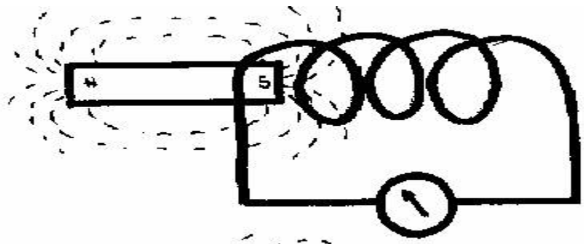
ELECTROMAGNETISM

If a magnet is moved into a coil a voltage will be generated across the coil. Once the magnet is stationary in the coil the voltage will cease. However, a reverse voltage will be generated when the magnet is withdrawn from the coil.

Electricity is only produced when the magnetic field is actually moving across the wires of the coil. Only relative movement is necessary -IE the magnet could be fixed and the coil be moved across the magnetic field.

The actual voltage generated is proportional to the *rate of change of the magnetic field*.

In other words, a faster movement will generate a greater voltage.

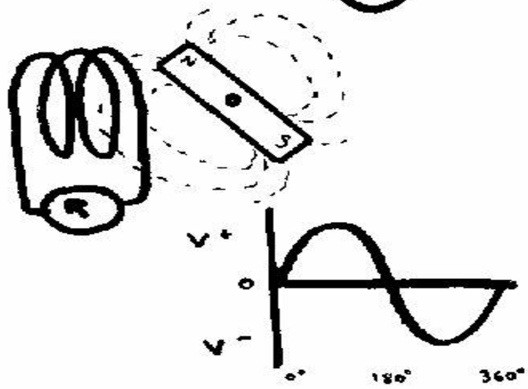


GENERATOR

If a magnet is rotated near or within a coil a voltage will be generated in that coil. The voltage will not be constant but will vary like a sine-wave.The voltage will be maximum when the end of the magnet passes the coil and minimum when it is broadside to the coil. As the rotation of the magnet continues its 'other' end will pass the coil. This generates the opposite voltage - the other half of the voltage sine-wave.

This is called an ALTERNATING VOLTAGE.

This will produce an alternating current (AC) in circuits connected to it.



ELECTROMATIC INDUCTION

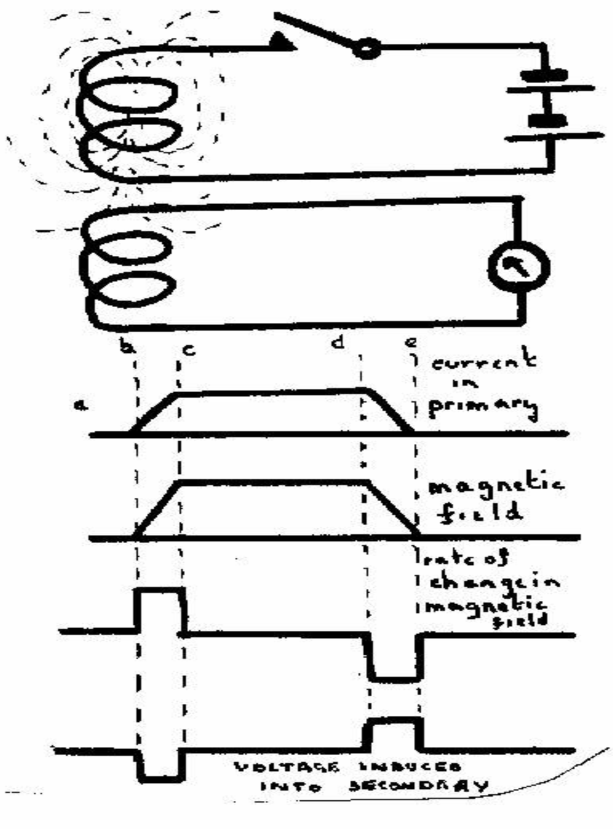
Moving a magnet into a coil produces a voltage because the magnetic lines of force pass (or cut) through the turns of wire. Now consider the circuit where a battery, coil and switch are connected in series. With the switch open (a) there is no current flowing and hence no magnetic field around the coil.

