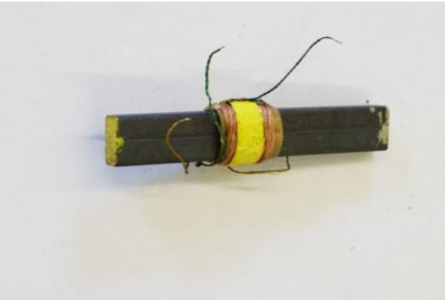
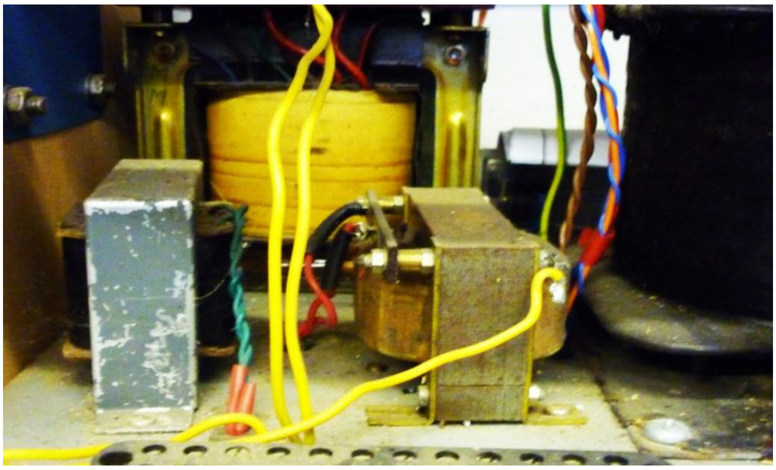
Inductors

- An inductor is usually a coil of wire - it has the property of "Inductance"

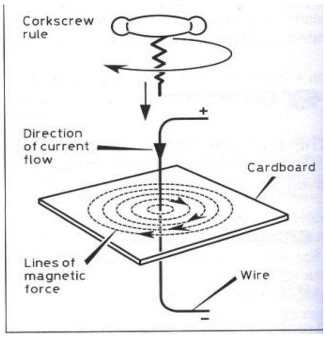




- The inductance results from magnetic effects associated with an inductor

- A magnetic field surrounds any wire carrying a current.
  If the wire is coiled the magnetic field is strengthened
  If an iron core is inserted in the coil the magnetic field is further strengthened

Fig 5.9



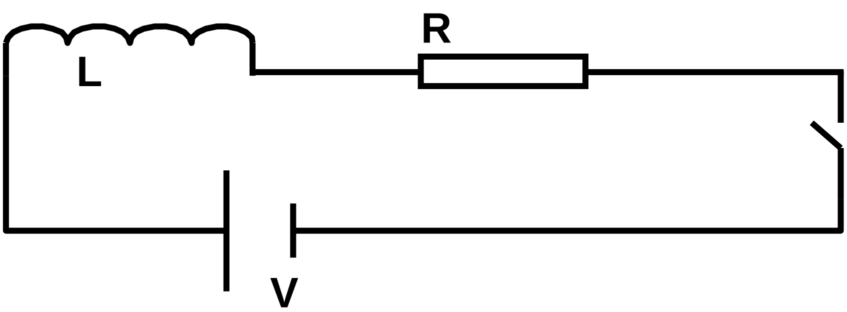
- If a wire or a coil is moved through a magnetic field a voltage will be induced in the coil.
- The amount of voltage depends on the strength of field and the rate of moment.

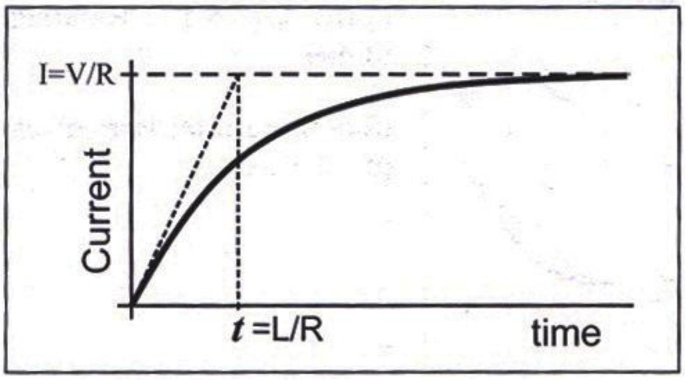
- A voltage is also induced in a stationary coil by a varying magnetic field

- A coil that has a steadily increasing current - causing a steadily increasing magnetic field - will induce a voltage into any coil within the magnetic field - including the one causing the field.

