Western Cape Government

Western Cape Education Department

Directorate: Curriculum FET

ELECTRICAL TECHNOLOGY

(Power Systems and Electronics)

REVISION NOTES

2024

Grade 12

RLC Components in AC Circuits

WEEK 2	WEEK 3	WEEK 4
RLC	**RLC**	**RLC**
Effect of alternating current on R, L and C components in series and parallel single phase circuits	• Inductive reactance $X = 2\pi fL$ • Capacitive reactance impedance • Power • Phase angle • Power factor • Phasor and wave representation • Resonance • Q factor & bandwidth	**Calculations** • Series and parallel combination circuits containing ONE resistor, ONE capacitor and ONE inductor • Frequency changes • Phasor and wave representation • Resonance • Phasor diagram

RLC FORMULA SHEET

RLC CIRCUITS

$X_L = 2\pi f\ L$

$X_C = \dfrac{1}{2\pi f\ C}$

$f_r = \dfrac{1}{2\pi\sqrt{LC}}$

Series

$I_T = I_R = I_C = I_L$

$Z = \sqrt{R^2 + (X_L - X_C)^2}$

$V_L = X_L$
$V_C = I_T\ X_C$
$V_T = I_T\ Z$

$V_T = \sqrt{V_R^2 + (V_L - V_C)^2}$

$I_T = \dfrac{V_T}{Z}$

$\cos\theta = \dfrac{R}{Z}$

$\cos\theta = \dfrac{V_R}{V_T}$

$Q = \dfrac{X_L}{Z} = \dfrac{X_C}{Z} = \dfrac{V_L}{V_S} = \dfrac{V_C}{V_S} = \dfrac{1}{R}\sqrt{\dfrac{L}{C}}$

$BW = \dfrac{f_r}{Q}$

Parallel

$V_T = V_R = V_C = V_L$

$I_R = \dfrac{V_R}{R}$

$I_C = \dfrac{V_C}{X_C}$

$I_L = \dfrac{V_L}{X_L}$

$I_T = \sqrt{I_R^2 + (I_L - I_C)^2}$

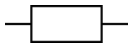
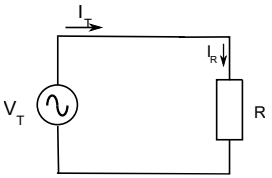
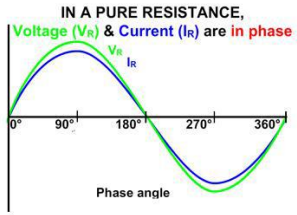
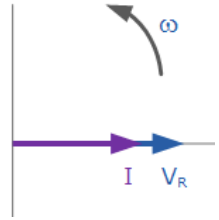
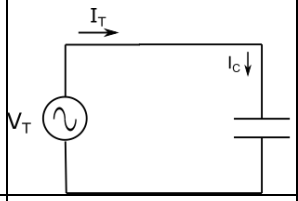
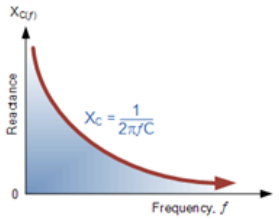
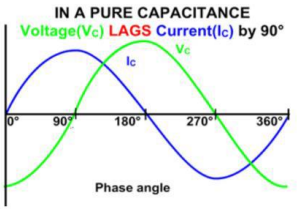
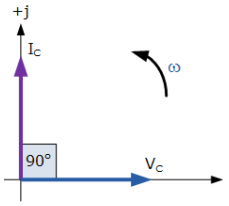
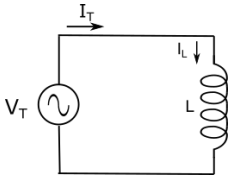
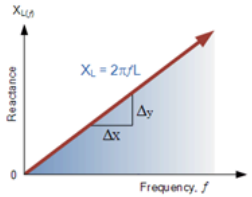
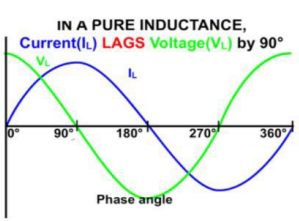
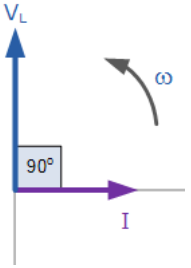
$Z = \dfrac{V_T}{I_T}$

