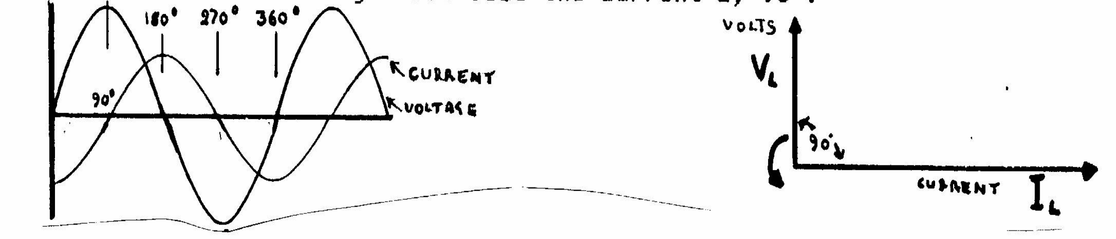
AC. CIRCUITS

This lesson introduces inductors into our AC. circuit. We then look at the result of having various combinations of capacitance, inductance and resistance in the same circuit. This leads us to the very important subject of *resonance.* The lesson concludes with a look at radio frequency transformers and of filters.

Inductance

In an inductor the voltage will lead the current by 90°.




The value of an AC current that flows through a coil will depend on its inductance and the frequency, of the supply. The opposition to current flow is known as inductive reactance **X** L . Inductive reactance is measured in Ohms.

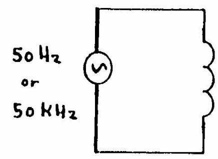
$X_L = \omega \times L$ (Remember that $\omega = 2\pi f$ and L is in Henrys)

Example

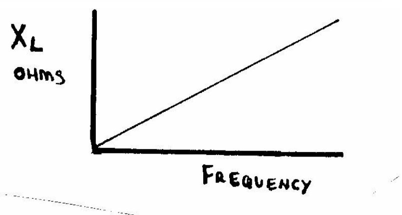
What is the inductive reactance of a 2 Henry coil at 50 Hz and 50 kHz ?

At 50 Hz : $X_L = 2\pi 50 \times 2 = \mathbf{628}$ Ohms

At 50 kHz : $X_L = 2\pi 50000 \times 2 = \mathbf{628}$ kOhms

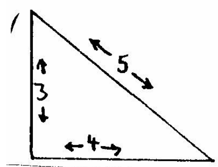



As the frequency increases the inductive reactance also increases therefore the current will decrease.




A little more math's…

Pythagoras said that the "square of the hypotenuse (long sloping side) is equal to the sum of the squares of the other two sides of a *right angle triangle. This is best explained by the following example*:




$Z = 3^2 + 4^2 = 9 + 16 = 25$

Therefore $Z = \sqrt{25} = 5\,\Omega$

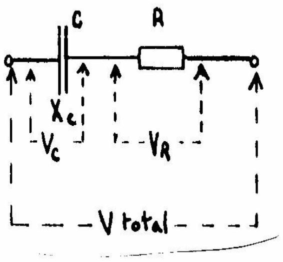
If you draw some triangles to scale you will find that this is correct - try it for yourself... When using vectors, to solve AC problems, it is usually necessary to find the length of the diagonal when the two sides of a rectangle are known. You will see that the diagonal conveniently divides the rectangle into two equal triangles.

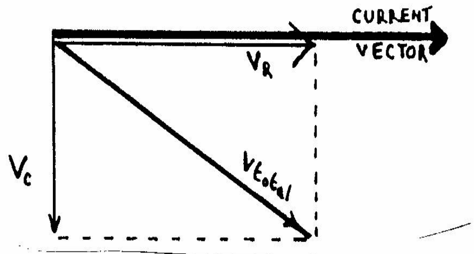
 

A.C. CIRCIJITS CONTAINING **CAPACITANCE AND RESISTANCE**

Remember that the voltage across a capacitor lags the current by 90° and the voltage across a resistor will be *in-phase* with the current.

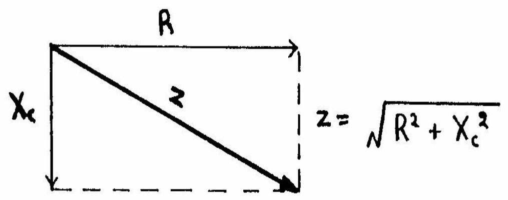
In a <u>series</u> circuit, the <u>current</u> through each component is the same, so it is taken as the *<u>reference vector</u>*. The reference vector is always drawn horizontally, left to right.



