Electronics Enclosures Thermal Issues
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Lecture – 04
CEDT worked examples 1

This is the second what you call part of the lecture, where we actually get down to how do we do some simplified calculations. And how is the temperature kept under control.

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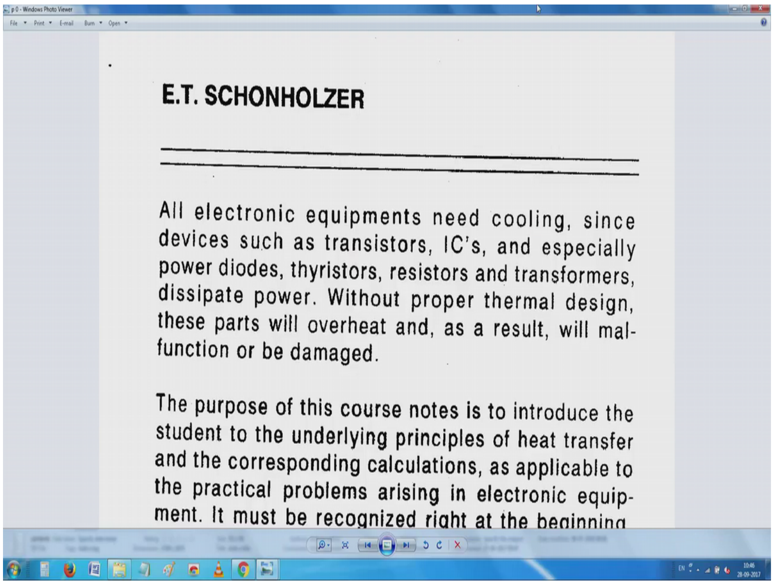

As I have pointed earlier, you about that notes. A professor schonholzer worked on this for quite some time, and when these note down so that students can understand; what otherwise is likely to be a threatening and complicated course; which generally heat transfer people spend a lot of time. And then right now we will start here.

So, I have read up read it out yesterday without looking at the notes saying, we need to keep the big temperatures down such that the components do not fail or do not malfunction. Most components have this problem of heat interfering with their function. Simplest thing I can what is obvious what you can talk about is the temperature coefficient of resistance of a normal resistor. So, as you see as you increase the, what you call temperature, some of them have a positive temperature coefficient, some of them have a negative temperature coefficient. Best example we can give is the good old incandescent bulb.

We all know, or if you look it up you will notice that. Typically, if you take a 100-watt bulb, it takes around 450 milli amperes with our, what you call 230 to 250. This thing while it is running which is good, a 100-watt bulb; which takes around you know 0.45 amperes say 230 volts. So, typically the dissipation is expected to be around 100 volts. Again, I tell a around 100, because unless we actually measure the current and the voltage, we cannot compute that thing. Now comes the little bit of an unknown, well known, unknown, the moment the bulb heats up in the steady state this takes this.

But in the starting there will be an inrush of current because the so called cold resistance of an incandescent filament is slow. On the worst cases it can take around 10 times it is capable of taking 4 and half amperes. Sometimes, you cannot even measure it. Because the rate of change of the current di by dt is. So, what you call high very quickly, the peak current comes back and stabilizes to the rated current. While in the case of a device like a as you said a static, I am sorry passive device it is not a very bad thing to do. First of all, it ensures quick heating. Secondly, the total thermal mass of that is sufficient. So, that once it reaches the temperature there is a minor what you call self-regulation in it.

If the, what you call voltage falls down or goes down, there is something which happens; however, in the case of active devices typically, or what you call semiconductor junctions there is a that voltage is very critical. At if it inks increases a beyond a points suddenly everything buzz. There will be a puncture through and if you take a typical transistor npn transistor happily there will be a fantastic puncher through so that between the collector and emitter there will be a dead short. And which is a very easy way of checking a transistor what do you do take a transistor and input a multimeter and check a various leads and you know forward diodes and all that stuff.

Now, can you look at my notes here you see one of the things is, without proper thermal design parts will overheat and the result will malfunction or damage case of passive components. There is one way are this thing and then second point we are slowly coming to this saying.

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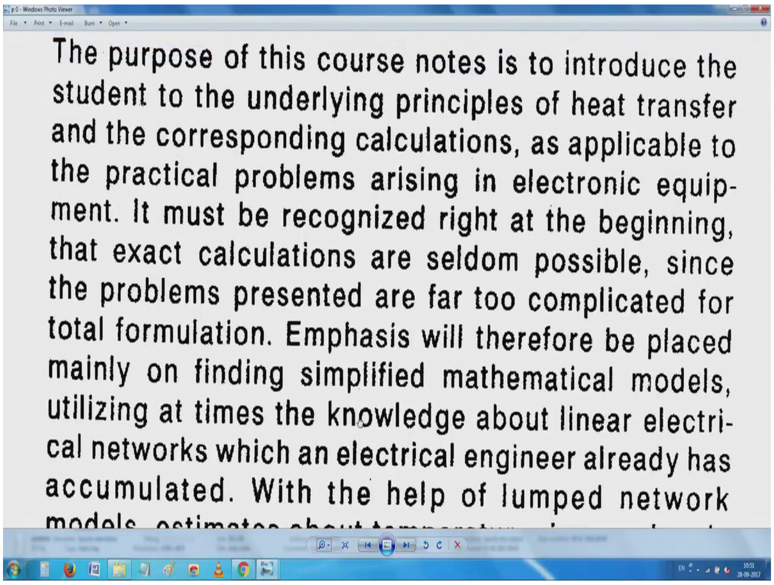

The purpose of this course and the notes is to introduce the students to underlying principles of heat transfer, calculations as applicable to the problems arising in electronic equipment. It must be recognized right at the beginning, that exact calculations are seldom possible since the problems presented are far too complicated for total formulation.

