Electronic Packaging and Manufacturing
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Lecture – 25
Thermal Management 4: Heat Sink

Welcome back and today we will continue from where we left off in the last lecture. We are still discussing and will probably keep discussing for next few lectures thermal design, Thermal Management and cooling technologies ok. So, in the last class if you recall we discussed thermal resistances and during that we looked at (Refer Time: 00:41) architecture, we looked at integrated heat spreader architecture package architectures that is and in all these cases we were looking at something called a heat sink, it is a cooling solution. So, what is the heat sink and therefore, what are the different cooling solutions that we will talk about? We are going to look at that in this lecture ok.

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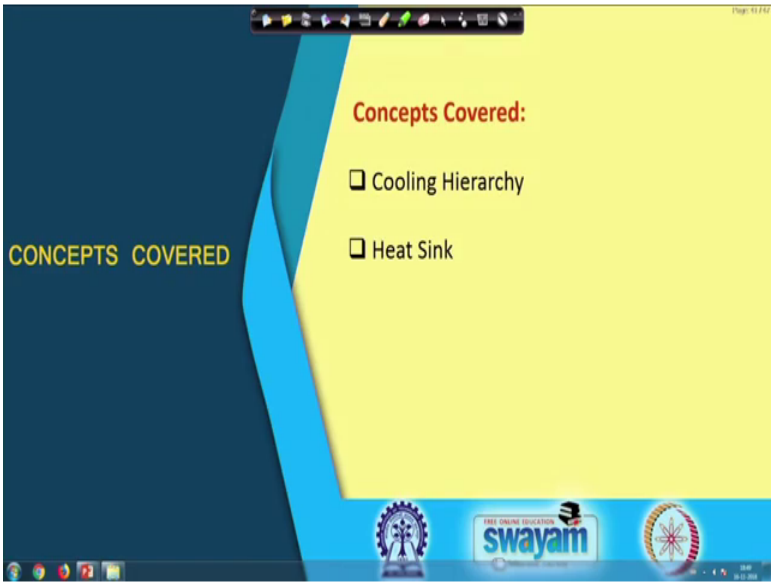

So, the concept that we are going to cover today will look we will take a small slide of just a single slide on cooling hierarchy and then we will start with heat sink ok. So, let us move on.

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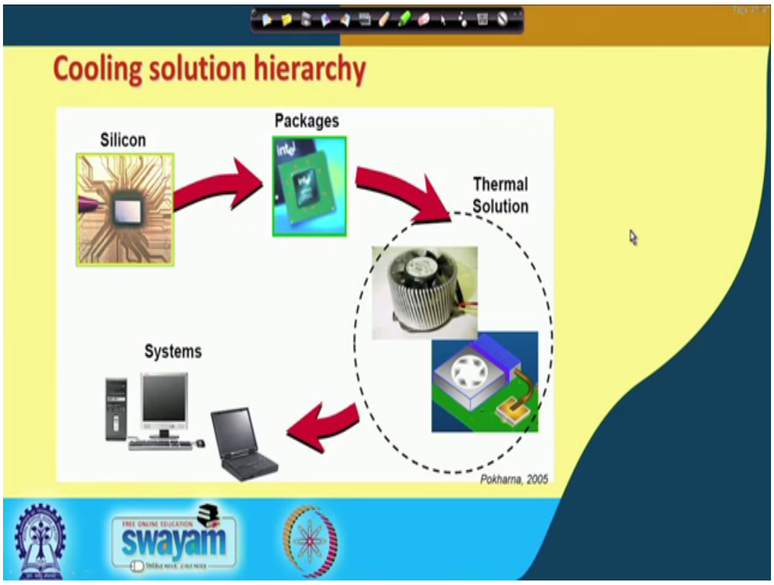

So, this is cooling solution hierarchy. So, you have a piece of silicon and then your piece then you put it in a package which is the first level packaging that we talked about and then this package goes into a motherboard. So, its first level second level altogether and then we put a thermal solution which can look in which can take various forms we are going to look at all those the thermal solutions that is what thermal engineers do.

And then this thermal solution goes into the overall system and within the system depending on the number of micro processors that needs to be cooled there can be multiple thermal solutions. Now the one thing I would say is during this entire discussion on thermal design and management we are going to focus on computing products laptops, desktops, tablets ok.