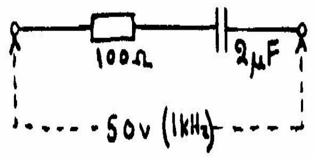




The total voltage across the circuit is the VECTOR SUM of the component voltages. (IE the length of the diagonal)

The resistance and capacitive reactance can also be shown vectorially. The resultant (diagonal) is the *impedance* and is measured in Ohms. Thus, the impedance Z is equal to the VECTOR SUM of the resistance R and the reactance XL.




EXAMPLE: What current will flow in the following circuit ?




$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 1000 \times 2 \times 10^{-6}} = 79.57\Omega \text{ (APPROX } 80\Omega\text{)}$$

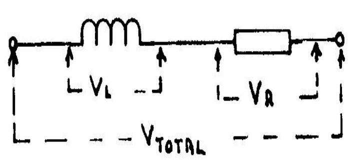
$$Z = \sqrt{(100 \times 100) + (80 \times 80)} = 127.8\Omega \text{ (APPROX } 128\Omega\text{)}$$

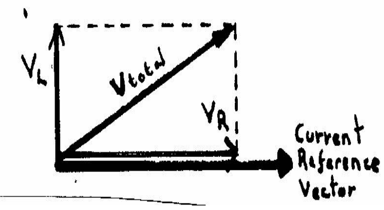
The current can now be calculated using Ohms Law. I=V/Z = 5O/128 = 0.391 Amps

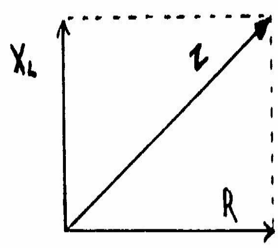
AC. CIRCUITS CONTAINING **INDUCTANCE AND RESISTANCE**

The voltage across an inductor leads the current by 9O°. The voltage across the resistor will, of course, be in-phase with the current. As this is a *series* circuit the *current* is taken as the *reference vector*.

The total voltage across this circuit is the VECTOR SUM of the voltage across the resistor and the voltage across the inductor.



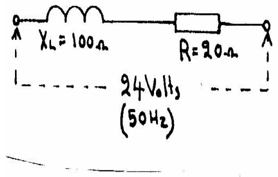



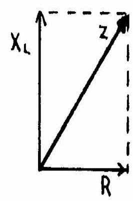

The impedance of the circuit is found by vectorially adding the inductive reactance to the resistance. As before, this can be found using Pythagoras or by scale drawing.

**L and R in series:EXAMPLE**: What current will flow when an inductor, having a reactance of 100 Ohms and resistance of 20 Ohms, is connected across a 24 Volt 50 Hz supply ?

Using Ohms Law,
I = V/Z = 24/101.9
= 0.235 Amps

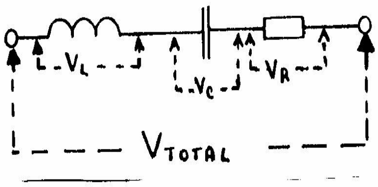


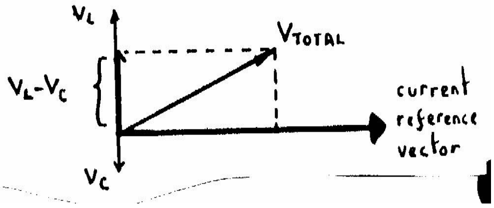




$$Z = \sqrt{100^2 + 20^2} = 101.98\Omega$$

## INDUCTANCE. CAPACITANCE AND RESISTANCE IN SERIES

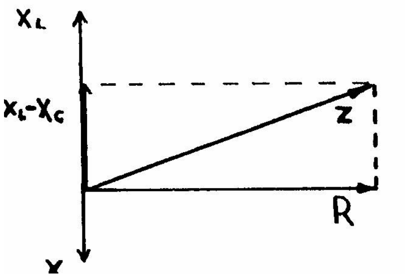
Take current as the reference vector.
The voltage across the inductor will lead the current by 90°
The voltage across the capacitor will lag the current by 90°
The voltage across the resistor will be in-phase with the current.