- In the case of the coil causing the field - the polarity of the induced voltage will be opposite to the external voltage - this is termed the "Back EMF".

- When a battery is connected across a coil through a resistor the current does not immediately become **I=V/R** because of the effect of the back EMF

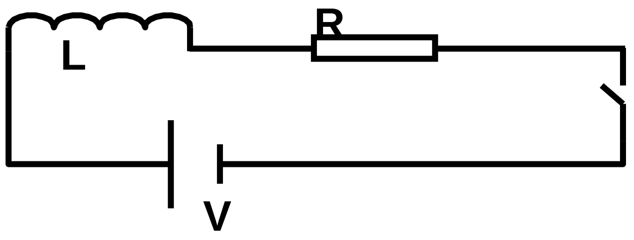


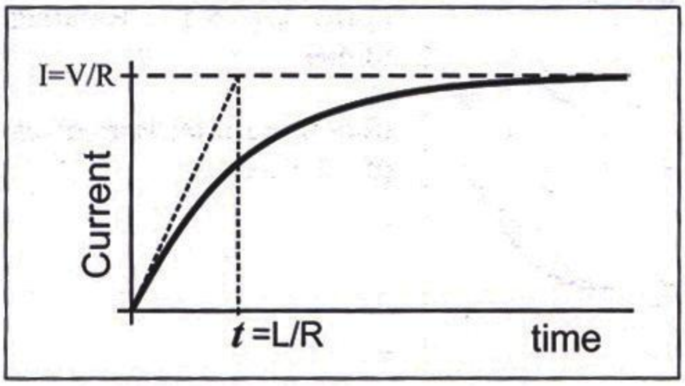


- A coil of more turns will have a higher back EMF for a given rate of change of current and for a given supply voltage the current will rise more slowly
- **"Inductance"** is the name given to this **backEMF** effect
- Inductance increases with - the number of turns - with increasing coil diameter - with closeness of the spacing of turns - and with the core material.
- An inductor stores energy in its magnetic field
- The unit of inductance is the **Henry**
- If a coil has 1V induced into it by a current that it is increasing/decreasing by 1 amp per second the inductance of the coil is **1 Henry**
- Common core materials are - **air - ferrite - iron**
- The ability of a material to enhance the magnetic field is known as its **"Permeability".**

1mH = one thousandth of 1H = 0.001H = 1 H x 10^{-3}
1µH = one millionth of 1H = 0.000001H = 1H x 10^{-6}

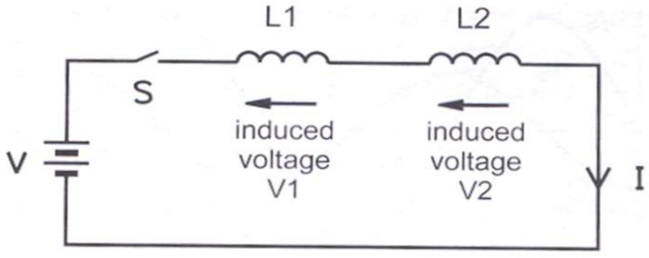
L - R Circuits





- The time constant of an L-R circuit is - **L/R**
- The current is taken to have reached a maximum at **5 x L/R**

Inductors in series and parallel



- In series - $L_{total} = L_1 + L_2 + L_3$ etc
- In parallel - $1/L_{total} = 1/L_1 + 1/L_2 + 1/L_3$