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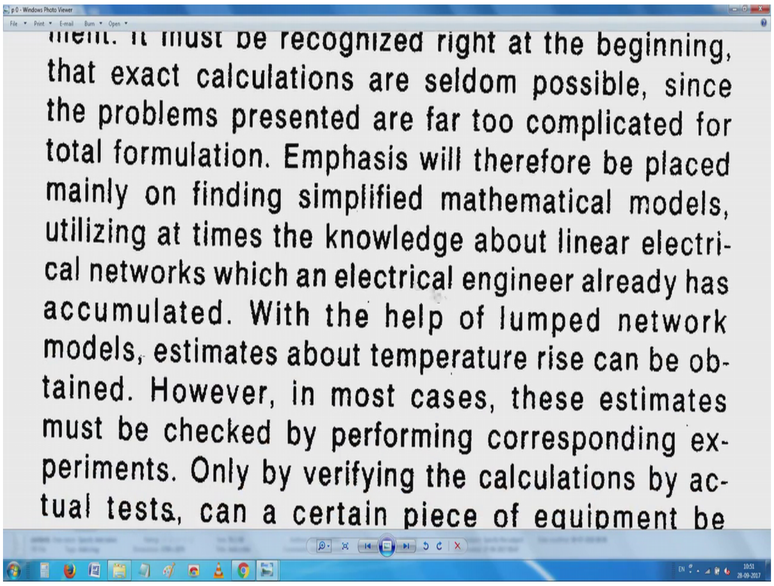

Emphasis will be placed mainly and finding simplified mathematical models, utilizing at times and knowledge about linear electrical networks which in electrical engineer already knows. I hope you understand this. I am sorry, for I mean allow me to reframe it. I am sure you will understand this, and it is relatively easy. In fact, we have online network or what you call resistive network what you calculators, if you put all the resistive elements and if you attach them. You will know that given a voltage here eventually what will be the current that passes through it, and what will be the voltage at that point.

So, here we come to an important what you call electro thermal equivalent. One of them is electrical potential is a little similar to temperature. And electrical current is similar to the flux that is passing through. And then the total voltage there now correspondingly corresponds to same thing, the potential into the flux that we have. It makes sense, absolutely no problem most places, but did not easy to understand. Typically, when in the early times when the led is came, the merchant establishment kept on repeating something which is taken in turn from the compact fluorescent lamp. CFL nothing saying this is a 10-watt CFL. It is true, but the function of a lamp is to illuminate nothing to do with the wattage.

So, they will put a bottom thing saying this 10-watt CFL will replace typically a 25-watt incandescent lamp, with highlighted letters with the same total light output. In that case the total light output is the lumens. But if you have bought one of those and try to replace it around in your house you will notice slightly something which is different. One of the first things you will notice it appears to dimmer. Second thing you will notice is the color does not seem to be what you are accustomed to in a accost incandescent lamp.

So, we have other complications which are arise out of it. I will leave it there same thing here; electrical engineer already has accumulated. With the help of lumped network models estimates about temperature rise can be obtained.

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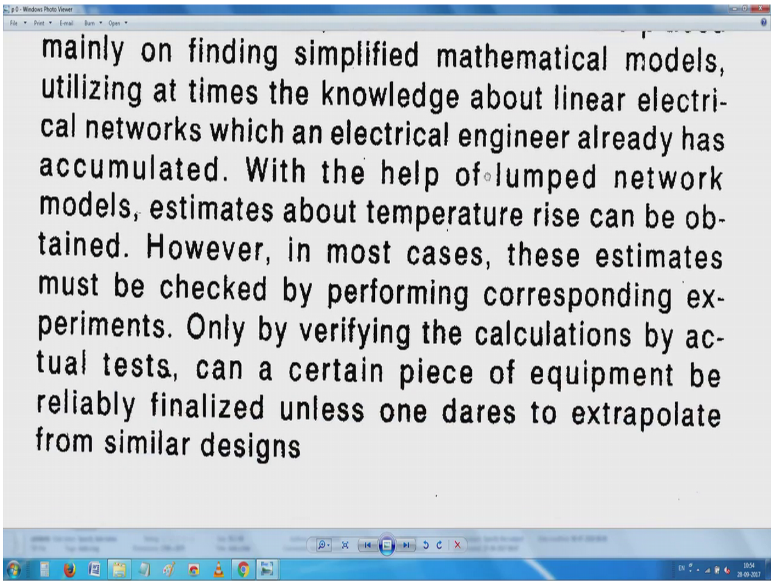

These estimates must be checked by performing corresponding experiments. Only by verifying the calculations by tests, in a certain piece of equipment be reliably finalized unless one dares to extrapolate from similar designs. We have this issue about the similar design saying, some are scalable, some are you can use the same model here, otherwise you need to do it again.

Best example is if you look into a fan catalogue. They will tell you 2 different things. One is a static pressure. Another is the amount of air flow; which is CMF. Static pressure so many inches or millimeters CMF and then we assume that static pressure and the CMF can happily be multiplied and it is useful. But it is the same way as you take a small cell. I have a small cell inside my hearing aid; which is typically a 1.5-volt zinc air cell. And I am sure this 1.5 a zinc air cell is very, very different from the pentor cells, the double a cells which are useful everywhere. Which are again very different from in the chemistry what you have in the double a itself we have half a dozen chemistries. Starting all the way from the simple zinc carbon, then you have the, what you call zinc chloride, then you have the rechargeable.

Then eventually right now you have the lithium ion cells. And a new thing comes into the picture at that time, what is it there is an internal resistance and you try to discharge it the internal resistance comes in 2 way. So, if you take the model of a cell, 2 very simple things will come. First of all, there is a theoretical electrochemical difference, and what it is capable of giving a nickel cadmium cell is capable of giving 1.25 volts. And a zinc carbon cell typically is not 1.5 it is 1.65 volts. So, if you take a one of the zinc carbon cells directly, which is in the blister pack and fresh, carefully without opening the blister pack make 2 small things, and measure with a multimeter, invariably it will show more than 1.6 or 1.65. It is a good indication that it is new slowly it will come out.

But that the first instant the peak voltage will come down. And what causes it is the internal resistance. And what the why it loses voltage is across if you put one more resistance, it will represent the self-discharge. I have given you a very common example; so that, you can understand what these are you understood know. Again, this resistance seems to be varying when we are pushing in current in a rechargeable cell, and then when you are what you call trying to draw current out of a rechargeable cell. So, which is probably the reason why it is very difficult to make a fuel gauge for a battery-operated car. We have a problem there.