$\cos\theta = \dfrac{I_R}{I_T} = \dfrac{Z}{R}$

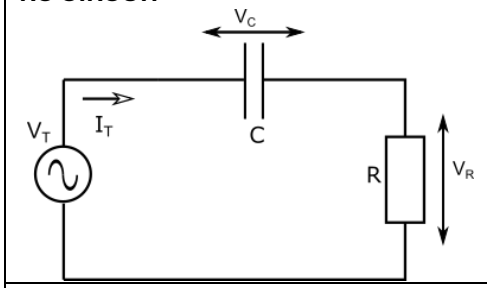
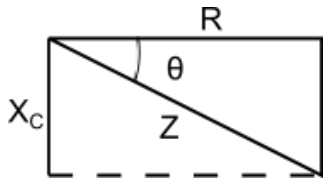
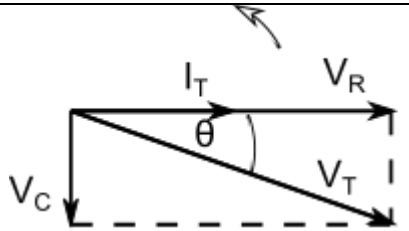
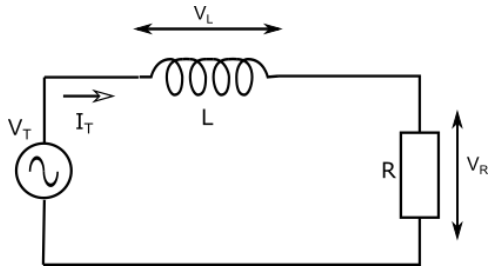
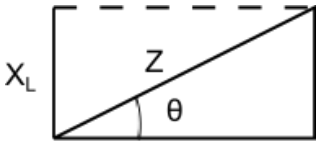
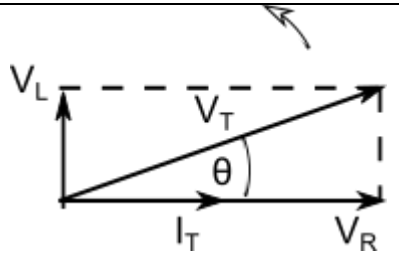
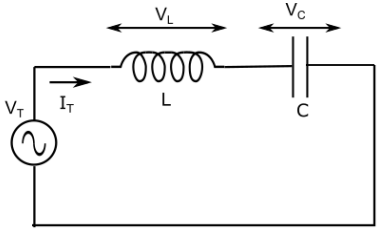
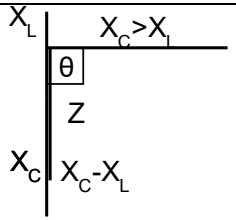
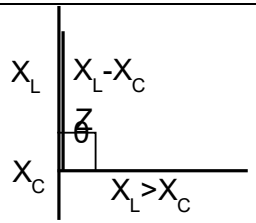
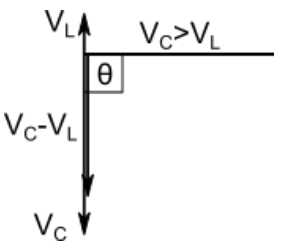
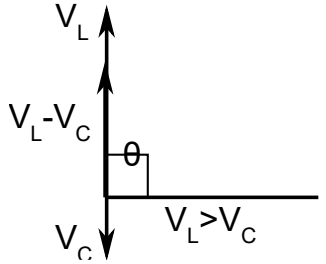
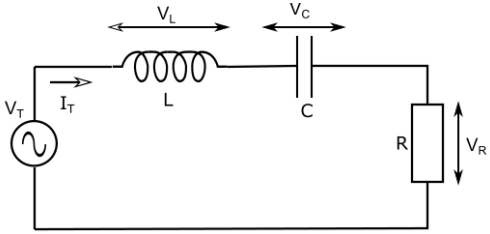
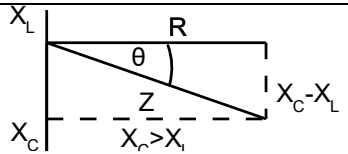
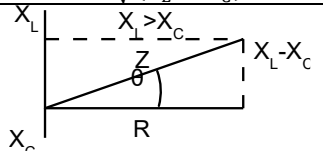
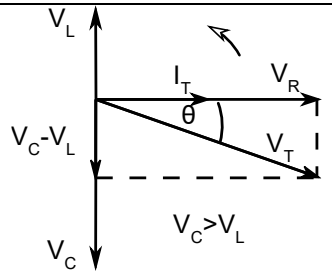
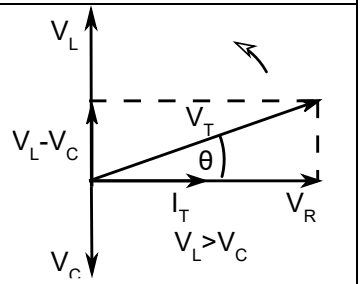
$Q = \dfrac{X_L}{Z} = \dfrac{X_C}{Z} = \dfrac{V_L}{V_S} = \dfrac{V_C}{V_S} = \dfrac{1}{R}\sqrt{\dfrac{L}{C}}$

$BW = \dfrac{f_r}{Q}$

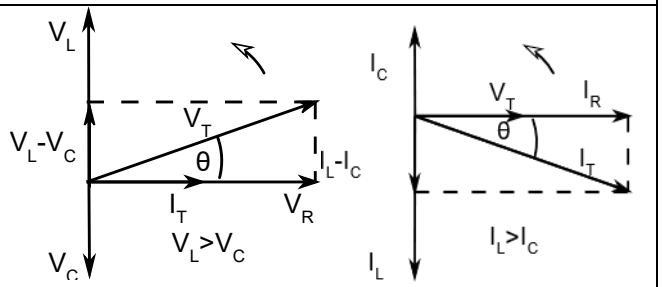
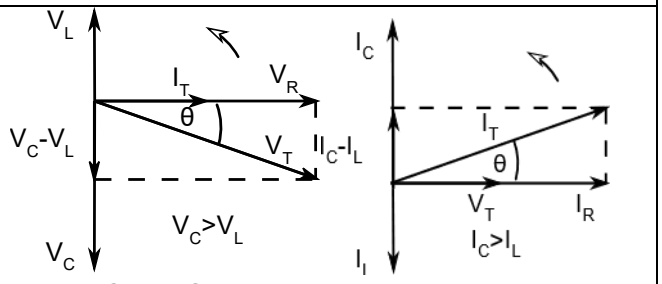
CHARACTERISTICS OF RLC COMPONENTS

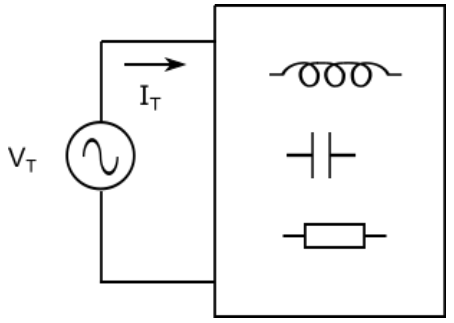
COMPONENT	SYMBOL	DEFINITION		FREQUENCY DEPENDENCE		WAVEFORM	PHASOR
RESISTOR An electronic component that limits or regulates current in a circuit.	 Ohm, Ω R	**Resistance** A fundamental property that quantifies how strongly a given material resists the movement of electric charges.	**Resistance** Resistance is a measure of the opposition to the flow of electric current in a material or an electrical component. Measured in ohm (Ω). 	Measured as the ratio of the circuit voltage to the current when they are in phase.	The resistance of the resistor is independent from the supply frequency and stays constant at all frequencies.	 $I_R = \frac{V_R}{R}$	 I_R and V_R are in phase
CAPACITOR A capacitor is an electronic component that stores and releases electrical energy in a circuit.	 Farad, F C	**Capacitance** Capacitance is a measure of a capacitor's ability to store and release charge; store energy in an electric field, and to oppose changes in voltage.	**Capacitive Reactance** $X_C = \frac{1}{2\pi fC} = \frac{V_C}{I_C}$ Unit - ohm (Ω) 	Capacitive Reactance is a measure of opposition to the flow of alternating current (AC) caused by the capacitor in a circuit and it opposes changes in voltage.	Depends hyperbolically on the supply frequency: $y = \frac{a}{x}, a = \frac{1}{2\pi C}, x = f$ Inverse proportional relationship – the capacitive reactance decreases as frequency increases. 	 $I_C = \frac{V_C}{X_C}$	 (**CIV**)IL I_C "leads" V_C by 90° **C: capacitive** **I before V**
INDUCTOR An inductor is a passive electronic component that stores energy in a magnetic field.	 Henry, H L	**Inductance** Inductance is an electrical property of an inductor that quantifies its ability to oppose changes in electric current passing through it by generating a back electromotive force (back-EMF); and a measure of the ability of an inductor to store energy in a magnetic field.	**Inductive Reactance** $X_L = 2\pi fL = \frac{V_L}{I_L}$ Unit - ohm (Ω) 	Inductive Reactance is a measure of opposition to the flow of alternating current (AC) caused by the inductor in a circuit and it opposes changes in current.	Depends linearly on the supply frequency. $y = ax, a = 2\pi L, x = f$ Direct proportional relationship – inductive reactance increases linearly with an increase in frequency. 	 $I_L = \frac{V_L}{X_L}$	 CI(**VIL**) I_L "lags" V_L by 90° **L: inductive** **I after V**

