Electronics Enclosures Thermal Issues
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Lecture – 07
Sample heat sinks

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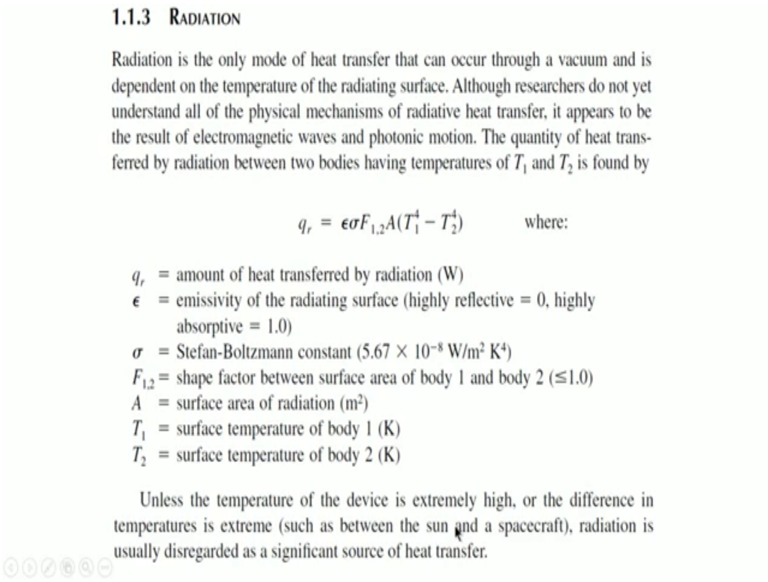

1.1.3 RADIATION

Radiation is the only mode of heat transfer that can occur through a vacuum and is dependent on the temperature of the radiating surface. Although researchers do not yet understand all of the physical mechanisms of radiative heat transfer, it appears to be the result of electromagnetic waves and photonic motion. The quantity of heat transferred by radiation between two bodies having temperatures of T_1 and T_2 is found by

$$q_r = \epsilon\sigma F_{1,2}A(T_1^4 - T_2^4) \qquad \text{where:}$$

q_r = amount of heat transferred by radiation (W)
ϵ = emissivity of the radiating surface (highly reflective = 0, highly absorptive = 1.0)
σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m^2 K^4)
$F_{1,2}$ = shape factor between surface area of body 1 and body 2 (≤ 1.0)
A = surface area of radiation (m^2)
T_1 = surface temperature of body 1 (K)
T_2 = surface temperature of body 2 (K)

Unless the temperature of the device is extremely high, or the difference in temperatures is extreme (such as between the sun and a spacecraft), radiation is usually disregarded as a significant source of heat transfer.

In general, radiation does not have so much of an effect at the normal temperatures which we deal with, that was what I was trying to tell I just wanted to show you the authentic what you call statement from the book by which you can understand that it is ignored in the end I will try to show you this.

Radiation is the only mode of heat transfer it can occur through a vacuum. If we see the first conduction I mean before that it comes to convection; convection is a lot related to mass transfer exchange of heat because of a cooling medium and how these things will what you call affect each other. So, if you take a think like an automobile the source of the heat is the combustion chamber and through conduction it comes out of the cylinder or the combustion chamber.

There, you directly have a medium typically a liquid medium; it could be as I said what you call coolant mixed with an antifreeze propylene glycol or equivalent to that. So, you have bi conduction to a fluid which is liquid in that case and the whole thing comes to the front heat exchanger in the front. In case you are not followed these lectures in a sequence incidentally is loosely called a radiator it does not do any radiation instantly and it is a matter of convenience that is painted black. So, non black even white works as efficiently and then there the heat that is what you call generated in the cylinder will come back and then you exchange that heat in the heat exchanger to ambient air.

So, eventually the last thing is air cooling and there again say when the vehicle is in movement you would probably do not even need that so called fan and in case you are not followed my other lectures there is no fan belt all fans are now cooled electrically and there is usually a small sensor some of the fans have too speed otherwise a simple on off control is there as long as your vehicle, as moving forward probably the fan is off or it is idling and just moving along with the air without causing too much of any hindrance and when it is stationary or there is a tailwind and there is not much of what you call heat convection taking place then the fan is switched on.

So, when there is a headwind and when you are moving you do not need the fan. Hence, you find the sticker also so, that all comes back. So, we have this thing is in the case of conduction it is basically a solid in the case of convection we have this various types of media. Finally, in the case of radiation is the only mode of heat transfer that can act through a vacuum and it is dependent on the temperature of the radiating surface. You see the last line unless the temperature or device is extremely high, or the difference in temperatures is extreme, such as between the sun and a spacecraft, radiation is usually disregarded as a significant heat of heat transfer, this is the one I was looking for anyway. I think I have cut and pasted it here.