Alternating currents and voltages

Production of AC

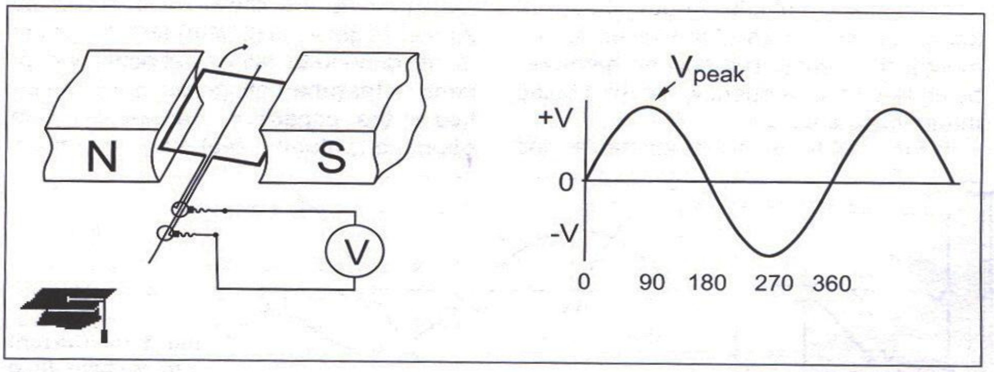


Fig 5.12: Production of AC

- The generated voltage follows a sign curve

f = frequency in cycles per second

T = the time for one cycle (the period)

f = 1/T **T = 1/f**

- If the peak voltage is defined, then the voltage at any other time can be calculated from sine tables.

- It is not usual to quote the peak voltage but the -

Root Mean Square (RMS) value

The RMS voltage is the equivalent to the DC voltage that would deliver the same average power.

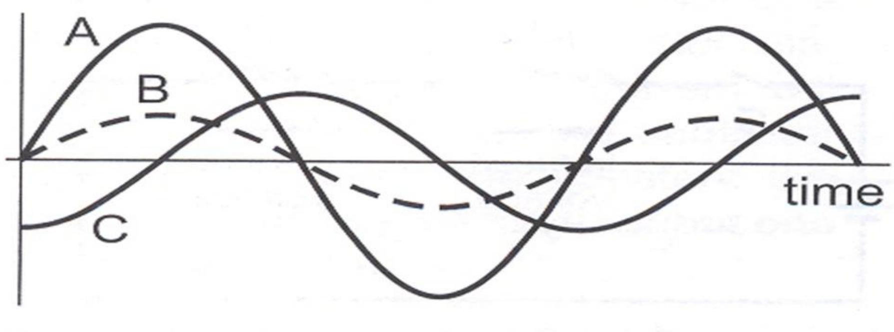
$V_{rms} = V_{peak}/\sqrt{2}$ $V_{rms} = 0.707 \times V_{peak}$

- eg. - The UK mains supply is 230V (RMS) - the peak voltage =

$$230/0.707 = 325.3V$$

Frequency and Phase

- **The concept of phase -**

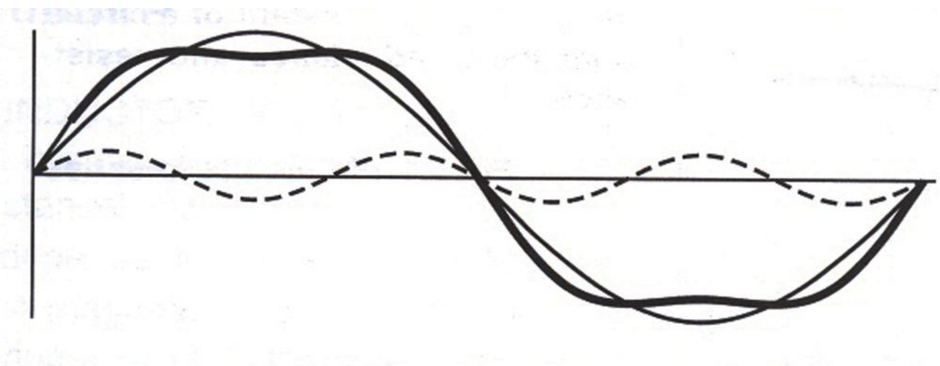


A & B are in phase - is C leading or lagging and by how much?

Harmonics

- Harmonics are exact multiples of the **"fundamental frequency"**

Odd and even harmonics **Harmonic distortion**



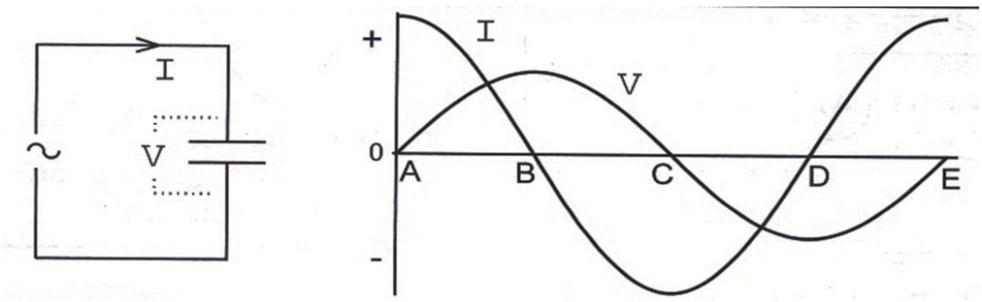
Resistors and AC

- Ohms law always applies to resistors - whether the supply voltage is AC or DC

- In the case of an AC supply the current and voltage will always be in phase

Capacitors and Inductors with AC

- When an AC supply is applied to a capacitor - the current leads the voltage by 90 degrees.



