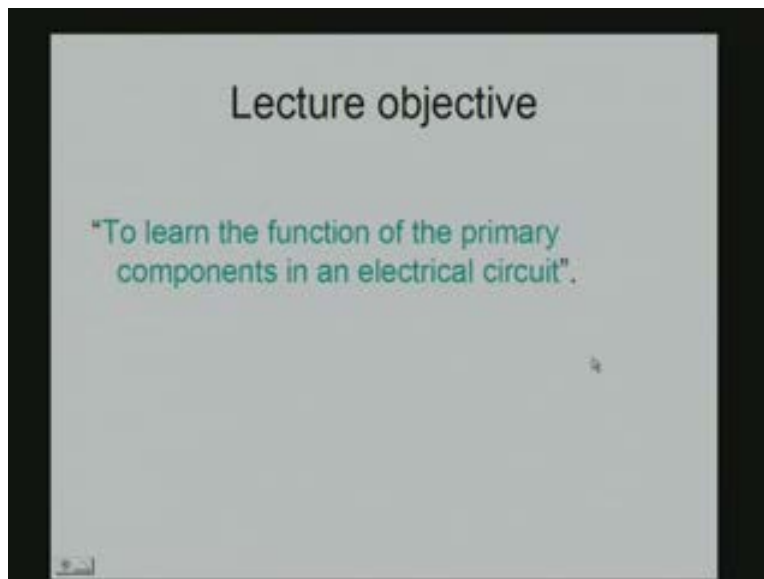


**Basic Electrical Technology**  
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**Department of Electrical Engineering**  
**Indian Institute of Science, Bangalore**

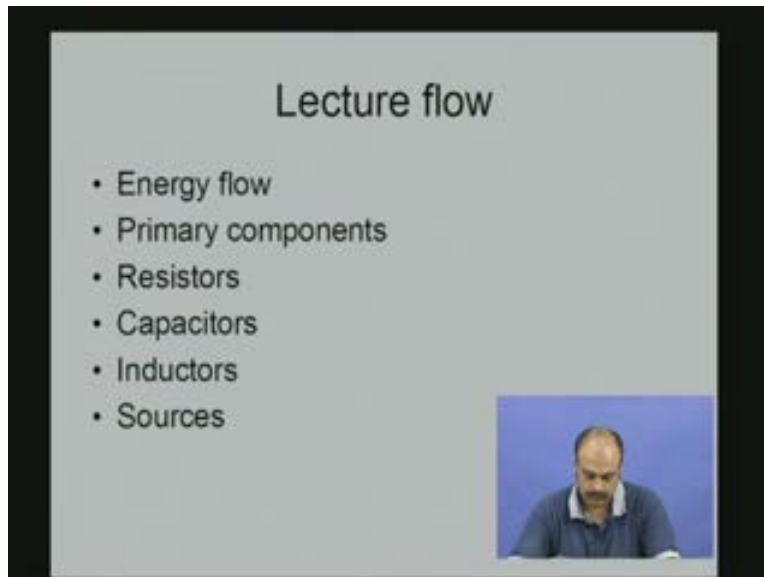
**Lecture - 03**  
**Passive Components**

Today we will be discussing on three of the most primary elements in electrical technology. They are the resistors, the capacitors and the inductors. So that is the basic objective in this lecture to learn the function of the primary components in an electrical circuit.

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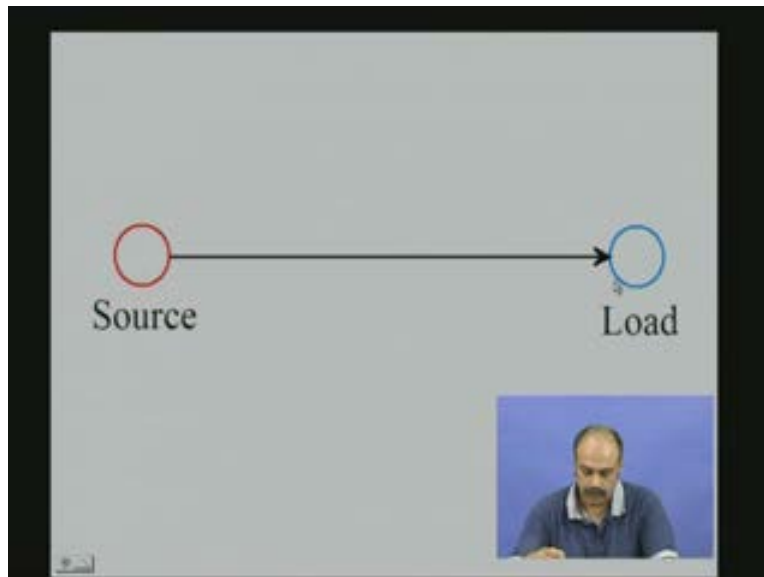


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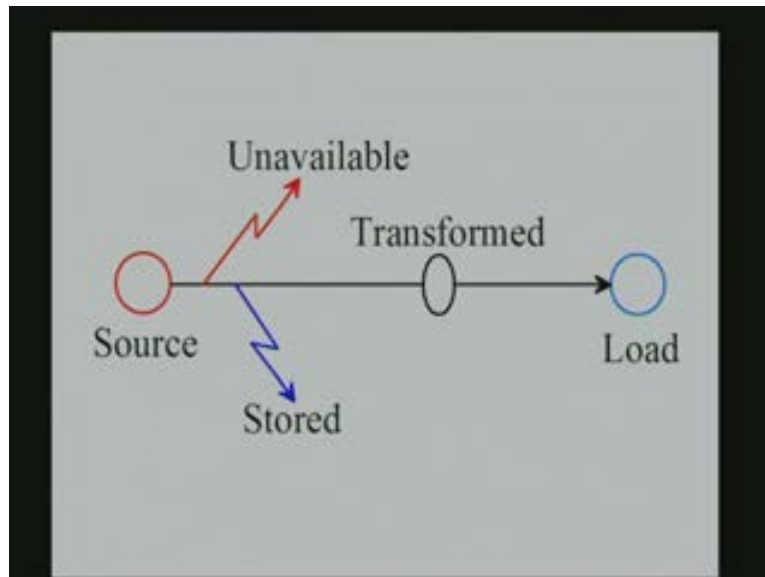
The lecture flow for this lecture is as follows: first we will discuss energy flow; how the energy flows on the source to the destination, this will be followed by a generalised description of the primary components, this will be followed by the discussion on resistor and then the capacitors and then this is going to be followed by a discussion on the inductors. Then later on after discussing these three primary elements we will focus our attention on the sources. So let us now look at how the energy flows.

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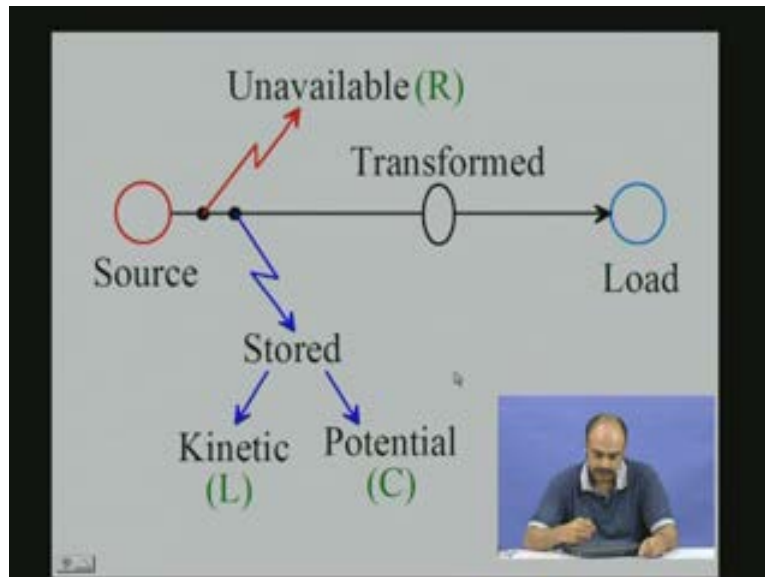
Energy always flows from the source to the load; it emanates from the source and then terminates with the load. In the process of flowing from the source to the load many things happen to the energy. One of the things that happen to the energy is that it gets transformed. It can get transformed from electrical energy to heat energy, from electrical energy to magnetic energy or to mechanical energy or to a translational mechanical energy and so on and so forth. There is something else that can also happen to this energy in the process of moving from the source to the load. It can get lost; lost meaning that the amount of energy becomes unavailable to the load.

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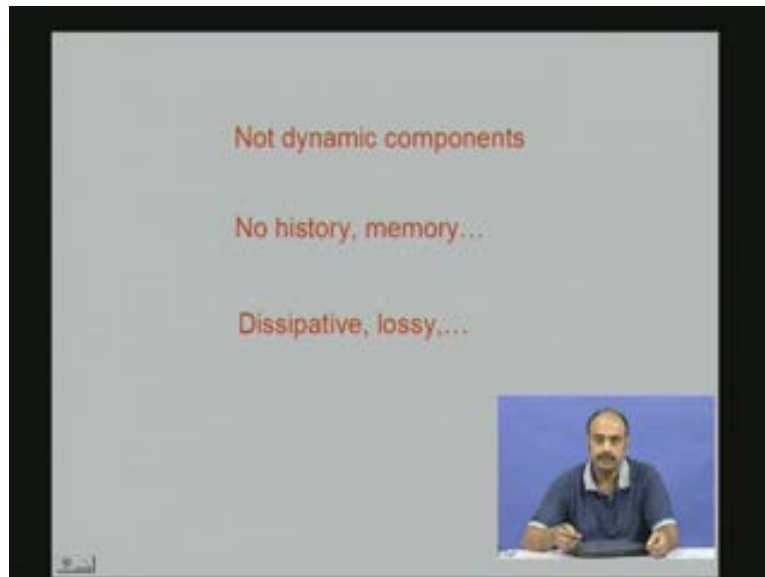
Further this energy can also get stored and it can get stored in two forms: the kinetic energy or the potential energy. These are the only two forms that it can get stored. So here we see that the energy that gets lost that becomes unavailable to the load, remains lost but the energy that gets stored in either the kinetic form or the potential form can later be recovered and sent either to the load or back to the source; one of these things can happen as you will see by and by in future circuits. So the energy get lost as heat most of the time in a component called a resistor which is denoted by the letter R here and the energy gets stored in the kinetic form in a component called inductor which has an inductance value as indicated by letter symbol L here and it can get stored in the potential form in a component called the capacitor denoted by the letter symbol C here.

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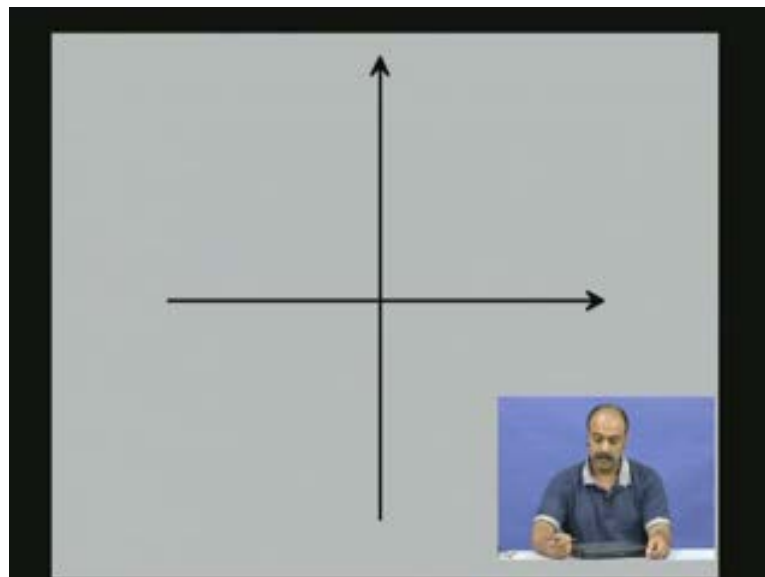


So now let us look at these primary components one by one, the resistors first. What are these resistors what are the features of this resistors. First of all it is non-dynamical not a dynamic component what does it mean. It means that it is an algebra component and whatever is there in the input comes as the output at that incident yet every incident by incident; there is no history, there is no memory and it cannot remember the past states or the past values; and further the most important functional property of resistor is that it has to dissipate, it is lossy and most of the dissipation occurs as heat.

