Fundamentals of Power Electronics
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Lecture – 04
Components of a Typical Power Electronic System

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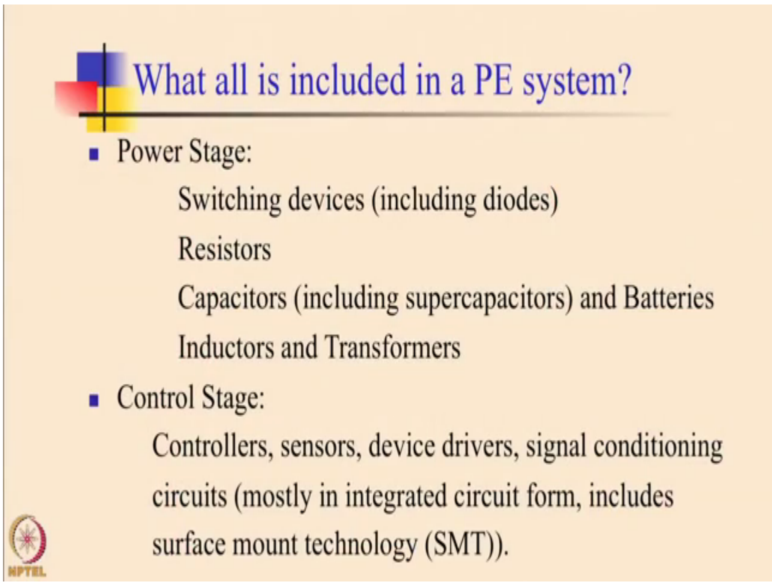

Welcome back to Fundamentals of Power Electronics. Any power electronic system consists of two stages, a power stage and the control stage. The power stage, which is a very common name given to the power circuit or the power electronic system yes. So, it has the switching devices inputting diodes it has got resistors; also whether we want them or not we do need resistors for various applications.

We have capacitors and now these days even super capacitors have become important and batteries are also playing role a big role in several power electronics systems these days. The other current components are the inductors and the transformers. The control stage it actually is mostly electronics, it consists of you know controllers, sensors, device drivers, signal conditioning circuits and most of them are actually in the integrated circuit IC form and it also includes these days surface mount technology devices. So, this is all you can expect in a power electronic system to be present a modern power electronic system ok.

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Here, you see the various packages in which the power devices are available. So, what you see in the you know towards the back side are two IGBT modules. So, these are fully controllable devices meaning that they can be controlled; through their control terminals whether its turning on or turning off they can be completely controlled through this controlling terminal.

And you know, so these are like available either as module, you know sometimes they are actually having a module which is consisting of 2, such devices IGBT's they also have modules which are available with full 6 devices. So, that they can form some very standard power electronic circuits; such as the DC to AC inverters ok. Now what you see at the forefront are some of the other packs like the TO 220 packs, which actually are showing various types of devices. We have the transistors here, bipolar junction transistors; we have the metal oxide semiconductor field effect transistors; we have on the very right side you know a stud type diode ok.

So, we have various forms in which these devices are available and which are actually used in all circuit layout depending on the requirement and the application.

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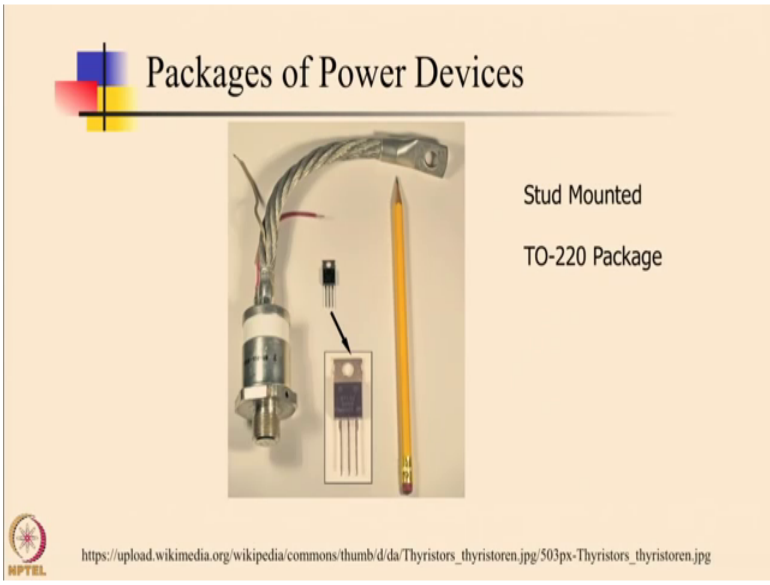

This is another picture of showing the power devices. On the left side is a thyristor ok; you know thyristors still remains the device for the highest power levels required in the power industry. So, though the thyristors have a very distinct disadvantage, in this in the sense that they cannot be turned off; after they have been turned on it is not possible to turn them off without using forced commutation or unless there is a natural switching which is unless there is a natural commutation which is taking place.

Type two switches, thyristors or the SCR's once triggered into conduction cannot be turned off through the gate control; they can only be turned off. When the current through them goes to 0 and a reverse bias voltage appears across the device for a minimum duration of time. This is often achieved by using commutation circuits; by commutation we mean, that we are trying to divert the current through the thyristor into an alternative path. So, that the thyristor can be switched off this is called the process of commutation.

Still these devices they remain important and that is why it is important to familiarize you with such devices. On the right side for comparison, we just put a TO 220 package a plastic package of a very low power it is a 13 ampere 600 volts thyristor device while the one on the let just stud type the left side one, is actually a 800 volt 100 mph thyristor device.

So, this is a comparison between the two and they have been shown in the backdrop for comparison with a led pencil. So, you can just estimate their size; heat sync is another important component of the power stage. Heat sink is a high heat capacity body on which the power device is placed. This allows the power device to stabilize the temperature the heat sink is usually a metallic material which provides a high heat capacity.

So, that the device temperature does not go very high in a short time and it gets the necessary time to stabilize with respect to temperature before experiencing very high temperatures.

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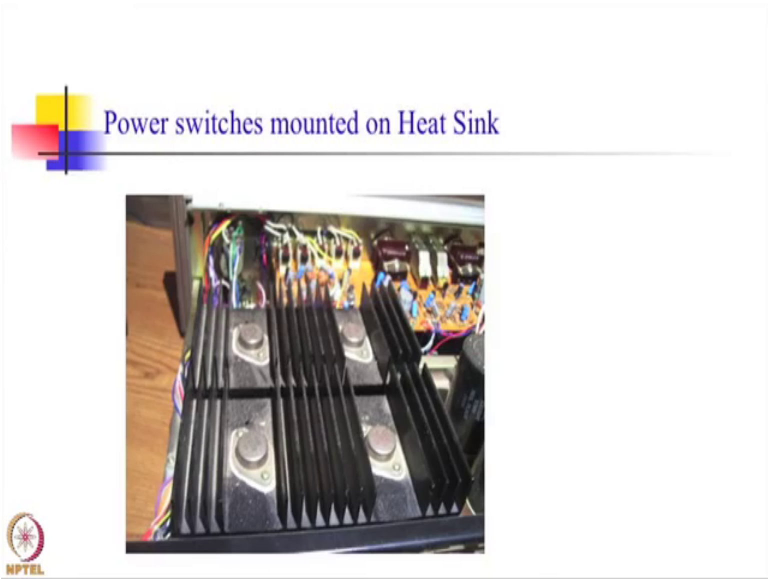

The slide shows, the power devices mounted on the heat sink. You can see very clearly the fins which are actually provided to facilitate the easy passage of heat into the ambient.

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The second slide shows, a component which is mounted on the heat sink along with a fan which is used for forced cooling. In several applications a fan is required for forced cooling apart from a heat sink.

Now, resistors they are used for various purposes ok; the resistors are used for example, as snubbers they are used for voltage balancing ok, they are used for current measurements we all know that we use current shunts and then the voltage that appear across these very low resistance current shunts is then used to you know present a current ok. They are also used for damping; if there is a unnecessary energy surplus energy which is actually circulating in a system; then you use these resistors to dump it; you know less it actually kills some other useful component of the circuit. So, these are some of the not all, but some of the very important you know applications of resistors in power electronic systems; power electronic circuits.