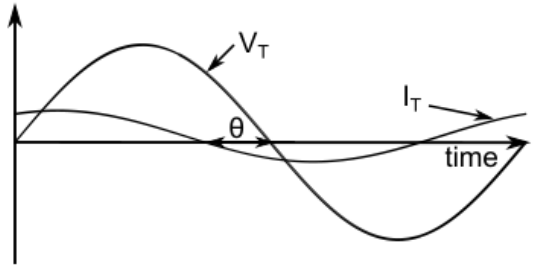
CHARACTERISTICS OF SERIES RLC CIRCUITS

COMPONENT	IMPEDANCE TRIANGLE		PHASOR DIAGRAM	
RC CIRCUIT 	 $Z = \sqrt{R^2 + X_C^2}$			
RL CIRCUIT 	 $Z = \sqrt{R^2 + X_L^2}$			
LC CIRCUIT 	 $Z = \sqrt{(X_C - X_L)^2}$	 $Z = \sqrt{(X_L - X_C)^2}$		
RLC CIRCUIT 	 $Z = \sqrt{R^2 + (X_C - X_L)^2}$ CAPACITIVE	 $Z = \sqrt{R^2 + (X_L - X_C)^2}$ INDUCTIVE	 $V_T = \sqrt{V_R^2 + (V_C - V_L)^2}$	 $V_T = \sqrt{V_R^2 + (V_L - V_C)^2}$

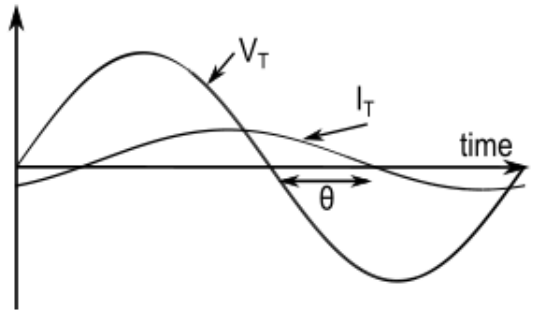
POWER SUPPLY CONCEPTS

SUPPLY VOLTAGE	The voltage V_T of the power supply, indicated as an RMS value in AC circuits.	The power supply voltage is equal to the vector sum of the voltage across the resistor V_R and the voltage across the capacitor and inductor (the reactive voltage: $V_L - V_C$ or $V_C - V_L$).
SUPPLY CURRENT	The current supplied by the power supply, indicated as an RMS value in AC circuits. The current depends on the impedance of the circuit	The current consists of the current through the resistor and the inductor and capacitor current (the reactive current).
PHASE ANGLE	The shift in phase between the supply voltage V_T and supply current I_T which results from the behaviour of a complex circuit containing reactances and resistances.	If the power supply voltage is described as $V_T = A \sin(2\pi ft)$ then the lagging or leading quantity is described as $I_T = B \sin(2\pi ft \pm \theta)$, where θ is the phase angle.
CIRCUIT IMPEDANCE	The ratio of the power supply voltage and current. A complex quantity consisting of a resistive and a reactive part. $Z = \frac{V_T}{I_T} = R + X\angle \pm 90°$	Impedance is the total opposition to the flow of alternating electrical current in an AC circuit and is expressed in Ohms. It is the sum total of all resistances, capacitive and inductive reactances.
LAGGING	When the supply current lags behind the supply voltage. The circuit is inductive.	 SERIES PARALLEL
LEADING	When the supply current leads the supply voltage. The circuit is capacitive.	 SERIES PARALLEL





LEADING



LAGGING

RESONANCE CONCEPTS

QUALITY FACTOR

The ratio of the energy stored to the energy wasted,

$$Q = \frac{energy\ stored}{energy\ wasted}$$

The amplification factor of an RLC circuit – for a series circuit, the factor with which V_L and V_C is larger than V_R, and for the parallel RLC, the factor with which I_C and I_L is larger than I_T.

SELECTIVITY

A measure of how well a resonant circuit responds to a range of frequencies and rejects others.

A circuit is said to be more selective if the response has a sharp peak and narrow bandwidth. This is achieved with a high Q factor. Q is therefore a measure of selectivity.

BANDWIDTH

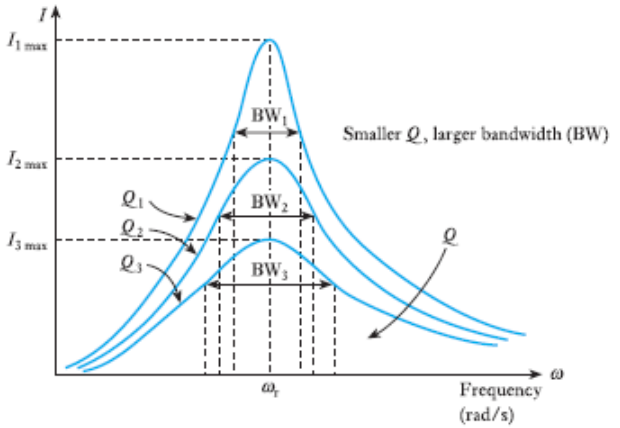
The bandwidth of a circuit is defined as the frequency range between the half-power points when $I = I_{MAX}/\sqrt{2}$. The bandwidth, BW, equals $f_H - f_L$, where the frequencies f_H and f_L are referred to as half-power points or frequencies. They are also referred to as cut-off frequencies.

$$BW = \frac{f_r}{Q} = f_H - f_L$$

$$f_r = \frac{f_H + f_L}{2}$$

$$f_L = f_r - \frac{BW}{2}$$

$$f_H = f_r + \frac{BW}{2}$$

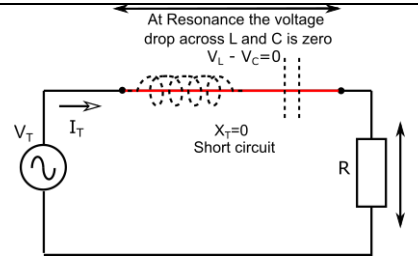


The frequency response of a series RLC circuit.

The quality factor (Q) of the circuit describes how sharp the resonance peak is. A higher Q indicates that the circuit can store energy more effectively and has less energy loss relative to the stored energy.

RESONANCE

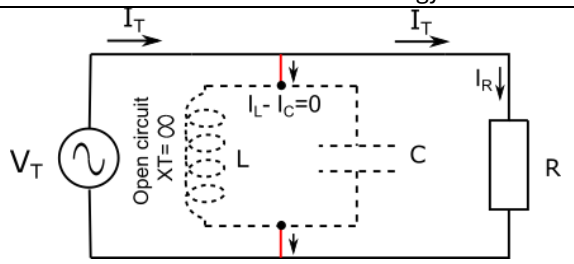
The capacitive and inductive reactances store energy that oscillates between them, the energy being at one moment stored as electrostatic energy in the capacitor, and a quarter of a cycle later as magnetic energy in the inductor. At the resonant frequency, when the capacitive and inductive reactances are equal, they transfer equal energy, and the circuit appears resistive.