But that being said it may be most of the principles the philosophies many of the technologies that we are going to talk about are can be easily applicable and also are applied in various other products as well ok. Various other electronic products in telecom products in battery management center battery management systems so on and so forth or even appliances like TVs consumer appliances ok, consumer electronics and say all right. So, let us move on and this is the cooling solution hierarchy.

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So, a typical thermal management solution in a computing product looks like this in case of a desktop and you may have had the experience if you have ever opened the desktop chassis you may have seen this. On the piece of silicon you will see a fan and you will see something that looks like this its a base with you know some metal plates coming out extruded to the base and coming out in the normal to the base in the form of an array. So, that is called a heat sink finned heat sink and the fins can be straight fins can be curved the fan actually can be at the top and can be blowing from one end.

So, all these configurations are possible and this is called a fan heat sink combination. Actually if you go to any of these you know ecommerce sites like flip in India Flipkart Amazon you can actually order many of these and what I will try to do is in the next lecture I will try to bring some of these actual samples and show it to you ok. In a notebook system; however, what we have is something called a heat pipe. So, here also you see a fan and a heat sink this is actually heating probably not very clear from here, but these are actually these are plates one after the other its an array of plates one after the other and the fan blows air through this fin array.

So, this is also a fan heat sink arrangement, but unfortunately this fan heat sink is too large to be placed directly on the piece of silicon directly on the CPU. So, therefore, what is done is we use a cooling solution a cooling technology called heat pipe. So, you have the silicon your thermal interface material you have a copper plate and then within the copper plate we embed something called a heat pipe which on the other end is connected to this heat sink through which the fan is blowing the air. So, what happens is this heat pipe actually conducts the heat or transfers the heat transports the heat that is generated at the at this location at the location of the silicon very efficiently from this location to that location from the silicon which is the hot junction to the heat sink which is where it is cooled ok.

So, at this point let us. So, it looks like a rod of copper rod, but actually it is something called a heat pipe and we will see what a heat pipe is how it works and so on what is inside so on and so forth ok. But what I am trying to say over here is in a notebooks or a basically a laptop system this is a very common cooling solution alright this is a in a laptop it is not possible to keep the fan and heat sink on the p on this on the CPU directly because, the amount of space that is available at the location of the CPU is too small especially in the height.

Because, you have a very thin box and the motherboard runs in between on top of which is the CPU and sometimes on the bottom also can be, but mostly at the top. So, you have only a few millimeters that is left, but the fan and heat sink that you need for cooling needs to be much thicker and larger. So, therefore, you take it outside the motherboard footprint. And look and use that you or you place the heat sink and this and the fan in a location which is outside the footprint of the motherboard. But then how do I transport the heat which is generated at location a to location b heat pipe is one of the most efficient techniques for that we will see that how it works alright.

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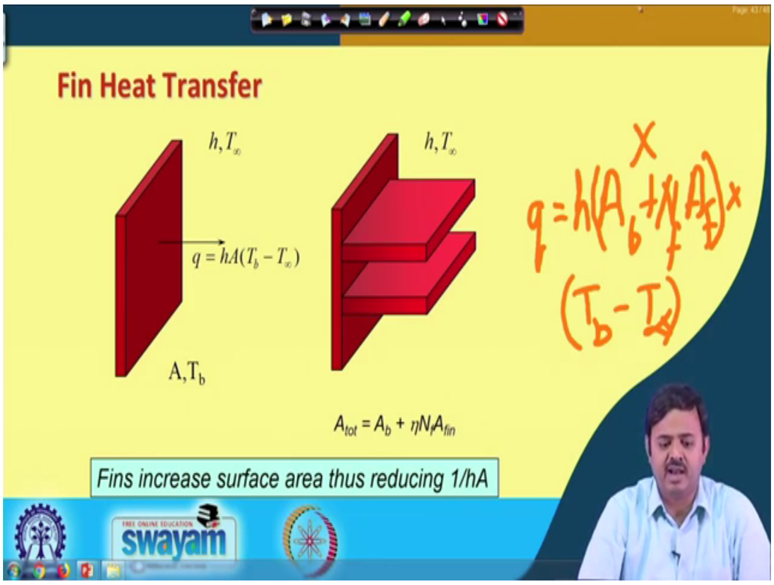

So, now before we go to heat sink we will just spend one slide on what is called fins and what is finned, what is the advantage of having heat transfer using a fin ok? So, again people who have taken undergraduate heat transfer under mechanical engineering this is something very familiar to you. So, fins are you know appendages let us say that is attached to a surface.