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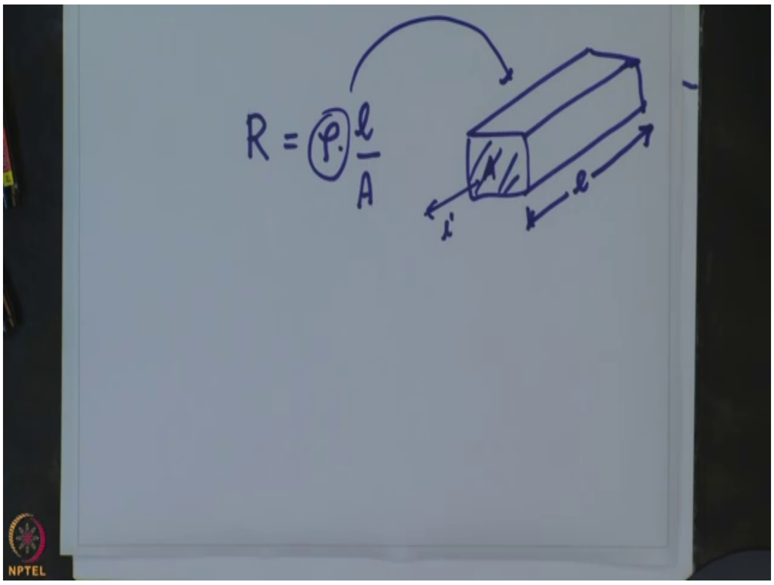

Now the basic relationship of resistance remains the same irrespective of what is the type of the resistor and how it is made. So, the resistance is given by this formula where you know. If I consider, this as the as a solid bar and I say that this is the area of cross section through which a current is flowing i and it has got a length l and rho is actually the property of the material which actually makes up this bar this rod. So, the resistance is given by the product of resistivity into the length by the area of cross section through which the current is passing ok.

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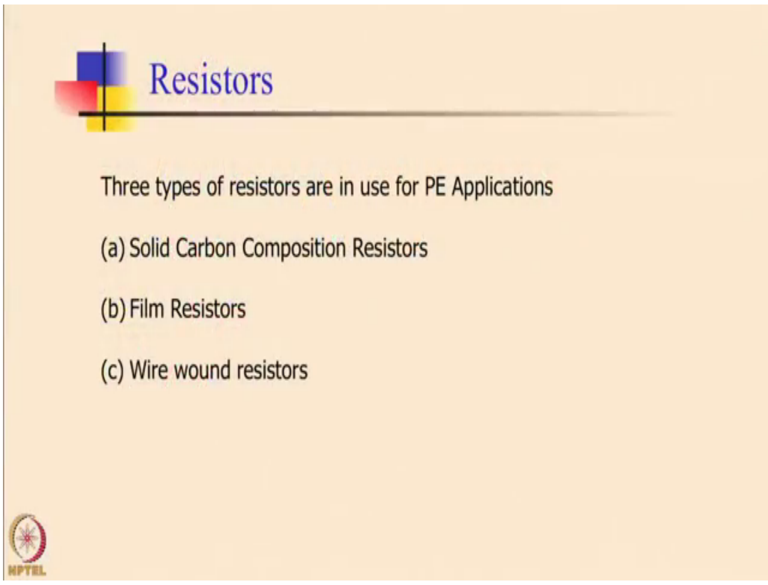

Now, depending on the application it can various types of resistors you know, they are they are available the ones for power applications you know they are typically can be divided into three varieties. One of them is a solid carbon composition resistors, the other is the film resistor and the third one has wire wound resistors.

Solid carbon composition resistors are made by crushing the carbon and ceramic and mixing them in the right proportion to achieve the desired resistance value. However, these are not very accurate values and could vary up to 5 to 10 percent. The film type and the wire wound resistors have a cylindrical or tubular core made up of pure ceramic.

For the film type resistors, the carbon or the metal film is placed around the ceramic body and precisely cut in the form of helical grooves; which gives very accurate resistance values up to 0.1 percent tolerance. The wire wound type resistors use the nickel chromium or the nichrome wire. One of the specialty of the nichrome wire is that its resistance does not change much with the changing temperature. The wire wound resistors can give an accuracy of around 5 percent.

Another issue with wire wound resistors is that they also have a large parasitic inductance. Therefore, they cannot be used in applications where the parasitic inductance might be a concern in the working or the measurements. You know one of the properties that we are looking at resistors is they know that their resistance do not change significantly with temperature ok.

They are they are they are having a good noise characteristic they have a good voltage rating. So, basically the you know when we apply the material, you know when we use the material in a resistor its dielectric strength should be enough that it does not break down; you know when we apply the voltage that you need to apply to a given circuit. So, basically you know these are some of the tradeoffs when you use these different resistors.

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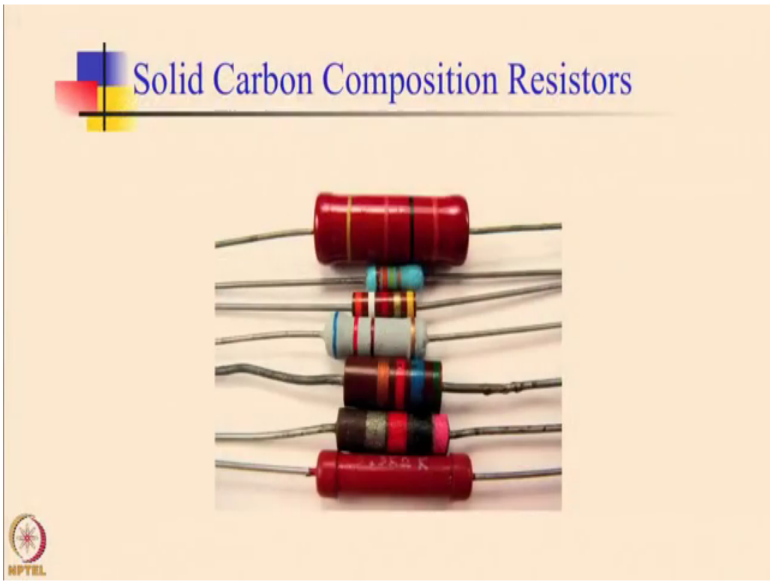

Now, I will just show you some pictures. So, these are the solid carbon composition resistors about which I mentioned, which are actually made with the mixture of ceramic and carbon and the ratio of the carbon and the ceramic decides the resistance values. So, these are some of the solid carbon composition resistors and you can see the colored bands ok. And you know these colored bands are as per a code which can be decoded and they actually represent the value of the resistance represented by each of these resistor. So, there are golden and silver bands which actually tell whether these are 5 percent or 10 percent tolerant resistors.

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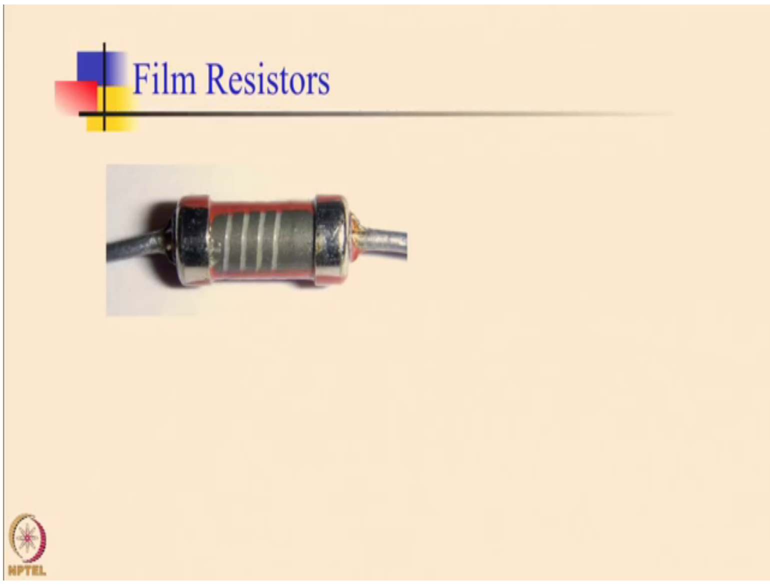

Here is a film resistor, and you can see that there is a carbon coating which has been done around the core; a ceramic core on the 2 sides you can see the nickel caps ok; the nickel metal caps. And you can see the grooving's made in a you know helical structure, and these are very accurately made with the help of computers. So, you can actually very precisely control the value of resistance. We can also see the leads how they have been fused with the caps of the two sides and how this you know resistor has been realized.