When the switch is closed a (b) current will start to flow. Although this current builds up very quickly it is not instantaneous. This is important as the magnetic field is only changing while the current is changing.

If a second coil is held near to the first, the magnetic field will 'grow' across it. This magnetic field will induce a voltage into the secondary coil.

Once the primary current has reached its steady value (c) there will be no change in the magnetic field so the secondary current will return to zero. When the switch in the primary circuit is opened (d) the current will drop back to zero(e) and the magnetic field will collapse back across the second coil and a further secondary voltage will be induced.

This time it is in the reverse direction.



MUTUAL INDUCTION

The battery and switch, of the previous example, are now replaced by an AC supply.

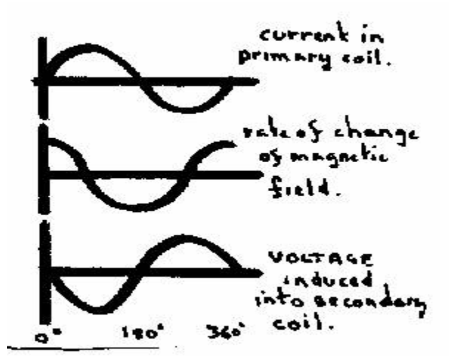
The alternating current in the primary coil produces a changing magnetic field.

Remember, it is the *rate of change* that is important.

The maximum rate of change, in a sine-wave, is when The value passes through the 'zero line'.

As a result, you will see that the voltage induced into the secondary coil is "up-side down" when compared to the primary current.

The sine-wave is based on rotation, therefore one complete revolution is 360 degrees. In our case the input and output currents are shifted by half a revolution and are said to be *180 degrees out of phase*.



This is the principle of transformers and is known as *mutual Inductance*.

IE A changing current in one circuit can induce a voltage into a secondary circuit. The actual voltage in the secondary depends upon the turns-ratio and efficiency of the magnetic coupling between primary and secondary.

Mutual Inductance between two coils is measured in units called Henrys.

Two coils are said to have a mutual inductance of I Henry if, a current in primary coil changing at a rate of one Amp per second nduces one Volt into the secondary coil.

SELF INDUCTANCE

A steady current, passing through a coil, produces a steady magnetic field.

If an attempt is made to change this current the resultant change in the magnetic field will induce an out-of-phase voltage into itself.

This reverse voltage will oppose the original change in the current. This effect is formally stated in Lens's Law:-

When the current through an inductor changes the voltage induced in it is in such a direction as to oppose the original change.

This opposition to the change in current is known as self inductance and it is also measured in units of the Henry.

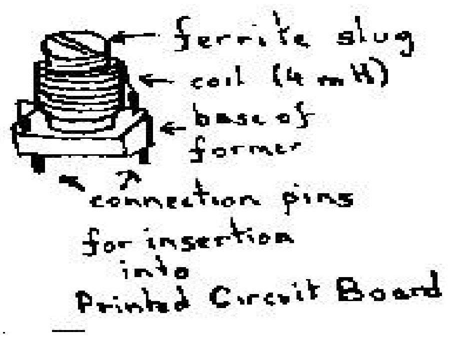
> A coil has an inductance of 1 Henry when a current through it, changing at a rate of 1 Amp per second, induces a voltage of 1 Volt across itself.

This leads us to the following important result. An alternating current, as it is changing all the time, finds it very difficult to pass through an inductor.

The higher the AC frequency the higher the opposition.

INDUCTORS

The value of an inductance depends mainly on the number of turns in the coil and the core, if any, that they are wound on. The inductance of an air cored coil is increased by winding on more turns of wire or by inserting an iron or ferrite core. Conversely, the inductance can be reduced by using less turns or by removing or partially removing the ferrous core. However, a brass core will actually reduce the inductance below the air core value.



Many small coils are fitted with a threaded ferrite core (slug) so that it can be screwed in or out to give the required value of inductance.

