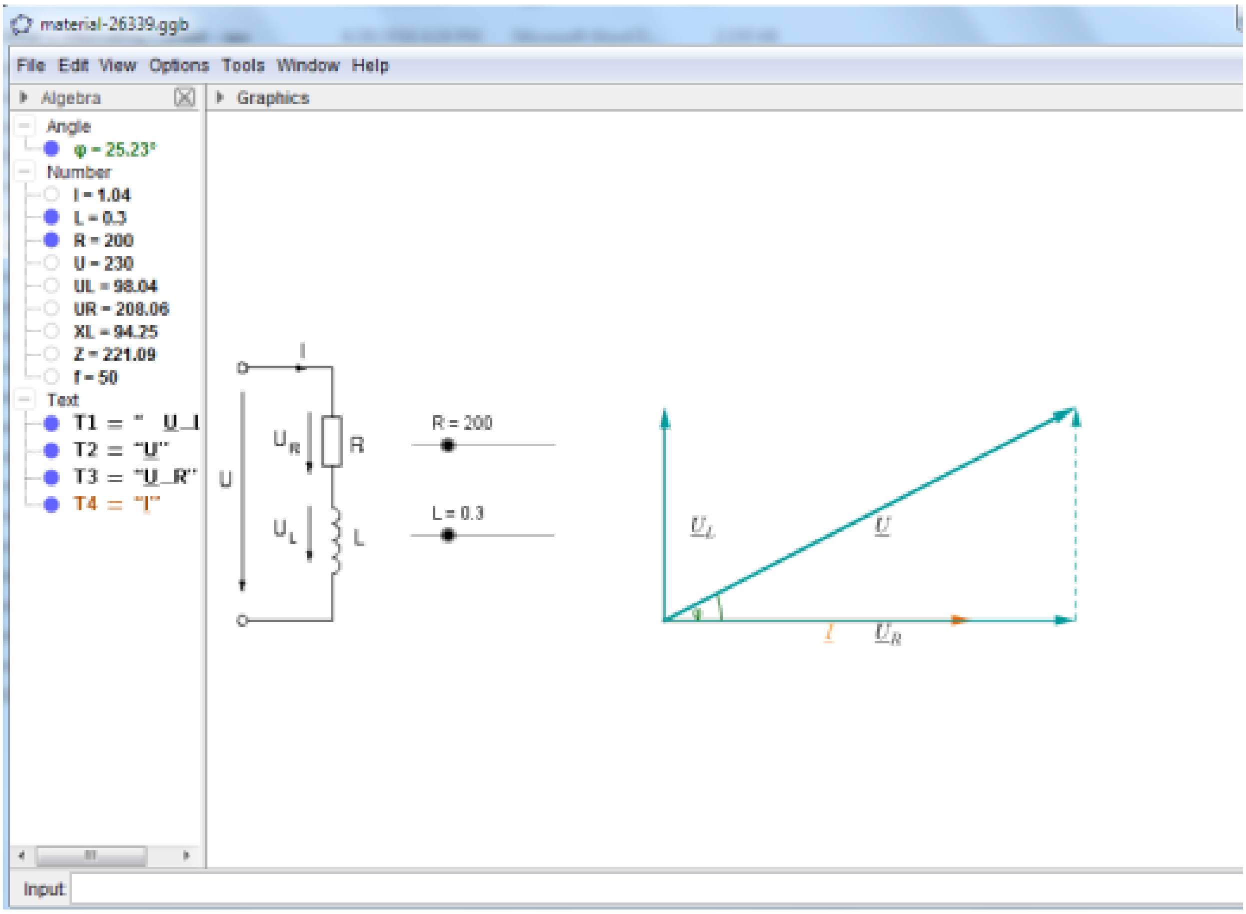
For inductor

$$V = V_0 sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I = I_0 sin\, \omega t$$

The current in the inductor and resistor remains the same because they are connected in series but the voltage across the inductor and resistor differ in phase by π/2.

Use the GeoGebra App to see the change in ϕ if the values of resistance R and inductance L are changed.



https://www.geogebra.org/material/show/id/GJde6zxW#download-popup

https://www.geogebra.org/m/GJde6zxW

https://www.geogebra.org/m/ASny9d8H?doneurl=%2Fmaterial%2Fshow%2Fid%2FGJde6zxW

The net voltage is

$$V_{net} = \sqrt{V_R^2 + V_L^2}$$

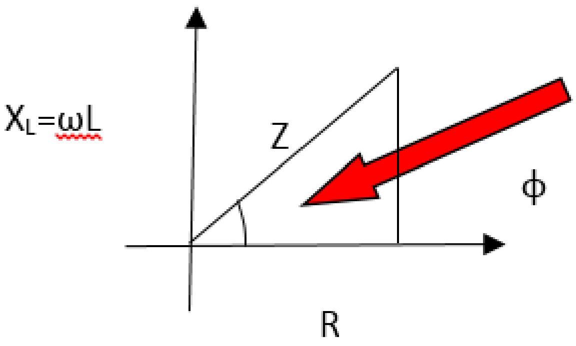
The above description is geometrical and does not convince us completely. We can draw the corresponding phasor diagram in terms of resistances. The resultant will depend upon the values of R and X_L.