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These are some examples of the wire wound resistors ok, their various types what you see on the lower left corner is actually a variable resistor. So, its basically used as a rheostat. And what you see on the right side right bottom corner is actually a wire wound resistor which is actually mounted on a heat sink; because a lot of heat is actually dissipated when the resistor operates because of i square r. And there are some resistance particularly high power ones and wire wound resistors are used for higher power rating as well. So, that is why these heat sinks are also there. So, these heat sink option wire wound resistors are also available ok.

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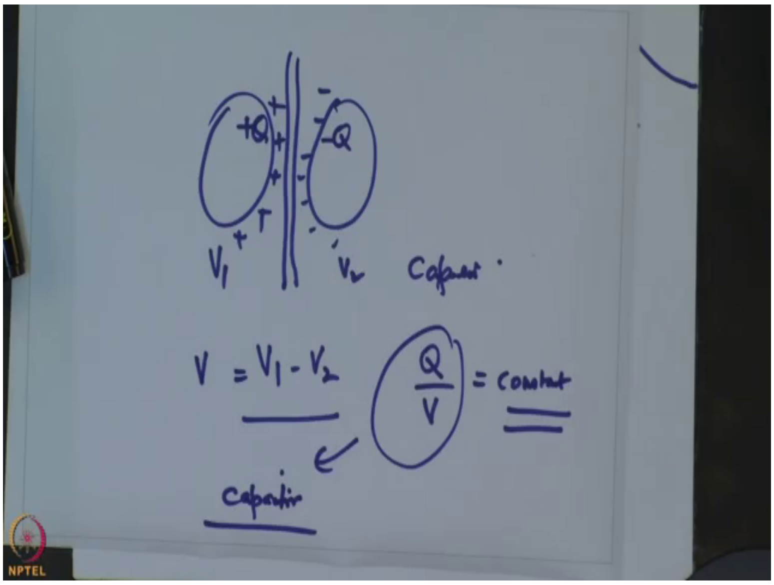

The other important element about which we are going to talk about is a capacitor; you know and a capacitor you know it is nothing, but when you have two conductors ok; which are lying close to each other. One of them is having a you know set of plus charge and the other is having ok. So, these are let us say two conductors as I have just drawn here, let us say there are some positive charges here and there are some negative charges here and you actually separate them through an insulator such as a dielectric.

If you put that there then this actually amounts to a capacitor. The voltage of this is V 1 and the voltage of V of the second conductor is V 2 then the potential difference between the two is V 1 minus V 2 ok. Now we can actually very easily show that you know the charge Q, where, Q actually is a positive Q charge on the left conductor and a negative Q charge on the right conductor Q by V is actually a constant.

We can show that, this Q by V is a constant and actually this is what represents capacitance. So, the capacitance is actually defined by Q by V and we can see that for very low values of voltage a given capacitance can hold more charge little mathematical you know manipulations. W e can easily show, that the capacitance is it actually is nothing but is given by epsilon naught A by d this formula ok.

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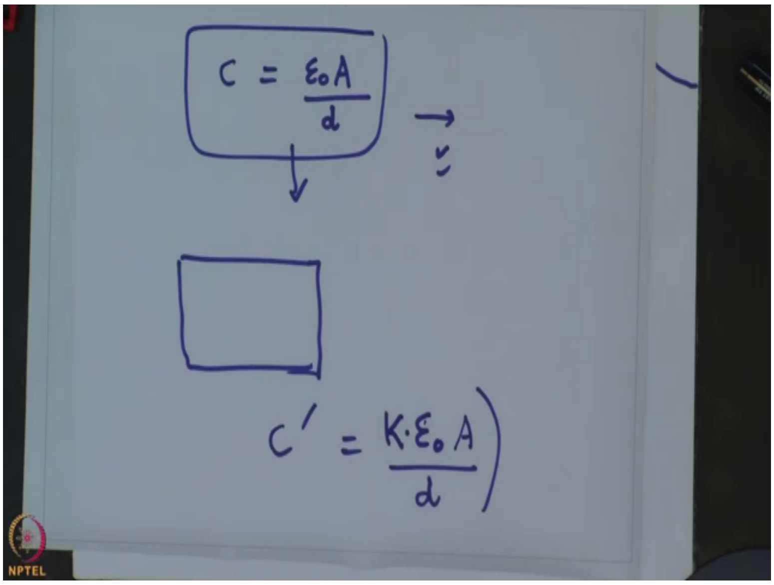

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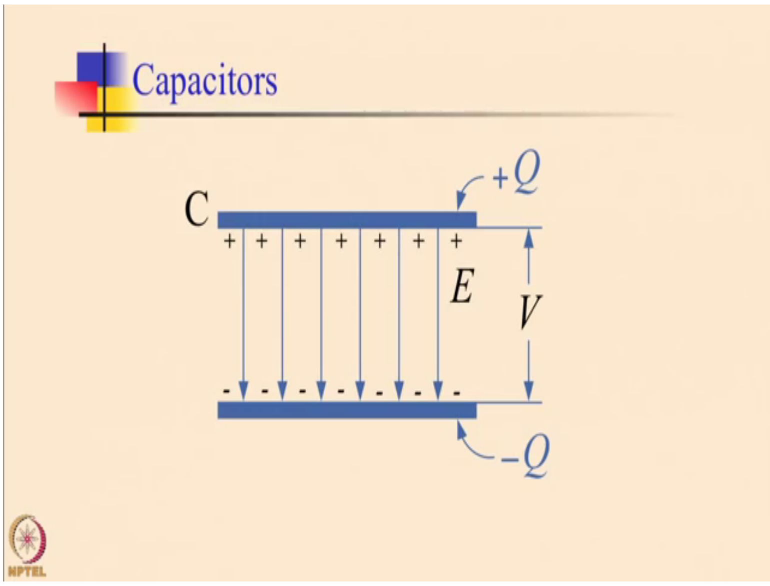

So, if you just see the slide you know on your screen. It actually shows a very special form you know not the very general form that I showed you in the beginning with 2 conductors. Now these are 2 parallel plates which are carrying a charge plus Q and minus Q and there is a electric field; which goes from positive side to the negative side E and there is a potential between the two which is given by V. Then you know, if the other dimensions d that is the distance between the 2 plates and A the area the surface area of these plates is known, then the capacitance is given by C is equal to epsilon naught A by d.

Now, if there is air between these plates. This is the capacitance that you get, but if you actually insert a dielectric ok; which is actually having several dipoles which actually get aligned when you place them in between the field that is created between the 2 plates they actually get aligned. And they actually, result in the net reduction of this electric field which actually has a effect of causing an increase in the capacitance. So, basically your capacitor now becomes C dash equal to epsilon naught multiplied by a dielectric constant K into A by d.

So, if you see this expression, K epsilon naught A by d ok; it is K times C which was the original capacitance with air used as dielectric ok. So, the basically we want to use a dielectric, which will have a dielectric strength, which can be are a higher voltage without breaking down or also it will give a higher capacitance. It will be able to give me a higher length dielectric constant which will be then scaling up my capacitance value drastically. So, actually I will be able to reduce the size for a small area or within a small area I can then pack a bigger capacitance that is the main idea.

Now there are 3 types of major types of capacitors which are used in power electronic systems depending on the specific applications ok. One of the things is that the dielectrics when you insert between the 2 plates it actually incur losses. Therefore, they are specified as you know with RMS current rating, because the i square r losses are there and also dielectric losses are there.

There are two important points when we talk about capacitor one, when we talk about the dielectric strength, the e field strength you know at which it will break down. So, you would actually apply how much potential before the electric field between the plates it breaks down. So, you actually need to use a material dielectric material off of it that will not happen. The other is the dielectric constant which actually ends up multiplying the capacitance net capacitance value of a given you know 2 plates.