SERIES RLC CIRCUIT AT RESONANCE

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$V_L = V_C = QV_T$$



PARALLEL RLC CIRCUIT AT RESONANCE

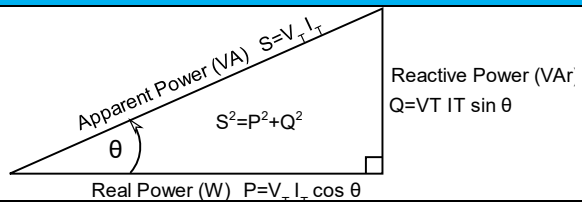
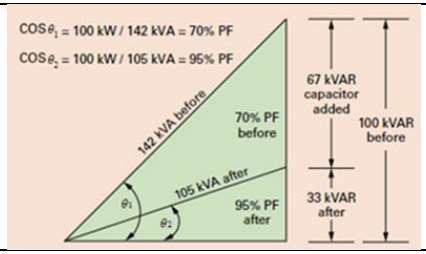
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$I_L = I_C = QI_T$$

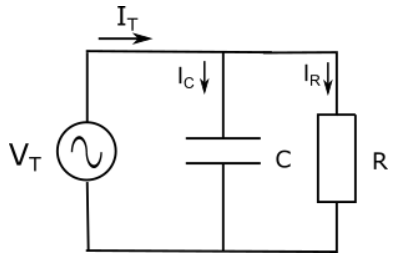
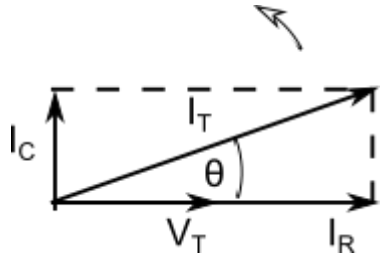
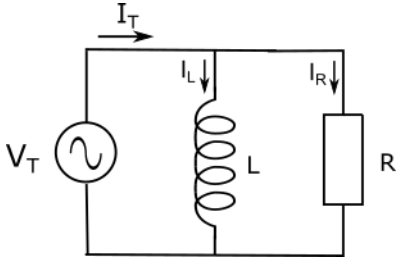
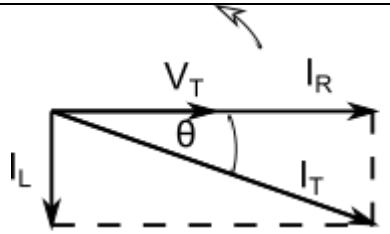
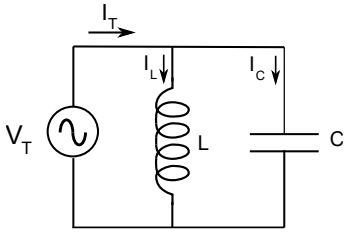
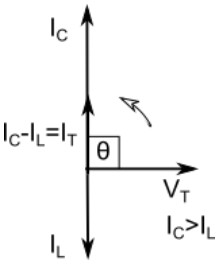
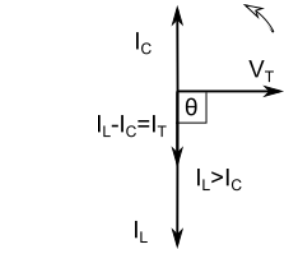
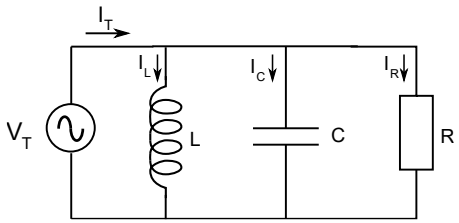
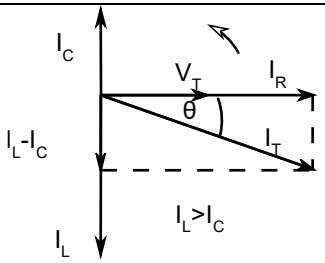
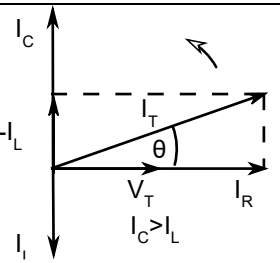
QUANTITIES

QUANTITIES AT RESONANCE	SERIES	PARALLEL
Phase Angle	$Phase\ angle, \theta = 0°$	$Phase\ angle, \theta = 0°$
Power Factor	$Power\ factor, cos\theta = 1$	$Power\ factor, cos\theta = 1$
Impedance	$Impedance, Z = R$ (minimum)	$Impedance, Z = R$ (maximum)
Reactance	$Reactances, X_L = X_C$	$Reactances, X_L = X_C$
Current	$Voltages, V_L = V_C$	$Currents, I_L = I_C$
Voltage	$Resistor\ voltage, V_R = V_T$	$Resistor\ current, I_R = I_T$
	$Current, I_T = maximum$	$Current, I_T = minimum$