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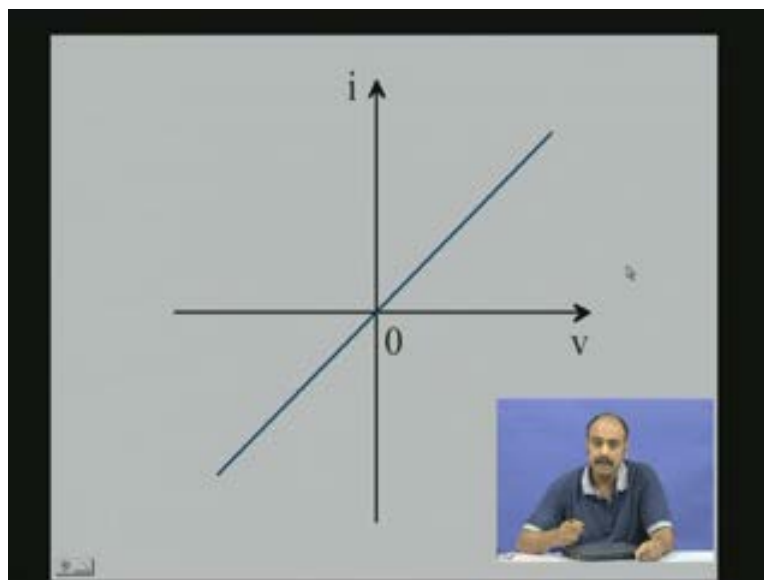


So let us try to characterise these resistors. In fact, most of the components generally we characterized by the  $iV$  characteristic. We put the  $V$  voltage on the  $x$  axis and  $i$  on the  $y$  axis. So here in this particular diagram  $V$  is the independent axis and  $i$  is the dependent axis. So in this  $iV$  characteristics we plot the character of the resistor as you see here is a straight line and **the slope**

the slope in this case is  $i$  by  $V$  is  $1$  by  $R$  or  $1$  by the resistance value. So this is how the resistance is described (Refer Slide Time: 6:18). So, if you see here in this graph if this line representing the resistor is aligned along the vertical axis that is the  $y$  axis then the slope is infinite which means that  $R$  is  $0$  and this would represent short circuit.

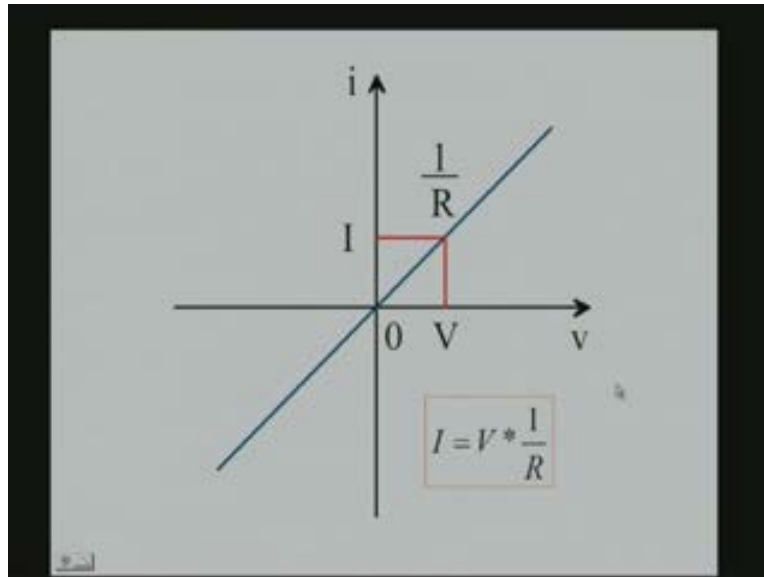
On the other hand, if this resistor line is aligned along the  $v$  axis that is the  $x$  axis then  $R$  is infinite as the slope is zero slope of this line is zero. So we see that the resistor line can vary from short circuit along the vertical axis to open circuit along the horizontal axis and in-between it can take any value from zero to open circuit. This is the  $V$ - $I$  characteristic of a resistor of a simple resistor.

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Now coming back to this  $V$ - $I$  characteristic let us take a point on the voltage axis and then draw a line directly up on to the resistor characteristic line (Refer Slide Time: 7:40) and from that intersection point we draw another line which intersects the current. So at this point we see that voltage here gets multiplied by the slope  $1$  by  $R$  and results in the current. So you have the voltage multiplied by this resistor resulting in this current.

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That becomes the governing equation for the resistor  $I$  equals voltage  $V$  by  $R$  or it can also be written as voltage  $V$  equals current  $I$  into  $R$ . It is basically the same equation which is algebraically represented in a slightly different manner.

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Governing equations

$$I = \frac{V}{R}$$
$$V = I \cdot R$$

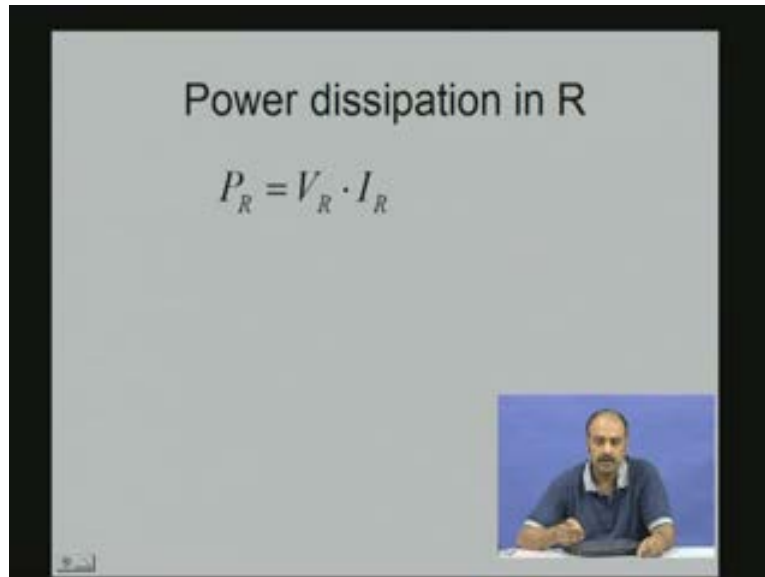
Ohm's Law

The slide displays the governing equations for a resistor. At the top, it says "Governing equations". Below that, the equation  $I = \frac{V}{R}$  is shown in a box. Below that, the equation  $V = I \cdot R$  is shown in a box. At the bottom, the text "Ohm's Law" is written in red. In the bottom right corner, there is a small inset video of a man sitting at a desk, likely the presenter.



This is called the Ohm's Law; one of the most fundamental laws in electrical engineering which you will be using almost throughout your life.

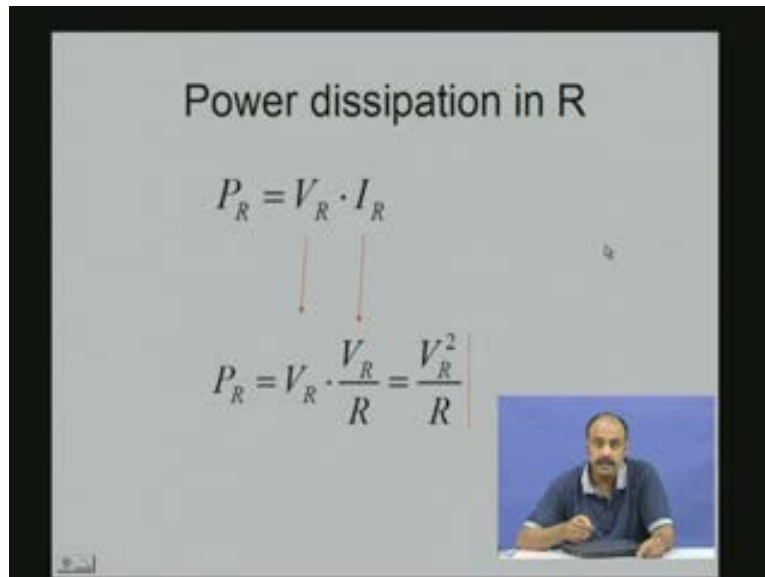
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Another important character in the resistor is its power dissipation because we said that energy is going to get lost in the resistor as heat, we need to quantify how much amount of this energy gets lost. Power in watts is equal to voltage in volts into current in amps (Refer Slide Time: 9:00). So  $V_R$  is the voltage across the resistance and  $I$  is the current through the resistance so the product of this  $V$  into  $I$  will give you the wattage or the power that gets dissipated in this resistance.

Now this  $V$  itself we saw by Ohms law can be written as  $I$  into  $R$  current into  $R$  and into further component of current which is equal to  $I$  square  $R$ . So the equation for the power is  $I$  square  $R$ .

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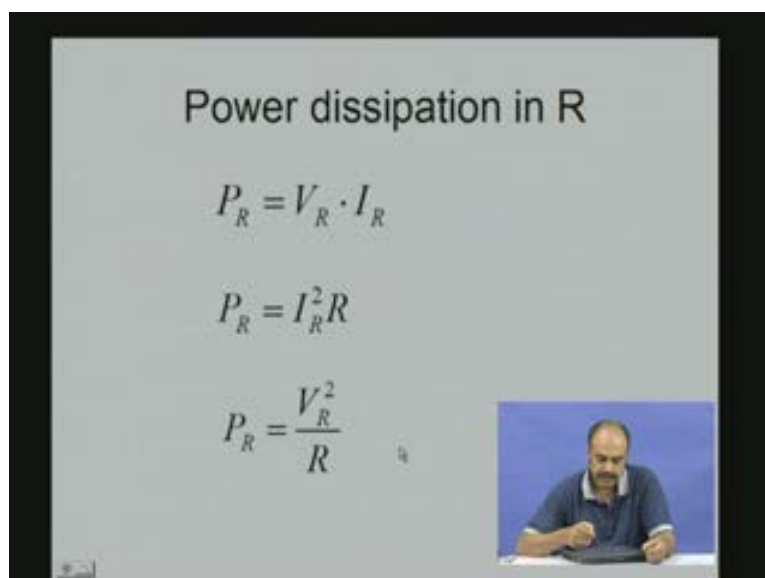


Power dissipation in R

$$P_R = V_R \cdot I_R$$
$$P_R = V_R \cdot \frac{V_R}{R} = \frac{V_R^2}{R}$$

The power dissipation can also be written as  $V_R$  and  $I_R$  can be written as  $V_R$  by  $R$  as we saw earlier in the governing equations, this gives  $V_R$  square by  $R$  that is voltage square by  $R$ . So, summarizing we see that the power dissipation or resistor can either be  $I$  square  $R$  if you know the current or if you know the voltage across the resistance then it is  $V$  square by  $R$ .

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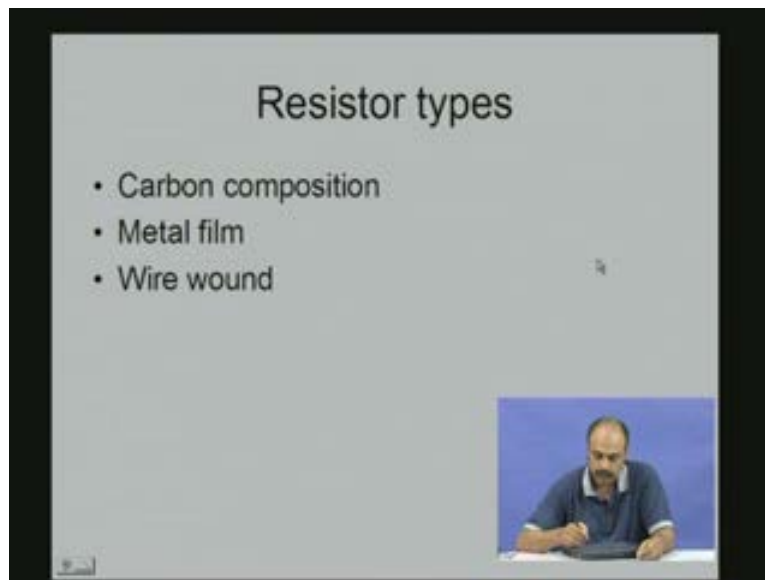


Power dissipation in R

$$P_R = V_R \cdot I_R$$
$$P_R = I_R^2 R$$
$$P_R = \frac{V_R^2}{R}$$

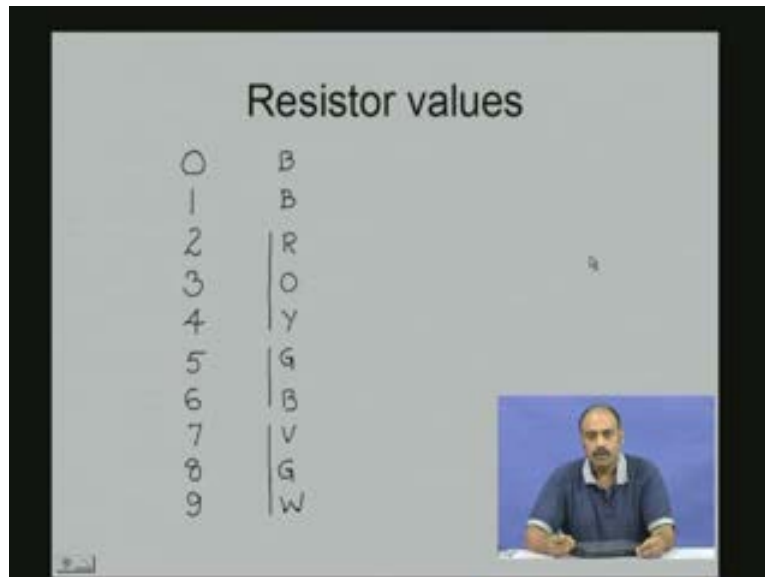
So you see here the summarization of the power. Power is  $V R$  into  $I R$ , power dissipation in the resistor is also  $I^2 R$ , power dissipation in the resistor is also  $V^2 / R$  depending upon which variables are known at any given point of time.