Now one very important factor apart from the dielectric strength and the dielectric constant is the dissipation factor d ok. Now this d is actually if you represent the capacitors admittance as G plus G time’s B then, it is a ratio of G to B the real part to the imaginary part that actually determines you know what losses will take place. So, actually because G is a real part which will actually be responsible for the losses. So, you would actually want the admittance corresponding to a given capacitance; it actually is not having any real part ok.

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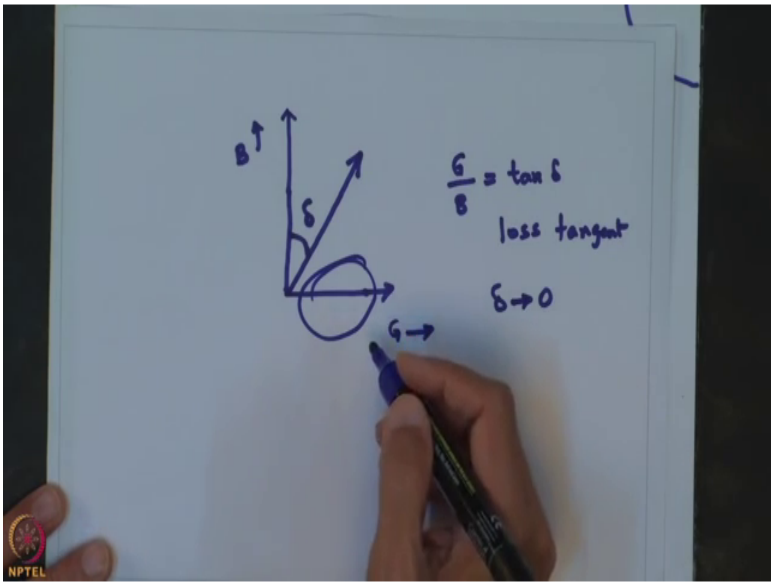

So, if I was to represent this on a diagram; it would look something like this. B shown on the y axis and G shown on the x axis and this is the resultant admittance. If we denote the angle between the resulting admittance and the y axis that is B by delta, then G by B is equal to tan delta which is also called the loss tangent and is a measure of the losses in a capacitor.

Now ideally we would like the delta to go to 0, so that the real part which is this, this axis is 0. So, there is no projection of this you admittance onto the real part which actually means that it is a completely imaginary admittance.

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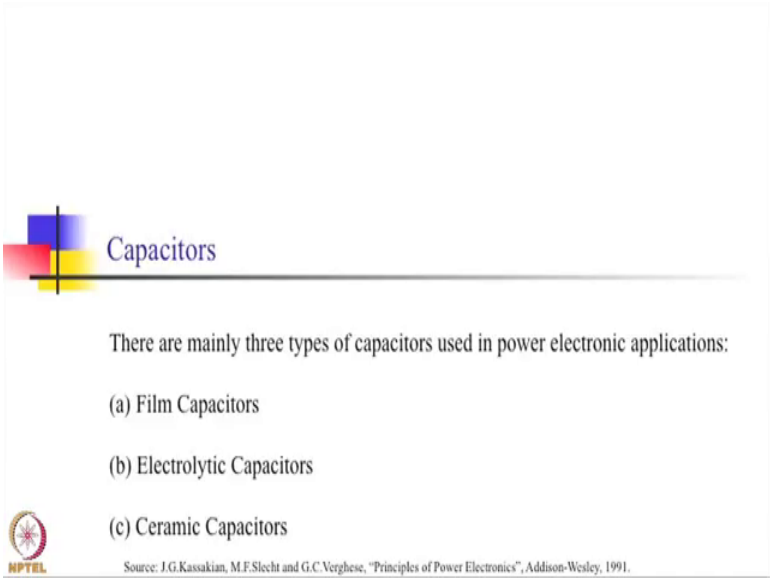

Now, there are 3 types of capacitors which are film type, electrolytic type and the multi layer ceramic type capacitors. The film capacitors which are the first in this category, these are used usually for very large current low capacitance values like for example, resonant power circuits or in snubbers; where you need very small values of the capacitance, but the amount of currents that you handle is very large. Actually it is an unpolarized capacitor it does not have a positive or a negative terminal.

So, you can connect it either way ok. The way it is made is that you actually take too long foils which are made up of some conducting material; which actually 2 foils and between which you actually sandwich you know some dielectric material and then you roll this sandwich this entire thing into a cylinder ok.

So, I will show you some pictures which are there with me which will actually depict film capacitor. Now there are three types of dialectic material which are in use; one of them is the polystyrene, the other one is polycarbonate which has a dielectric constant of something like three and polypropylene is a very very useful it was really turned out to be a very superior quality dielectric, it has a dielectric constant of like 2.3 ok. The dielectric loss is very less in both polycarbonate and polypropylene type of capacitors; in case of film capacitors which can be used for high frequency applications as well.

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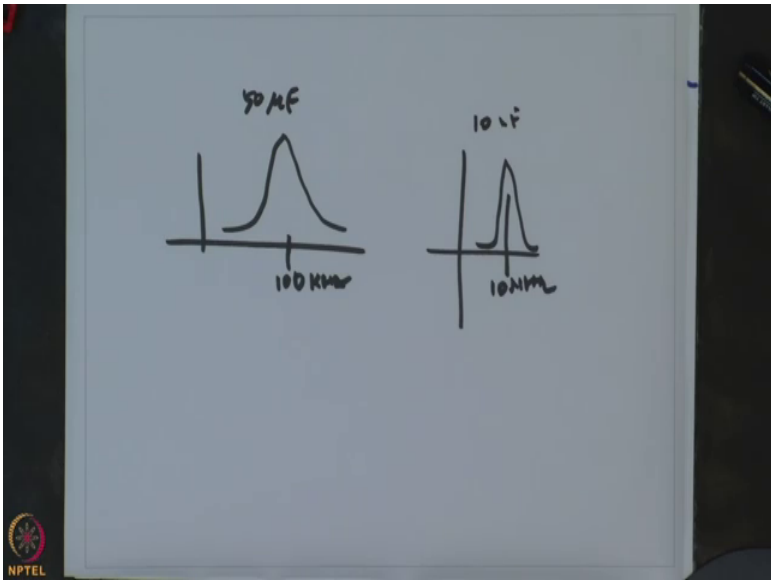

You know it is observed that, you know a 50 micro farad polypropylene film capacitor would actually show a resonance peak, you know add something like 100 kilohertz ok. So, this is a peak that it will show and if you take for example, 10 nanofarad film capacitor it will show a peak at something like 10 megahertz. So, it will just show a peak at that it will resonate at that.

Now these things of course, are important to understand because you know these when you talk about capacitors when you talk about inductors or when we talk about resistors they are not pure resistors or capacitors or inductors. They have the other elements also for example, a resistor would also have parasitic capacitance and inductance associated with it for example, a wire wound resistance is also having an inductive component a major inductive component therefore, we have to see what applications we are doing and then only we should decide whether we can use. So, if there is an application where the presence of inductor will create problems I cannot use a wound wire resistance ok.

Similarly, here when we see the capacitance case we need to be sure that we are you know away from these resonant points. So, there are parasitic within the capacitor which are going to cause a very high gain at these points when the frequencies will match; and result in this kind of a resonance. So, this can create problems in the circuit and deteriorate the performance. So, that is why it is important to see the parasitic equivalent resistance of all these elements.