EDDY CURRENTS

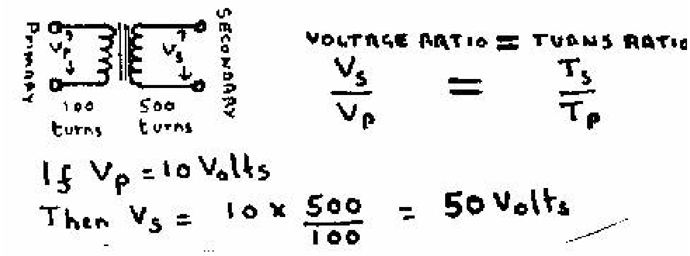
If the core of an inductor is able to conduct electricity then it will absorb some of the power and the inductor will be a poor lossy one. Currents will circulate in the core and are known as eddy currents. Eddy currents can be prevented by making the core, even metallic, highly resistive.
Examples:- ferrite, dust iron and laminations.

TRANSFORMERS

The basis of a transformer is mutual induction - a current changing in one circuit will cause a changing current in a second circuit. To ensure that the transformer is efficient there must be good magnetic coupling between the primary and secondary circuits. At low frequencies this means that the primary and secondary coils must be wound on the same magnetic core.
Audio and mains transformers have cores constructed of a stack of soft iron laminations that are oxidised to ensure that they are insulated from each other.
This will prevent losses to the circulating eddy currents.

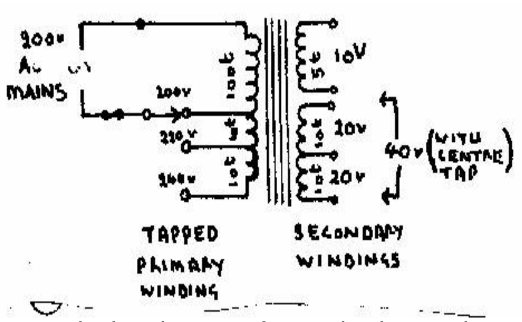
However, for the purposes of calculations, transformers will be assumed to be perfect.
IE Power In = Power Out

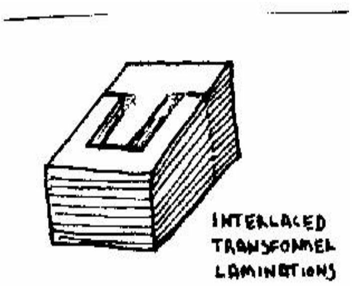
If there are twice as many turns on the secondary as on the primary then the voltage out will be twice the input voltage.
VOLTAGE RATIO = TURNS RATIO
This example is called a (voltage) step-up transformer,



Assuming no losses then the Power Output will equal the Power Input.
Therefore, as the voltage has gone up then the current must go down by the same ratio.
If the above transformer has a primary current of 1 Amp then the i/p power will be 10 Watts (W=V x I). With no losses the olp power must also be 10Watts.
As the o/p voltage is 50 V then the o/p current will be 10/50 Amps or 200 mA. However, this transformer is still known as 5 to 1 step-up transformer as this refers to the turns or voltage ratio.

MAINS TRANSFORMER

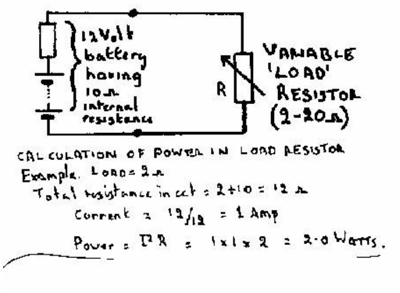




A typical mains transformer is shown above. The mains supply is connected to the primary. This example shows a primary of 120 turns. To cater for a range of supply voltages there are "taps" at 20 and 10 turns from the end. There are several secondary windings and the number of turns on each is dependant on the required output voltages.

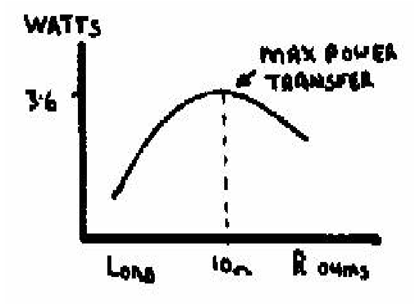
The construction of the transformer core, shown as 4 parallel lines in the diagram, is made up of many soft iron laminations. The primary and all the secondary windings are wound round the central leg. It is about half size for a mains transformer that could be found in a small radio or tape recorder. The laminations are less than 1 mm thick - and many of them.