So, that it increases its surface area if you look at a fish for example, fishs fins its an appendage extended surface area protruding out of its body. So, for in the nomenclature of heat transfer and heat sink this is how a fin looks, let us say I start with a hot plate placed in a cooler ambient, the heat transfer coefficient is h the plate is at a temperature T b and I will say why b why not plate for p or surface for s or s for surface p for plate I will talk about that.

But in such a scenario if this area of this plate is A then what is the amount of heat transfer h A T b minus T infinity, agree that is what it is you will stop cooling. And let us say this is not enough I put a just a copper plate and you do this and you and we and you find that you know the amount of heat that you can dissipate is not enough ok. So, one is you go back to the electrical design as I was not possible I cannot cool this much and then he will ask did you try did you think of other methods ok. So, its better we do it ourselves in the beginning. So, what can we do? So, then one of the most common ways is to I have this plate and I take another rectangular plate and attach it in a direction normal to the surface in this manner ok.

So, this becomes a fin because this is protruding out of the surface its like an appendage protruding out or protruding out of the surface and for a moment let us assume that this is a perfect contact. You add another one like this and you keep adding one after the other as much as this can permit and once again even though this slide tends to show that the thickness of this plate and the thickness of the fin is the same it does not necessarily have to be that. In fact, in many cases the base is much thicker than the thickness of the fin all right.

So, therefore, what happens I increase the amount of surface area that is available for heat transfer, earlier it was now if you look at this you have the fins and you have the base of the fin earlier you had just the base only. Now you understand why I use the subscript b for this because finally, this becomes the base of the heat sink this is where the heaters heater is attached this is what is placed on the CPU which is the which is the heat source.

So, therefore, now I have increased the surface area. So, what should what should it be what should be my total heat transfer then you can say q of sorry we can write then q is therefore, h times area of the base plus area of the fin times the number of fins correct. And then times Tb minus T infinity I can write this and you can see that my since my area has gone up the amount of heat that I can dissipate also goes up; however, the problem is I cannot write like this.

So, this expression is actually not correct the correct expression is actually what is shown at the bottom over here A total is area base plus number of fins times area fin, but there is something at the multiplier denoted by eta and eta is actually called I am sorry what happened.

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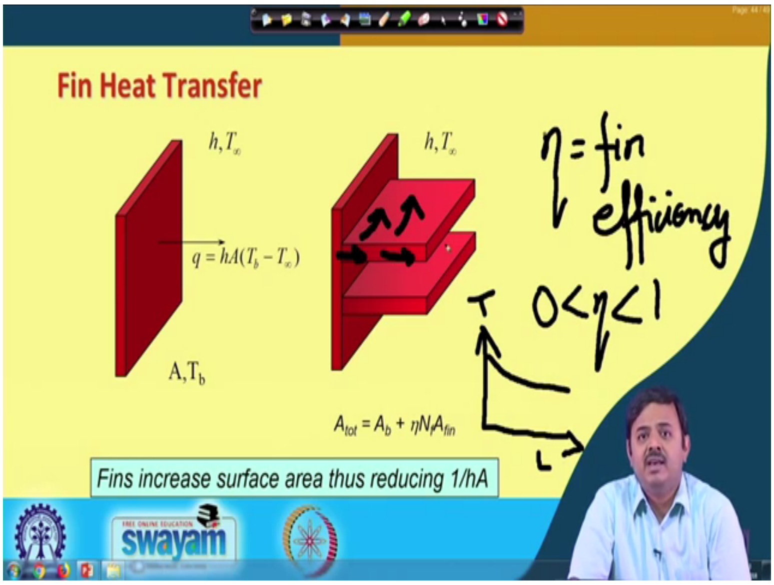

This eta is actually called the fin efficiency and it typically lies between 0 and 1. Now what is fin efficiency or why does it come because why does the heat get how does it help us in heat transfer earlier it was completely by convection, but now what happens is part of the heat gets conducted through this through this surface and then gets convicted out right or then gets lost by convection from these lateral surfaces and then whatever is the exposed base area still participates in the convection heat transfer all right.

So, many times typically you would say well I should subtract the thickness of the fins from the base yes of course; you should, but then also keep in mind that you have the thickness at the top as well. So, anyway one can come up with a lot of more accurate versions of this, but this is more or less widely used area of the base plus number of fins times area of each fin times the fin efficiency. Now why does fin efficiency arise? Fin efficiency arises because the entire fin remembers the heat is getting conducted through here.