You have seen that radiation really it does not help, if somebody says I mean I am not saying he is ignorant he is making you to understand that three modes each share equally not true and, in fact, two of them share the proper radiation you can ignore. Unless the temperature difference is very large and often in physics that is for you to explain to for you to understand they will give you an example of a boy I mean sorry a student shining in the sun wearing dark clothes versus a student standing in the sun wearing white clothes.

It does make a difference, because there the dark clothes incidentally are also good radiators of heat. In this case a radiation takes place both rays from the sun it absorbs the heat similarly if you see the white is not that good they radiate the difference is small enough. So, you feel slightly better it is not as if no there is a drastic difference in that they are slightly better.

Similarly, shade temperatures are lower than the direct sun temperatures. So, now you know the radiation thing radiation makes sense only when sun temperatures and very large temperatures are involved. Now, does it make sense? Yes, of course, it makes sense. This where I think know, I think I should point out I somewhere towards the end in the end of the series I will show you if you see a bread toaster and if you look inside oh of course, these days they are safe otherwise you can push the that post button down and then and that you can see that red radiating heater coils inside.

So, when you keep your toast I mean when you keep your bread slices inside, in fact, mind you the bottom is usually block with a tray which will collect all the crumbs crumb tray. They are not too much of convection most of the heating is by radiation. Now, we come to the important thing the outside does not feel so hot. So, how is it managed? Next time if you see carefully you can touch the outside look I do not put your finger inside I know you are not so bad. Do not believe this old fellow.

So, outside that do not feel hot; the case of the thing does not feel hot. You know, why? Because, all they do is they put two thin highly polished aluminium foil coated plates on both sides that is enough for the radiation to they reflected back. It has two advantages; one of it is it will allow the radiation to get back and do its work and it will prevent cooling from outside and there is also a small gap which is kept there, that gap is an air gap that air gap is sufficient because conductivity of this air is poor; secondly, since we have the crumb tray at the bottom and the whole thing is sealed not much of convection takes place as such the heat of that plate does not you know affect us. You will find it slightly warm.

In fact, very early vintage toasters had things the other way. Both sides you could open the sides on both sides which have a grill, put the toaster I mean what you call bread pieces, close them then they will get toasted because is the less single heater inside. Take it, open them again reverse supposed to put back and like a tea ceremony toasting ceremony toasting ceremony was grid. So, you can probably keep it there and enjoy and if it is somebody who takes in charge of these technical things they used to make a big thing about it. This show again now the sorry for the story and distraction the issue there is conduction is very real, convection is real and this radiation needs to be in the case of electronic cooling it is not important, when you want to heat something it is real, you cannot ignore it. However, just because we cannot see it does not mean we cannot I mean it does not exist there?

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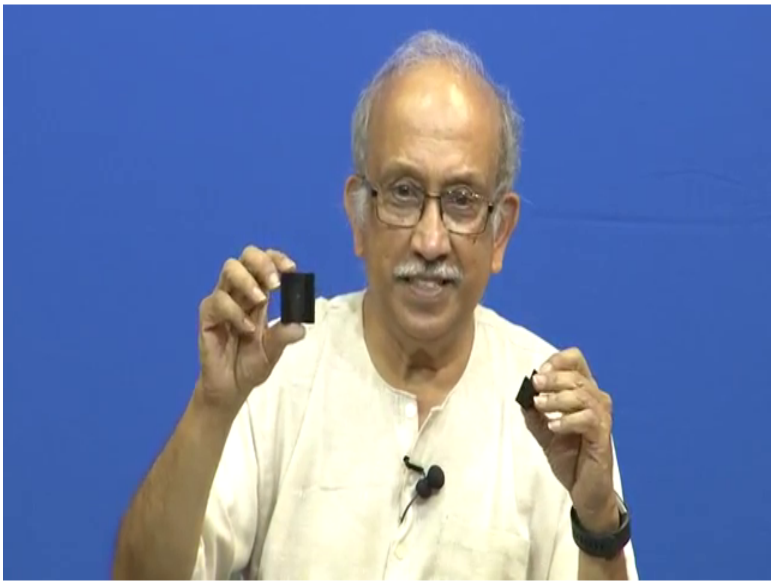

So, if you were to coat something black, like this and there is it is exposed to sunlight maybe through a window or if it is a car thing we were leave in the sun it is likely to pick up heat from the, I mean from the sun or even reflected light. So, you do not feel I mean you do not see them coated like this anymore.