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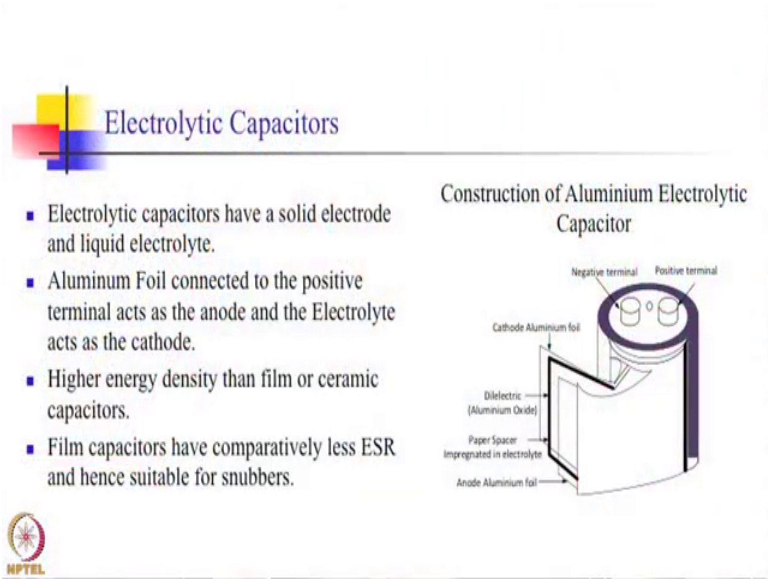

Now, the second form of capacitor after the film capacitor is the electrolytic capacitor, now an electrolytic capacitor can give you a much higher capacitance per unit volume compared to the film capacitors. So, in that is the reason why they have a high series resistance ok. They are also you know suffer from the you know inability to withstand high reverse voltages and that is why you know they are actually unipolar capacitors you cannot actually choose the terminals for plus and minus you know arbitrarily. There is a fixed positive terminal and there is a fixed negative terminal. So, these are basically you know what are called polarized capacitors and they are used basically for DC systems for DC circuits because of this ok.

So, when the electrolytic capacitors you know they are formed with either aluminum they use aluminum or they use tantalum. Tantrum electrolytic capacitors are you know able to give more capacitance per unit volume, but they are also more expensive you know because of the material you know itself; tantalum is more costly than aluminum. And you know the first step there are various ways in which these aluminum and tantalum capacitors are made ok.

The first step is if we take the aluminum electrolytic capacitors the first you know first thing that is done is to chemically H the aluminum foil ok. The idea is to increase the porosity to increase the area of this and actually it is increased almost 100 to 100 25 times you know that area by this etching process. Then you know a thin layer of aluminum oxide Al 2 O 3 which is having a dielectric constant of something like K is equal to 8.4.

Which means, that now the capacitance that what we are going to make will be 8.4 times, what it would be if there was air which was used here instead of Al 2 O 3 ok. So, that is used a form on the this etched aluminum foils body ok. Now this oxide then is actually covered with a liquid electrolyte ok, on all over this and it constitutes a plate of the capacitor. And next to this is actually a second foil of aluminum is actually placed which actually is used for the electrical contact, you know with the electrolyte and the other side of this aluminum foil is used as a negative terminal of the capacitor.

So, basically what you have is the aluminum foil which is etched then next to it is the aluminum oxide Al 2 O 3 with a dielectric constant of 8.4 which is working as a dielectric. Then, you have actually a the plate form with the help of a liquid electrolyte and then you have a second file of the aluminum coming in ok which is in touch with this electrolyte.

Now, it is this electrolyte which is present here which is the cause of low life of you know these aluminum electrolytic capacitors. Over the years over the time this electrolyte liquid electrolyte it actually escapes out of the unit and the capacitors looses its you know properties and its no longer a capacitor ok. The tantalum oxide you know it actually has 3 times the dielectric constant that an aluminum oxide layer can provide so; obviously, these are giving a significant difference when it comes to the size for example, size of the capacitor compactness and so on, but then as I said they are all they are very expensive. The third type is the multi layer ceramic capacitors which are made by you know stacking many layers of you know thin ceramic sheets ok and actually on these sheets a metal screen is printed.

So, actually you print what is called a metallic screen on top of this and there are several of these layers which are stacked ok and sintered to form you know a solid capacitor or monolithic solid capacitor. So, this is a ceramic capacitor that is how its going to look like and usually, you know it will be marked with an NPO or COG symbol. So, whenever you see NPO or COG mark (Refer Time: 27:12) you know that this is a ceramic capacitor. And usually they are actually available in 2 classes, class 1 and class 2. Which actually depends on their capacity to withstand temperature, what is the range of temperature in which they can wall and also how much is the variation in their value ok.

So, how much is their value at 25 degree centigrade and how much it varies at a given temperature. So, usually this is given in the form of a data and this is also alpha numerically it is actually printed on the capacitor; which can be decoded and we can find out what is the minimum and the maximum temperature; and what kind of deviation in the value of the capacitance that one can actually expect to happen ok. The thing is that you know these ceramic capacitors typically you have very low resistance values ok. And so they are highly desirable, but at the same time they are very expensive ok. So, compared to you know electrolytic capacitors for example, we have very expensive ok.

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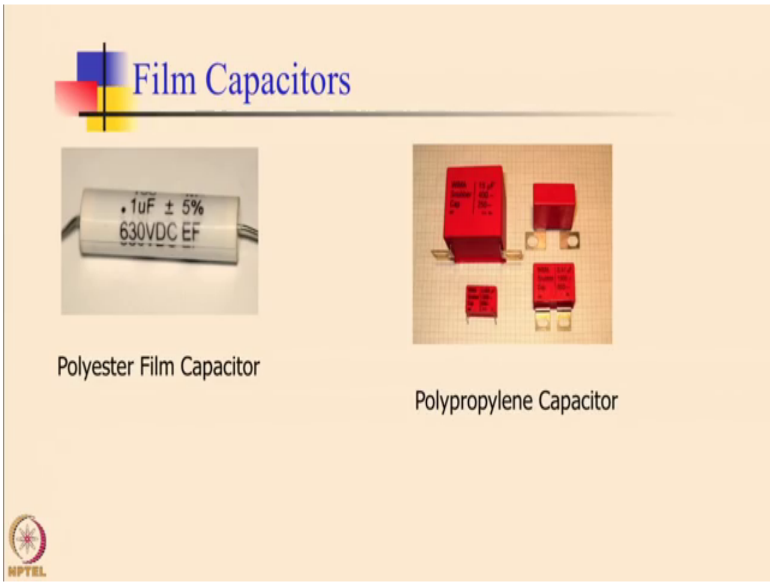

So, here are some pictures just to show you how they look like. So, what you see on the screen at the film capacitors the one on the left side is a polyester film capacitor a polystyrene film capacitors. So, basically polystyrene has been used in the film capacitors, you know as dielectric. And on the right side is a polypropylene capacitor so, you have actually the polypropylene plastic or the polymer which has been used between the metallic plates; or the foils when this particular capacitor has been made ok and we already discussed their properties and usefulness and relative advantages.

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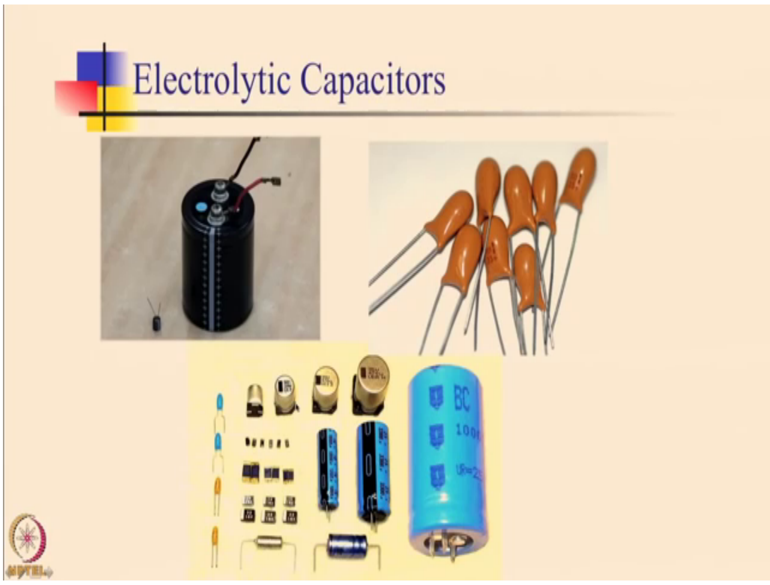

These are electrolytic capacitors these are the most popular and common ones on the left side at the top you see a typical aluminum electrolytic cell capacitor on the right side are the tantalum electrolytic capacitors ok and at the bottom you see a full assortment of various types of electrolytic capacitors that consists of aluminum as well as tantalum ok. And of course, depending on whether the electrolyte is wet or solid you also have the categorization of the electrolytic capacitors has wet, electrolyte or with solid electrolyte or the dry electrolyte. So, these are dry capacitors as they are called.