The voltages across the inductor arid the capacitor are 180° out of phase with each other. In other words, one is straight up and the other is straight down. The result of these two can be found subtracting one from the other.
It is this result that forms one side of the rectangle that is used to calculate (by vectors) the total voltage. (The other side of the rectangle is the voltage across the resistor)

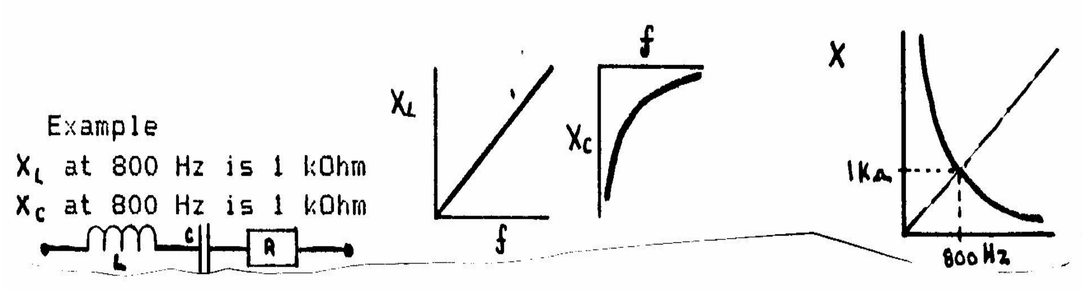
**IMPEDANCE**
The capacitive reactance will be 180°out of phase with the inductive reactance. The resultant reactance is found by subtracting one from the other.
This reactance is then added vectorially to the resistance and the result is called the i**mpedance** of the circuit. Impedance is measured in Ohms.



## THE "MAGIC" FREOUENCY - <u>RESONANCE</u>

Remember that inductive reactance is proportional to the frequency and capacitive reactance is inversly proportional to frequency. If one of the graphs is inverted and super imposed on the other it can be seen that there is one frequency when inductive reactance is equal (and opposite) to the capacitive reactance. This frequency is known as the resonant frequency of the circuit .



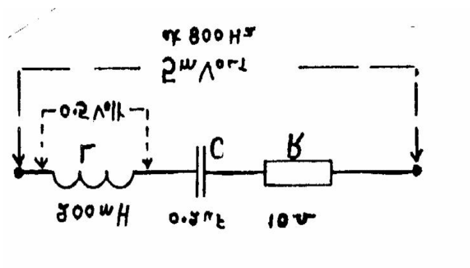

This is called a **series tuned circuit** and the **frequency** at which the inductive reactance is equal and opposite to capacitive reactance is its **resonant frequency (fo)**

At the frequency of resonance the inductive reactance will be cancelled out by the equal and opposite capacitive reactance. Therefore at resonance, the impedance of the circuit will be equal to the resistance only. Thus, at resonance, the current flowing will be V/R Ohms.
The resonant frequency (fo) a tuned circuit can be calculated if the values of inductance and capacitance are known:

$F_o = 1/2\pi\sqrt{LC}$ **This important formula applies to *<u>both</u>* series & parallel circuits.**

### Q FACTOR

This is best explained with an example.
The supply voltage is 5 mill volts at 800 Hz
The resonant frequency of this circuit is 800 Hz
At resonance the circuit is purely resistive.
The current flowing will be:
I = V/R = 0.005110 = 0.5 mA




The reactance of the 200 mH inductor (at 800 Hz) is 1000 Ohm. The voltage across it will be: XL x I = 1000 x 0.5 mA = 0.5 Volts.

*This is 100 times the supply voltage!* In the same way, at resonance, there will be 0.5Volts across the capacitor but it will be 180° out-of-phase with the voltage across the inductor.

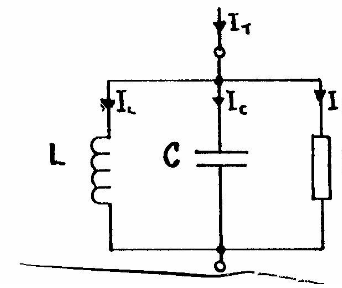
The ratio of the voltage across the inductor (or capacitor) to the supply voltage, at resonance, is called the Magnification or *Q Factor*.