- When an AC supply is applied to an inductor - the voltage leads the current by 90 degrees.

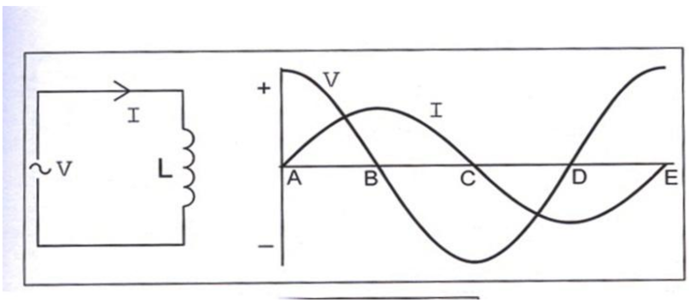
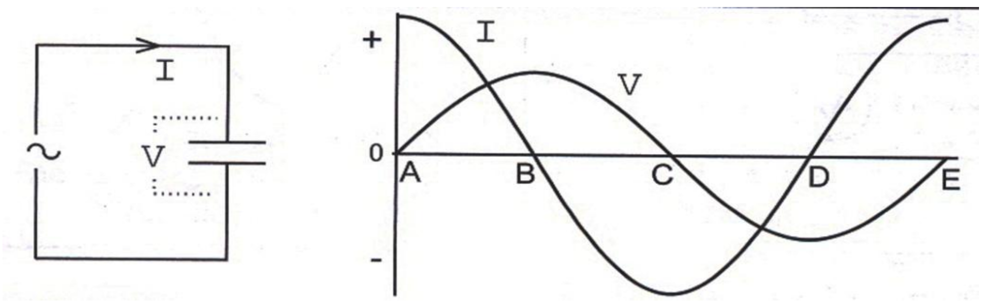


Fig 5.16: Current and voltage in an inductor

Reactance

- For a resistor V/I always = resistance

- But for a capacitor?



- Different answers for different moments in time.

- We take the RMS value of V and I

V/I = Reactance, in ohms Ω

- Whenever the word reactance is used it means the current and voltage are 90 degrees out of phase.

- For a larger capacitor - the charge will be greater for a given voltage -
  - so the current will be greater for that voltage - so the capacitive reactance will be smaller.

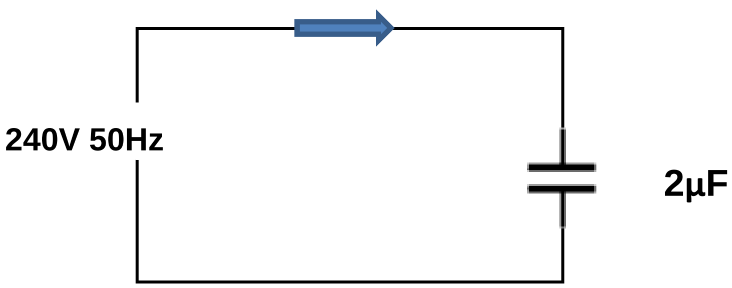
$$X_c \ \alpha \ 1/C$$

- Similarly X_c is inversely proportional to frequency

- The actual formula for the capacitive reactance of a capacitor is -

$$X_c = \frac{1}{2\pi f C}$$

- **Example**



What is the X_c of the capacitor?

What current will flow?