So, but the good point is if you have a proper model of that, it is very easy for us to predict the performance of a similar chemistry. So, one thing called the model is there which takes kind of all this, if you have the patience know check for that. Now coming back, we can reliably finalize if similar designs already exist if somebody else has done. So, we will start with the first point here.

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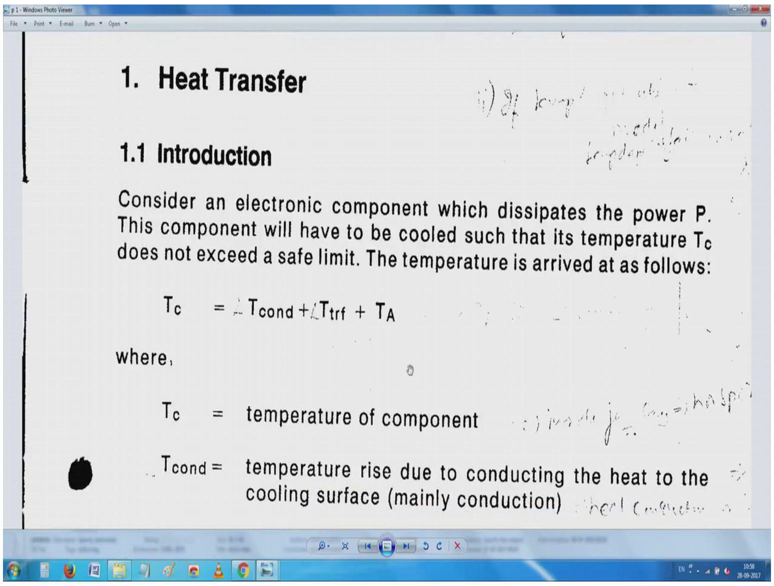

Typically, the starting point is this. Imagine there is a component c invariably Tc means know, at least in these equations the bottom they have written saying the temperature of the component. And the extreme right we have the ambient temperature, temperature of cooling medium.

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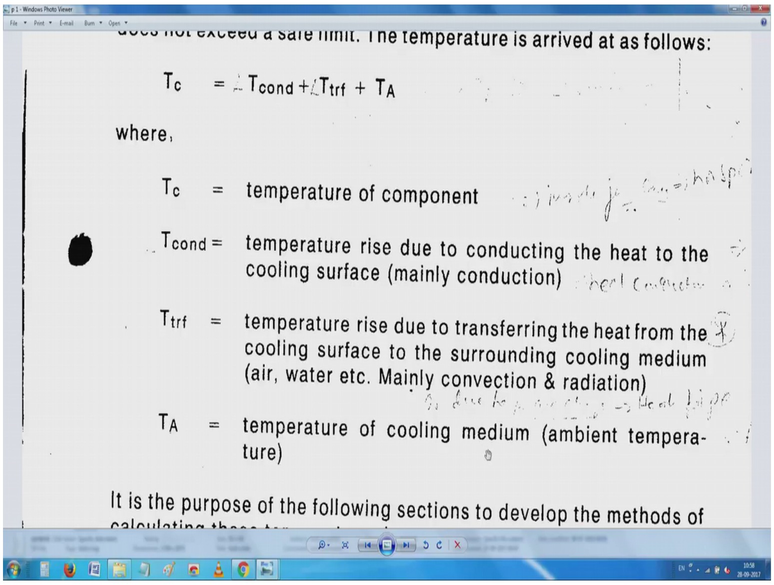

In this case it could be simple air. And it could be another, what you call surface in contact. And we have 2 important things that being introduced. One is temperature rise due to convicting the heat to the cooling surface.

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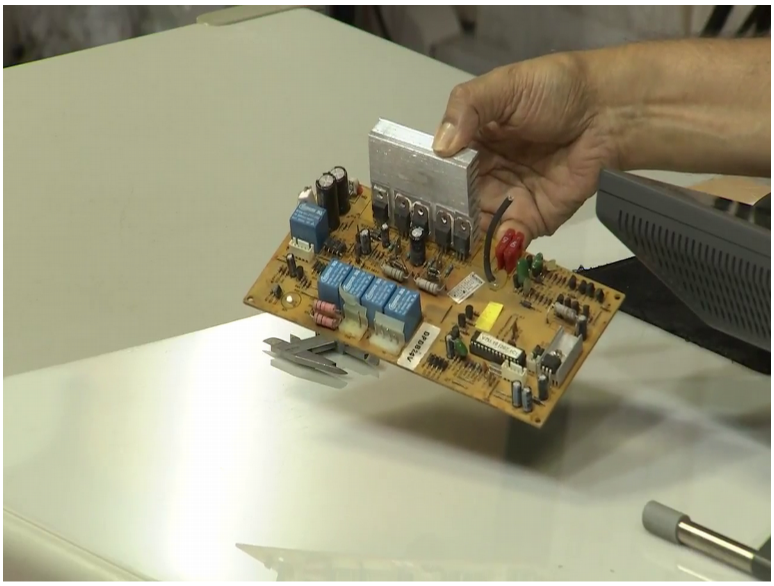

And then in the back can you see what I am holding with my thumb you have a that the aluminum heat spreader, and then you have to I am sorry, 5 some power devices. So, very first fundamental thing is the conduction between the power devices, and the heat spreader what we have here.

Now, if you see the cross section of the heat spreader. You have all these very, very beautiful thing. I have actually unscrewed it and kept it reading you are seen here.