POWER CONCEPTS

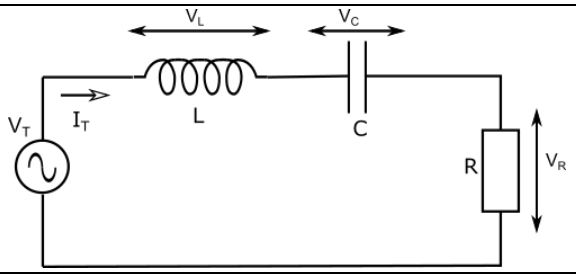
POWER TRIANGLE	Real Power, Reactive Power and Apparent Power in an AC circuit can be represented by the three sides of a triangle called a Power Triangle.		As these three elements are represented by a "right-angled triangle", their relationship can be defined as: $S^2 = P^2 + Q^2$, where: P is the real power in watts (W), Q is the reactive power in volt-amperes reactive (VAr) and S is the apparent power in volt-amperes (VA).
APPARENT POWER	The apparent power is the product of the rms voltage and current and is related to the active power by the power factor.	The apparent power is a useful means of rating certain equipment and represents the total power taken from a source. All AC sources are rated in VA, as the power factor is determined by the load. A transformer is also considered to be a source.	$Apparent\ Power, S = V_T I_T$ $Serie: Apparent\ Power, S = I_T^2 Z$ $Parallel: Apparent\ Power, S = \frac{V_T^2}{Z}$
REACTIVE POWER	The reactive power is the peak rate of energy storage in the reactive elements of a circuit. The average rate of energy storage is zero, the energy continually flowing into and out from the reactive components. The reactive power is sometimes referred to as the imaginary power – a way of saying that it is not real.	Reactive power does not perform useful "work," but circulates between the generator and the load. It places a heavier drain on the power source, as well as on the power source's distribution system. Reactive power is measured in kilovolt-amperes-reactive (kVAR). Reactive power (kVAR) sustains the magnetic field. Reactive power is necessary to provide a magnetising field required by motors and other inductive loads to perform their desired functions.	$Series: Reactive\ Power, Q = I_T^2 X^2$ $Parallel: Reactive\ Power, Q = \frac{V_T}{X^2}$ $Reactive\ Power, Q = V_T I_T \sin\theta$
ACTIVE POWER	The active power, sometimes also referred to as the real power, is the rate of energy conversion or dissipation taken as an average over one or more complete cycles.	Working power (kW) to perform the actual work of creating heat, light, motion or machine output.	$Active\ Power, P = V_T_I_T cos\ \theta$ $Series: Active\ Power, P = I_T^2 R$ $Parallel: Active\ Power, P = \frac{V_T^2}{R}$
POWER FACTOR	The ratio of true power to apparent power. $\cos\theta = \frac{P}{S}$	Power factor is the ratio of working power to apparent power. It measures how effectively electrical power is being used. The ideal power factor is unity.	An inductive circuit where the current "lags" the voltage is said to have a lagging power factor, and a capacitive circuit where the current "leads" the voltage is said to have a leading power factor.
POWER FACTOR CORRECTION	Power factor correction attempts to minimise the reactive power taken from the supply to increase the effective use of power. It attempts to make $cos\theta = 1\ or\ \theta = 0°$	Power factor correction is the process of compensating for a lagging current by creating a leading current by connecting capacitors to the supply. A sufficient capacitance is connected so that the power factor is adjusted to be as close to unity as possible.	

CHARACTERISTICS OF PARALLEL RLC CIRCUITS

COMPONENT	IMPEDANCE	PHASE ANGLE	PHASOR DIAGRAM
RC CIRCUIT 	$I_R = \frac{V_R}{R} = \frac{V_T}{R}$ $I_C = \frac{V_C}{X_C} = \frac{V_T}{X_C}$ $I_T = \sqrt{I_R^2 + I_C^2}$ $Z = \frac{V_T}{I_T} = \left(\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C}\right)^2}\right)^{-1}$	$\cos\theta = \frac{Z}{R}$ The phase angle is leading as the circuit is capacitive.	
RL CIRCUIT 	$I_R = \frac{V_R}{R} = \frac{V_T}{R}$ $I_L = \frac{V_L}{X_L} = \frac{V_T}{X_L}$ $I_T = \sqrt{I_R^2 + I_L^2}$ $Z = \frac{V_T}{I_T} = \left(\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L}\right)^2}\right)^{-1}$	$\cos\theta = \frac{Z}{R}$ The phase angle is lagging as the circuit is inductive.	
LC CIRCUIT 	$I_C = \frac{V_C}{X_C} = \frac{V_T}{X_C}$ $I_L = \frac{V_C}{X_L} = \frac{V_T}{X_L}$ $I_T = I_C - I_L$ $Z = \frac{V_T}{I_T} = \left(\frac{1}{X_C} - \frac{1}{X_L}\right)^{-1}$ $X_L > X_C$ $I_C > I_L$	$I_C = \frac{V_C}{X_C} = \frac{V_T}{X_C}$ $I_L = \frac{V_C}{X_L} = \frac{V_T}{X_L}$ $I_T = I_L - I_C$ $Z = \frac{V_T}{I_T} = \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^{-1}$ $X_C > X_L$ $I_L > I_C$	$\cos\theta = 0$ The phase angle is $\pm 90°$ depending on whether the circuit is capacitive or inductive.	 
RLC CIRCUIT 	$Impedance, Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}},$ $X_C > X_L$ $Z = \frac{V_T}{I_T}$ INDUCTIVE	$Impedance, Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C} - \frac{1}{X_L}\right)^2}},$ $X_L > X_C$ $Z = \frac{V_T}{I_T}$ CAPACITIVE	$\cos\theta = \frac{Z}{R}$ The phase angle is leading or lagging depending on whether the circuit is capacitive or inductive.	 INDUCTIVE $I_T = \sqrt{I_R^2 + (I_L - I_C)^2}$  CAPACITIVE $I_T = \sqrt{I_R^2 + (I_C - I_L^2}$

SERIES AND PARALLEL RLC CIRCUIT COMPARISON

SERIES RLC CIRCUIT



$$Impedance, Z = \sqrt{R^2 + (X_L - X_C)^2}, X_L > X_C$$

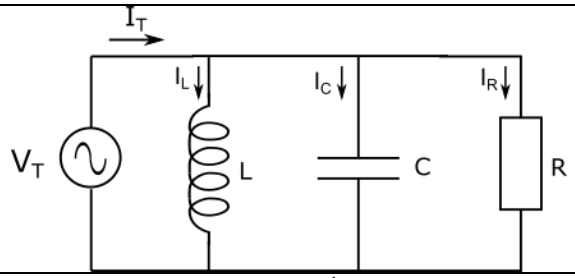
$$Impedance, Z = \sqrt{R^2 + (X_C - X_L)^2}, X_C > X_L$$

$$Z = \frac{V_T}{I_T}$$

$$V_T = \sqrt{V_R^2 + (V_L - V_C)^2}, V_L > V_C$$

$$V_T = \sqrt{V_R^2 + (V_C - V_L)^2}, V_C > V_L$$

PARALLEL RLC CIRCUIT



$$Impedance, Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}}, X_C > X_L$$

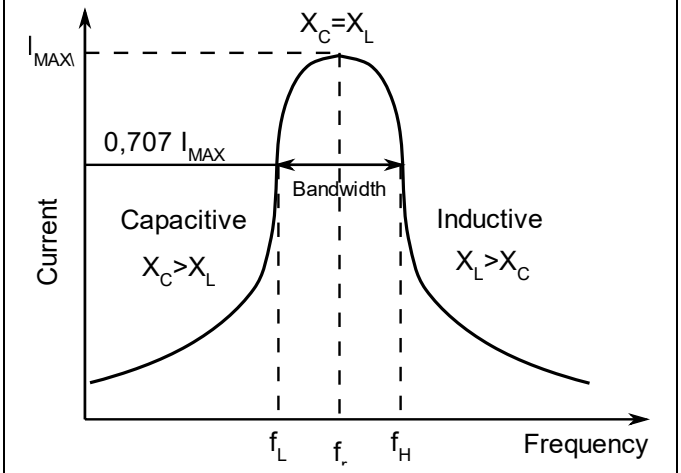
$$Impedance, Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C} - \frac{1}{X_L}\right)^2}}, X_L > X_C$$