MATCHING



A 12 volt battery, having an internal resistance of 10 Ohms, is connected across a variable resistor.
The power dissipated in the resistor is then calculated for several values of the variable load resistor.

LOAD	WATTS
2	2.000
6	3,375
10	3.600
14	3.500
20	3.200



When these results are plotted on a graph it can be seen that most power is dissipated in the load resistor when it is set to 10 Ohms. Note that the internal resistance of the battery was also 10 Ohms....
Maximum power transfer takes place when the load is matched to the source.
The example worked out above was a simple DC circuit but it does prove the principle of matching. In fact this is usually applied to Alternating Currents where it is important that the AC resistance of the load should be matched to the AC resistance of the source.
Another word for "AC resistance" is Impedance.

For example, it would be very inefficient to connect a 3 Ohm loud speaker to a radio receiver having an output impedance 600 Ohms. IT MUST BE MATCHED.

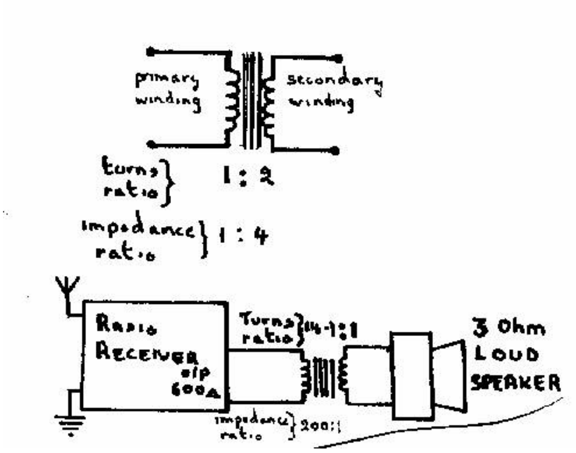
A transformer can be used to transform one impedance to another.
However, it must be noted that the IMPEDANCE RATIO of a transformer is the SQUARE of the TURNS RATIO.

IMPEDENCE RATIO = (TUNRNS RATIO)^2

The TURNS RATIO of this transformer is 1:2
Thus the IMPEDANCE RATIO is 1:4

TUNRNS RATIO = √ (IMPEDANCE RATIO)

In the above case of the radio loud Speaker, the impedance ratio is 600:3 or 200:1
The square root of 200 gives the required turns ratio (14.1) Try this for your self on your calculator.



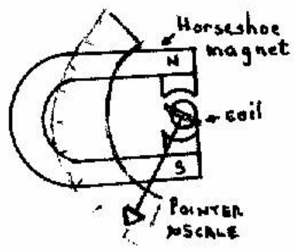
MAGNETISM in MOTION
If a wire, carrying an electric current, is placed into a magnetic field it will try to move.
The actual direction in which it goes is formally stated by Fleming in his left hand motor rule.
(No need to remember it for the RAE)
If the thumb and first two fingers of the left hand mutually at right angles (go on, try it) so that First finger is in the direction of the magnetic Field and the seCond finger in the direction of the Current then the thumb will point in the direction of the Motion.

Mr Flemming has another rule - the right hand one but that applies to generators. To ensure that you select the correct one, just remember that motors drive on the left....
The force on one piece of wire is small. However, if the wire is wound into a coil of many turns and placed into a magnetic field, real use can be made of this force. Electric motors and moving coil meters use this principle.

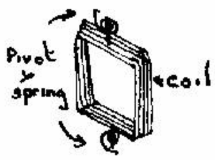
MOVING COIL METERS

The amount of force on a conductor, carrying a current in a magnetic field, is proportional to the current flowing - assuming that the magnetic field remains constant.

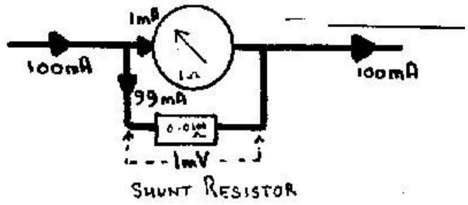
This is the principle of the moving coil meter. A length of thin wire is wound into a square shaped coil. This coil, with a pivot at top BC bottom, is mounted in the gap between the pole pieces of the horseshoe magnet. A pointer is fixed to the coil so that the actual movement is measured against a fixed scale. The scale is graduated in Volts, Amps or Ohms.