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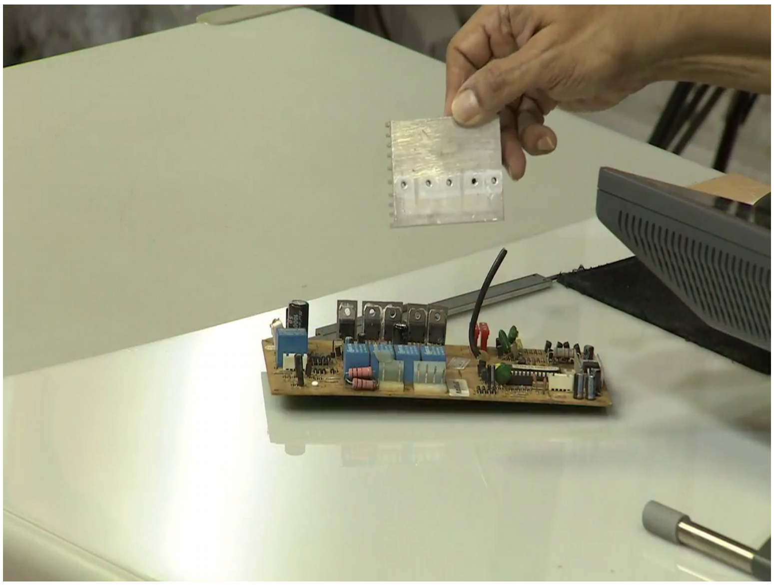

Because the worked example talks about that white thermal paste, that is often used with that. So, there is a thermal paste and then again coming back which I was talking to you yesterday. See each of these devices has a small insulator stuck on this. I will try to remove the insulator can you see; we have a small insulator in this case. It is a, what is called a sill pad, or silicon I am sorry, silicon pad.

So, while so, this my notes talks here about temperature ratio to conducting the heat to the cooling surface and then temperature ratio to transferring the heat from the cooling surface to the surrounding cooling medium mainly, convection and occasionally by radiation. So, I will just scroll it up a little. The purpose of the following is to develop methods of calculating the typical temperature rise.

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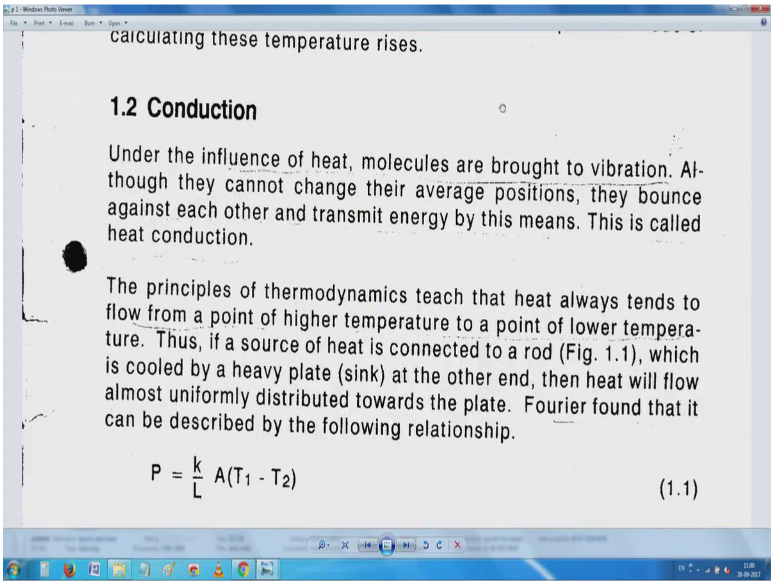

So, you see here, we all studied in our physics saying how energy is transmitted.

So, I am neither a mathematician nor a physician. I am sorry, a physicist, please read it and then if you have anything else you are welcome to get back the magic thing is saying heat is conducted by no change in mass. The basic material does not change the position. The molecules or whatever it is stay in position, and then some vibration takes place and there is a energy in transition. It is not a fluid which is movement.

Because, often now when we think about a current there is this is very peculiar thing a current as in water that is you know something is moving, but electrical engineers understand, that it is not a fluid in moment it is a energy in transition. You have a high energy state to a lower energy state, and this is how it is typically heat conduction involves transmission of energy by vibration.

The principles of thermodynamics, teaches that heat always tends to flow from a point of higher temperature to a point of lower temperature.

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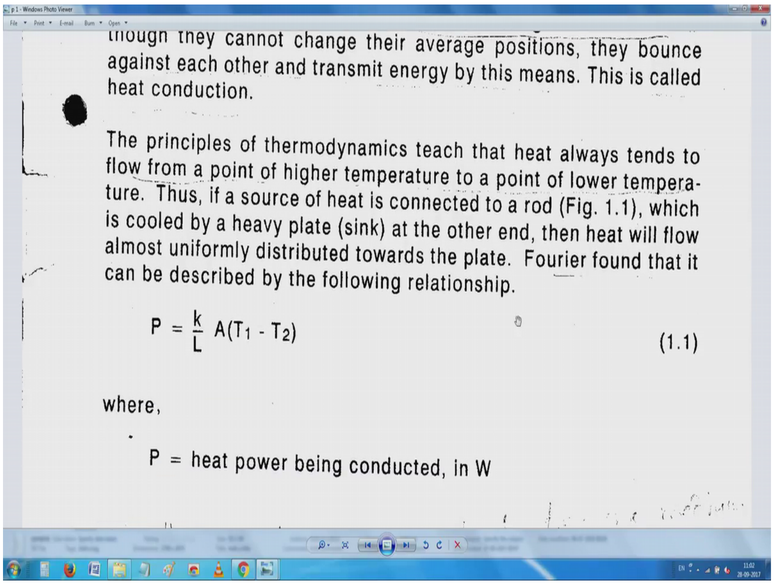

The source of heat is connected to a rod in the next thing, which is cooled by heavy plate. Flow will flow uniformly distributed towards the plate. Fourier found out that it can be described very simple equation. One is the, we will start with watts; watts are a useful thing, because everything can be accommodated in the k that is shown here. If you increase one of the temperatures, and keep the other temperature constant; obviously, more power is passed. Alternatively, if more power is passed, the temperature raises on it is own; which we have noticed in most of the places.

If you anytime any you know increase in temperature is there, it will more heat is conducted through this. Now the second important thing is a lot of it depends on the contact area. I have this small sill pad.