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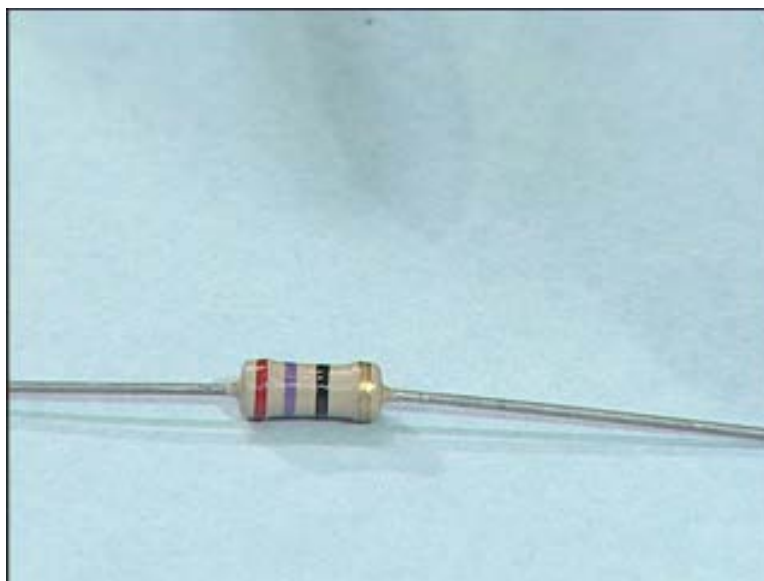
There are different types of resistors. One is the carbon composition resistor, the way it is made you have the metal film resistor the wire wound resistors and such and many other many more types.

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How does one know what is the value **of the resistor** of a given resistor. Let me show to you a resistor, how practical real world resistor looks like.

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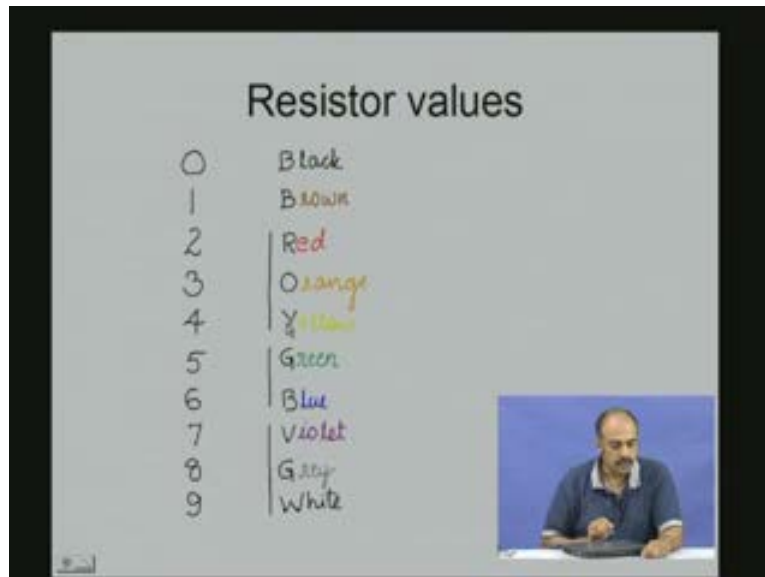


So what you see here is a resistor which has two leads. There is one lead here, there is another lead here which gets connected to your circuit and this portion (Refer Slide Time: 11:38) is the resistive portion which impedes the flow of the current and there is going to be a loss;  $I^2 R$  loss or the  $V^2$  by  $R$  loss or  $V$  into  $I R$  loss any one of those equations.

This is a carbon compound resistor. It is a half factor resistor. You see that there are some bands on the resistor here, some red band, violet, black so on and so forth. The resistor value is recognised by the band the colour bands that are drawn on the resistor. So the colour coding is as follows. We see here on this slide that there are these numbers from 0 to 9, 0 1 2 3 4 5 6 7 (Refer Slide Time: 12:27) and each number has an associated colour **which I am writing here**. the 0 is represented by black, 1 is represented by brown, 2 by red so on and so forth; 3 is orange, yellow, green, blue, violet, grey, white till 9. So each colour here given represents a numeric value.

Now it is pretty difficult to remember the order in which the colours are written so therefore we normally have a key. You look at the first letters BB ROY R O Y GB VGW these two are phrases GB and VGW you can remember it as phrases; GB is the short form for Great Britain, VGW is the short form for Very Good Wine. So you can remember the whole phrase the whole colour code as BB ROY Great Britain Very Good Wine which will give you the order the sequence in which you can remember the colour codes which represents the numeric values.

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So how do we read the colours in the colour code?

Now look at this resistor here (Refer Slide Time: 14:05) it is having starting with the red colour as its left most band colour band, then you have the violet colour band and then followed by the black colour band and there is a fourth colour band here at the extreme right extreme and that colour band represents the tolerance variation of the resistance with temperature. So the value is given by only these first three colour bands.

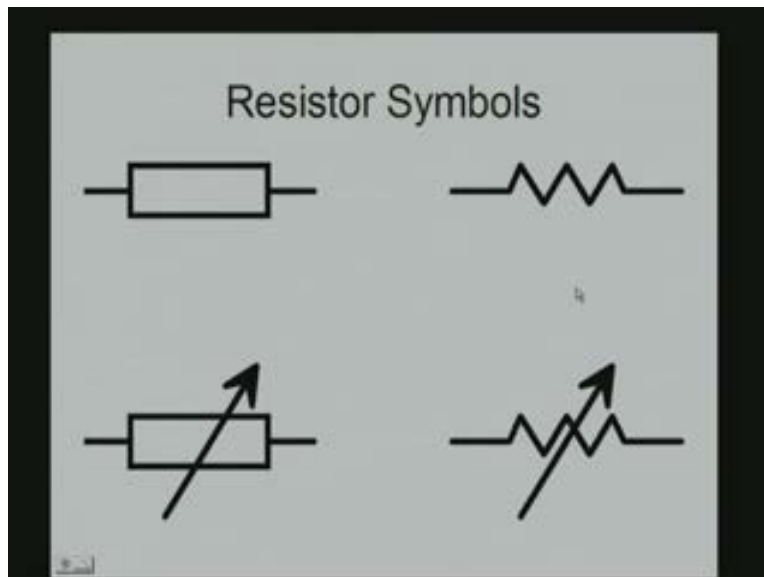
Now, the first band represents the first significance digit, the second band the second significant digit, the third band is the multiplier 10 to the power of something whatever that colour represents. So here for example; if we take that particular resistance you have the first band which is a red, the second band which is a violet and the third band which is black. So the first band red we put 2, the second band also gives you the next significant digit which is violet which is number 7 here and the third band which is black is the multiplier which is 10 to the power of the numeric value of black which is 0 because numeric value of black here is 0 so the value of the resistor is 27 into 10 to the power of 0 which is 1 which is 27 ohms and the symbol for ohm is the Greek letter omega. This is how you read the colour code from the value of the resistor, from the colour code as indicated.

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### Resistor values

0	Black	
1	Brown	R V Bl
2	Red	
3	Orange	
4	Yellow	27 10 <sup>0</sup>
5	Green	
6	Blue	27 x 10 <sup>*</sup>
7	Violet	
8	Grey	27 ohms $\Omega$
9	White	

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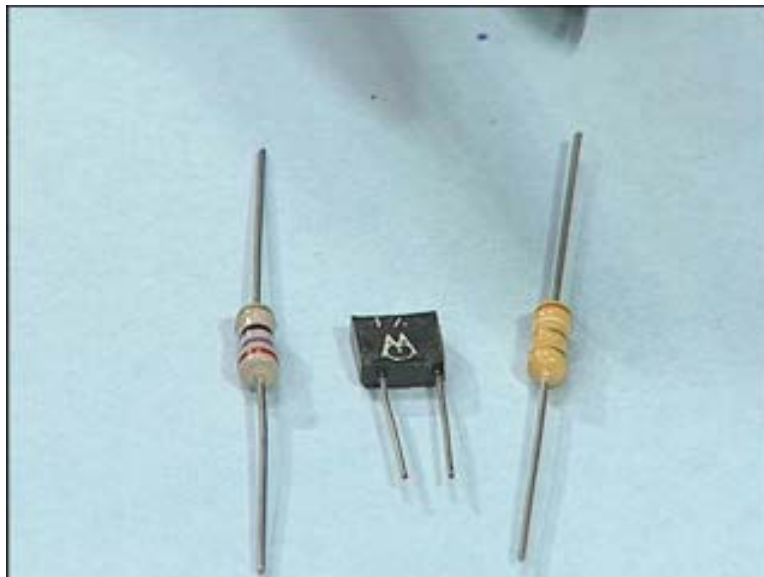


The resistors are shown by various symbols in the textbook. You have a rectangular box with two leads, you have a zigzag set of lines connected to the two leads this is one form of representation and you have a rectangle box and then an arrow in-between to represent a variable

resistor and also in this form a zigzag with an arrow as a variable resistor. These are the various symbols of resistors.

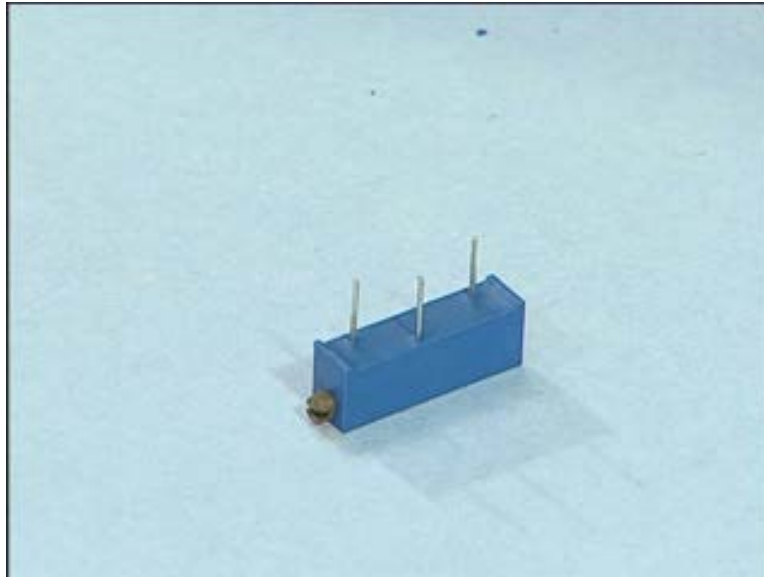
Before we go into the new topic let us look at some real world resistors. This is one of the resistors that you just saw (Refer Slide Time: 16:58) while we were calculating the value of the resistors. It is a carbon compound resistor. Likewise here is another carbon compound resistor, this is also **half watt** resistor, and you also have a look at this resistor size-wise relatively this is a quarter watt resistor. I will put in a different value or a different type of resistor you see this resistor here (Refer Slide Time: 17:30) this is a box type, this is made differently, this is called a metal film resistor and this is more precise than this in terms of variation with respect to temperature and such and they are generally used for frequency tuning components.

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There is another type of resistor here slightly different from the type that you saw. This has three terminals. This is a variable resistor just like we saw in the symbol here two terminals and an arrow in between it is that component. You have two terminals and the third terminal is the tap which represents the arrow which varies with respect to either of the two terminals. There is a screw here which can be rotated to position the centre tap value at any arbitrary value depending upon the particular circuit.

So, if we connect a voltage across these two extreme terminals the voltage across that is going to be fixed because the resistance across the two extreme terminals is fixed and if we rotate the screw the centre tapped position keeps varying and the potential of the centre tapped value with respect to its extreme terminals keeps varying and therefore we say the potential is varying with respect to the extreme terminals and this is called a potentiometer, it is a variable resistor.

Apart from these resistors there are other resistors also which are bigger in size to handle higher wattages.

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Now here is one such component, this is also a potentiometer similar to low wattage blue box that you saw previously. This also has three terminals. these two (Refer Slide Time: 19:31) are the extreme end terminals of the resistor and this central terminal is the centre tap which actually will vary with respect to the end terminals and the variation of the centre tap can be attained by rotating this vertical knob which is around here.

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There is this other type of fixed resistor; this is also actually carbon compound. But you see that this is slightly bigger than the half watt and quarter watt resistors to handle much higher power dissipation capability. These are the high wattage resistors which will go in to your circuits. There are still higher wattage resistors available in the market.

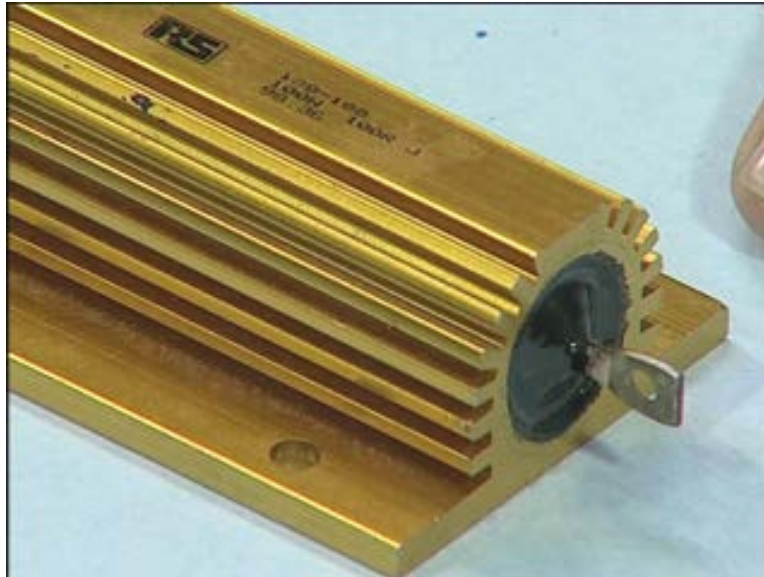
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This is a 25 watt resistor, this a wire wound resistor and you will see that the value of the resistors are written on the body of the resistor and here you do not see the colour coding. In fact, in high wattage resistors there are no colour codes but the value is directly written on the body of the resistor.