$2\mu F = 0.000002F = 2 \times 10^{-6}F$

$$X_c = \frac{1}{2\pi f C}$$

$$X_c = \frac{1}{2\pi \times 50 \times 2 \times 10^{-6}}$$

$$X_c = \frac{1}{200\pi \times 10^{-6}} = \frac{10^6}{200\pi} = \frac{10^4}{2\pi}$$

$$\mathbf{X_c = 1590\Omega}$$

$$\mathbf{X_c = V/I \qquad I = V/X_c}$$

I = 240/1590 = 0.15A (or 150mA) RMS

If this capacitor was connected across the output of a transmitter on 80m

V= 240V f = 3.5MHz

$$\frac{1}{2\pi \times 3.5 \times 10^{6} \times 2 \times 10^{-6}} = \frac{1}{2\pi \times 3.5 \times 2} = \frac{1}{44}$$

X_C = 0.023Ω

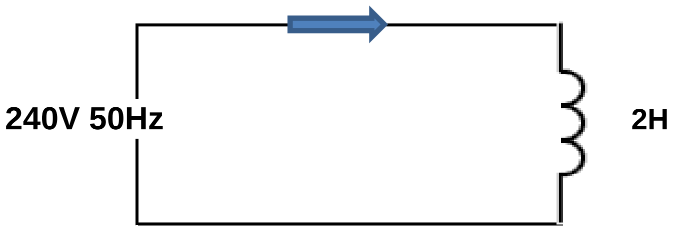
I = 240/0.023 = 10,434A

Inductive reactance

- A larger inductor has a larger reactance $X_L \alpha L$
- The inductive reactance increases with frequency $X_L \alpha f$

$X_L = 2\pi fL$

Example



What is the X_L of the inductor? What current will flow?

$X_L = 2\pi fL$

$X_L = 2\pi \times 50 \times 2$ = **628Ω**

$I = V/X_L$ = 240/628 = **0.38A**

If this inductor was connected across the output of a transmitter on 80m

V= 240V f = 3.5MHz

$X_L = 2\pi fL$

$X_L = 2\pi \times 3.5 \times 10^{6} \times 2 = 44 \times 10^{6}$

=44MΩ

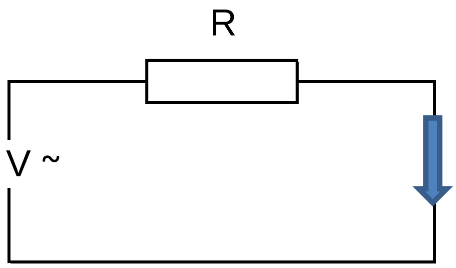
$I = V/X_L = \frac{240}{44 \times 10^{6}} = 5.5 \times 10^{-6}$ = **5.5 μA**

L and C Summary

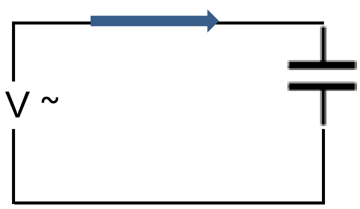
- An inductor is a short circuit to DC
- A capacitor is an open circuit to DC (once it has charged)
- As the frequency rises a capacitor tends towards a short circuit and and an inductor to an open circuit

Phasor Diagrams

V & I in phase



V & I 90^{o} out of phase



- What if there is both C & R in the circuit?

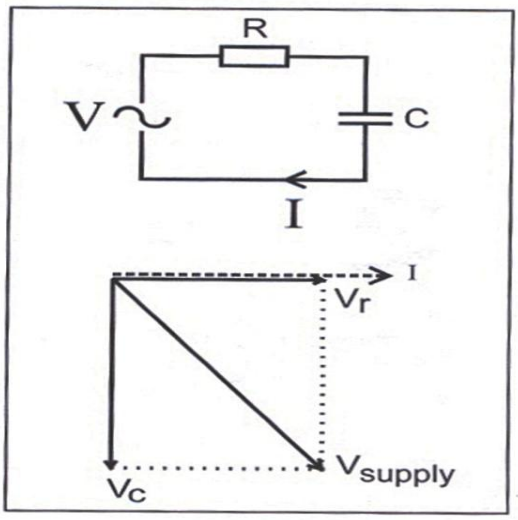


Fig 5.19: Resistor and capacitor in series

The current is common to both the resistor and inductor

The voltage across the resistor will be in phase with the current

The voltage across the capacitor will lag the current by 90º

- The relationship between the supply voltage and the current is established from the vector diagram