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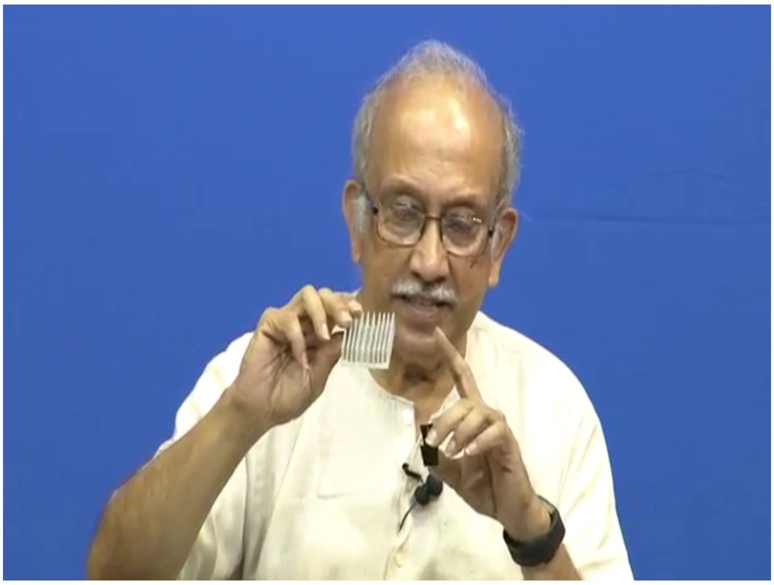

Most of the time it is a natural process of anodizing and then they close it by dipping it is mostly in water and sometimes a small called you know a metallization and all a metal anodization is done. So, this is real saying radiation takes place by any two bodies having temperature of T 1 and T 2 is found by emissivity of the radiating surface highly reflective is 0, highly absorptive is 1. So, I can go back to the manuals and check for the emissivity of various material.

So, usually we have polished aluminium, normal aluminium polished copper and so many other materials. There you will notice whenever they talk about painted surfaces emissivity does not change; what looks black to us is not very serious. The difference is between maybe 0.8 and 0.85 between black and what non black is, but not effective understood know between white and black.

So, maybe you can try, I will not what you call get into a discussion or argument. Not long ago, around 20, 30 years black cars were considered hot, meaning they feel hot inside and white cars were considered cool. So, both ways know even the word hot and cool we have hot rods and you know cool thing you know that now, these days after I do this thing they have found out it is not really true and the difference may be very small so, and more light enters through the windows. So, if you put a proper what you call IR blocking glass especially the main windshield and in the normal running thing you will not find any difference, in fact, it is cooler.

So, radiation is real, just like conduction and convection is real. Only problem is we have this emissivity of the radiating surface which you need to follow, then another important thing is surface area of radiation, which is very real.

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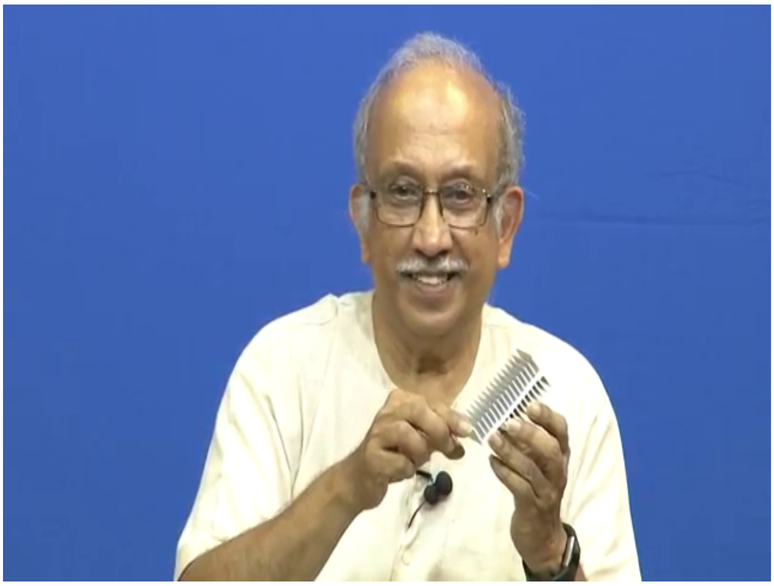

So, if you take a heat sink like this. Fins are close and they are not deep, imagine you have deep fins; then, other than this small area which is you know part of the base that part of this base here not much of too much of radiation is there and because of the depth know also you know it takes a total internal reflection and the total surface which is represented it is not high, you understood know. So, this area also it is not easy to calculate the, we have a shape factor between surface area body and body two. So, we have this issue of how much is it exposed and all later on we will come to this and then this Stefan Boltzmann constant comes directly from fundamental understanding of the physics behind this.