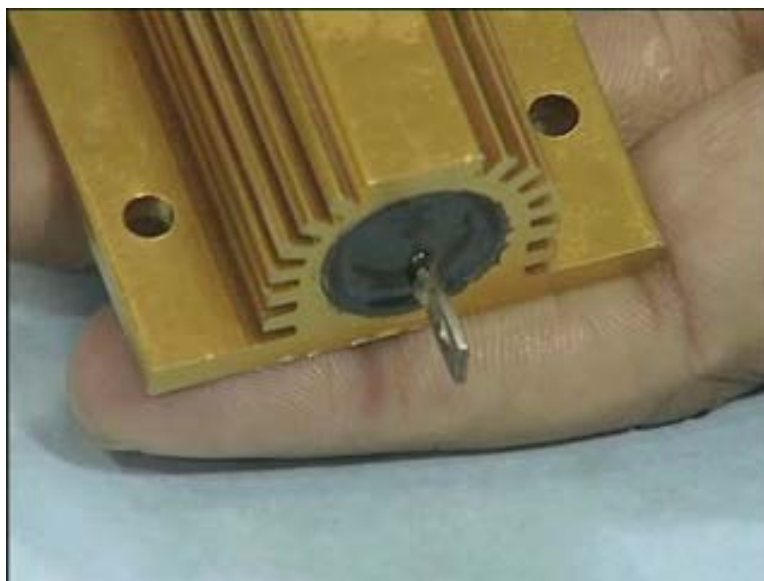
Another high wattage resistor which is actually of similar size compared to the 25 watt resistor that you saw just now is something like this which has a heat sink also. You see the two terminals here and the value written on that one 100 ohms. It is a 100 watt resistor which has four times more power dissipating capability than the previous wire wound 25 watt resistor but of similar size. It is basically because of the heat sinks that are encapsulating the actual resistor and which can dissipate the heat more effectively.

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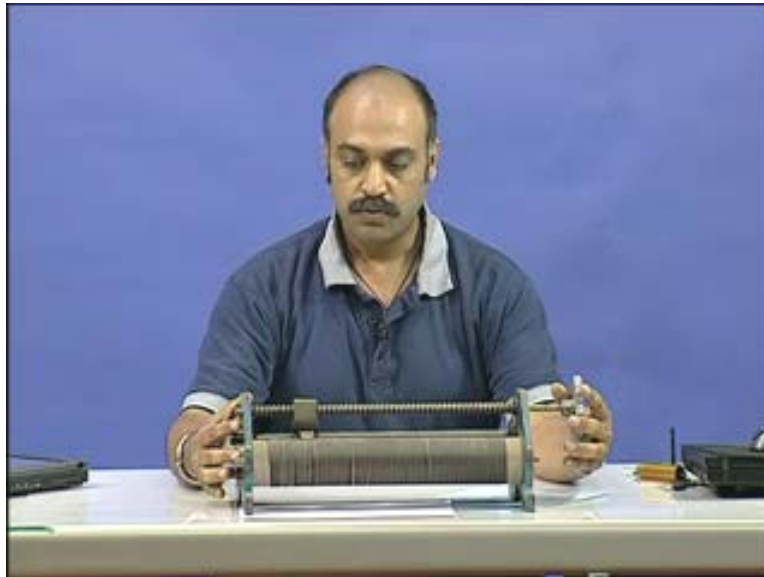
And this has four mounting holes which can be mounted on to another aluminium based plate or base metallic sheet which can dissipate the heat much more effectively.

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Now we shall look at still bigger resistors. In fact, these are not the limiting values of the power wattages of the resistors. In fact, in the industry you see that the wattage resistors can be as high as even 1000 watts, 10000 watts and so on and so forth. But let me show you a 1200 watt resistor which is variable, which looks something like this, it is pretty heavy. So let me place it here.

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You see that there are two cylinders. Are you able to see? I will hold it like that.

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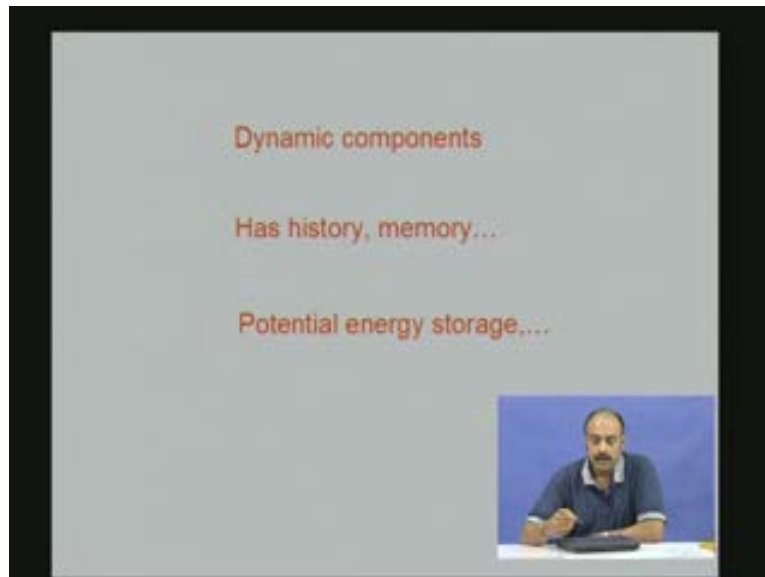
There are two cylinders composed of wire wound wires, this gives the resistors..... they are connected in parallel so that they can handle higher current and therefore more dissipation. This can handle something like 25 amps and they are 2 ohms which means something like 1250 watts.

Now there is a lead screw arrangement here (Refer Slide Time: 22:55) with a centre tap which can move around here; I can vary this knob here and therefore change the position of the centre tap. Now the centre tap is connected to this knob here. The one extreme terminal is here, the other extreme terminal is on this side and therefore you have the two extreme terminals and the third centre tap is terminated here. This is also a potentiometer but in the high power regions of operation this type of resistors are called rheostats; you can also get fixed resistors of high powers also.

Now, coming back to our topic of the basic components we were till now looking at the resistor component the one which dissipates energy and if we go back to one of our earlier slides of energy flow we saw that we were focussing till now on this component (Refer Slide Time: 24:05) which takes away the energy or the energy that gets lost in flowing from the source to the load and that component is a resistive component.

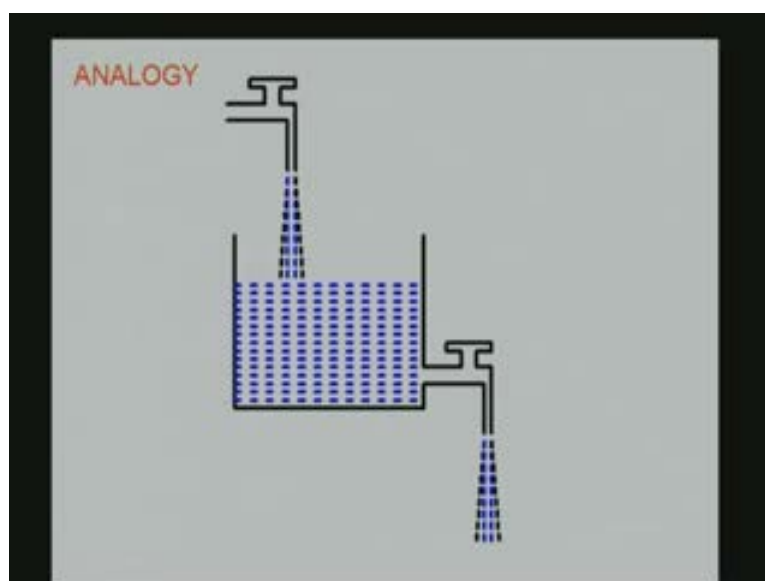
Now let us have look at the storage components that is the kinetic storage and the potential storage. Let us first look at the potential storage component which is the capacitor. So what are the capacitors? Comparing with the resistors we see that the capacitors are dynamic components. What does it mean by dynamic components? Means it can remember, it has history, it can store the past states or the past values, it can have initial conditions that is what a dynamic component means it is not algebraic its presence is based on previous values and therefore they have memory.

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Now, the fundamental functional difference between the capacitor and the resistor is at this can store energy whereas the resistor dissipates the energy, use up the energy. So this stores potential energy in the potential form.

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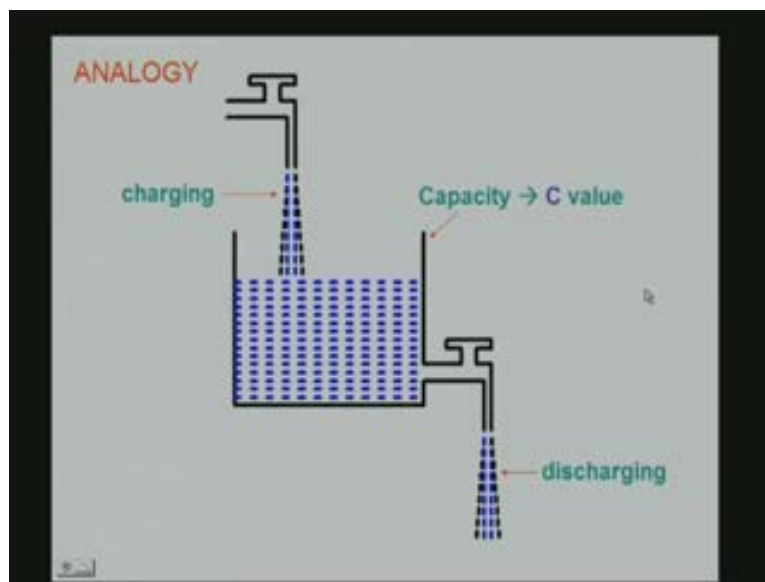


So how does this store the energy?

Let us look at a very simple analogy that most of us would have seen in real world. This is a picture of a tub with an outlet at the bottom and there is a tap which fills water and the water is continuously flowing up through the bottom tap. The inflow and the outflow can so be adjusted that there is a particular height of water which is built up and this is the buffer water. So this water that is getting stored in this bucket is something like stored potential energy. That is how the concept of the capacitor can be related to this particular analogy.

We say that the input flow of water is something like input flow of charges into the capacitor and that is called charging and the flow of **water charges out** capacitor or flow of water out of the tub is something like discharging the energy which is in the tub or which is in the capacitor that we are analogously calling.

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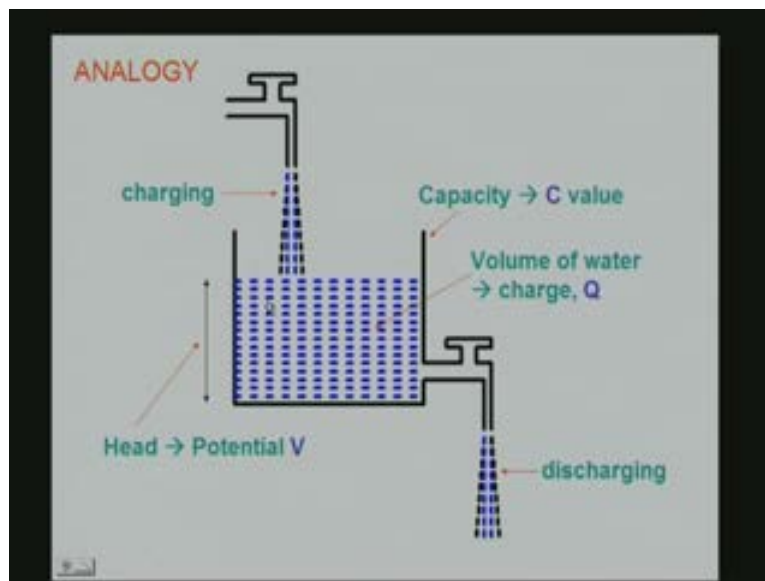


The capacity of this drum or bucket is analogous to the capacitance value of the electrical component capacitor and the height or the head of water that is going to get stored in this bucket is the potential of the energy and that potential is the voltage potential in the case of the

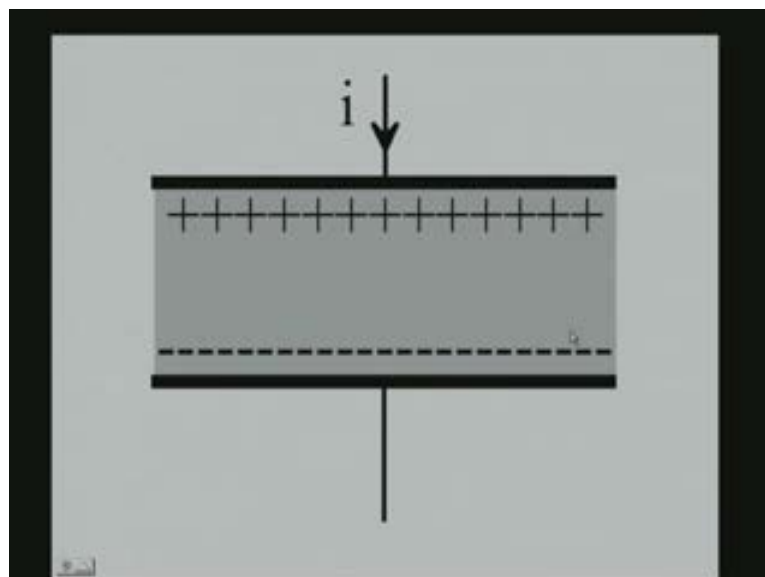


capacitor. Therefore, analogously this particular system which we probably see every day like the bucket getting filled with water and then getting discharged will relate very well to a capacitance action and the volume of the water is actually the charge that is put into the bucket or that put into the capacitor.