$V_{supply} = \sqrt{(Vr^2 + Vc^2)}$

$\frac{V_{supply}}{I}$ = Impedance Z

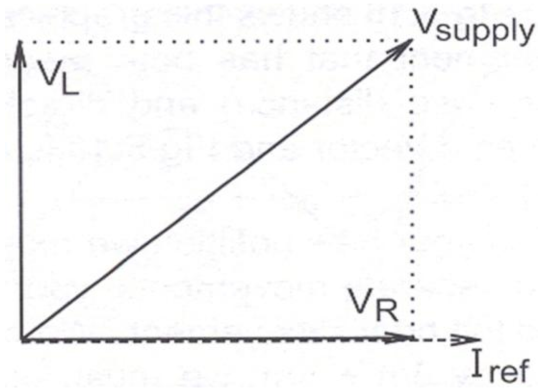
When V & I are in phase V/I = Resistance (R)

When V & I are exactly 90º out of phase V/I = Reactance (X)

When V & I have a phase difference that is not 0 or 90 then V/I is called -

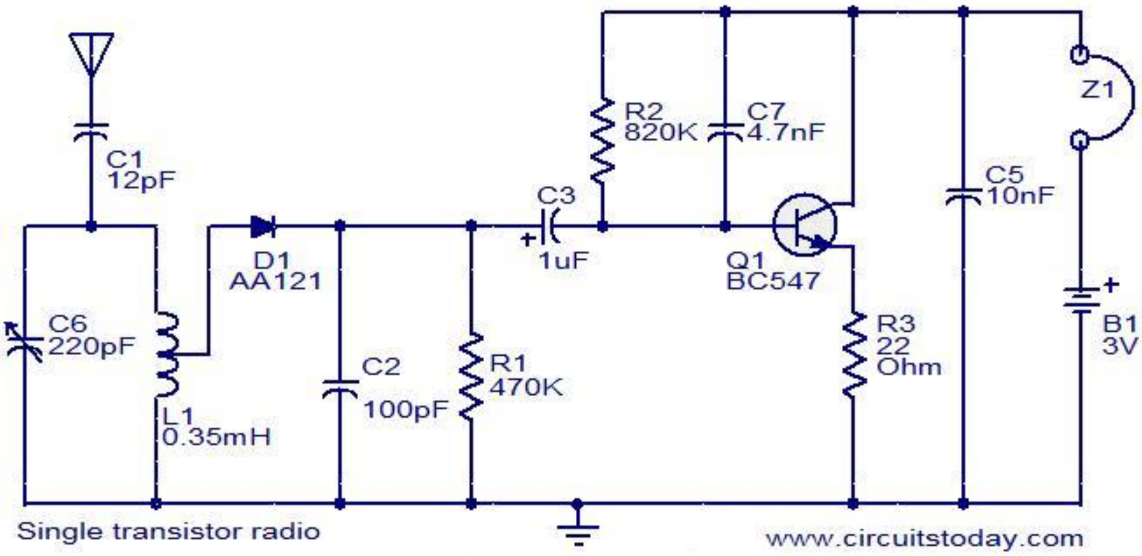
- Impedance (measured in ohms)

Resistor and Inductor in series

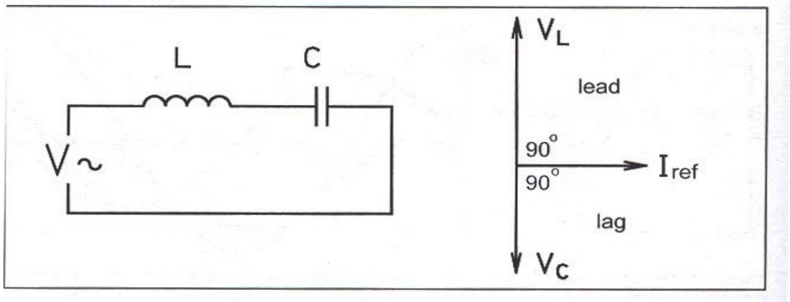


- $V_{supply} = \sqrt{(Vr^2 + V_L^2)}$

Coupling, decoupling and blocking



Series resonance



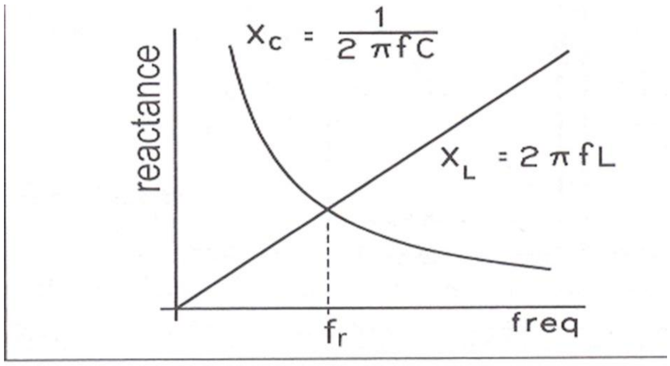


Fig 5.22: Reactance of L and C

- At a certain frequency $X_C = X_L$ this is the resonant frequency
- V_C and V_R will be equal and opposite
- The impedance will be zero at the resonant frequency