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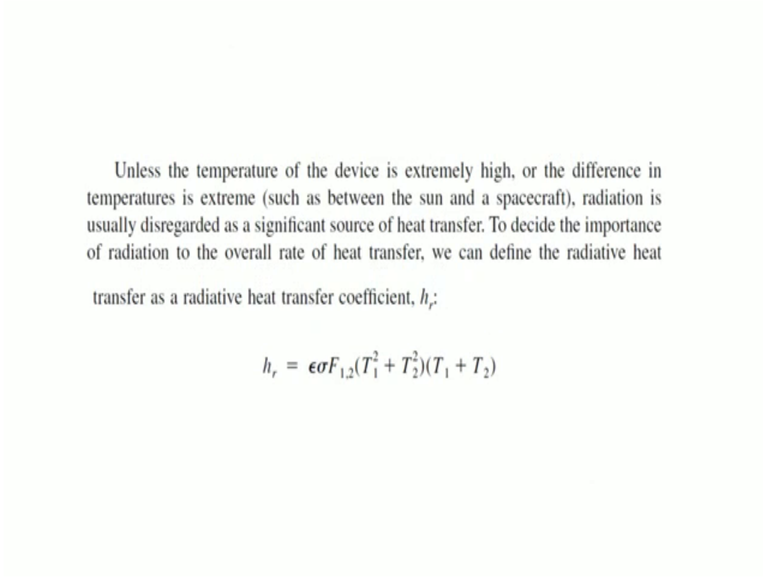

Unless the temperature of the device is extremely high, or the difference in temperatures is extreme (such as between the sun and a spacecraft), radiation is usually disregarded as a significant source of heat transfer. To decide the importance of radiation to the overall rate of heat transfer, we can define the radiative heat transfer as a radiative heat transfer coefficient, h_r:

$$h_r = \epsilon\sigma F_{1,2}(T_1^2 + T_2^2)(T_1 + T_2)$$

Unless the temperature of the device is high, such as between sun and a spacecraft, radiation is a disregarded as a significant source of heat transfer. However, to decide the importance overall heat transfer we can define these things. So, they have all these things know I mean for this thing you just have a how to calculate a heat transfer coefficient in radiation which is referred to here, in this earlier thing if you multiply both of them to get this q r know and then you have this area and these things you end up with this.

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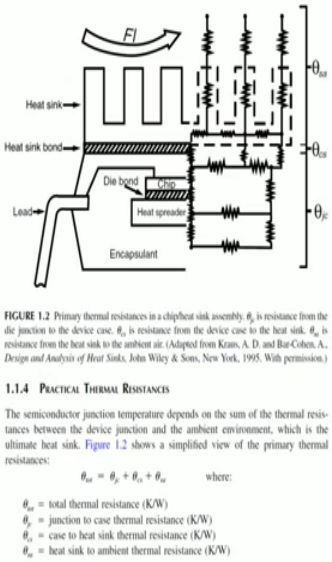

FIGURE 1.2 Primary thermal resistances in a chip/heat sink assembly. θ_{jc} is resistance from the die junction to the device case. θ_{cs} is resistance from the device case to the heat sink. θ_{sa} is resistance from the heat sink to the ambient air. (Adapted from Kraus, A. D. and Bar-Cohen, A., *Design and Analysis of Heat Sinks*, John Wiley & Sons, New York, 1995. With permission.)

1.1.4 Practical Thermal Resistances

The semiconductor junction temperature depends on the sum of the thermal resistances between the device junction and the ambient environment, which is the ultimate heat sink. Figure 1.2 shows a simplified view of the primary thermal resistances:

$$\theta_{tot} = \theta_{jc} + \theta_{cs} + \theta_{sa} \qquad \text{where:}$$

θ_{tot} = total thermal resistance (K/W)
θ_{jc} = junction to case thermal resistance (K/W)
θ_{cs} = case to heat sink thermal resistance (K/W)
θ_{sa} = heat sink to ambient thermal resistance (K/W)

Now, we come to while all that part is only for us for understanding, in real life it is a very complicated structure. So, I have shown you about you will see here this is directly from the chip, primarily thermal resistances and chip heat sink assembly. While I was talking to you I was showing you all the devices which are at the system level you will see here that even if the chip level the same thing works here.