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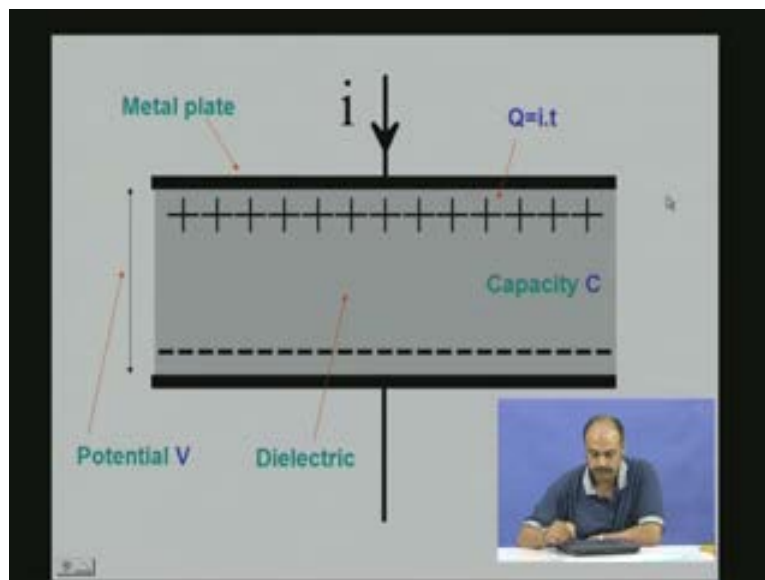


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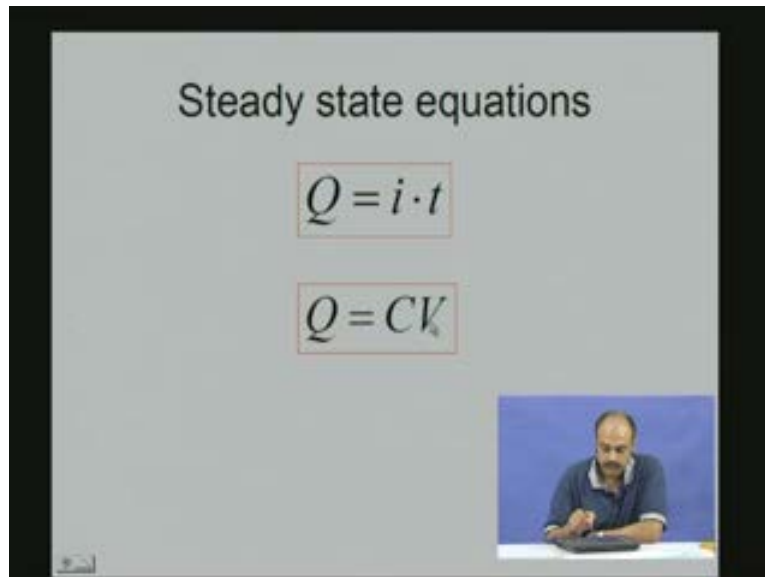


Now the capacitor looks something like this in its most primitive form. It has two plates: there is one plate here (Refer Slide Time: 27:42) there is another plate here and in between there is a non-conducting dielectric material. So the charges..... let us say there is a current flow so the charges come and accumulate on this let us say they are the positive charges and then it will induce equal amount of negative charges on the other plate and there is a potential difference between these two plates which is the potential. So this charge accumulation is called the potential storage in the capacitor which has a capacity  $C$ . So, that is the metal plate as I indicated, this is the dielectric, this is the capacitor with capacity  $C$  and the charge  $Q$  is current into time. The current into the time is the amount of charge that gets accumulated here and the difference between **the potential at between** these two plates is the potential  $V$  or volts.

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(Refer Slide Time: 29:04)



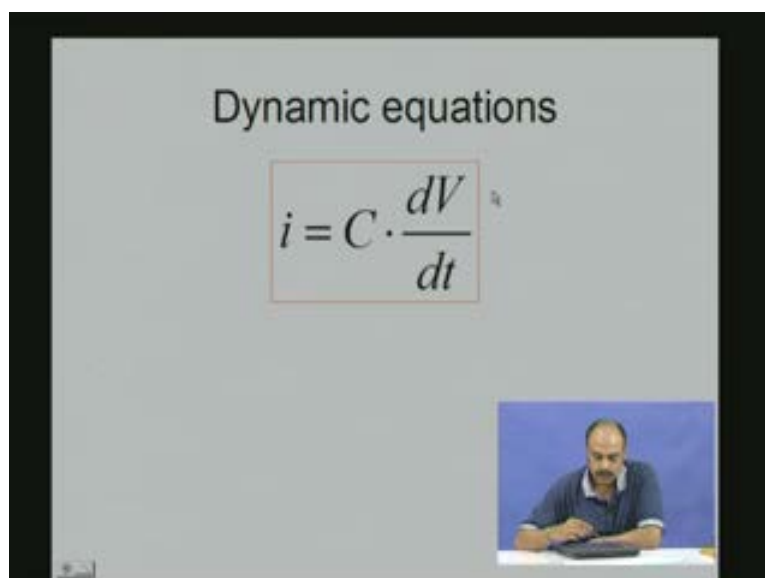
Steady state equations

$$Q = i \cdot t$$
$$Q = CV$$

A small video inset in the bottom right corner shows a man with a beard and glasses, wearing a blue shirt, sitting at a desk and looking at a laptop.

So here are the steady-state equations for the capacitor. The charge  $Q$  is related to the current and time in this fashion. The current into time is equal to the charge. The charge is also equivalent to the capacitance or the capacity of the capacitor into the voltage  $V$ .  $Q$  is equal to  $CV$ ,  $Q$  is equal to  $i t$  these are fundamental steady-state relations.

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Dynamic equations

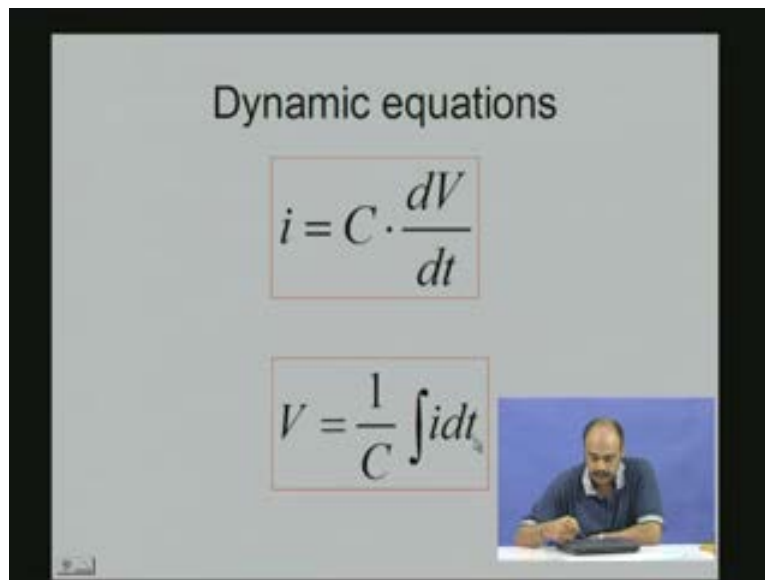
$$i = C \cdot \frac{dV}{dt}$$

A small video inset in the bottom right corner shows a man with a beard and glasses, wearing a blue shirt, sitting at a desk and looking at a laptop.

The dynamic equations, the steady-state equation is when everything is under stable operating conditions nothing is varying nothing is changing. In dynamic conditions when there are transients when there are step changes so these are the dynamic equations which are the more general equations; under steady-state constraints you will see the earlier steady-state equations coming into play.

Hence, in the case of the capacitor the voltage across the capacitor is remembered by the capacitance, so the voltage is the state value. The current through the capacitor is always zero in the average value. The average value of the current is always zero in the capacitance under steady-state conditions. But under dynamic conditions you will see that it is given by this equation  $i$  is equal to  $C \frac{dV}{dt}$ . Or the voltage is given by  $V = \frac{1}{C} \int i dt$  is exactly this equation written in a different form.

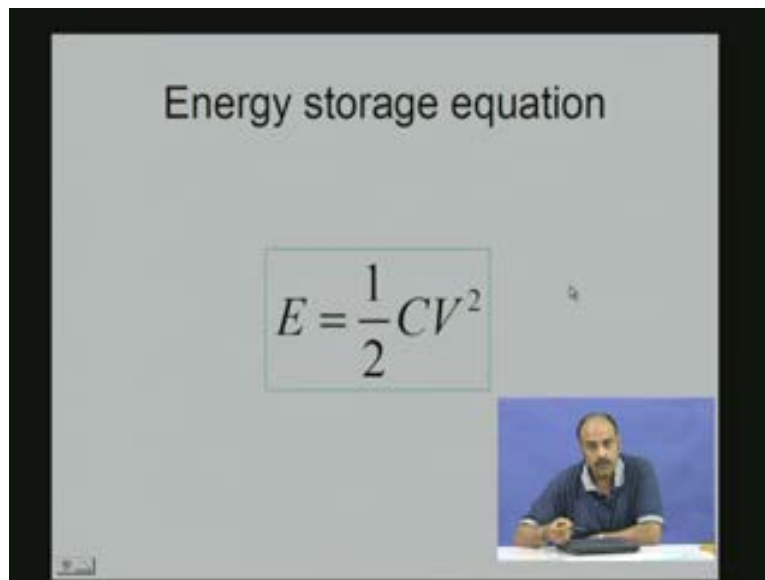
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Now this integral here implies that there can be history, there can be initial condition. So the initial condition as far as the capacitance is concerned will be a voltage value. So therefore capacitor remembers voltages, it can remember the immediate past value of the voltages and voltage is the state value or the state variable for the capacitance and in the case the capacitance

the voltages cannot change suddenly it can only change smoothly or continuously, there cannot be a discontinuous change in voltage because of this fundamental equation the integral equation, the V here on the left hand side cannot have a step change.

(Refer Slide Time: 31:22)



The image shows a presentation slide with a light gray background. At the top, the text "Energy storage equation" is displayed. In the center, the equation  $E = \frac{1}{2}CV^2$  is shown inside a light green rectangular box. In the bottom right corner of the slide, there is a small inset video frame showing a man with a beard, wearing a blue shirt, sitting at a desk and looking towards the camera.

The energy storage we saw that the capacitor is a potential energy storage component and therefore what is the amount of energy that gets stored in the capacitance and that is given by E the energy which is equal to 1 by 2 CV square or half CV square. You see that the energy storage variable is V here the potential therefore it is a potential storage component half CV square and that can be obtained by simple derivation. We know that the wattage is V into i and V into i into time is going to be the energy watt seconds so integral of that over the period of time or period will give you the energy which is as given here.

(Refer Slide Time: 32:23)

Energy storage equation

$$E = \frac{1}{2} CV^2$$

Potential energy storage

So we say that as the capacitor has the voltage variable here and the energy equation and its state variable of the state value is the voltage or the history that it can remember is the voltage which is the potential therefore it is called the potential energy storage component.

(Refer Slide Time: 32:45)

- 
- Capacitor types
- Polarised
    - Electrolytic
  - Non-polarised
    - Ceramic
    - Polymer
    - Metallised polyester
    - ...

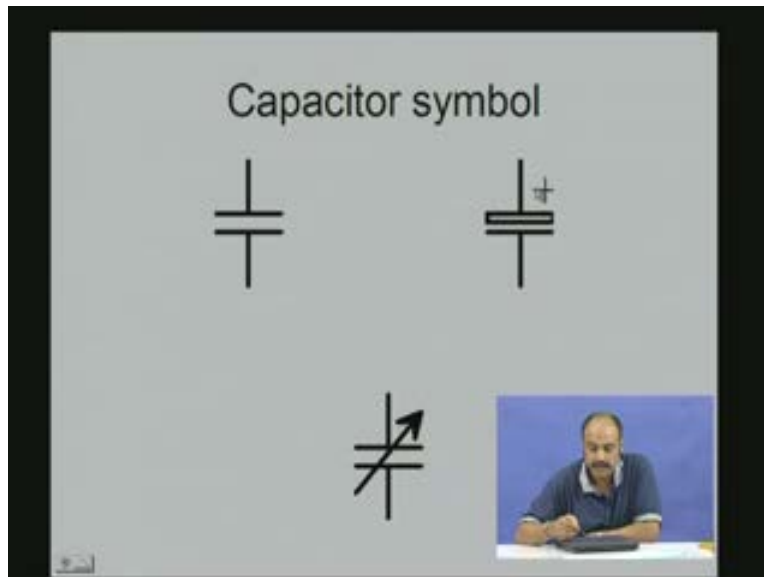
The capacitors also come in various forms, various types and different materials that are used in the manufacture of capacitors. So you have basically two types, broad categories of capacitors: the polarised capacitor and the non-polarised capacitor.