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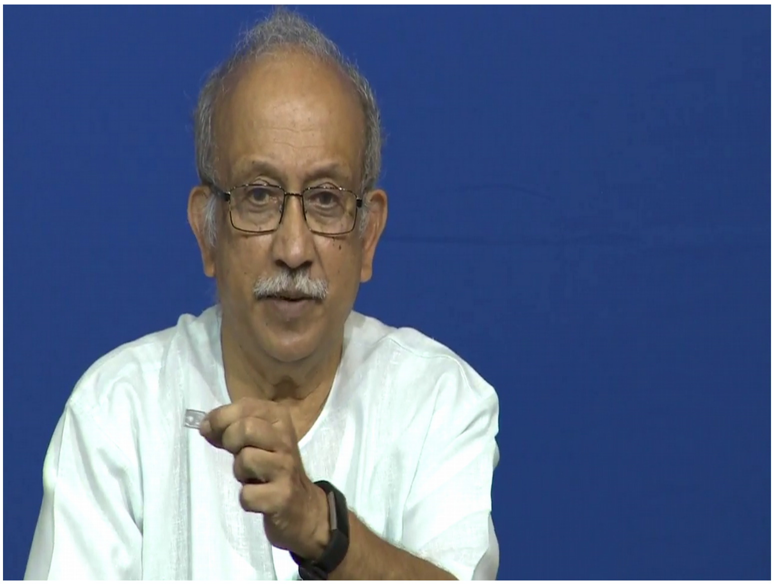

I will keep it here. And this can you see here typically it is around you know 12 mm by around I think 18 mm. A lot depends on the area of contact. While this is being, the actual area of contact this actually represents what is given here on the back of this to 3 package.

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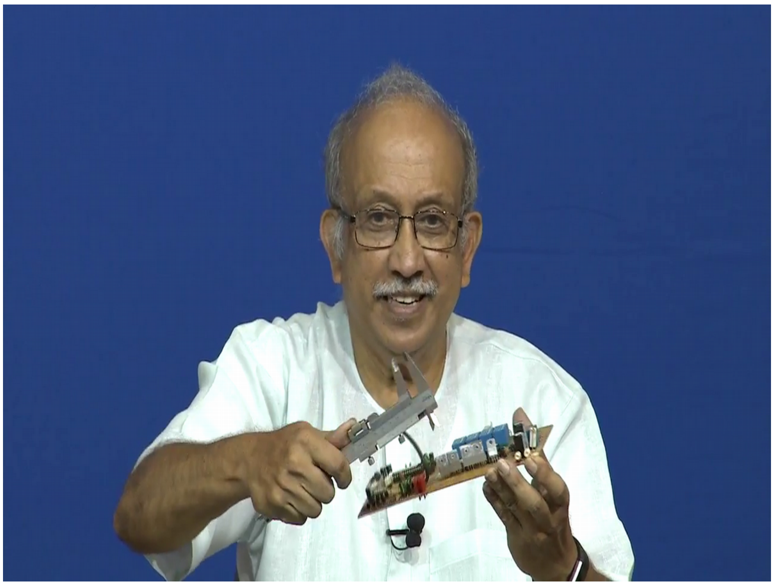

You have seen this here, we have something here, we have something here.

So, if I take a what you call, I am sure you are familiar with this caliper. So, we have something here, and then we also have a width. I can read it, but I do not want to read it.

Because I want you to go and check or much easier is for you to go check on the manufacturers catalog, he will give you exactly what is the dimension of the conduction plate that is attached to the transistor. Usually there is no issue about it. Usually at the surface what we are interested is surface not so much interested in whether it is aluminum, whether it is copper, or this separate doped some other material.

But what we are interest interested is the area. So, the more the contact area; obviously, more power can go easy to understand. Next comes is something which is not very what you call intuitive that is that L, big L. This L represents the length around the conduction. Long conduction, how long it is conducted? You understand know how far it is conducted. Some of you I am sure are very familiar with the high school or maybe middle school example of conductivity of materials.

So, you have a round cup. That cup has 3 rods attached to it. Made of different materials one of them is usually copper, another is that steel rod, and third will be usually an insulated rod or one with this thing. So, they put hot anything oil or something. And then each of these rods which are down typically have a small slider attached to it.

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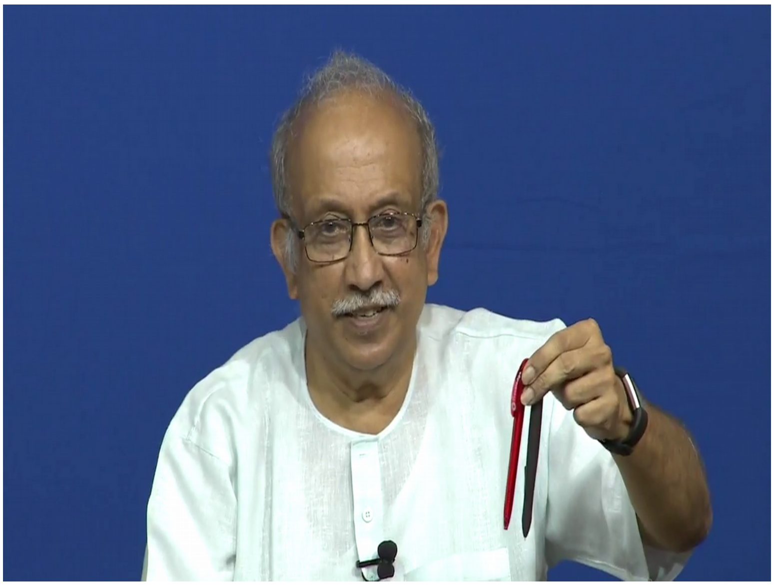

Imagine you have 3 of these rods, and then you have a slider attached to I will keep the bottom approximately same. Imagine you have a slider attached to it. We have 3 of them. And the top hisses firmly braced to a container, and we pour hot oil into that. And before starting the experiment, these are fully immersed in hot water, and coated with wax.

We have boiling wax; you coat it and then take it out.

And along with it you also put the slider push the slider up, often keep it horizontal let it dry up see what has happened all of them have reached the room temperature and the slider is up in that it is nothing but a tube some of them usually, there will be sometimes there will be a what you call a scale attached to it. Otherwise there will be a pointer so that colossal students can see it.

Now comes the interesting experiment. If you fill it with hot water of the waxes it. The one which has the highest conductivity, in this case now let me say this is copper. This slides very fast all the way almost to the bottom. Because the teacher would have done the experiment earlier and the one which has a slightly lower conductivity, it only comes a halfway. The one which is not a conductor it stays on the top; which is a good starting point for us to understand. The length of conduction also is important, how far away the conduction is.

So, I hope the next slide starts this properly.