The resultant is called impedance. It is represented by Z . The SI unit is Ohm

So we have in an AC circuit

- **Resistance due to a resistor**
- **Inductive reactance or capacitive reactance due to an inductor or a capacitor**
- **Impedance which is a combination of resistance and reactance**

Now let us draw a triangle using R and X_L



$Z = \sqrt{R^2 + X_L^2}$

The current in the circuit will be given by

$I = \frac{V_{net} = \sqrt{V_R^{\ 2} + V_L^2}}{z = \sqrt{R^2 + X_L^2}}$

The phase difference between net voltage and current will be

$\phi = tan^{-1}\left(\frac{V_L}{V_R}\right)$

$\phi = tan^{-1}\left(\frac{X_L}{R}\right)$

Think About These

- **What if we have a very large resistance with an inductor of small reactance value?**
- **What if we choose X_L on the x axis and R on the y axis?**
- **What if the R and X_L axis are not at right angles?**
- **Will the current always lag the voltage even if the inductive reactance is small?**
- **How would the phase angle change if the frequency of the AC changes with time?**
- **What does phase angle predict?**
- **What would be the shape of the Z vs. f graph?**

Circuit Containing Capacitance and Resistance in Series

A resistor–capacitor circuit (RC circuit), composed of resistors and capacitors driven by a ac source.

A simple RC circuit is composed of one resistor and one capacitor in **series.**

Figure below shows capacitor connected in series with a resistor of resistance R through sinusoidal voltage:

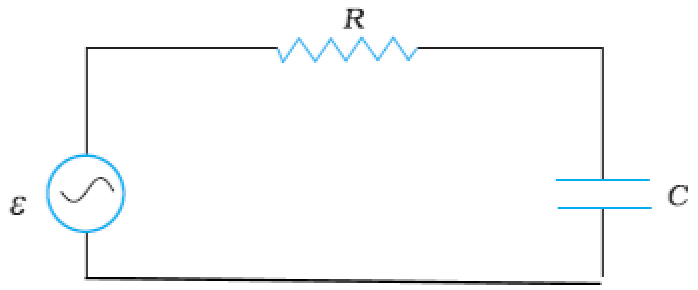
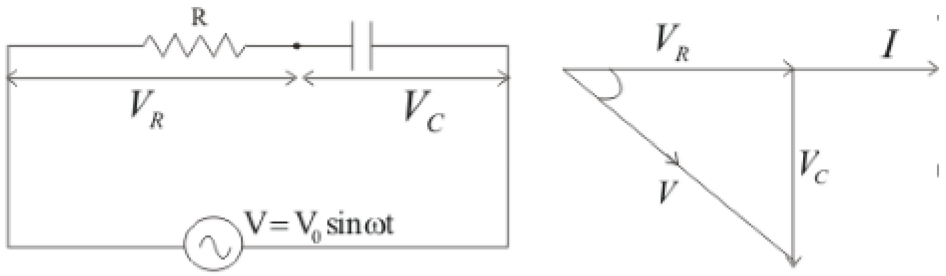


Figure below shows a circuit containing capacitor and resistor connected in series through a sinusoidal voltage source of voltage $V = V_0 sin\,(\omega t)$



AC Circuit with R and C — Phasor Diagram

In this case instantaneous potential difference across R is

$V_R = IR$, and

Across the capacitor C is

$V_C = 1/\omega C$

In this case V_R is in phase with current I and V_C lags behind I by a phase angle 90^0

The Figure shows, phasors diagram where vector OA represent the resultant of V_R and V_C this is the applied Voltage. Thus,

$$V = \sqrt{V_R^2 + V_C^2}$$

$$V = I\sqrt{R^2 + \frac{1}{(\omega C)^2}}$$

$V = IZ$

Where Z is the **impedance of the circuit**, given by

$Z = \sqrt{R^2 + X_C^2}$

X_c *is the capacitive reactance* $= \frac{1}{\omega C}$

In this case the applied voltage lags behind the current by a phase angle ϕ

Foe resistance only:

$I = I_0 sin\omega t$

$V = V_0 sin\omega t$

For capacitor only:

$I = I_0 sin\omega t$

$V = V_0 sin\left(\omega t - \frac{\pi}{2}\right)$

Because C and R are in series, the current in both should be the same .