By polarised capacitor what I mean is that there are two terminals like in a resistor; one terminal should always be more positive with respect to the other terminal, so that is a polarised capacitor. In the case of a non-polarised capacitor either terminal can be more positive than the other terminal at any given point of time. So there is no restriction that one terminal should always be more positive than the other terminal.

In the polarised capacitor the electrolytic capacitor is one which is most commonly used and in the electrolytic capacitor the two significant or more popularly used capacitors is the aluminium electrolytic capacitors and the tantalum capacitors. tantalum capacitors are a bit more accurate in terms of the capacity, the aluminium electrolytic capacitance have lesser tolerance meaning the variation is much more, it can vary from minus 40 percent to plus 100 percent than the value of the capacity compared to the value of the capacitor that is written on the name plate of the capacitor.

In the case of the non-polarised you have the capacitor name, type name based on the material of the dielectric that goes into it; the ceramic dielectric type or the polymer based rather metalized polyester; metalized polyester is something which is having very low tolerance to changes in the environment and therefore their use of frequency tuning applications and things like that.

(Refer Slide Time: 34:45)



These are the symbols that you normally encounter in the literature in the circuits electric circuits for the capacitor. This is the most common symbol that you will encounter; two parallel lines with two leads coming out like that and this is another symbol which is normally used for electrolytic capacitance, one with thicker box type rectangular box type terminal and another terminal which is a line. The box type has a plus there indicating that it is a polarised capacitor so that has to be always positive with respect to the other terminal.

And then you can also have variable capacitors with an arrow indicating that it is a variable capacitor. There is also a capacitor with the following symbol which you also will come across the literature. A terminal which is attached to a straight line plate and another terminal attached to a curved plate; this is also sometimes used for electrolytic capacitors that are polarised capacitors with the straight line plate indicating plus and positive with respect to the curved plate capacitors. This is also one of the symbols that you would be coming across more commonly.

Let us now look at some of the capacitors that you will find in the real world.



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If you look here that is spread out there are a few capacitors. The smallest one here is the paper capacitor and unlike again as I told you earlier that in the case of the resistors you have the colour codes for the values; for the capacitors the values are printed on the body of the capacitor itself so you need not remember any colour coding for this. This is normally used for decoupling in electronic circuits (Refer Slide Time: 36:58), this is another ceramic capacitor, these are non-polarised, these are all non-polarised capacitors here what you see on the front. This box type here is a polyester capacitor used for frequency tuning applications; this has very low tolerance meaning it does not vary much with temperature.

Now these two black capacitors that you see they are polarised. They are what you call the electrolytic capacitors and **they are** specifically here in this case what I have here is the aluminium electrolytic capacitors. They are very frequently used in power supplies for actually holding the charges, they can hold large quantities of charges and they come in very large capacities.

So these capacitors in general used for actually holding the charges whereas these capacitors (Refer Slide Time: 38:00) also do the same type of holding the charges but their application is

more power frequency tuning, decoupling and things like that. This is aluminium electrolytic; you see there is one short lead and there is one long lead and that is to distinguish the positive and the negative pole. But even otherwise on the body of the capacitor there will be a plus or a minus sign put near one of the terminals to distinguish it from the other pole.

Here (Refer Slide Time: 38:35) this is slightly of a higher capacity capacitor which is as you can see something like 4.7 Microfarad written on the body. There is also another value which is written here 100 volt. For all capacitors there are two things that you will see on the name plate: one is the capacitor value in Farads or Microfarads or Nanofarads or Picofarads that will be written, the second number or the value that you will see on the name plate is the voltage that it can withstand because beyond which there is dielectrial breakdown and then you will see that it will get spoilt or it will get damaged. So you should not apply a voltage to the two terminals which is higher than what is written on the name plate which means that this is a 4.7 Microfarad 100 volt capacitor and you should not exceed the voltage of 100 volts here.

Now let us have a look at few other capacitors that are bigger in size. Why should the capacitor be bigger in size?

In the case of resistor we saw that as the dissipation amount of heat it has to dissipate increases the size also increases. But here the capacitors are not supposed to dissipate but still you see that they come in various sizes right from small to the big. There are two things with which you are going to determine the size: one is the voltage. If you need to design a capacitance which is supposed to withstand a very high voltage then also you need to have dielectric in between which can withstand that feel which can withstand that voltage and therefore the size grows up.

Then another thing is the capacitors gets polarised and if the frequency of polarisation is high than the internal molecules or the polarisation zones which gets alternatively polarised depolarised in one direction than the other direction that will cause some heat called the equivalent resistance or the equivalent series resistance in the capacitance which will cause some heat to get lost. Even though ideally a capacitor is not supposed to lose any energy a practical capacitor will always have equivalent amount of resistors which will lose the heat because of the polarising de-polarising effect of the charges in the capacitor and this will in general be

represented in the equivalent circuit as equivalent series resistance or equivalent parallel resistance whichever, one may want to use. So, high yield capacitor is not lossless, it has some loss in it due to these practical limitations. Therefore, due to that the size also will vary. So as the currents in the capacitor increase the sizes will also go up because the ESR is going to dissipate.

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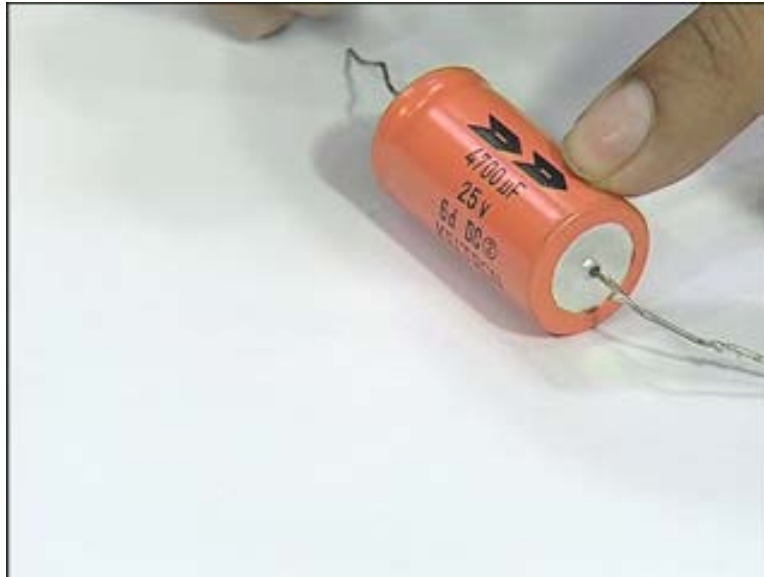
Now here is another non-polarised capacitor which can handle much higher current than the ones you just saw which means that higher current carrying capacitors should have lower equivalent series resistance or ESR. So this is one such non-polarised capacitor normally used for snubber applications. I will also show you another capacitor.

(Refer Slide Time: 42:33)



This is an electrolytic capacitor polarised of similar size. You see here the two terminals and see here the marking the minus marking (Refer Slide Time: 42:42) which means this terminal which is closest to the minus marking is negative and the other terminal is positive so that other terminal should be more positive than this terminal. So always look for the polarising mark on the capacitor which says that that terminal should be either more positive or less positive than the other terminal. Let me show you something bigger. Do you see this capacitance with some marking here?

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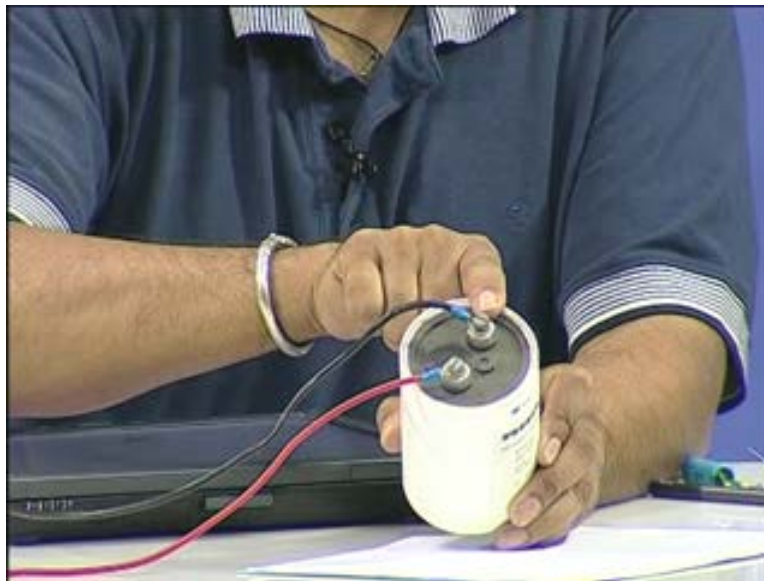
Now this capacitance has leads on this side. This is an axial lead capacitance. It is 4700 Microfarad capacity value. You see the minus sign here with the arrow sign which means this lead is negative which means this lead should be more positive than this at every instant of time so this is a polarised capacitor. Similarly, there is another electrolytic capacitor which I just showed you.

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This is radial lead as against the axial lead here. In the market you will find these two types of varieties: the axial lead electrolytic capacitor and the radial lead electrolytic capacitors. The polar polarity is of course indicated here on this type. I will now show you one more capacitor which is still bigger in size.

(Refer Slide Time: 44:44)



Look at this capacitor. It has two terminals and this is a polarised capacitor. If you can see here there is a plus mark which means that this terminal has to be more positive with respect to this terminal at every given point of time. And here you see the values written; the two main values which we keep looking in the capacitor which is the capacitance value and the voltage withstanding capability (Refer Slide Time: 45:00).

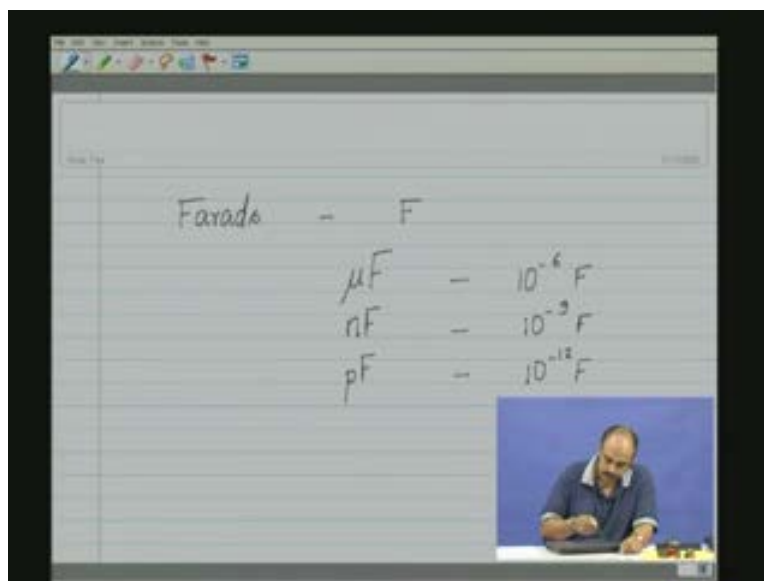
So if you see in this you see that it is a 2200 microfarad capacitor and it can withstand up to 450 volts DC and these are other numbers which you will find which indicate the tolerance value, it can go from minus 50 percent to plus 100 percent and so on and so forth depends upon the capacitor, the make of the capacitor and things like that. So, apart from this you can also find still higher capacity capacitors but it will be along those lines.

Therefore, generally the higher capacity capacitors the one which is supposed to store energy as a buffer they are generally electrolytic capacitors. The non-polarised capacitors are generally used for decoupling to see that the average current in that particular lead or the particular wire is zero and also for frequency tuning applications to determine the frequency of a particular circuit element these are things for which the non-polarised capacitors find applications.

The next topic that we shall discuss is the inductor which is the second storage element which stores the kinetic energy. So far we had a look of capacitors of various sizes and types. Before we go to the next topic that is the inductors I would like to mention that the capacitors have the unit called Farads with a letter symbol F. You saw that on all the capacitors the name plate reading shows Farads. But it is prefixed by some other Greek symbols like Micro, Pico, Nano and so on and so forth because the most common capacitors have symbols written like this called microfarad which represents 10 to the power of minus 6 Farads, Nanofarads which represents 10 to the power of minus 9 Farads, Picofarads which represent 10 to the power of minus 12 Farads.