So, I will lead and then you have a heat sink and then for you or to understand this modelling in my earlier lecture I showed you how the heat is conducted away from a board. So, there is a board in which all this a nice coloured picture here instead, he has you know the what you call Remsburg is given this issue of what you call the thermal resistance between the heat sink to ambient thermal resistance between case to heat sink then thermal resistance between junction to case.

So, practical thermal resistances he given here why these are important tears the heat sink manufacturer usually by empirical or by actual measurements he will give you data regarding what is the theta sink to ambient thermal resistance as so many degrees centigrade per watt. So, it is for you to now use that and somehow calculate junction to case and case to heat sink usually even junction to case are there. So, case to heat sink is wherever all over what you call innovativeness comes and we try to make the maximum.

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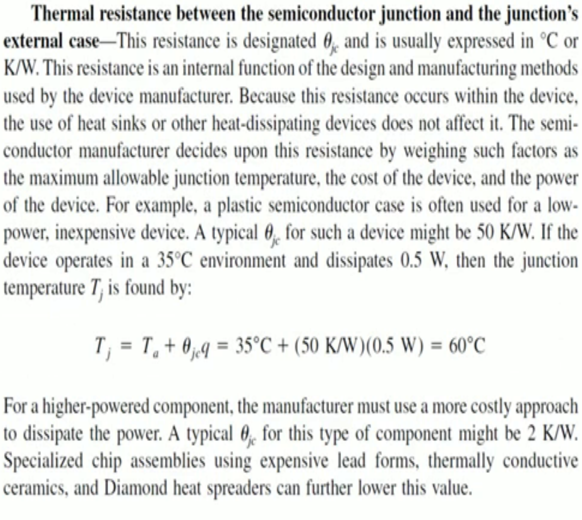

Thermal resistance between the semiconductor junction and the junction's external case—This resistance is designated θ_{jc} and is usually expressed in °C or K/W. This resistance is an internal function of the design and manufacturing methods used by the device manufacturer. Because this resistance occurs within the device, the use of heat sinks or other heat-dissipating devices does not affect it. The semiconductor manufacturer decides upon this resistance by weighing such factors as the maximum allowable junction temperature, the cost of the device, and the power of the device. For example, a plastic semiconductor case is often used for a low-power, inexpensive device. A typical θ_{jc} for such a device might be 50 K/W. If the device operates in a 35°C environment and dissipates 0.5 W, then the junction temperature T_j is found by:

$$T_j = T_a + \theta_{jc}q = 35°\text{C} + (50\ \text{K/W})(0.5\ \text{W}) = 60°\text{C}$$

For a higher-powered component, the manufacturer must use a more costly approach to dissipate the power. A typical θ_{jc} for this type of component might be 2 K/W. Specialized chip assemblies using expensive lead forms, thermally conductive ceramics, and Diamond heat spreaders can further lower this value.

Junction to case is expressed in degree centigrade. Is an internal function of the design and manufacturing method used by the device manufacturer, because this resistance occurs within the device heat sinks are other heat dissipating device does not affect it. The semiconductor decides I mean manufacturer to decided the resistance by varying such factors as the maximum allowable junction temperature, the cost of the device and power, for example, plastic semiconductor is often used for a low power in x and so, device. So, K is not kilo, it means degrees Kelvin per watt. If the device operates in a 35 degree environment dissipates 0.5 degree. So, the junction temperature can become 60 degrees.

However, for a high powered component the manufacturer might use a costly approach to dissipate the power. For this type of component may be 2 degree Kelvin I mean centigrade per watt. Here we get into this thing know we end up with all these, what I said what oh it is very heavy.

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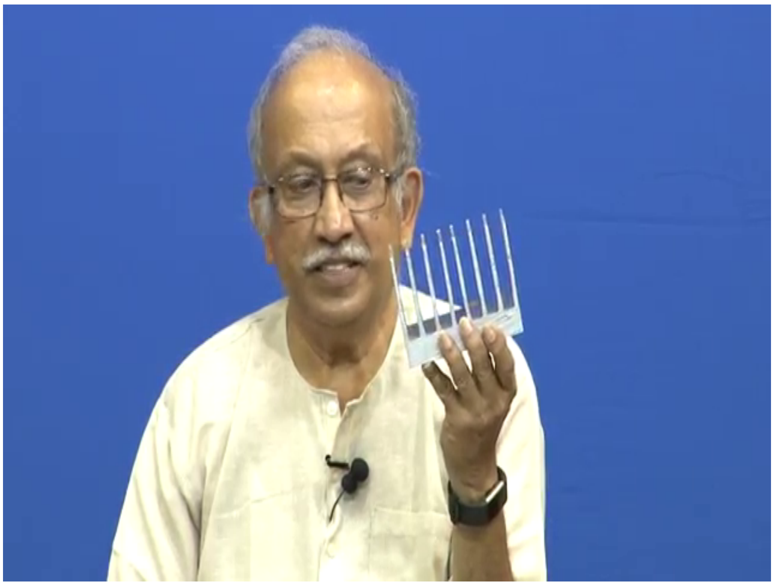

All these beautiful what you call heat dissipaters in which you have a mass here and then you have a tapered fin; the tapered fin in this case is not too prominently tapered, but, however, if you see this case it is very prominently tapered.