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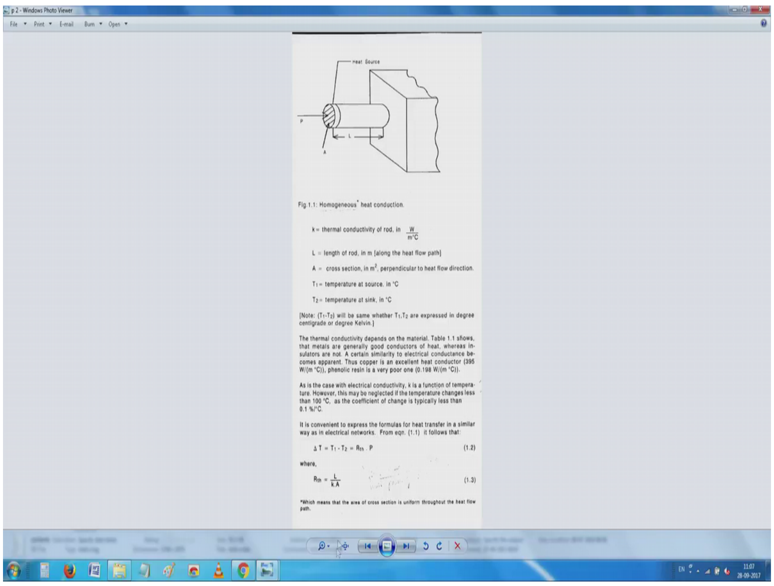

It didn't get scanned then you do not worry about it. Yeah, I will start here; I think I will get back next time. After doing several experiments, this proportionality basically this proportionality constant has been replaced by sorry, the proportionality symbol has been replaced by a constant to make things easy. Since this is already in degrees centigrade.

And then you have an area, and then this is what you call m square, this is m and this, whole thing know per meter per degree centigrade. The thermal these things know has been made directly here.

This typically you know gives you of various materials.

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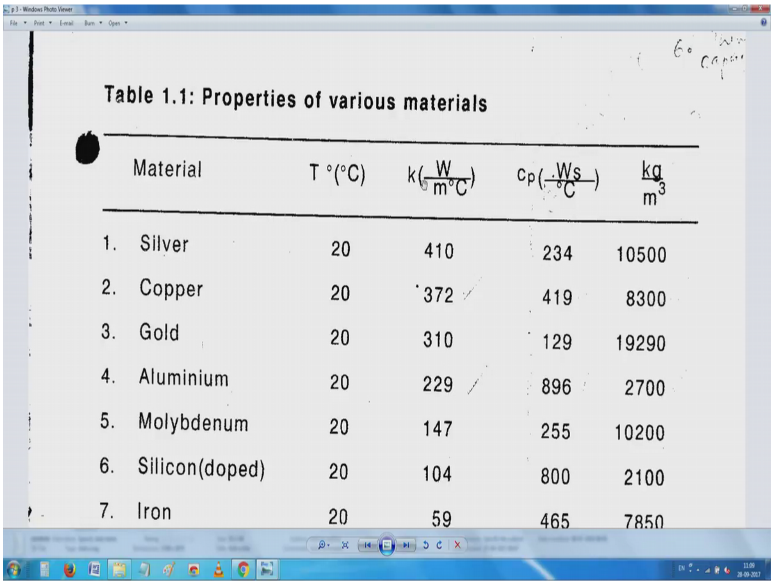
Table 1.1: Properties of various materials

	Material	T °(°C)	$k(\frac{W}{m°C})$	$c_p(\frac{Ws}{°C})$	$\frac{kg}{m^3}$
1.	Silver	20	410	234	10500
2.	Copper	20	372	419	8300
3.	Gold	20	310	129	19290
4.	Aluminium	20	229	896	2700
5.	Molybdenum	20	147	255	10200
6.	Silicon(doped)	20	104	800	2100
7.	Iron	20	59	465	7850

You see here for example, silver know k is watts per meter degree centigrade. Have seen this? And this I will come back to the, this thing completely. So, you have here we have already know things like for aluminum for a silver copper everything. Beautifully, the k has been defined. And it is available on the, what you call most textbooks. It is available if you go down, we will come to the somewhat what you call irritating and not so.

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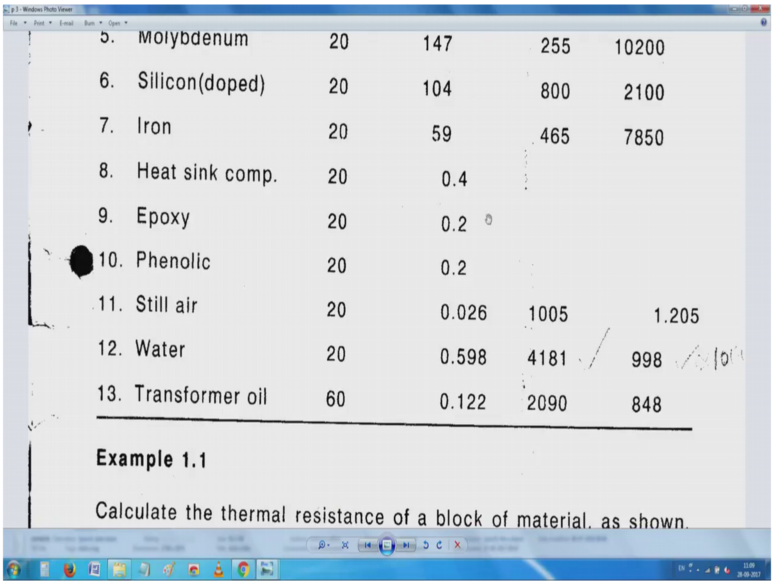

5.	Molybdenum	20	147	255	10200
6.	Silicon(doped)	20	104	800	2100
7.	Iron	20	59	465	7850
8.	Heat sink comp.	20	0.4		
9.	Epoxy	20	0.2		
10.	Phenolic	20	0.2		
11.	Still air	20	0.026	1005	1.205
12.	Water	20	0.598	4181	998
13.	Transformer oil	60	0.122	2090	848

Example 1.1

Calculate the thermal resistance of a block of material, as shown.