But the voltage across the resistance is $\frac{\pi}{2}$ ahead of the voltage across the capacitor

The net voltage of the circuit will be given by

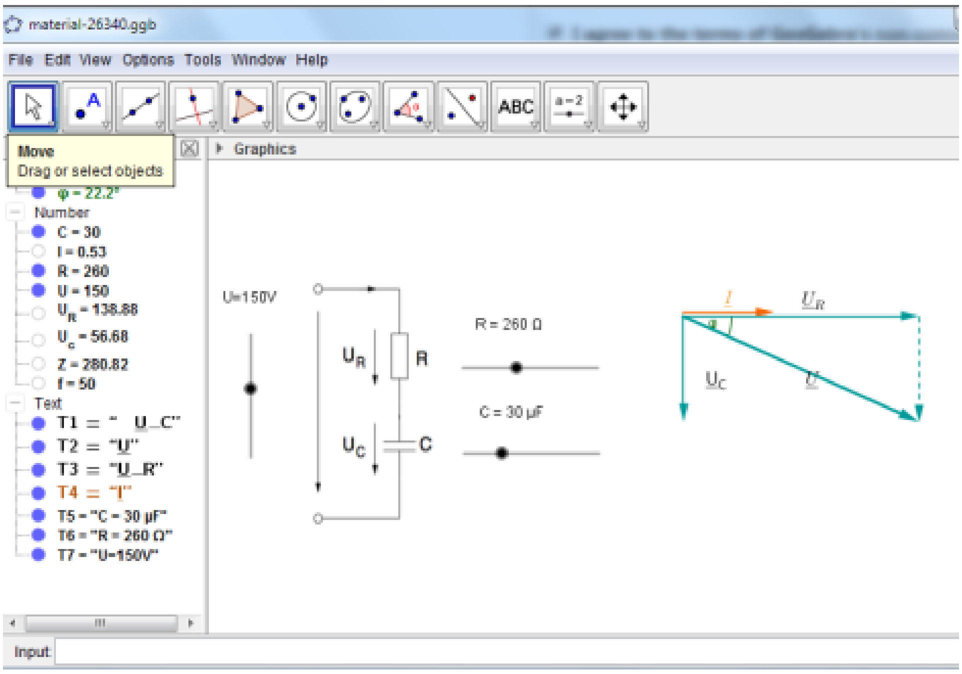
$V = \sqrt{V_R^2 + V_C^2}$

We can use GeoGebra App to visualize this

Check on the link given below, you may change the magnitude of

- R
- C and
- V

See the change in phase difference between net voltage and current



https://www.geogebra.org/m/Ew43BgKj?doneurl=%2Fmaterial%2Fshow%2Fid%2FGJde6zxW

The net obstruction to the current in the circuit is the impedance given by

$$Z = \sqrt{R^2 + X_C^2}$$

$$thus\ ,\ current\ in\ the\ circuit\ \ I = \frac{\sqrt{V_R^2+V_C^2}}{\sqrt{R^2+X_C^2}}$$

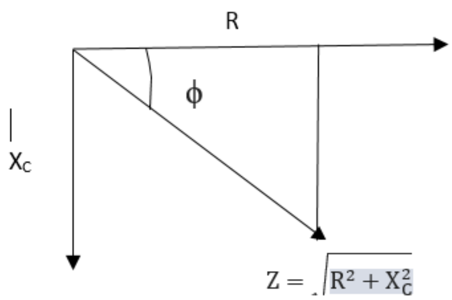
The phase difference between net voltage and current is

$$\phi = tan^{-1}\left(\frac{V_C}{V_R}\right)$$

or

$$\phi = tan^{-1}\left(\frac{X_C}{R}\right)$$

On an impedance triangle the phase difference ϕ may be seen as following

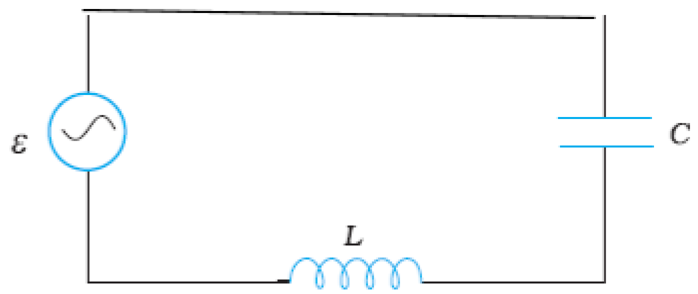


LC Circuit

An LC circuit, also called a resonant circuit, tank circuit, or tuned circuit, is an electric circuit consisting of an inductor, represented by the letter L, and a capacitor, represented by the letter C, connected together.