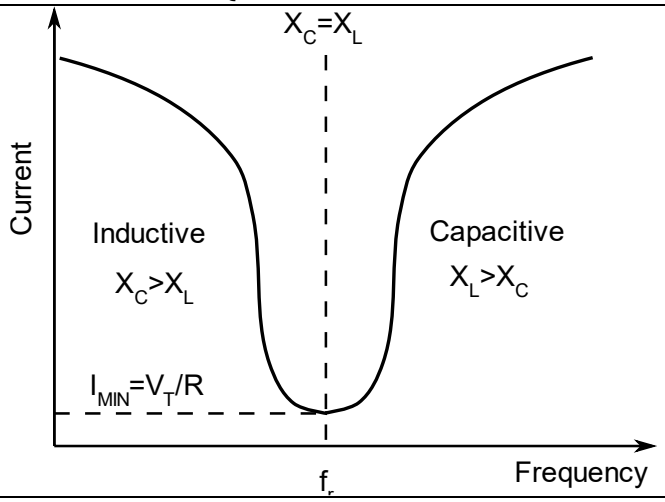
$$Z = \frac{V_T}{I_T}$$

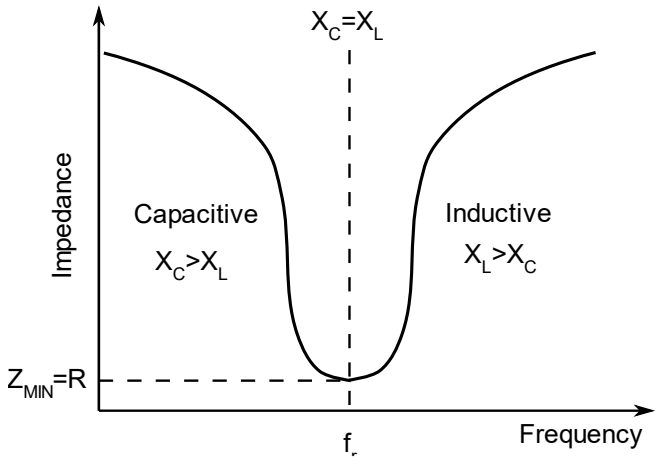
$$I_T = \sqrt{I_R^2 + (I_L - I_C)^2}, I_L > I_C$$

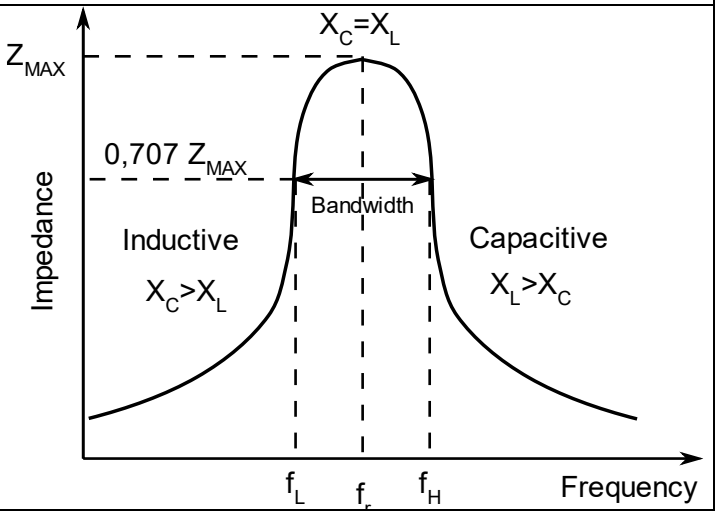
$$I_T = \sqrt{I_R^2 + (I_C - I_L)^2}, I_C > I_L$$

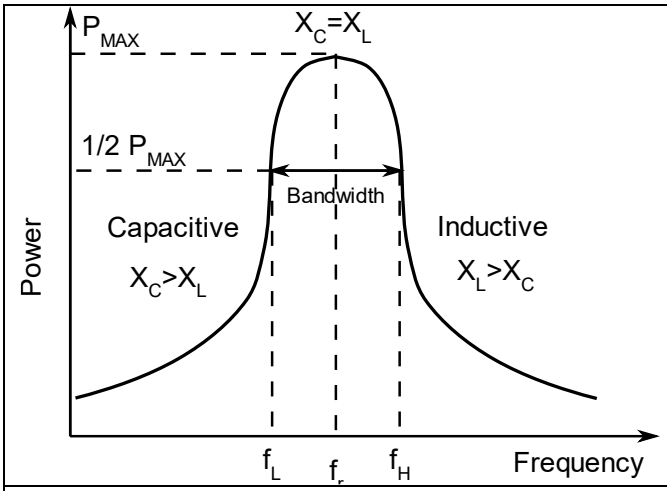
BEHAVIOUR AT AND AROUND RESONANT FREQUENCY

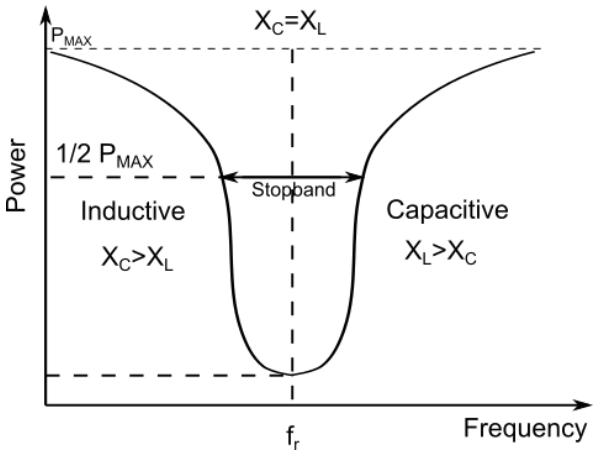












$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

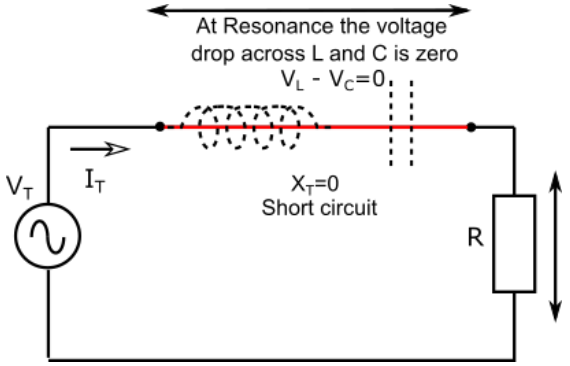
$Q = \frac{X_L}{R} = \frac{X_C}{R}$ (only valid at resonant frequency)