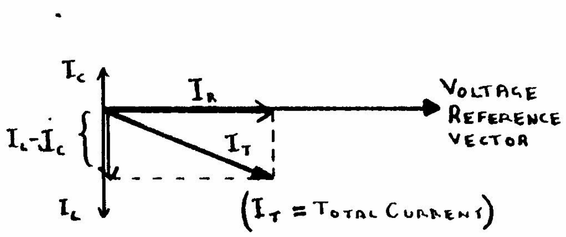
 

## I NDUCTANCE, CAPACITANCE AND RESISTANCE IN PARALLEL

In a parallel circuit, the voltage across each component is the same, but the current through each component will differ.
The current through the *resistance* will be *in-phase* with the voltage.
The current through the *inductor* will *lag* the voltage by 90° (*This is two ways of* )
The current through the *capacitor* will *lead* the voltage by 90° *(saying the same thing!)*

The total current is found by vectors.
At the resonant frequency, the current through the inductor and the current flowing through the capacitor will be equal and opposite.
At resonance the current through either the inductor (or capacitor) will be "Q" times the supply current. "Q" is a measure of the "goodness or quality" of a tuned circuit.
Q can be calculated in terms of reactance (capacitive or inductive) and resistance. Q = X/R

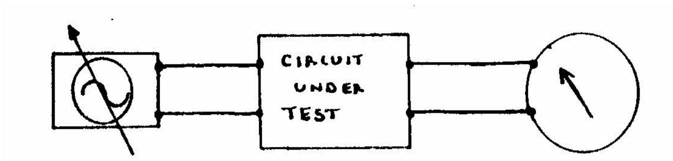



## RESPONCE CURVES

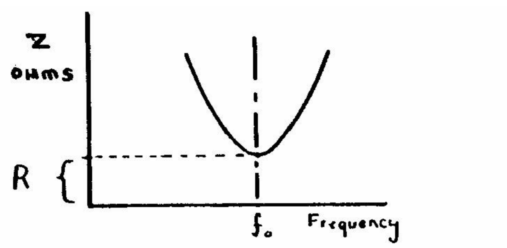
When looking at tuned circuits we will be confronted with graphs called responce curves. They are used to show how various quantities vary with changes in frequency.

To draw response curve the loss through a circuit is measured at various frequencies. The results are then plotted as a graph.



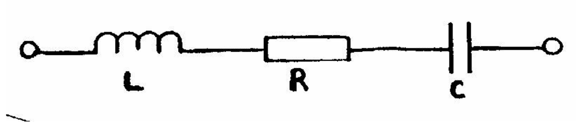

## RESPONCE CURVE for a SERIES TUNED CIRCUIT

This response curve shows how the impedance of a series circuit comprising an inductor, capacitor and a resistor) varies with frequency.




At resonance you will see that the total impedance is equal to the value of the resistor. IE Z = R

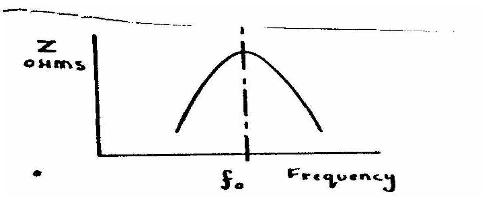
A *series* tuned circuit has its *minimum* impedance at its resonance frequency and is called an *acceptor* circuit.
Therefore current flow wi1l be a maximum When its frequency is equal to the resonant frequency of this series circuit.



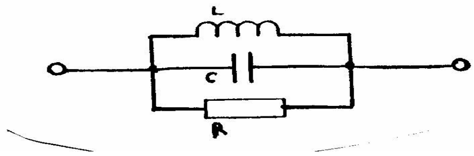

 

**RESPONCE CURVE for a PARALLEL TUNED CIRCUIT**

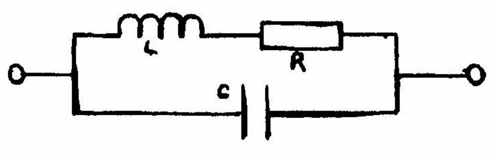
The responce curve for a *parallel* tuned circuit shows that the impedance is *highest* at the *resonant frequency*. A *parallel* tuned circuit is known as a *rejector* circuit.




So far, we have taken the parallel circuit to be as shown on the right. All three components are in para11el.

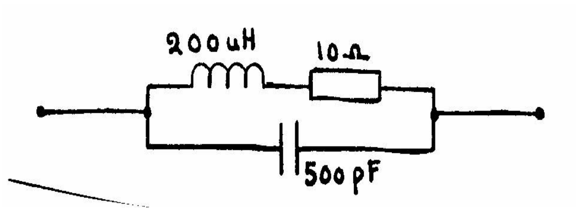



In practice, a parallel circuit will be as on the right. The resistance in the circuit will be that of the wire in the inductor. This resistance will act as if it were in series with the inductor.