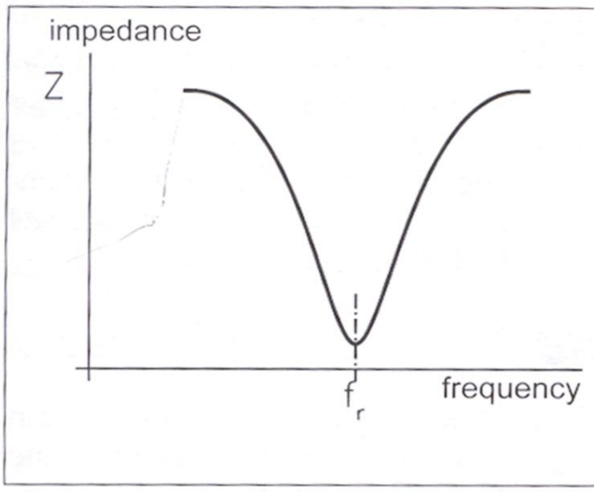


Fig 5.23: Series resonance

$$X_L = 2\pi fL \qquad X_C = \frac{1}{2\pi fC}$$

$$2\pi fL = \frac{1}{2\pi fC}$$

$$\mathbf{f = \frac{1}{2\pi\sqrt{(LC)}}}$$

- Example find the resonant frequency of a series tuned circuit if -

C= 200pf & L = 200µH

$$f = \frac{1}{2\pi\sqrt{(200 \times 10^{-12} \times 200 \times 10^{-6})}}$$

$$f = \frac{1}{2\pi\sqrt{(40000 \times 10^{-18})}}$$

$$f = \frac{1}{2\pi\sqrt{(4 \times 10^{4} \times 10^{-18})}}$$

$$f = \frac{1}{2\pi\sqrt{(4 \times 10^{-14})}}$$

$$f = \frac{1}{2\pi \times 2 \times 10^{-7}}$$

$$f = \frac{10 \times 10^{6}}{4\pi}$$

f = = 0.7959 MHz

or = 795.9 KHz

Parallel Resonance

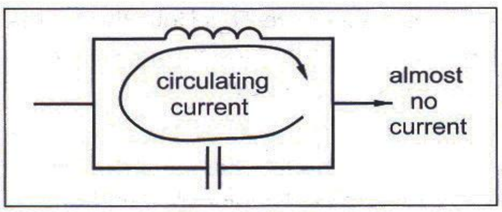


Fig 5.27: Circulating currents in a parallel tuned circuit

- When $X_C = X_L$ the currents in the two branches will be equal and opposite in phase so no current will flow into or out of the circuit

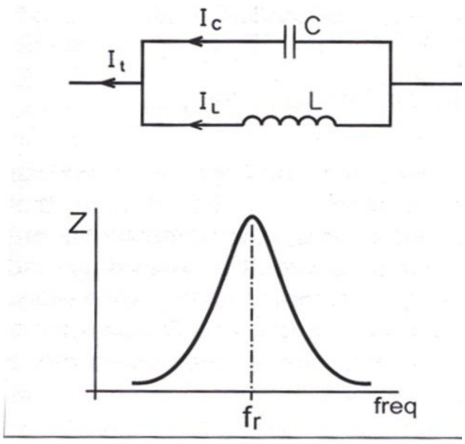


Fig 5.24: Parallel resonance

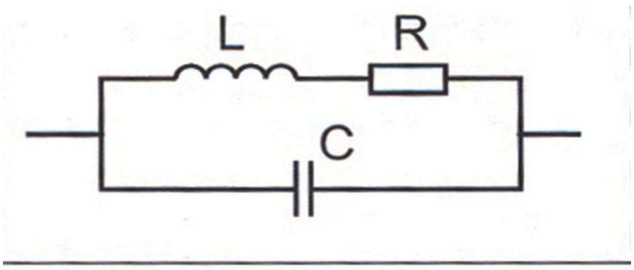


Fig 5.25: Parallel resonant circuit

- In theory the parallel tuned circuit has infinite impedance at resonance but in reality the inductive component is never exactly 90 degrees because of the resistance of the copper wire that forms the inductor.