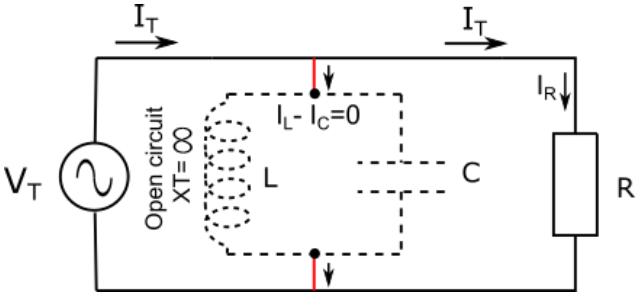
$$Q = R\sqrt{\frac{C}{L}}$$

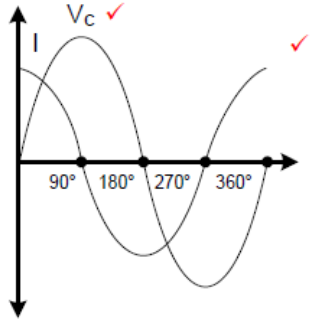
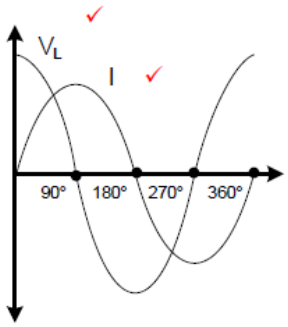
$Q = \frac{R}{X_L} = \frac{R}{X_C}$ (only valid at resonant frequency)

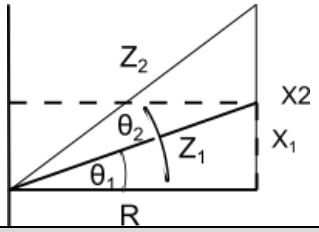
The impedance of the series RLC circuit is a minimum and resisitive and the current is a maximum at resonance. The frequency response is that of a bandpass filter which allow only the frequencies in a narrow range around the resonant frequency to pass.

The impedance of the parallel RLC circuit is a maximum and resisitive and the resultant current a minimum at resonance, This frequency response is that of a stopband filter, which allows all frequencies to pass except those lying within a small range of frequencies – the stopband. In this case the reject or stopband lies around the resonant frequency of the parallel resonant circuit, where the current is small.





	POSSIBLE QUESTIONS
1.	Define the term impedance with reference to RLC circuits.
	The total opposition to the flow of alternating current in a circuit comprising of resistance and reactance.
2.	Illustrate the phase relationship between current and voltage by drawing the waveforms of the following circuits: • Pure capacitive circuit • Pure inductive circuit
	 
3.	Explain how the value of the inductive reactance will be affected if the supply frequency is doubled in a series RLC circuit.
	The value of the inductive reactance will double/increase because the inductive reactance is directly proportional to the frequency of the supply voltage.
4.	Define the term resonant frequency
	The resonant frequency is the frequency at which the inductive reactance is equal to the capacitive reactance.
5.	Describe how a low resistance value affects the bandwidth of an LC tuned circuit.
	A low value of resistance produces a high Q-factor which results in a low bandwidth and high selectivity.
6.	Define the following terms: • Capacitive reactance • Inductive reactance
	• *Capacitive reactance is the opposition to an alternating current by the reactive component of a capacitor in an ac circuit.* • *Inductive reactance is the opposition to an alternating current by the reactive component of an inductor in an ac circuit.*
7.	Explain how the value of the current at resonance will be affected if the value of the resistance is doubled in a series RLC circuit.
	The value of the current will be halved as the circuit current is inversely proportional to the circuit impedance and the circuit impedance is equal to the resistance at resonance.
8.	Explain why the voltage drop across the inductor at resonance is greater than the value of the supply voltage in a series RLC circuit.
	The voltage across the inductor at resonance is an amplified version of the supply voltage by the Q-factor.
9.	Define the following with reference to RLC circuits: • Power factor • Q-factor of an inductor in a resonant circuit
	• *Power factor is the ratio of the true power to the apparent power.* • *The quality factor of an inductor refers to the ratio of the inductor's reactance to its internal resistance during resonance.*
10.	State TWO applications of RLC circuits.
	• *Wattless voltage dividers* • *Timing circuits* • *Filter circuits* • *Oscillating circuits* • *Radio-tuning circuit* • *Radio transmitter circuits* • *Radio receiver circuits* • *RF Amplifiers*

11.	Describe how an increase in impedance, while keeping the resistance constant, will affect the phase angle and the power factor in a series RLC circuit.
	When the impedance of the circuit is increased, the power factor will decrease therefore increasing the value of the phase angle. $\cos\theta = \frac{R}{Z}$ 
12.	List THREE characteristics of an RLC series circuit at resonance.
	• $Impedance\ is\ resistive: Z = R$ • $Reactive\ voltages\ are\ equal: V_L = V_C$ • $Full\ power\ supply\ voltage\ appears\ across\ the\ resistor: V_R = V_T$ • $Capactive\ and\ inductive\ reactances\ are\ equal: X_L = X_C$ • $Power\ factor\ is\ unity: \cos\theta = 1$ • $Phase\ angle\ is\ zero: \theta = 0°$ • $Circuit\ current\ is\ a\ maximum: I_T = maximum$ • $Impedance\ is\ a\ minimum: Z = minimum$
13.	Explain the relationship between the total current and the impedance in a parallel resonant circuit.
	In a parallel resonant circuit impedance is at maximum, and the total current is at minimum.
14.	Define the following terms with reference to RLC circuits: • Phase angle • Capacitance
	• *Phase angle is the shift in phase between the supply voltage and the current in a circuit which contain reactances and resistances.* • *Capacitance is the ability of a capacitor to store an electric charge.*
15.	Explain the effect Lenz's law has on an inductor in an RLC circuit connected across an alternating supply voltage.
	• It will cause the current to lag the applied voltage by 90° • It will oppose the current flow in the circuit. • Lenz's law states that when alternating current flows through an inductor, a back emf is set up which is opposite to the applied voltage.
16.	Name ONE application of a series RLC circuit at resonance.
	• *Tuning circuits.* • *Radio circuits.* • *Oscillator circuits.* • *TV circuits.* • *Filter circuits.* • *Band pass filter.*
17.	When choosing a component, name TWO factors that determine the quality factor of a series RLC circuit.
	• *The value of the series resistor.* • *The inductor/capacitor (L/C) ratio.*
18.	Describe what happens to the selectivity and band pass frequencies as the Q-factor of a series RLC circuit is lowered.
	As the Q factor of the circuit is lowered, its selectivity decreases and its bandwidth increases.
19.	Define the term half-power-points.
	• *Half power points are the upper and lower cut off frequencies in a circuit.* • *Point at which the output power has dropped to half of its peak value, at a level of approximately -3db.*
20.	Explain how the value of the Q-factor affects the value of the current.
	The higher the value of the Q-factor the greater the value of the current flow.
21.	Define capacitive reactance with reference to RLC circuits.
	Capacitive reactance is the opposition of the capacitor to alternating current in an AC circuit.
22.	State the phase relationship between the current and voltage in a pure inductive AC circuit.
	There is a 90° phase shift between V_L and I_L where I_L lags V_L by 90°.