In this practical parallel tuned circuit its impedance, at resonance, is known as the dynamic impedance or dynamic resistance. Dynamic Impedance = L/CR Ohms

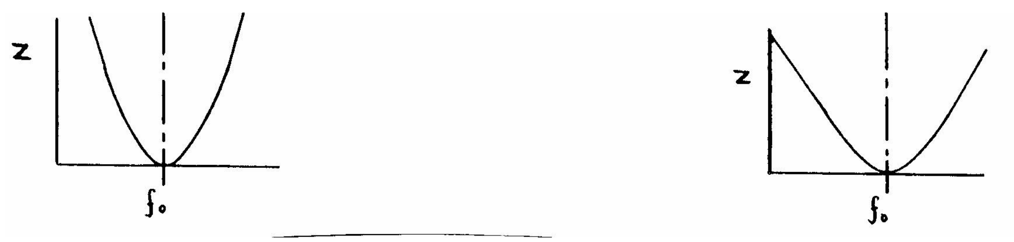
Example. L = 200μH C = 500 pF
R = 10 Ω
Dynamic impedance = 40kΩ




A high dynamic impedance is required in most practical circuits.

*Tuned circuits like this are used in oscillators and radio receivers etc. For example, they can be used to "select.' one frequency when many are present.*
*IE : Enables a receiver to .' tune in.' one station and ignore the others.*

**SELECTIVITY**

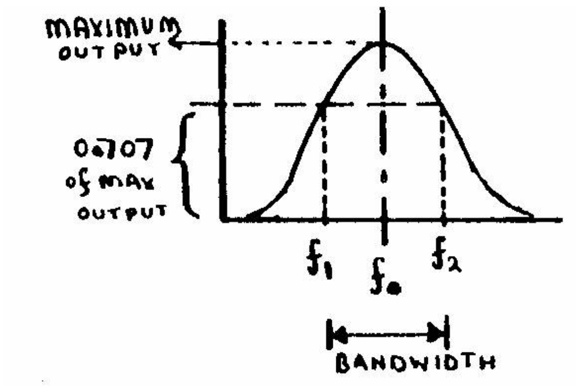



A high Q circuit has good selectivity A low Q circuit has poor selectivity

## Bandwidth

*The Bandwidth* of a selectivity curve is the frequency range where the output is at least 0.707 of the maximum value.



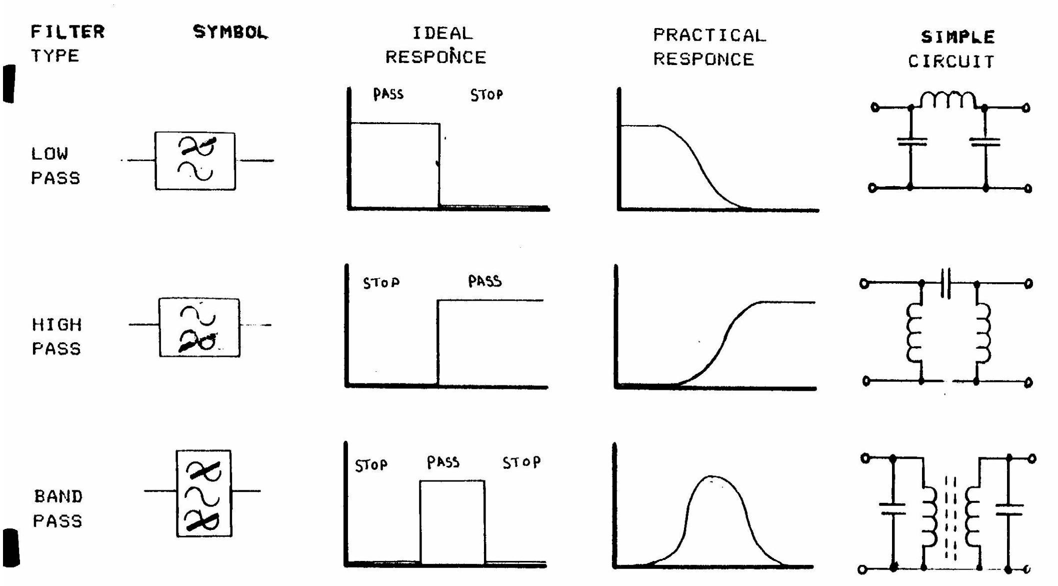

Q = Resonant Frequency divided by the Bandwidth.

$$Q = \frac{f_0}{f_2 - f_1}$$

A parallel tuned circuit would typically have a Q of 50.