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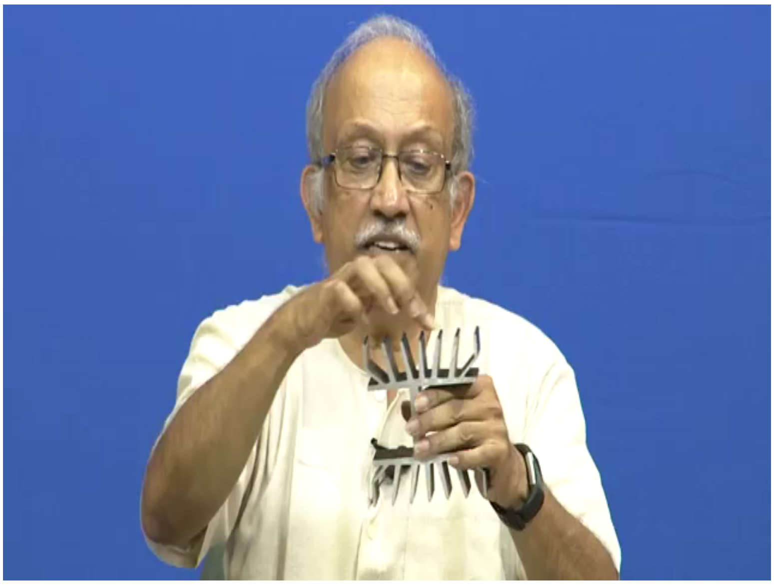

See in this, obviously, 1, 2, 3, 4 do the maximum amount of work. This other one is not of the similar design as it as it is already you are coming away from the centre and it is practically parallel because it is also used as a mounting device. So, we have here a way of holding it together in my sample this has been a thread has been tapped into it. You see the construction here, base thick, tip small to improve the fin effectiveness, but, however, this last fin it is not true because while this can also be used if you have to mount it on another aluminium plate or something a little bit of conviction can be taken off here.

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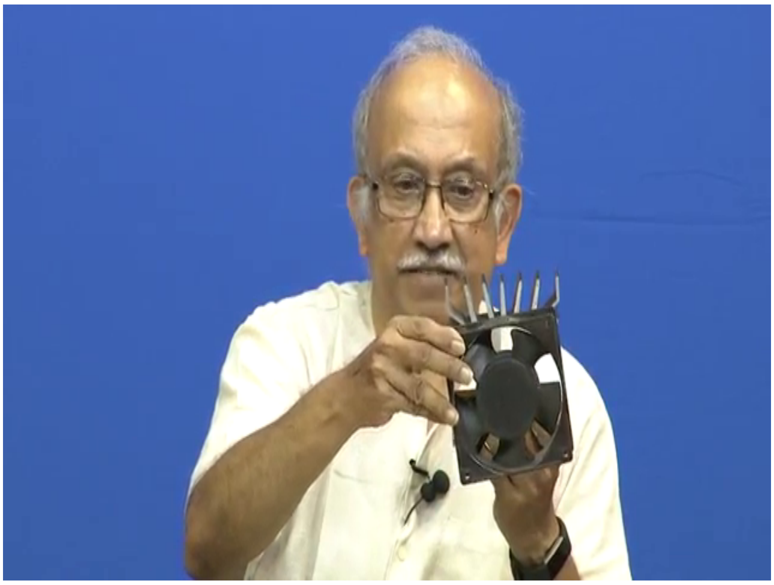

This is primarily made to work with this type of a fan, which is a 160 mm fan. So, by definition know this called a 160 HD, high density, 160 by 160 mm fan; if you attach it, some places they put two of these fans, one here and one there and try their best, but even there if you just keep on increasing the what you call the flow rate CFM or meters per second it is not a linear relationship only up to I mean it is effective only up to 2 or 3 meters per second beyond about 5 or 6 increasing anymore rather than increasing noise it does not help. So, all these things you know somebody has modelled them and they have made these things, some of them are existing, but modelling has helped us understand by increasing the base it. So, if you examine this heat sink versus this heat sink it is very obvious, oh yeah I think I will keep it here.