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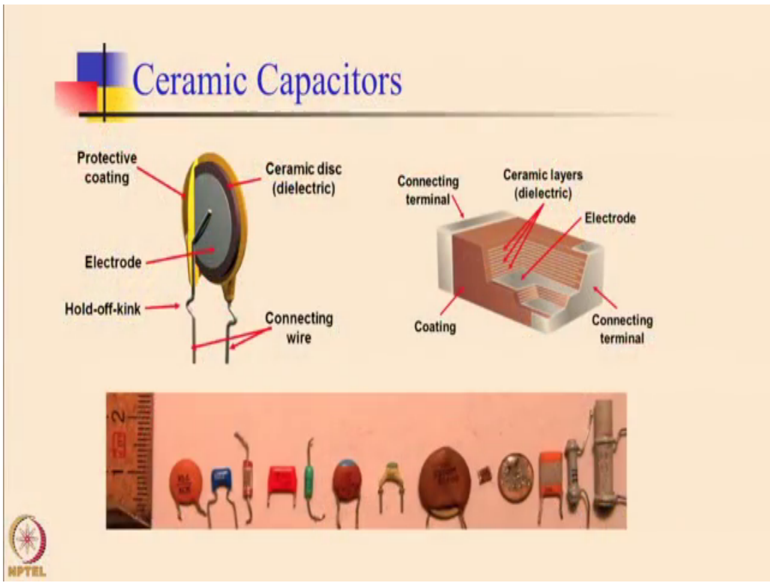

And here there is an assortment, which shows a ceramic capacitor on the right side is you know where you can see the stacking of the various ceramic layers with the metal printing on them. So, they are all stacked as you can see and the terminals are drawn electrodes are drawn so that you can connect the capacitor to the external circuit and the bottom you will see a variety of ceramic capacitors of all types. A capacitor is never pure in nature it has a parasitic component of resistance and inductance. A widely used equivalent circuit considering the effect of these parasitic elements of a capacitor is now drawn.

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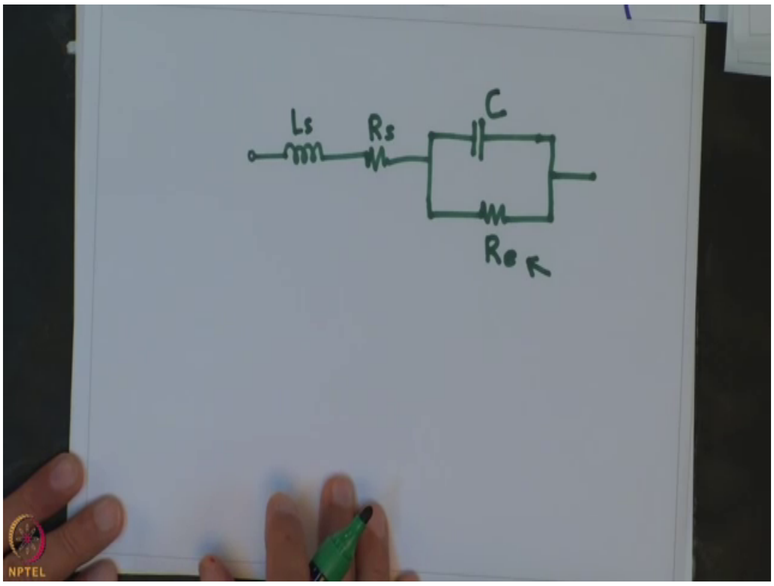

C is the main capacitance or the pure capacitor, Re represents, the insulation resistance or the dielectric resistance which is used between the plates of the capacitor Rs is the parasitic resistance which is on account of the lead resistance, Ls is the lead inductance which induces a parasitic inductance in the capacitor. While analyzing the capacitors or capacitor based circuits it is important to consider the effect of these parasitic components as they affect the performance of the system significantly.

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Now, super capacitors is a very special case energy storage devices there the super capacitors are actually also capacitors, but they have very different properties. One of them is that they are different from the conventional capacitors, that we just discussed like electrolytic capacitor and electrostatic capacitors ok. In super capacitors you know the charge is stored in an electrochemical interface that is formed between the electrode and the electrolyte. Super capacitors are also called double layer capacitors ok; what you see at the bottom you know there is a set of you know various types of super capacitors which are shown there; these are of various farad rating usually the super capacitors are available with very high capacity.

So, you know its not like micro farad or something they are actually farads, but the problem is that their voltage ratings are less ok; they cannot go for no more than 2.5 to 2.6 volts because, you know the distance between you know the 2 ends or the 2 plates. Which in this case happens to be the electrode and the electrolyte is very very small, it is only some molecules which are separating them and this causes a very high electric feed to be you know present, if you actually go for a higher voltage that will actually break and the capacitance property will be lost. That is why these are available only for very low voltage values, but their capacity is very high.

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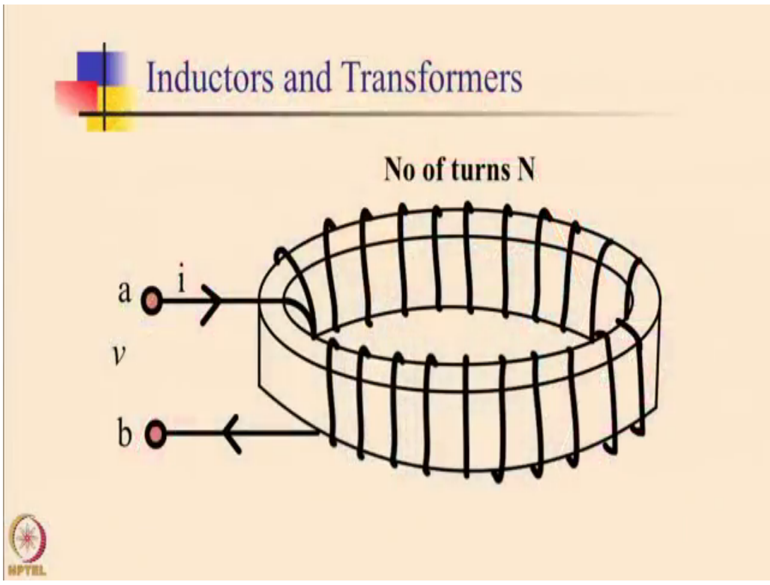

The other important components of a power electronic system are the inductors and the transformers. The inductors work as filters or snubbers or energy storage elements; which are fundamental to the working of certain power converters. The transformers are used for voltage or current transformation and galvanic isolation ok.

So, we are going to actually consider these things in details, but let me just tell you what are the various geometries in which these inductors and transformers are available. So, they are actually an inductor is nothing, but a wire which has been actually wound into a coil that is actually you know related with the flux linkage in the current. So, basically if I say lambda is a flux linkage then I can say lambda is equal to l i where l is the proportionality constant between the flux linkage and i.

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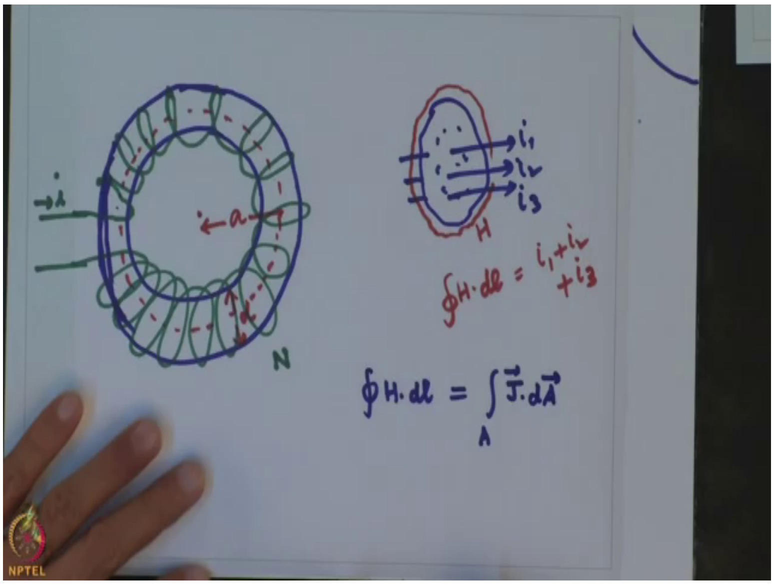

To understand the principles of inductor, let us consider a torus made up of plastic, there is a coil which is wrapped around it all over the periphery as shown. And there is a source connected to this coil which is causing a current i to flow in the coil. There are N number of turns, the width of the cross section of this torus is d, the distance from the center of this torus to the midpoint of the cross section of the torus is a, the dotted red line represents the mean flux part inside the torus. This is the basic structure of an inductor.