Great thing you see here we have so many of these things here. You have seen that probably epoxy something which we use for you know tightly bonding to something. Very, very poor compared to aluminum you see how far how bad it is aluminum right now here now shows something likes 229, and this shows 0.2 thousand times less, bad, isn't it?

So, you cannot use typically a 2-component adhesive or your superglue or anything to put something saying, hey it is working your so-called heat sink will be cooled. You will have probably the coolest heat sink you can imagine in the trade. But then you have components which are hot, probably it does not matter. Sometimes it does not matter, but a lot of times it matters. And heat sink component is only slightly better, it is only about twice. And we come to the real culprit here air, air is even one order lower.

So, if you compare the 220 in with this 220 0.2. It is a 1,000 times less conductive. Then the what you call aluminum. So, the slightest air gap between 2 contacting surfaces creates this problem. So, even if I were to take these beautiful measurements. I take this beautiful contact measurement.

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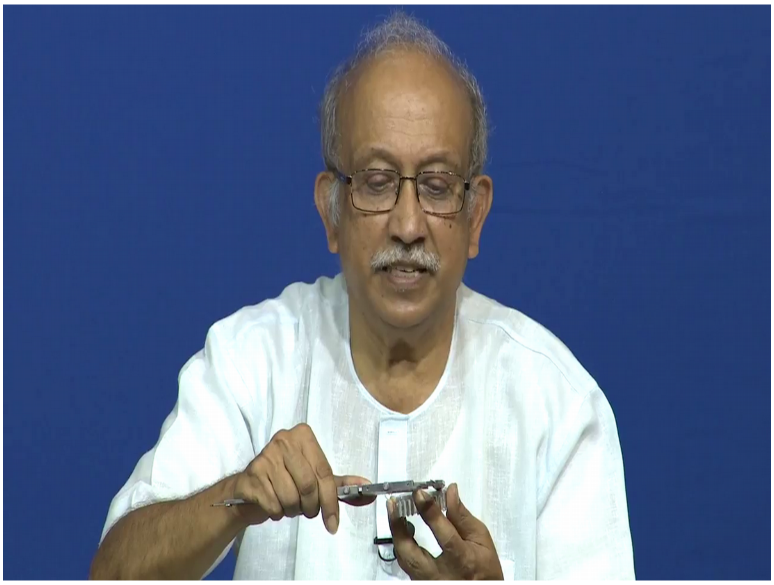

right now, I can see yeah, this is yeah, I exactly I mean I am for sure it out it is a 18 millimeters approximately, and here it is 12.

So, 12 by 18 a millimeters, that much area is available. Imagine when both the surfaces are in contact. They have a little problem, because the surface has more wrinkles than my old skin. A real surface is probably going to look like this because it has undergone a manufacturing process typically by drawing. So, if you look at it though you cannot look at it here.

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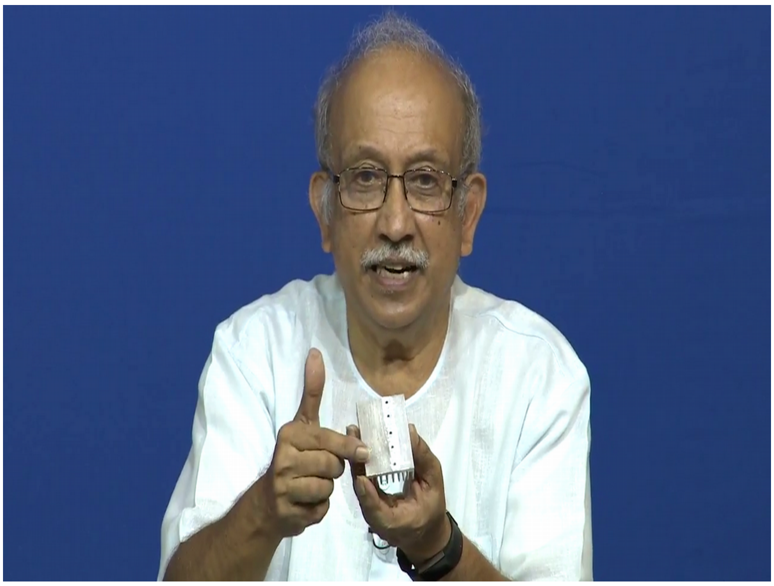

This has been cleaned, somebody has emery detrained all that. So, if you have to mount this semiconductor device directly on this. The chances of air pockets being there are very high. It is not very different even if you use a heat sink compound. First what you call shocking revelation here if you have not gone through it before sorry for repeating.

If you are one of the already people have tried it. You will notice the obvious way what they do is all the components already come with a very good surface finish. Typically, in the words you know a triangles and all are used, and what you call some more technical things about what is the rms value of the surface and all that is given; however, this heat sinks and all do not come with that type of 3 triangle finishes. They do not come with a beautiful array and so on like that.

So, what is done is they try to give a clean cut with the surface millett. Then they try to use a lapping compound and lap it just like you will do with a, your valve things in your automobile. All automobiles sitting in instantly inside the automobile you cannot afford to have a gasket. It is metal to metal sealing absolutely. You have a opening like this, and then the what you call car valve you know the exhaust and especially exhaust valve sits firmly in that. And the only way of making a, what you call make them sit firmly is they keep both the thing and then lap it by rotating a lapping a thing. A lapping component is used.

In the case of power semiconductors and all that know, those techniques are they continue to be used. As a compromise; however, if you have copper; which is slightly what you call malleable. And somehow you can ensure that no air is get trapped inside, you can also use things like a copper gasket. Follow know you use you see this copper gaskets occasionally on the exhaust manifolds of your automobiles. It is actually a very complicated thing. Now coming back if you go down, you will see that the thermal resistance of a block of material between 2 things varies also. See here, I will come back to this later.