Dynamic resistance

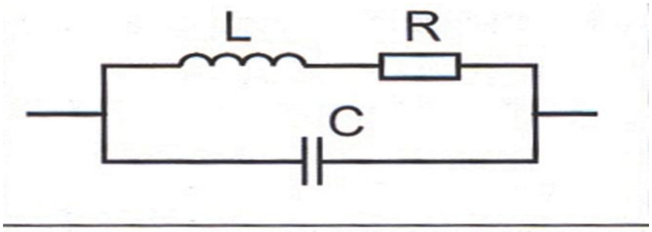
- Because the purely reactive components of the parallel tuned circuit do cancel the remaining small current and the voltage are in phase so the high impedance at resonance will be resistive and is known as -

- **Dynamic Resistance R_D (also known as Dynamic Impedance)**

$$R_D = \frac{L}{CR}$$

Find the R_D for the following circuit -

200µH **0.5Ω**



C=200pf

Fig 5.25: Parallel resonant circuit

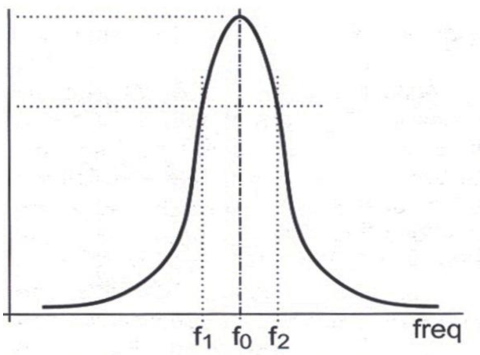
$$R_D = \frac{L}{CR}$$

$$= \frac{200 \times 10^{-6}}{200 \times 10^{-12} \times 0.5}$$

$$= \frac{10^6}{0.5} = \frac{1,000,000}{0.5} = \mathbf{2M\Omega}$$

Magnification factor Q

- The sharpness of a tuned circuit is expressed by its Q factor



- Q is the ratio of the reactance to the resistance of the coil

$$Q = \frac{X_C}{R} \quad \text{or} \quad \frac{X_L}{R}$$

- Q is also given by - $\dfrac{f_0}{f_2 - f_1}$

Where f_2 and f_1 are the frequencies where the voltage has fallen to 0.707 of the voltage at the resonant frequency.

Transformers

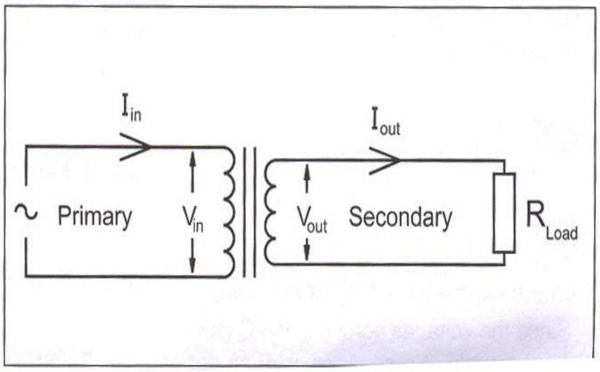


Fig 5.28: A transformer

- Output voltage determined by the ratio of the turns

$$V_{out} = V_{in} \times \frac{\text{Secondary turns}}{\text{Primary turns}}$$

Note - as I = V/R, if the voltage of the secondary is half the primary then the current in the secondary will be double that of the primary.

- $$I_{in} = I_{out} \times \frac{\text{Secondary turns}}{\text{Primary turns}}$$

For a 2:1 ratio transformer the input impedance is V/R and the output impedance is - $\frac{V/2}{2 \times I} = R/4$

- ie the impedance has been transformed by the square of the turns.

Crystals

- The properties of Quartz - the piezo-electric effect
- Very high Q - very stable
- Excite it to oscillate it at its natural frequency
- Series or parallel resonance

Temperature effects

- Temperature changes - cause expansion/contraction -
- - causes L and C to change - causes resonant frequency to change.

Screening

- Unwanted coupling between inductors

  Stray capacitance

  Screening cans