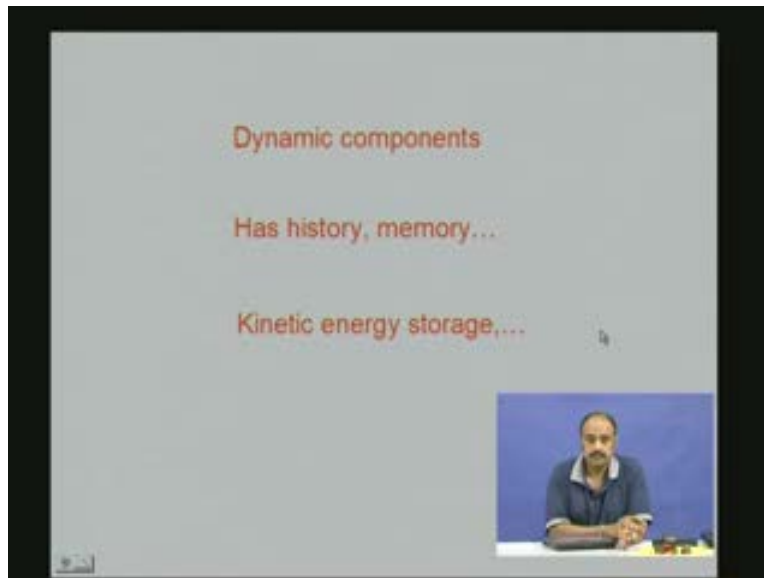
These three symbols that is these three units are the most common that you would come across in most of the capacitors. Of course you could have other intermediate units. But these are some of the most common that you will come across so you have to just be aware of that.

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So now we shall come to the next topic which is the third component in our list which is the inductor. We saw that the capacitor stored the potential energy. The inductor stores a kinetic energy. So what is the analogy?

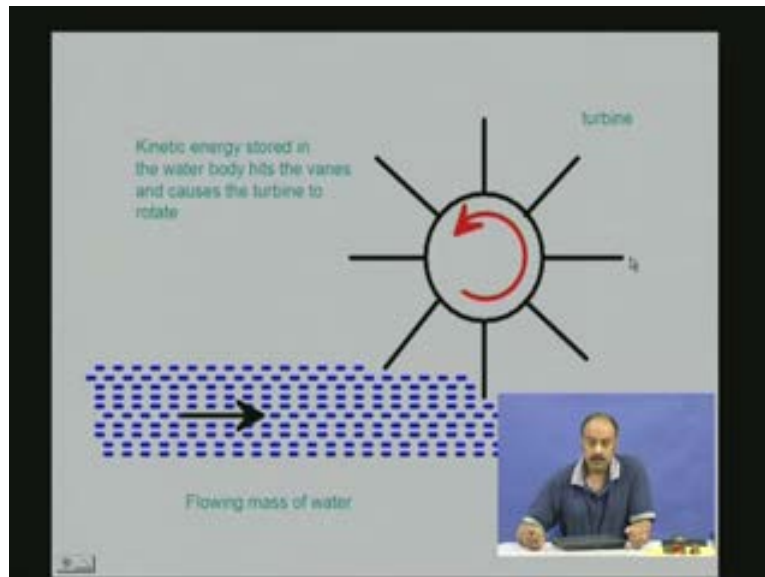
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And like in the case of the capacitors the inductors are also dynamic components meaning they can store the state; in this case the flow, the flow would be the current and it can have a memory like the capacitor had voltage as the memory it can have current as memory or the history so it can remember the currents, it can remember the current as a state variable and it stores of course the kinetic energy.



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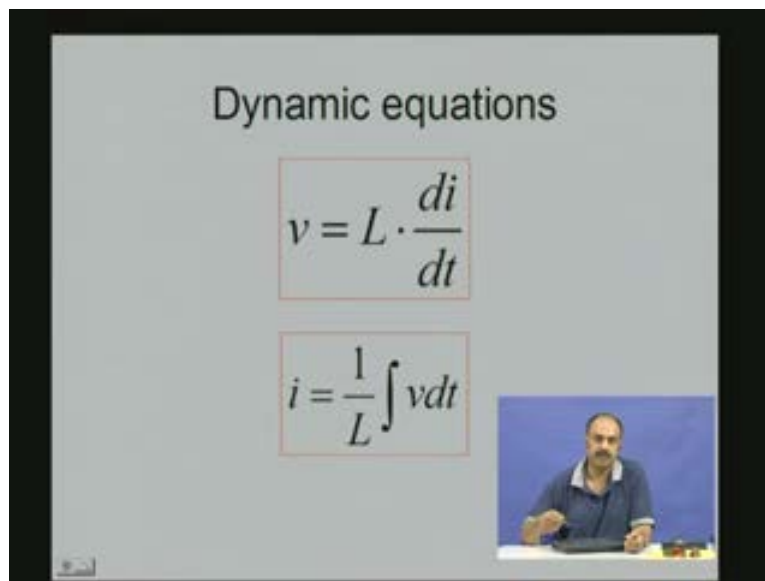


Consider this particular diagram here. You see that there is water flowing, a flowing mass of water, there is a wheel with some blades connected to the wheel and the wheel rotates anti-clockwise as shown here and how does the wheel rotate; the rotation of the wheel is by virtue of the fact that there is energy stored in the flowing mass or flowing body of water and that impinges on these blades and causes the wheel to rotate. So the flowing mass of water has some energy has some stored energy. A vehicle which is moving has some stored energy. A person who is walking has some stored energy which is the kinetic energy by the virtue of it being in motion. So it is that energy that we are talking of and it is that energy which the inductor stores equivalently in the case of the electric circuits and what is flowing is the current.

Therefore, the energy stored by virtue of current flowing is the kinetic energy which is stored in the inductor. So dynamic equations in the case of the inductor like in the case of capacitor very similar; you see the voltage across the inductor is equal to  $L \frac{di}{dt}$  that is the differential law of the current which is flowing through the inductor. Or putting it the other way the inductor current is equal to  $\frac{1}{L} \int v dt$ . Notice again here the occurrence of this inductor which means that it can store the state value, it has memory, it can store the history of what of the current. Thus, in the case of the capacitor it was the voltage because it was the voltage which was

equal to 1 by say integral of  $i$  vdt but in the case of the inductor it is the current which is equal to 1 by L integral of vdt so current is the state variable; in the case of inductor it is the current which is causing the energy to get stored unlike in the case of the capacitor which was the voltage just passing into gets stored as the potential energy.

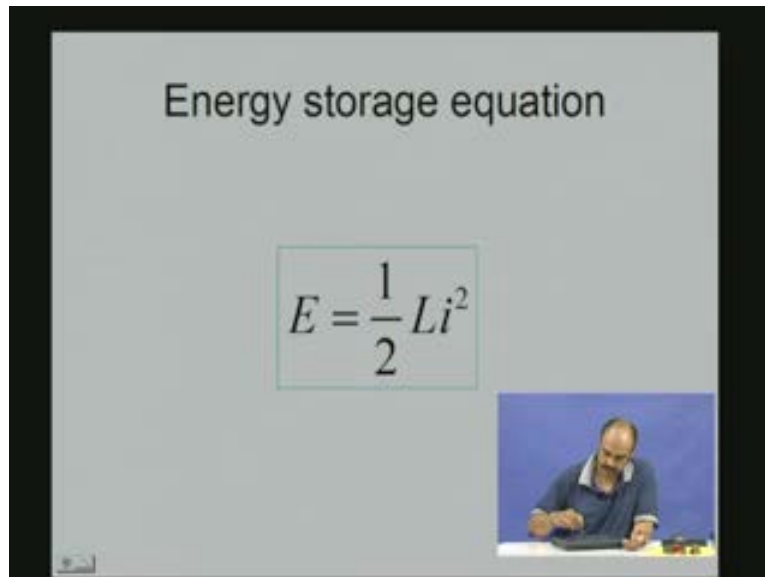
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So what is the energy storage equation?

In the capacitor it was half CV square, V was the state variable, and it was the potential so the potential energy was stored. In the case of the inductor i is the state variable, i is the flow, and the kinetic energy being stored in the flow is just half L i square as you see here on the screen.

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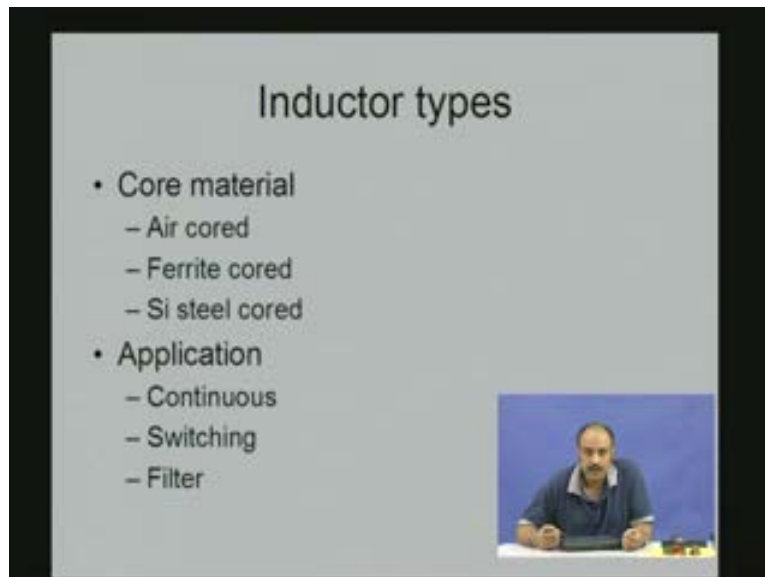


Energy storage equation

$$E = \frac{1}{2} Li^2$$

A small video inset in the bottom right corner shows a man with a beard and glasses, wearing a blue shirt, sitting at a desk and looking at a laptop.

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Inductor types

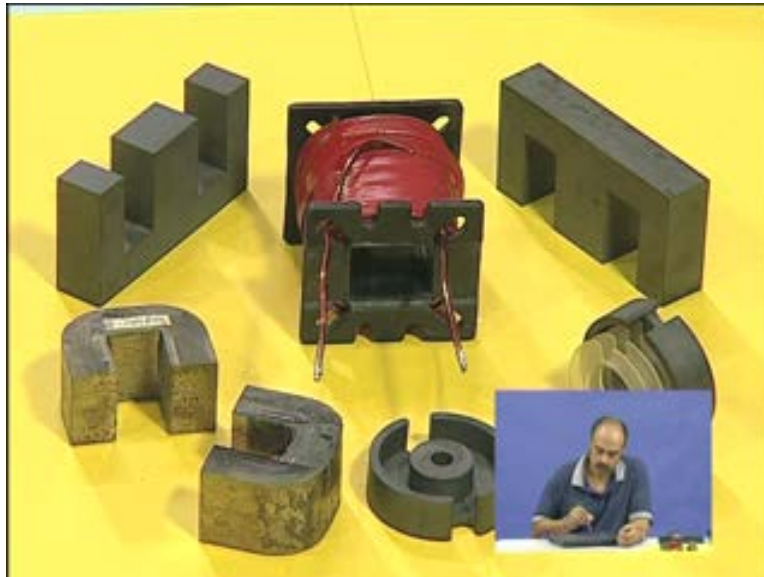
- Core material
  - Air cored
  - Ferrite cored
  - Si steel cored
- Application
  - Continuous
  - Switching
  - Filter

A small video inset in the bottom right corner shows a man with a beard and glasses, wearing a blue shirt, sitting at a desk and looking at a laptop.

The inductor also comes in different types based on the core materials. We have the air cored inductor, the ferrite cored inductor, the silicon steel cored inductor and also it can be categorised based on applications: the continuous applications, the low frequency applications, the switching applications which are more common, the switch mode power supplies, filter applications which

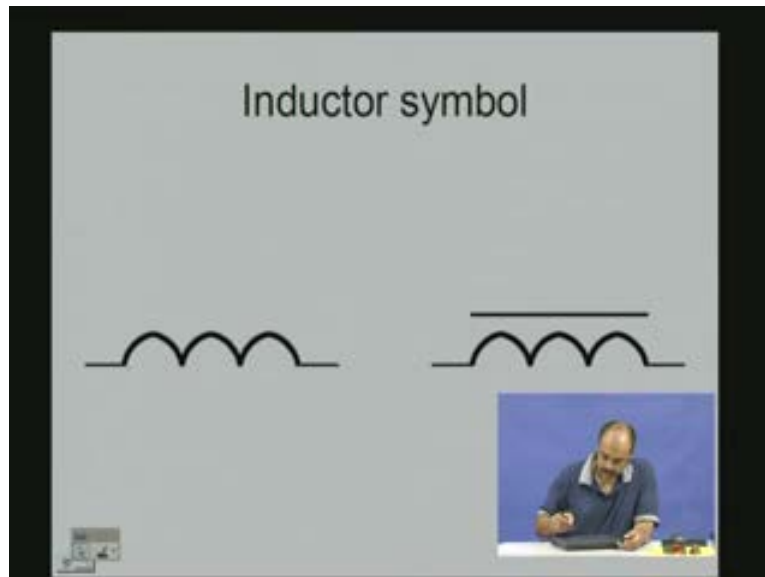
are used for removing the harmonics and things like these. The symbol for the inductor is as shown here.

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It is shown as coil because generally the inductor is manufactured with some coils bound around the core or it could be showed as a coil with a horizontal bar which indicates the presence of a core and if **the core is not** if the core is not there it could just be without the line which indicates it is an air core but this symbol without the line is also used for with core, with air core and all those things; saturable and so on and so forth.