LC circuits are used either for generating signals at a particular frequency, or picking out a signal of a particular frequency from a more complex signal. **They are key components in many electronic devices, particularly radio equipment; they are used in circuits such as tuners.**

An LC circuit is an idealized model since it assumes there is no dissipation of energy due to resistance. Any practical implementation of an LC circuit will always include loss resulting from small but non-zero resistance within the components and connecting wires.



This circuit behaves in a peculiar manner. The reason being one component inductor offers reactance in a way that the current lags the applied voltage, while the capacitive reactance makes the current lead in the circuit. The magnitude of X_L and X_C depend upon angular frequency ω or frequency of ac ($\omega = 2\pi f$).

Resonance occurs when an LC circuit is driven from an external source at an angular frequency ω_0 at which the **inductive and capacitive reactance are equal in magnitude**.

The frequency at which this equality holds for the particular circuit is called the resonant frequency.

The resonant frequency of the LC circuit is:

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

Where *L* is the inductance in henry, and *C* is the capacitance in farad.

To arrive at the above result we are only saying that the condition for resonance is

$\mathbf{X_L = X_C}$

Or

$$\omega_0 L = \frac{1}{\omega_0 C}$$

$$\omega_0^{\ 2} = \frac{1}{LC}$$

Or

Resonant frequency

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

The angular frequency ω_0 has units of **radians per second.** The frequency in units **of hertz** is:

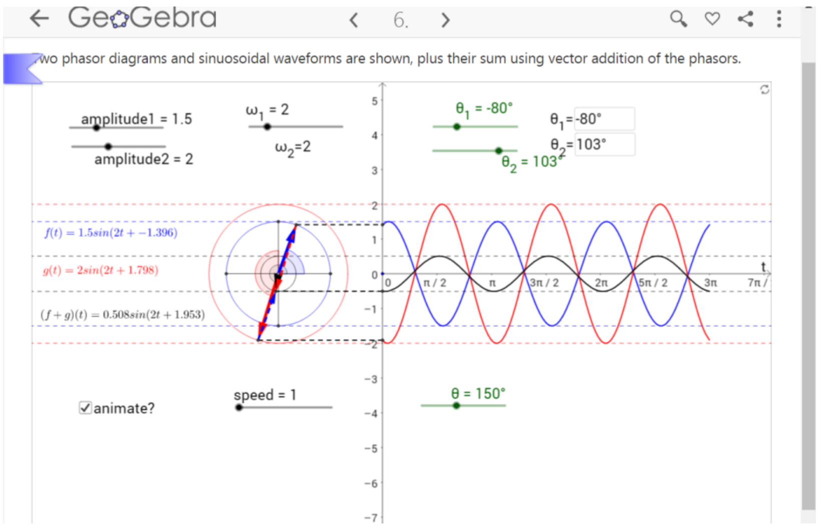
$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$$

What kind of phasor diagram can be drawn for an LC alternating current circuit?

Current in inductor will lag behind the current in capacitor by 180^0 or by $\frac{\pi}{2} + \frac{\pi}{2} = \pi$

So,At resonant frequency when the two would be equal and completely out of phase making the circuit impedance zero.

This condition is very useful in alternating current circuits and we will elaborate this in the next module.



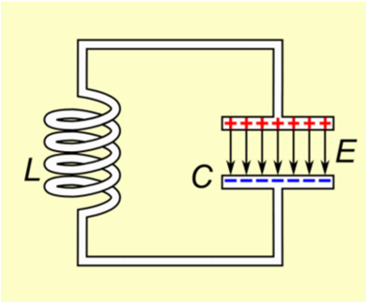
https://www.geogebra.org/m/mFgcewZk?doneurl=%2Fmaterial%2Fshow%2Fid%2FEw43BgKj#material/Bb87s4TS

https://www.geogebra.org/m/mFgcewZk?doneurl=%2Fmaterial%2Fshow%2Fid%2FEw43BgKj#material/DNbv8gtu

The two-element LC circuit described above is the simplest type of inductor-capacitor network (or LC network).

It is also referred to as a *second order LC circuit* to distinguish it from more complicated (higher order) LC networks with more inductors and capacitors. Such LC networks with more than two reactance may have more than one resonant frequency.

Notice the circuit given below has no power source, obviously the capacitor must have been first charged, the charging battery removed and the stored electrical energy in the capacitor being converted into magnetic energy around the coil due to changing current in it.