A core is provided to ensure a uniform magnetic field for the coil to rotate in. Delicate springs are fitted to the top and bottom of the coil to:
(a) conduct the current in and out of the coil.
(b) to provide the opposing force to balance the motor action.
The rotation is then proportional to the current flowing through the coil.



The BASIC MOVEMENT, as it is called, will normally have a coil resistance of less than 10 Ohms and are made to have a known Full Scale Deflection (FSD) - EG 50, 100, 5OOuA or 1, 5, lOmA However, this basic movement can be modified to measure higher currents by adding a shunt resistor in parallel with the meter. Thus, only a small proportion of the current to be measured actually passes through the meter coil.



Example. A meter having a FSD of 1mA has a resistance of 1 Ohm. What value of shunt is required to enable currents of up to 100 mA to be measured?

The shunt resistor must by-pass 99 mA. The voltage (V) across the meter coil is:
V = I x R = 1/100 x 1 = lmV

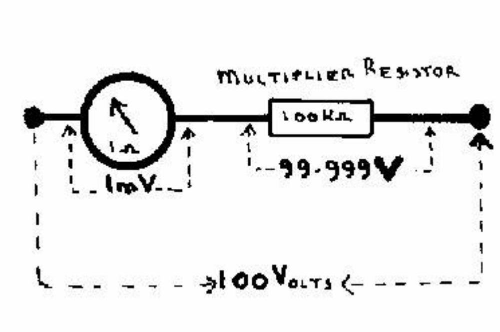
The shunt resistor is directly in parallel with the meter coil so it will also have 1 mV across it.

Knowing the current (99mA) through the shunt and the voltage (1mV) across its ends enables its resistance to be calculated our friendly Ohms Law.
R = V/ l = 0.0101 Ohms

As you will see, shunts usually have a very low resistance, and are often made from flat strips of metal rather than wire.

MOVING COIL METERS (continued)

The meter movement can also be modified to allow the measurement of higher voltages. This time a resistor, known as a *multiplier*, is connected in series with the movement. To measure voltages up to 100 Volt then 99.999 Volts must be dropped across the multiplier as the movement itself only requires 1 mVolt for full sale deflection.
When measuring 100 V there will be a current of 1mA flowing through the movement and the multiplier.
Once again, using Ohms Law the series resistor can be calculated:-
R = V/I = 99.999/0.001 = 100000 Ohms or 100 kΩ



The sensitivity of a meter is quoted in Ohms per Volt. The
higher the better but typical good meter would have a sensitivity of 20 kOhm per Volt.
A good ammeter has a very low resistance to avoid reducing the current in the circuit under test.
A good voltmeter has a very high resistance so as to take minimum current from the circuit under test.

If a small battery is included in the meter, in series with the coil, then the scale can be calibrated in Ohms. A variable resistor is included in the meter to compensate for changes in battery voltage. This meter is then called an Ohm-meter and is used to measure resistance.
A basic meter movement can have various shunts and multipliers can be built-in so that several ranges of Amps and Volts can be incorporated.
Ohms ranges are usually included and the multi-purpose meter is called a MULTIMETER.

LESSON 3 QUESTIONS
Q3.1) Describe a simple experiment to show that there is a magnetic field around a wire that is carrying an electric current.

Q3.2) What will happen to the magnetic field (in 03.1) if the wire is wound into a coil?

Q3.3) Why does a transformer not work when supplied with direct current?

Q3.4) A transformer has 100 turns on the primary and 20 turns on the secondary.
The transformer is connected to a mains supply of 200 Volts at 50 Hz.
What is the output voltage?

Q3.5) What is the purpose of impedance matching?

Q3.6) If it is necessary to match 250 Ohms to 25 Ohms what would be the *turns ratio* of a suitable transformer?

Q3.7) Describe how a moving coil meter works.

Q3.8) What are shunts and multipliers?

03.9) Do you listen to Amateur Bands? What receiver do you use?

03.iO)Why does an I.F. transformer often have a ferrite core?

03.11)Define the unit of inductance.