You have seen this is thin and parallel this one is thicker the base and tapered and also there is a I right now I am not able to think why this whether this radial design helps or not, probably it helps otherwise they would not have done it. This is where first thing is you have not too much of what you call control on the junction to case issues about a package, but the semiconductor packages have been improving a lot by which know what was simple if you remember the old transistors, diodes and all the original glass bit diodes for a problem that OA series, then later on when transistor came we had AC 127, 128. You had a cover and then you have to put a small radial fin heat sink on it.

Later on, power transistors came where you have a base on which things are directly mounted; typical examples are the TO-3 package which you find behind power amplifiers and all, the old power amplifiers you have an oblong oval thing that is a TO-3 package. At one time TO-3 package was the solution for everything, smaller variant of it is called it ii was TO-66 later on stud mounted devices started coming. So, you have a thick copper stud. So, you have things like a three eighth inch or little smaller typically one fourth inch or when no 4 mm and one eighth inch, it is a big stud and directly on top of it they used to mount the active device.

So, diodes even today come within that thing. So, you have diodes which come with a half inch stud. So, if you can directly motive call tap a hole put this inside and then one of the pictures next know shows you how to what you call tap a hole and why put these inside one of the pictures next you know show you have to mount a diode and why this various packages have evolved is basically of this trying to reduce this one, theta junction to case, we need to what you call reduce the thermal resistance. So, various packages have evolved over it.

But, if you just reduce it whatever packages is available at the, what you call in the junction is now passed on to the case. Now, we have to make things to how to cool the case, that is why you have things like that pentium cooler or in the case of our para electronics you have the various stud mounted transistors and as you go out now even HF or even VH of transmitters and all use these devices only and I do not know you will not dare comment on that, I expect that they work at very high frequencies, but the mounting and the lead out and all there know somebody has designed carefully.

So, if you look at this thing see the last thing specialized cheap assembly is using expensive lead forms, thermally conductive ceramics and diamond heat spreaders can lower this value. So, I expect that the gaming chips and all that lot of money is spent on these things and next time you have a chance have a look at a thermal the cooling device for a gaming thing. It usually has a nice beautiful gold colour, is aluminium, it has a nice radial fan and then the fins on both sides are given a beautiful gold anodizing. So, probably it is a sales point and allow me to make a guess anything that glitters has more sales value. Next slide shows us about sink to ambient.

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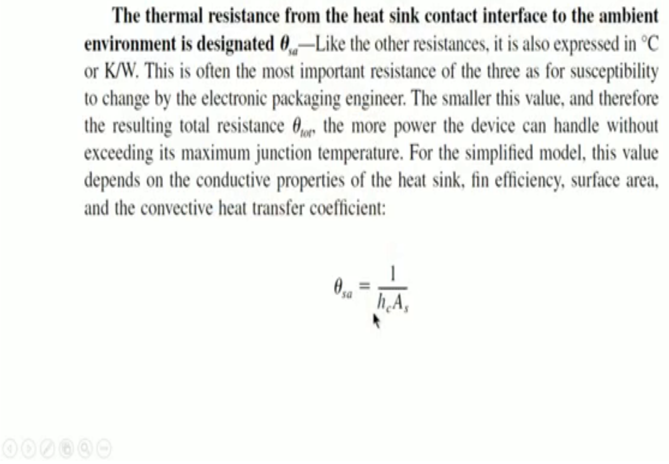

The thermal resistance from the heat sink contact interface to the ambient environment is designated θ_{sa}—Like the other resistances, it is also expressed in °C or K/W. This is often the most important resistance of the three as for susceptibility to change by the electronic packaging engineer. The smaller this value, and therefore the resulting total resistance θ_{tot}, the more power the device can handle without exceeding its maximum junction temperature. For the simplified model, this value depends on the conductive properties of the heat sink, fin efficiency, surface area, and the convective heat transfer coefficient:

$$\theta_{sa} = \frac{1}{h_c A_s}$$

Like the other resistances expert and degrees centigrade per watt. Most important resistance of the three are susceptible to change by the packaging engineer. So, all this what all I have been talking and all the samples which I have shown here are all very much related to how to lower this heat transfer coefficient in by convection or combined to this thing. The smaller this value the total resulting resistance a more power the device can handle without exceeding. The simplified model this value depends on the conductive propose of the heat sink, fin efficiency, surface area, convective heat transfer coefficient. So, both if you can increase this area and reduce you are this you are in business.