Now, if we apply the amperes circuital law; which says that if there is a surface and there is a current passing which is going through the surface let us say i1 i2 i3; then if I take the line integral of H the magnetic field intensity across this closed part which encompasses these currents. Then I can say that H dl line integral over this path would be equal to the sum of all these currents which are enclosed by it, using this amperes circuital law and applying it to this toroid this inductor that we have just defined. We can write H dot dl line integral and then this is equal to the surface integral of the current area density into dA where, dA represents an elemental surface area.

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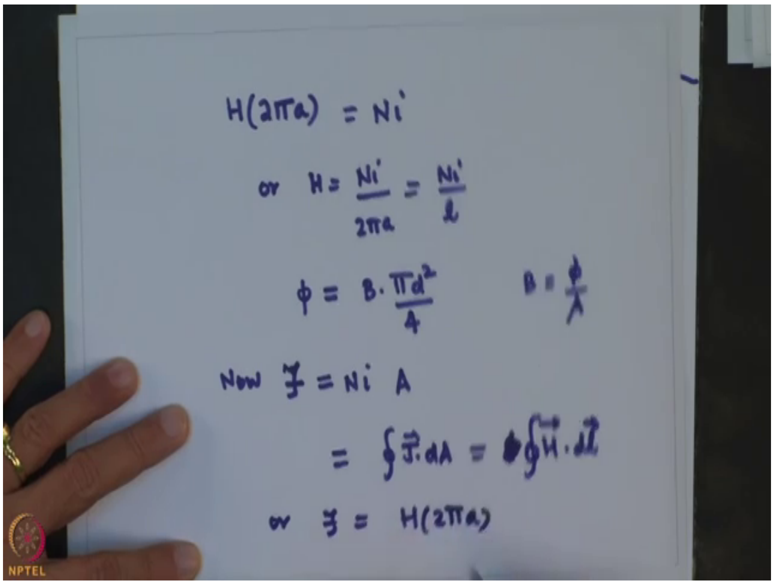

Assuming that, d is much much smaller than A. We can write H into 2 pi a which is nothing but, the mean flux path length is equal to N into i or H is equal to Ni divided by 2 pi a is equal to Ni by l. L is the mean magnetic flux path length. Since, a is much larger than d, it is to assume that the flux density B is uniform across the cross section of this plastic torus.

The magnetic flux density B is related to the magnetic intensity H by the relation B is equal to mu naught H where mu naught is the permeability of the free space. And we can therefore write, phi the flux which is established in the torus equal to B into pi d square by 4. Where we used the fact that B is nothing but phi over A the flux density or the area density of the flux.

Now, we can say that this flux is established due to the MMF the Magneto Motive Force defined by F equal to Ni amperes.

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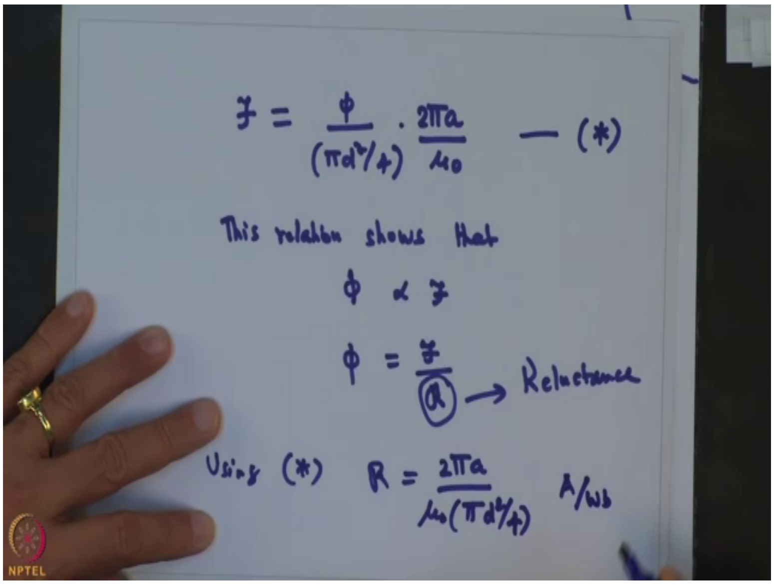

So, F can also be written as J dot dA surface integral is equal to H dot dl line integral. Or we can say that F is equal to H into 2 pi a; which can be written as phi divided by pi d square by 4 into 2 pi a by mu naught. The this relation shows, that phi is proportional to the magneto motive force F or using the proportionality constant.

We can write phi to be equal to MMF divided by R, where R is defined as reluctance. This relation may be compared with the standard electrical expression, in the electrical engineering which says correct is equal to voltage divided by resistance. In the case of magnetic circuits, it is the flux that is equal to the magneto motive force which is the equivalent of the voltage divided by reluctance; which is the analogous of resistance.

And using the relationship that we have got here let us call this as relationship star. So, using star I can see that this reluctance has this expression ampere per weber that is the unit of the reluctance.

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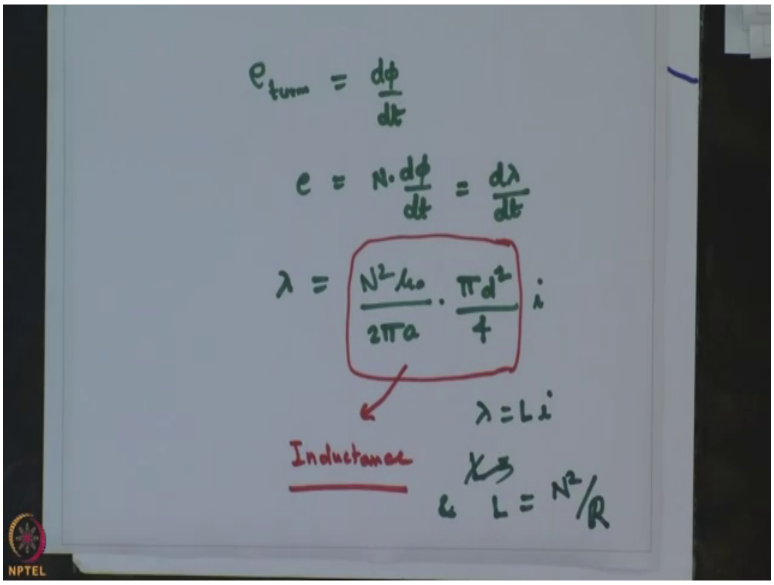

Now, looking at the torus and this inductor arrangement with N turns through which i is flowing causing a flux phi. We can say that, each turn is associated with an emf e turn given by e tor equal to d phi by dt therefore, the total induced emf considering all the turns is equal to e equal to N d phi by dt and if N phi is denoted by lambda, which is also called the flux linkage. We can say that it is also equal to we can also say that e is also equal to d lambda by dt or we can write that lambda is equal to N square mu naught by 2 pi a into pi d square divided by 4 into i.

Now, it is this expression that relates lambda with i that is called the inductance; which actually is like a proportionality constant between a flux linkage and the current. This should be compared with how the definition of capacitance arose when we considered the relationship between the charge and the voltage between 2 conductors which one having a charge. Another expression that can be written from here so we can write lambda is equal to Li and L is equal to we can show as N square by R just by manipulating the relationships that we have obtained.

Now, instead of the plastic torus suppose this torus is made up of a magnetic material, then it is found that the value of the inductance that would be achieved would be much higher. The use of core is therefore, a very highly desirable things when we try to design and fabricate inductors and transformers. The magnetic core is made up of magnetic material which is usually a ferromagnetic material or its alloy. Each of these magnetic material is actually characterized by its unique BH curve. Since we know that B is the flux density flux per unit area and H is nothing but, N into i the number of turns into the current we actually can get a BH curve by plotting i versus phi.