23.	State THREE conditions that will occur if the power factor is at unity in a RLC series circuit.
	• *Z = R* • *Phase angle = 0°* • $V_L = V_C$ • $X_L = X_C$ • *I is maximum*
24.	Define phasor diagram with reference to RLC circuits connected across an alternating voltage supply.
	A phasor diagram is a graphical representation of a sinusoidal alternating current or voltage in an RLC circuit.
25.	Define the term selectivity with reference to resonant circuits.
	Selectivity is a measure of how well a resonant circuit responds to a range of frequencies and excludes others.
26.	Explain the term inductance with reference to RLC circuits connected to an AC supply.
	• *Inductance is the created back-emf in an inductor that tends to oppose a changing electric current passing through it.* • *Inductance is the tendency of a coil to oppose a change in current flowing through it when connected to an AC supply.*
27.	Explain what is meant by a lagging power factor.
	A lagging power factor is when the current lags the voltage in an RLC circuit.
28.	Explain why the current and the voltage waveforms are in phase in a series RLC resonance circuit.
	At resonance, the circuit becomes resistive because the capacitive reactance and inductive reactance cancels each other, resulting with an in-phase relationship between current and voltage.
29.	Discuss the difference between the impedance and current at resonant frequency.
	The impedance will be maximum and the current will be minimum.
30.	Describe what is meant by the term in phase with reference to the relationship between the applied voltage and current in an RLC circuit connected to an AC supply.
	When the voltage and current waveforms start at the same time, have the same frequency resulting in a zero phase angle. *OR* *When any waveforms of electrical quantities start at the same time, reach their peak at the same time, pass through zero at the same time and end at the same time. (The two waves have the same frequency even though their amplitude may differ)*
31.	Name TWO applications of resonance as applicable to tuned circuits.
	• *Radio tuning circuits* • *Television tuning circuits*
32.	Explain how the value of the total current would be influenced if R is halved when a series RLC circuit is at resonance.
	The value of the current will be doubled.
33.	State the relationship between inductive reactance and frequency.
	Inductive reactance is directly proportional to frequency.
34.	Explain why the voltage across the inductor is greater than the value of the supply voltage in a series RLC circuit at resonance.
	• *The voltage across the inductor is greater than the supply voltage due to this being a series resonant circuit and to the voltage magnification of the Q-factor.* • *L and C forms a tank/oscillator which amplifies the voltage and supply each other with out of phase energy where the amplification is directly proportional to Q.*
35.	Explain the term reactance with reference to an alternating current circuit.
	Reactance is the opposition offered to the flow of alternating current by an inductor or capacitor in an AC circuit.

WHAT HAPPENS DURING RESONANCE IN AN RLC CIRCUIT?

- An AC supply applies a sinusoidal voltage across the circuit
- As the AC voltage rises, the capacitor begins to charge, accumulating energy as electrical potential energy
- When the AC voltage reaches a maximum and starts to drop, the capacitor discharges, causing current to flow through the inductor. This initiates energy transfer.
- The inductor responds by building a magnetic field, storing energy as magnetic potential energy.
- As the current continues to flow, the capacitor discharges completely, and the inductor now contains maximum current. The energy stored in the inductor is at its peak.
- As the AC supply reverses polarity, the magnetic field in the inductor collapses, causing the inductor to push energy back into the capacitor, recharging it (but with opposite polarity).
- This process repeats: the capacitor discharges into the inductor, and then the inductor discharges back into the capacitor. This back-and-forth transfer of energy continues, resulting in oscillations.

- At resonance, the inductive reactance and capacitive reactance are equal, allowing energy to oscillate efficiently with minimal resistance. This happens optimally at the natural frequency of the LC tank, given by

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

- As the oscillation continues, both the inductor and capacitor can develop voltages that exceed the supply voltage. This occurs because:
  - The current through the inductor, which generates a higher voltage drop across it , reaches its maximum when the capacitor is at its minimum charge.
  - Similarly, when the inductor discharges back into the capacitor, it can create a high voltage across the capacitor as the charge oscillates back and forth.
- When the power supply is tuned at the natural frequency of the LC tank, it supplies energy to the lossless LC tank at just the correct moment. Thus with every cycle extra energy is added to the capacitor and inductor.
  - Energy in the capacitor and inductor is directly related to the voltage and current across and through it.
  - The more energy, the higher the voltage and current, resulting in an increase in the voltage across both components to a value lots higher than the supply voltage, and only limited by resistive losses in both components.

SWING ANALOGY



Let's focus on how an increased amplitude (higher swing) can relate to what happens at resonance in an RLC circuit:

1. Higher Swing vs. Increased Circuit Amplitude

Swing: Imagine you're pushing someone on a swing. If you apply gentle pushes at the exact right frequency (the swing's natural frequency), each push adds to the motion, and the swing gradually goes higher with each push. Eventually, it reaches a large amplitude without you exerting a large force every time.

RLC Circuit: At resonance, the RLC circuit behaves similarly. When the input AC source is at the resonant frequency, the voltage across the circuit builds up with each cycle. This effect, often called voltage amplification, causes the current in the circuit to reach a peak without needing to increase the input voltage substantially.

2. Energy Build-Up and Minimal Effort

Swing: By pushing at the swing's natural frequency, each push adds constructively to the previous motion. With minimal effort, the swing reaches a much higher amplitude compared to random pushing.

RLC Circuit: Similarly, at resonance, each oscillation cycle contributes constructively to the overall energy in the circuit. The capacitor and inductor store and release energy back and forth, which creates larger oscillations in the current. This energy build-up, combined with the constructive interference of each cycle, leads to higher current or voltage at resonance, simulating an amplification effect.

3. Role of Damping (Resistance in the RLC Circuit)
Swing: Air resistance and friction at the pivot act like damping in a swing. A heavily damped swing doesn't build up much amplitude because energy is lost as heat or friction, even if you push at the right frequency.

RLC Circuit: In an RLC circuit, the resistor represents this damping. If resistance is low, the energy circulates more freely between the capacitor and inductor, leading to higher current or voltage at resonance. If resistance is high, this amplification effect reduces as more energy is lost as heat.

4. Achieving High Amplification
Swing: To achieve the highest possible swing (maximum amplitude), you need to push at the right frequency and minimize damping (reduce friction, for example).

RLC Circuit: For maximum voltage or current amplification in an RLC circuit, the input frequency must match the resonant frequency, and the resistance should be minimized. This will lead to a strong resonance effect, where energy oscillates between the capacitor and inductor, creating a larger overall current or voltage across the circuit.

SERIES RLC	PARALLEL RLC
$V_L = V_C = QV_T$	$I_L = I_C = QI_T$

NOTE THAT THE QUALITY FACTOR IS THE AMOUNT BY WHICH THE SUPPLY VOLTAGE OR CURRENT IS AMPLIFIED