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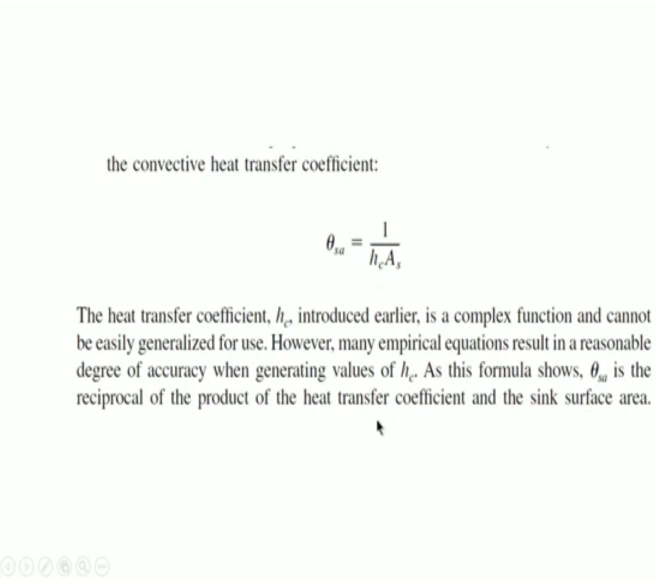

the convective heat transfer coefficient:

$$\theta_{sa} = \frac{1}{h_c A_s}$$

The heat transfer coefficient, h_c, introduced earlier, is a complex function and cannot be easily generalized for use. However, many empirical equations result in a reasonable degree of accuracy when generating values of h_c. As this formula shows, θ_{sa} is the reciprocal of the product of the heat transfer coefficient and the sink surface area.

It is a complex function and cannot be easily generalized for use. So, many empirical equations result in a reasonable degree of accuracy. Is a reciprocal of the product of heat transfer coefficient and the heat transfer surface area?

So, probably we have come to the end of this lecture at this point. Hence, we end up with this large paraphernalia of these materials, it is very heavy, oh (Refer Time: 24:20) oh, just lift it and show it to you. You have seen this? Monstrous I will not tilt it because it falls and it weighs a lot.

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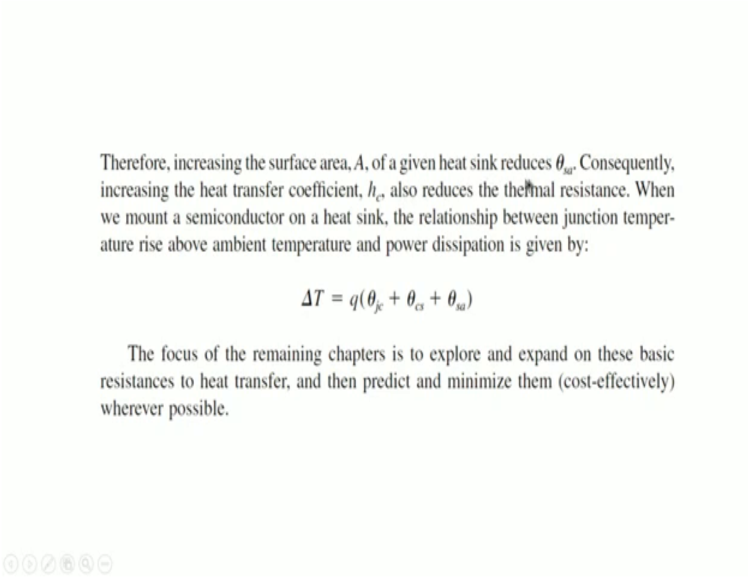

Therefore, increasing the surface area, A, of a given heat sink reduces θ_{sa}. Consequently, increasing the heat transfer coefficient, h_c, also reduces the thermal resistance. When we mount a semiconductor on a heat sink, the relationship between junction temperature rise above ambient temperature and power dissipation is given by:

$$\Delta T = q(\theta_{jc} + \theta_{cs} + \theta_{sa})$$

The focus of the remaining chapters is to explore and expand on these basic resistances to heat transfer, and then predict and minimize them (cost-effectively) wherever possible.

Now, the remaining slides which I will you know important things I will take and extract why I have done this is you can always go back maybe pause the video and when you buy the book you know where to look for these things. They show in the end is how do you predict and minimize the heat transfer coefficients so that the temperature rise is minimum.

So, thank you for patiently listening to probably a repetition of what I have covered earlier. The only difference being I have shown you some samples here and then you will not become an expert let me say like that you know experts have not become experts by just reading a book. So, you need to have some shop experience, go, check and all that and you cannot have short experience by burning devices. If you are very much prepared for this thing by reading up the theory and then next when you do the experiment, you will have proper values to do which we will continue maybe from the next lecture.

Thank you.