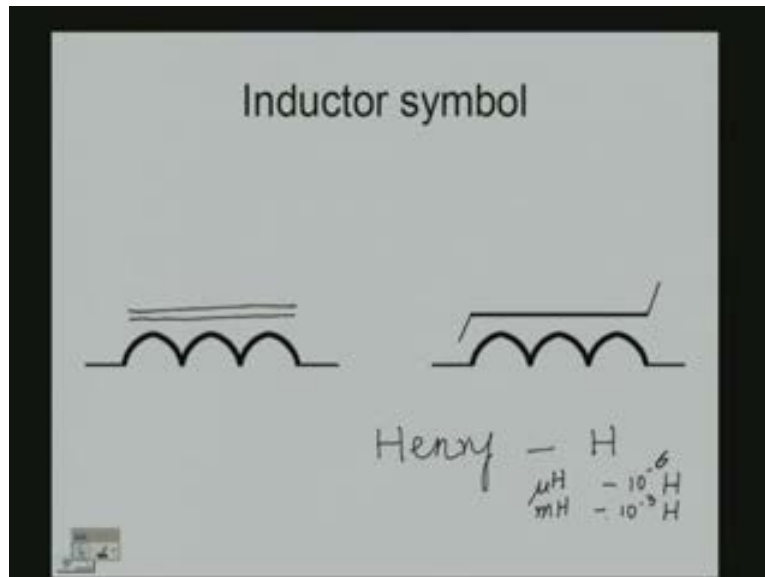
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One should note that if one is talking of a saturable core inductor then sometimes in the literature you see a symbol which is like that. Sometimes you will also see a symbol with a double line for the core. These are the various symbols that you will find in the literature but in general the basic symbol is **the curved surface** the curved lines indicating the coils in an electric circuit.

The inductor is having a unit called Henry denoted by the letter symbol H and like in the case of the capacitor it can be MicroHenry which represents 10 to the power of minus 6 Henry, MilliHenry which represents 10 to the power of minus 3 Henry or just Henries. These are two common denominations or the units the MicroHenry and the MilliHenry; you can also have NanoHenries and other denominations depending upon the application.

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Now let us see some practical real world inductors.

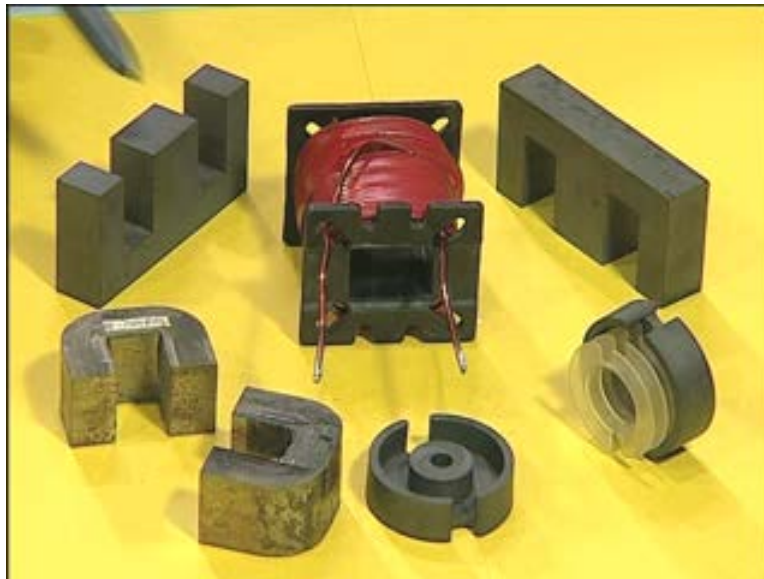
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You see here this is a practical real world inductor. You have these two terminals coming out here and there is a core here and the two coils here. Of course here for handling the current rating

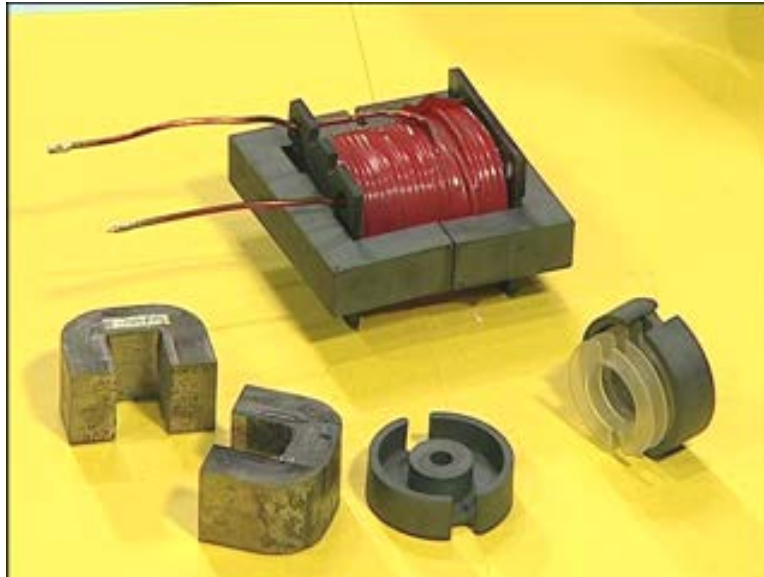
these two coils are paralleled; you see that these two wires are paralleled here, taken out here, the other at two ends are parallel and are taken out here. But it can also be as well just one coil here. Let us see a few other examples of the inductor here.

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Look at this frame here there are various components. This is an e core one half of the e core. This and this (Refer Slide Time: 55:35) together forms the total core in fact, this will go into this core and this called the Bobbin. On this Bobbin we wind the wires the copper wires; these are copper wires which are wound. And after winding you take this core put it like that and assemble it in this manner.

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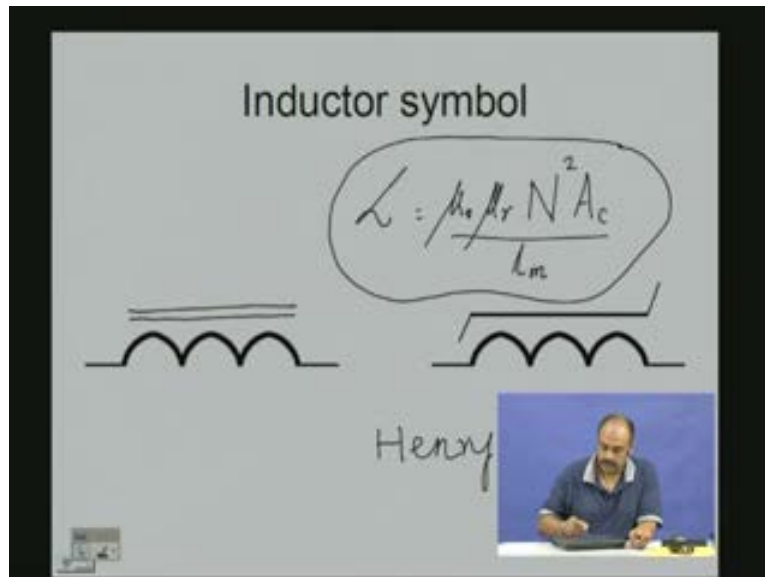


Now this becomes an inductor with a ferrite core. So this is a ferrite core. You have one end of the winding here (Refer Slide Time: 56:16) another end of the winding here goes through this coil there is a Bobbin and this Bobbin is fitted into the core is a ferrite core ferrite EE core.

You can also have different types of cores. This is a **MET** class type of core this is called a CC core (Refer Slide Time: 56:33) it goes from the geometry, this is a CC core. This is another ferrite core called the pot core. This has two halves (Refer Slide Time: 56:46); you have the Bobbin here, on the Bobbin is wound the copper wire and then it is placed within the pot core like that and then you enclose the Bobbin so you have the core enclosing the Bobbin and it flows through the coils. This is how the inductor has to be manufactured and it is basically dependent upon the following equation.



(Refer Slide Time: 57:45)



So you have  $L$  which is equal to  $\mu_0 \mu_r N^2 A_c / l_m$ . This is the inductor equation. You see that the inductor is proportional to  $N^2$ ; it is proportional to the cross section area of the core the cross section area of the core and it is also proportional to the magnetic path length of the core; inversely proportional to the magnetic path length of the core and it is also proportional to  $\mu_r$  the relative permeability of the core material and of course this is  $\mu_0$  which is the permeability here which is  $4\pi \times 10^{-7}$  H/m.

Hence, this  $\mu_0 \mu_r$  together is called the effective permeability  $\mu_e$  and that is what is generally adjusted in the type of the core material or if the core material has a very high permeability you try to adjust the material by introducing air gaps and there are various methods in which you try to adjust the effective permeability. This is of course the base equation in trying to get the value of the inductance, the core cross section area and the magnetic path length into account.

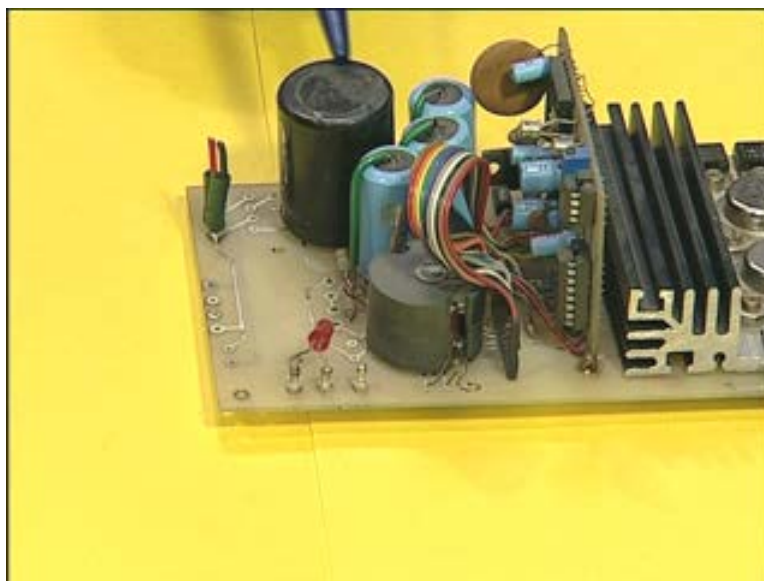
Let me show you a typical power supply board and let us try to identify the components and see how it is placed in the PCB so that you get an idea of the various components that will go into a practical circuit.

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Now this is a practical printed circuit board. This is in fact a SMPS a working Switched Mode Power Supply.

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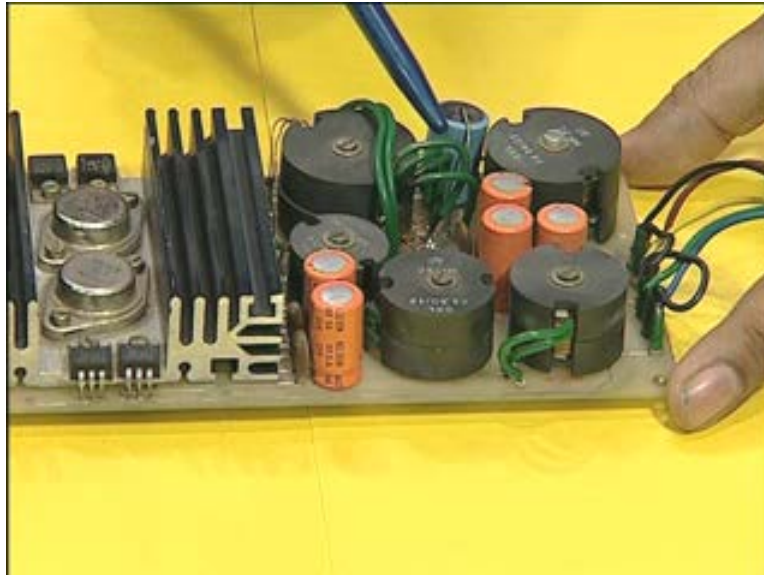
We have the outputs and here is the input, this is followed by a capacitor an aluminium electrolytic capacitor. Here you see three capacitors which are the non-polarised capacitors, there is a board here, it is a piggyback board which is riding on the big motherboard, you see ceramic capacitor here (Refer Slide Time: 59:49) etc so transistor, there is a potentiometer here and whole lot of resistors inside here on the board and you see the power devices mounted on the heat sink here.

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And then gradually if I move this board here what comes into focuses are some part cores.

(Refer Slide Time: 1:15)



This part core is used as transformer, these part cores (Refer Slide Time: 1:21) are used as inductors; again some electrolytic capacitors for the output, the part cores here are the ferrite part cores and they are normally for hybrid frequency applications. They can be used for applications ranging from 20 kilohertz to 100 kilohertz and special cores even up to 300 kilohertz. And further on if you want to use for low frequency applications like 50 yards applications one has to use not these ferrite materials but the silicon steel material.

**New** metal type of material can also be used for the intermediate frequency range of applications like 400 hertz to 1500 hertz and such. These part cores can be used right from 20 kilohertz to 100 kilohertz and in fact you have special ferrite cores which can go even up to 300 kilohertz and so on and so forth. So, these components here that are arranged on the printed circuit board is just the function of power supply here. We will give you an idea on how the physical components are mounted on to the board and are used in practice.