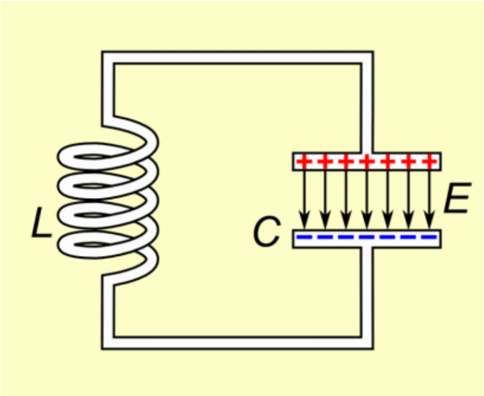


Source Wikipedia

To understand this further, if an inductor is connected across a charged capacitor; current will start to flow through the inductor, building up a magnetic field around it and reducing the voltage on the capacitor. Eventually all the charge on the capacitor will be gone and the voltage across it will reach zero.

However, the current will continue, because inductors resist changes in current. The current will begin to charge the capacitor with a voltage of opposite polarity to its original charge. Due to Faraday's law, the EMF which drives the current is caused by a decrease in the magnetic field, thus the energy required to charge the capacitor is extracted from the magnetic field. When the magnetic field is completely dissipated the current will stop and the charge will again be stored in the capacitor, with the opposite polarity as before.

Then the cycle will begin again, with the current flowing in the opposite direction through the inductor.



Source: Wikipedia

The **charge flows back and forth between the plates of the capacitor, through the inductor**. **The energy oscillates back and forth between the capacitor and the inductor until (if not replenished from an external circuit) internal resistance makes the oscillations die out.**

In most applications the tuned circuit is part of a larger circuit which applies alternating current to it, driving continuous oscillations.

If these are at the natural oscillatory frequency (Natural frequency), resonance will occur. The tuned circuit's action, known mathematically as a harmonic oscillator, is similar to a pendulum swinging back and forth, or water sloshing back and forth in a tank; for this reason the circuit is also called a *tank circuit*. The natural frequency (that is, the frequency at which it will oscillate when isolated from any other system, as described above) is determined by the capacitance and inductance values. In typical tuned circuits in electronic equipment the oscillations are very fast, thousands to billions of times per second.

Applications of LC Circuit

The resonance effect of the LC circuit has many important applications in signal processing and communications systems.

Resonant circuits have a variety of applications, for example, in the tuning mechanism of a radio or a TV set. The antenna of a radio accepts signals from many broadcasting stations. The signals picked up in the antenna acts as a source in the tuning circuit of the radio, so the circuit can be driven at many frequencies.

But to hear one particular radio station, we tune the radio. In tuning, we vary the capacitance of a capacitor in the tuning circuit such that the resonant frequency of the circuit becomes nearly equal to the frequency of the radio signal received. When this happens, the amplitude of the Current with the frequency of the signal of the particular radio station in the circuit is maximum.

It is important to note that resonance phenomenon is exhibited by a circuit only if both L and C are present in the circuit. Only then do the voltages across L and C cancel each other (both being out of phase)

- The most common application of tank circuits is tuning radio transmitters and receivers. For example, when we tune a radio to a particular station, the LC circuits are set at resonance for that particular **carrier frequency.**
- Both parallel and series resonant circuits are used in induction heating.

Summary

- In this module we learnt alternating current circuits with inductors and resistance, capacitors and resistance and inductor and capacitor.
- Behavior of RC, RL and LC ac circuits with circuit elements in series.
- The Phase relation between current and voltage depends upon resistance and reactance. Reactance depends upon magnitude of L or C and frequency of alternating current used in the circuit.
- The meaning of terms:
    1. **Resistance:** in a circuit the obstruction offered by a conductor to the current following Ohm's law.
    2. **Reactance:** In electrical and electronic systems, reactance is the opposition of a circuit element to a change in current or voltage, due to that element's inductance or capacitance.
    3. **Impedance:** Electrical impedance is the measure of the opposition that a circuit presents to a current when a voltage is applied. In quantitative terms, it is the complex ratio of the voltage to the current in an alternating current (AC) circuit.
    4. **Phasors:** InPhysics and Engineering a phasor, is a complex number representing a sinusoidal function whose amplitude (A), angular frequency (ω), and initial phase (ϕ) are time-invariant. Basically, Phasors are rotating vectors.
- **Resonant circuit: An LC circuit, also called a resonant circuit.**
- **Resonance frequency**

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

The resonance effect of the LC circuit has many important applications in signal processing and communications systems.