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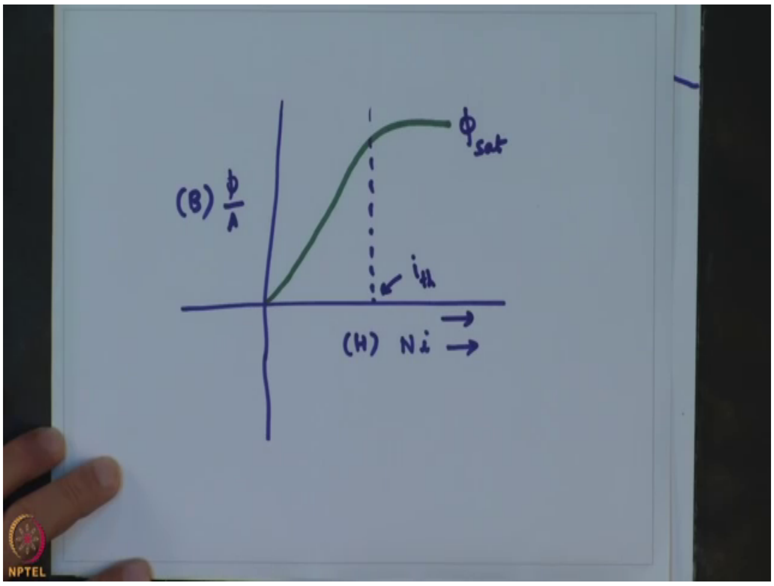

I will just draw a typical BH curve, considering only one curve in a typical BH curve would appear something like this; let me also mark the N into i on the x axis which is nothing but H and also phi over A on the y axis which is nothing but B and that is why its called a BH curve. So, what we see on the curve is that after a certain threshold value of the current assuming that the number of turns and the dimensions of the core are fixed. We can say that the flux phi saturates, no matter how much we increase the current after that the flux does not increase it said it remains at its saturation value, which we can denote as phi sat.

It is important that whenever we are dealing with a magnetic system we do not operate our system at currents more than a threshold value. So, if I call this to be a threshold value ith my current should not exceed ith to avoid saturation of the core. Saturation of the core leads to the shorting of the electromagnetic system and it actually will draw a large amount of current, which might cause other safety issues with the equipment or with the circuit. A transformer is just like a couple inductor.

Now, we just saw an inductor a coil which was wound around a torus. Now, if there are more than one windings more than one coil then this could be a coupled inductor or this could be used as a transformer; we will look at these details a little later. It is important to consider the equivalent circuit of an inductor taking into account the parasitic components that might be present in the inductor. Therefore, an inductor is never a pure inductor it also has a parasitic R and a parasitic C in it.

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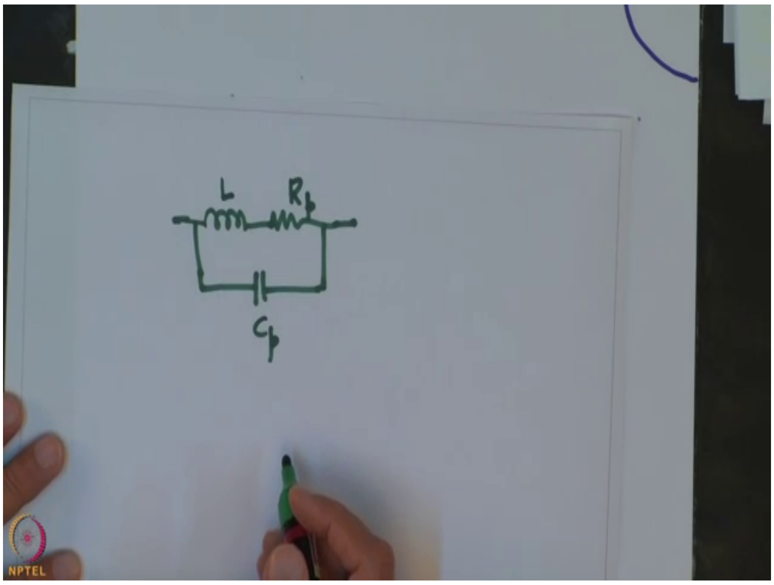

The equivalent circuit of an inductor maybe drawn like this; so this L is the main inductor, but along with it there is a parasitic inductor Rp and a parasitic capacitor which is because of the inter turn capacitance Cp. And whenever we are considering the inductor we must consider the effects of these parasitics. So, that we know that the operation of the circuit where this inductor is used will not be affected by these parasitic components.

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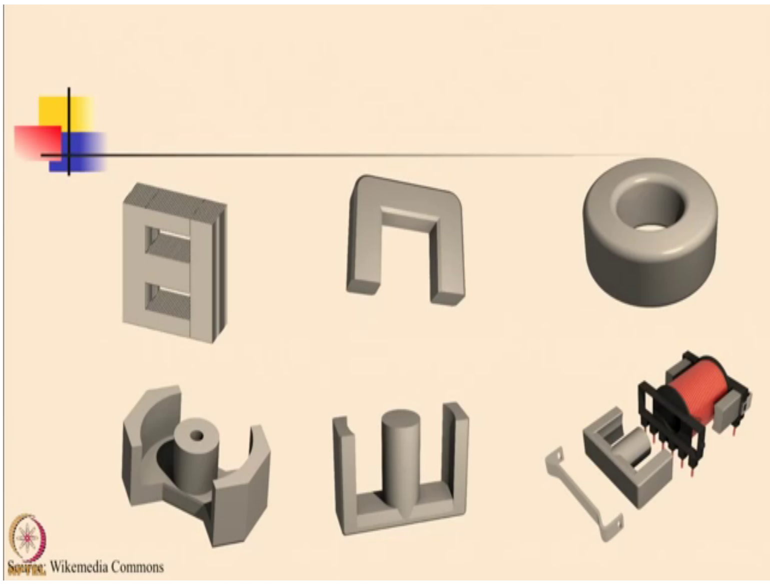

There are various types of course, the various types of geometries which you can see on the left side top is laminated low frequency pour that is used for low frequency applications. Typically this is a metal, which is made of silicon steel or which is also called transformer steel for our regular low frequency transformers and inductors this is useful. What you see in the middle on the right side in the top row is a C type core.

Now, another type another C type core is taken and merged with it and the winding is faced in between them. So, that the flux created by these coils it actually is limited by this core which is a C type core. What you see on the rightmost side in the top layer on the top row is you know a toroidal core now here there is a problem with the winding because, they are not open its a closed system.

So, you need something you know you need really a occasions winding though it can be done through machines; it can be done in an automated manner, but it is then turns out to be expensive and cumbersome. What you see on the lower left corner is a pot type core ok. So, basically you can see a pole in the edge of centre or on which the winding is placed and then this entire thing is closed from the top ok.

So, there is a exactly analogous element part which is exactly going and sitting symmetrically on top of this and will provide a closed magnetic path to the to the flux; that will be caused by the current that will flow through the coil. On the right side of the center of the lower row, you see an e type core and it works almost a same way. As the pot core the explanation is always the same only thing is the shape is different and this is actually an open core.

Now, what I show on the right side, bottom corner is actually an image where I have shown a bobbin. Now this bobbin is a structure which is realized either of hard paper board or plastic on which you can actually bind the your coil your bindings, you can put on that and then you can insert the magnetic core like for example, it is shown an E core is being inserted.

So, one has been inserted already from the fight right side and there can be one which is inserted from the left side as you can see and these are symmetrically inserted inside and due to the dimensions they exactly match with each other; they touch each other inside the bobbin and a closed path is formed for the flux which is created by the coil which is been wrong on this bobbin. And on the leftmost side there is a; there is a metallic clamper, which is used to actually hold the two E's of the core together. So, that they do not move.

So, that is how you realize. So, this could be if it is a single coil, this could be just an inductor or this could be actually places 2 coils where it could be working as a coupled inductor or it could be working as a transformer. Likewise more and more windings can be associated with any of these magnetic systems and you will therefore get the corresponding magnetic component and it actually varies as per the application. So, for various applications you will have various different types of these magnetic components which would be created ok.

So, with this I conclude this session and now in the next session we will start looking at some actual power electronic circuits and we will try to see, what exactly is required to analyze? What exactly is required to design them? What exactly is required to understand them? So, we look at those aspects in the next lecture. I thank you very much for your patience and attention.