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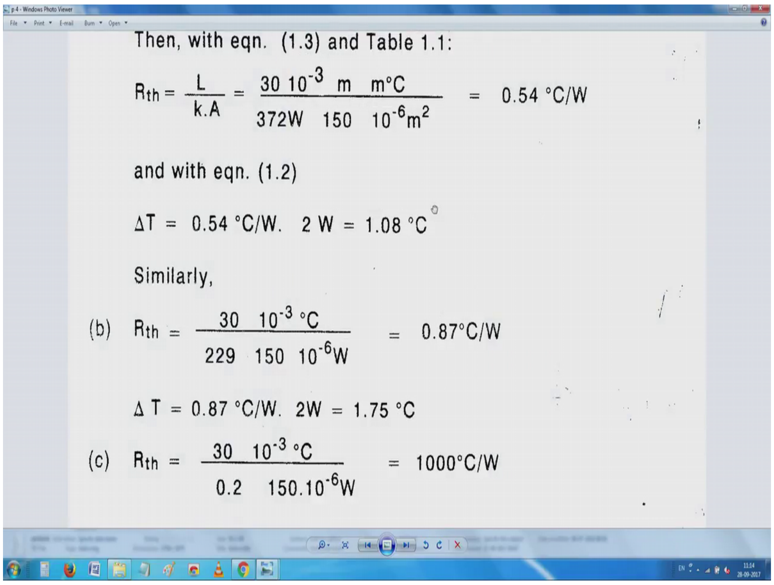

But at this point know, if you have the total length the pmm.

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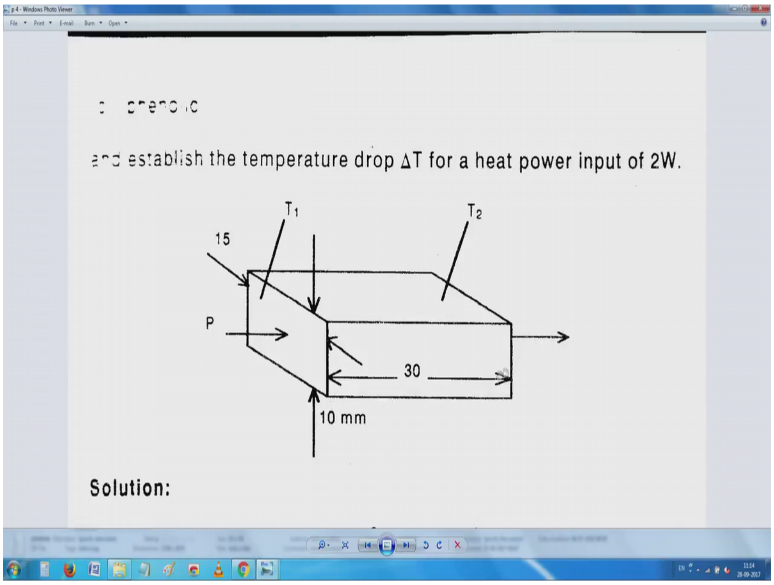

And then if you have this, what you call a thermal resistance are given a calculation depending on the material you have something you know which will come to this sort of thing.

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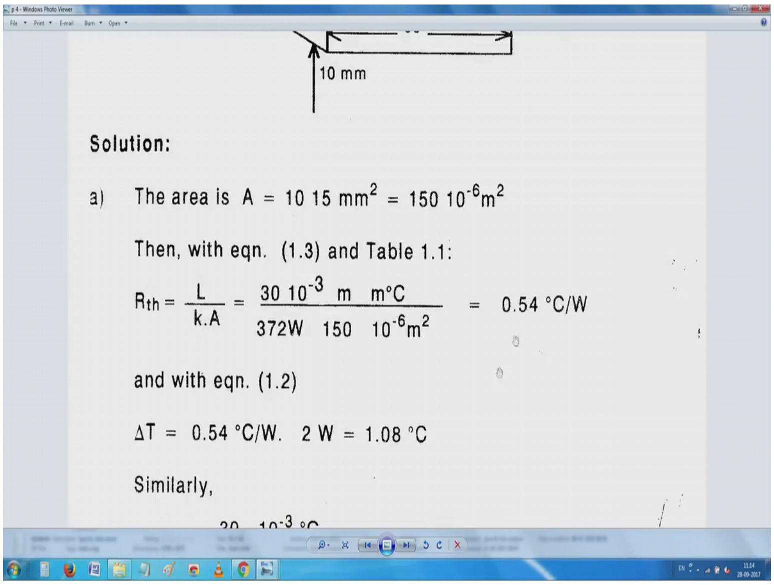

The important thing to watch here is, that the insertion of an insulating material into a heat flow path has to be planned with care. Even thin layers can lead to substantial increases in thermal resistance. So, in that case as an example just like that, know they have get this full what you call 30 centimeters length you see here 30 centimeters. And then you have 30 centimeters, this one is for copper, this is for aluminum. And in case you introduce any heat sink compound.

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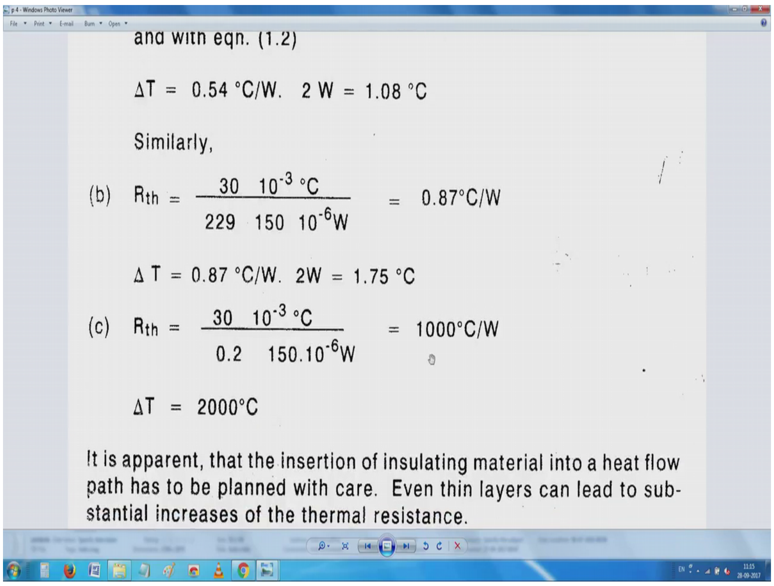

Or any other thing, know, or typically this is air. If there is an air gap, what could typically be reduced to 0.5 degree centigrade per watt has been increased to happily 1000 degree centigrade per watt. So, we have to do something in it. Now I will go back again to the starting point.