## FILTERS

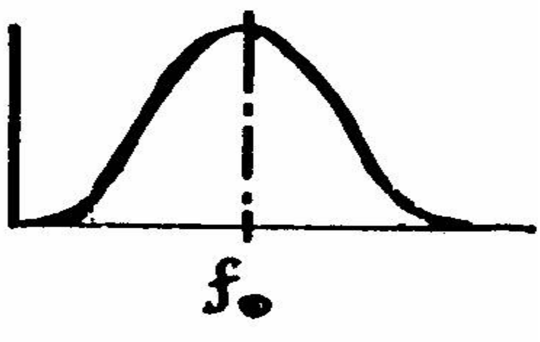
A 'filter' is a circuit that will pass some frequencies and reject others.
Ideally, the transition from pass to reject (or Stop) should be clear cut.




In practice the response will usually be somewhat rounded resulting in a more gradual change from pass to stop

**A Practical Band Pass Filter**

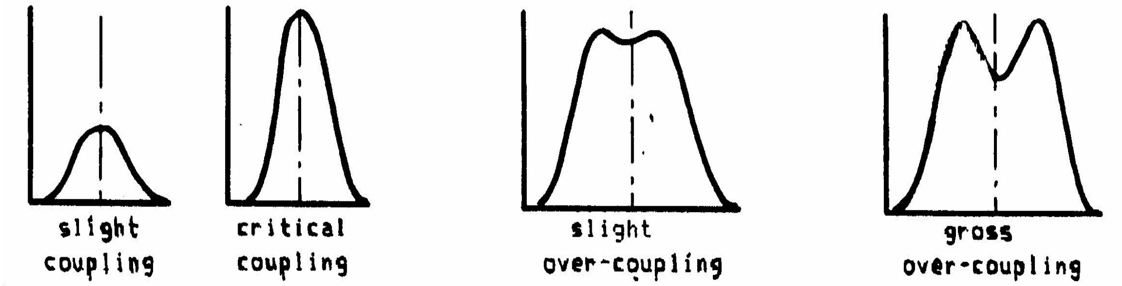
A simple tuned circuit has this response curve.




However, other response curves can be obtained if two such circuits are constructed so that their magnetic fields interact. This usually means that both coils are wound on the same or adjacent ferrite cores.

**Coupling between two coils**
The amount of magnetic coupling can be increased by moving the coils closer together.

The response curves for various amounts of coupling are shown below.




With slight over-coupling the response curve broadens out (IE increased bandwidth) and begins to resemble the *ideal filter*. If the coupling is further increased the double hump becomes eyesslve and eventually splits into two separate peaks.

**LESSON 4A QUESTIONS**

QUESTION:4A.1 What is reactance of a 200 mH inductor at 50 Hz & at 200 kHz ?

QUEST ION: 4A. 4 What is "back EMF" ?

QUESTION:4A.5 A 1.2731 mH inductor is connected in series with a 600 Ohm resistor. What is the resultant Impedance of this combination at 100 kHz ?

QUESTION:4A.7 A 0.0033 uF capacitor is connected in parallel with a 200 uH inductor. What is their resonant frequency?

QUESTION:4A.8 The components in question 4A.7 are now connected in series instead of parallel. What is their resonant frequency ?

QUESTION:4A.9 What is the effect of adding a resistor across a parallel tuned circuit ?

QUESTION:4A.10 What is the advantage of slight over-coupling in a radio frequency transformer ?

QUESTION:4A,11 Why does the reactance of an inductor go up as the frequency in increased ?

QUESTION:4A.13 Did you find this a difficult lesson ? Its easier from now on..

QUESTION:4A.19 At resonance, what is the impedance of a series tuned circuit comprising just inductance and capacitance ?

QUESTION:4A.20 A 14 MHz tuned circuit has a Q of 50. What is its bandwidth ?

Don’t struggle too much over this lesson. Have a go then let me fill in the gaps and answer your questions!