So, it is getting conducted and in the process it is also getting lost from this surface by convection clear. So, therefore, what happens is if I measure the temperature from the base to the tip I would see that the temperature actually if I measure the temperature along the length of the fin I would see that temperature actually undergoes a drop.

So, therefore, the entire fin is not at the base temperature and since it is not at the base temperature I cannot use you know Tb minus T infinity for this entire area clear. So, therefore, what we do is there is a complicated calculation which gives us this expression for the efficiency which is defined as the actual heat transfer divided by the heat transfer which we would have got had the entire fin been at the base temperature.

But in reality it is not going to be that and we will see that that depends on a variety of parameters it depends on the overall heat transfer coefficient h it depends on the conductivity of the material as well as a geometry of the fin ok. So, we are not going to get into the details of that if required, you can look up any heat transfer book and this is some a very basic chapter in conduction.

But the overall area goes up it is not absolutely directly the fin area that is added to the base area there is a multiplier which is less than one given by fin efficiency. But overall there is a significant increase in surface area and therefore, overall heat transfer and if we talk about thermal resistance fins increase surface area thus reducing the convection resistance 1 over h A because the A now is becoming higher larger clear.

So, later on what we will do is we will probably spend at least one lecture if not more in solving some typical problems and over there, I will give you some expressions to calculate this fin heat transfer or fin efficiency rather alright.

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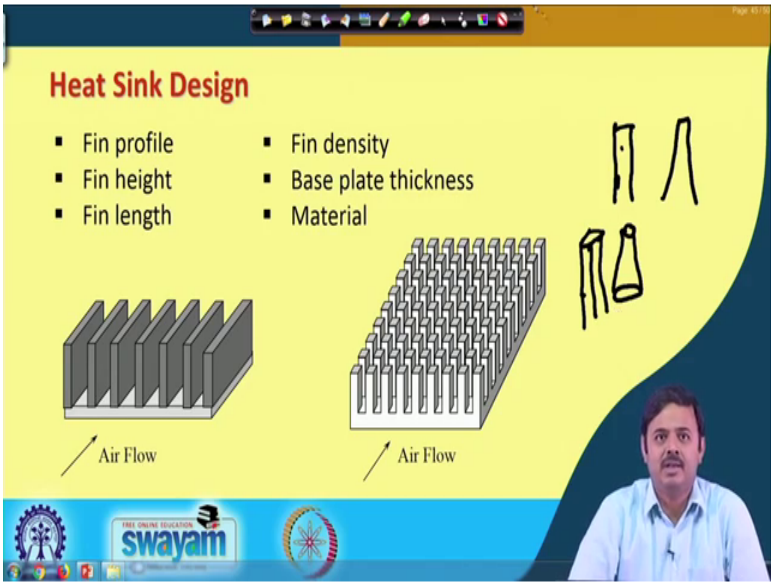

So, now let us move on and let us look at. So, when you have a number of these fins attached one after the other we get a heat sink alright. So, on the right hand side on the left hand side we see a base and fins attached to it in the form of a parallel plates it is called a parallel plate heat sink many people call in longitudinal fin heat sink alright. And air will flow through these passages between the adjacent fins and while passing through it is going to extract the heat from each of these surfaces as well as the base.

Now instead of a continuous longitudinal plate like this we can also have pins in this form. So, this is called a pin fin heat sink ok. So, a pin fin heat sink has its advantages in the sense we are not going to get into those details, but it does increase the mixing of air it is not a smooth flow between in a channel, but now the air flow becomes a little chaotic and which actually increases helps in increasing the heat transfer coefficient ok.

But however, it also increases something called a pressure drop or flow resistance we are going to talk about that later and that also we have to keep in mind. So, there is an advantage there is a disadvantage and any you know any problem in life actually is an optimization problem and so heat sink design is nothing different ok.

So, heat sink design what will it depend on its just the heat sink design, I am not even talking about air flow and all, it is going to depend on fin profile fin height fin length, length means in the direction of the air flow, height means quite evidently it is the height which is in the direction away from the base plate. Fin profile what does it mean? Well, it can be longitudinal fin, it can be pin fins, it can also be you know trapezoidal fin it does not have to be absolutely a rectangular cross section, it can be circular cross section, it can be annular fins so on and so forth. So, fin profile also does play a role it can be thick at the base and then go up.

So, what I am trying to say is the fin profile instead of being like this can be like this in 3D it can be in the form of a cone, truncated cone instead of a pin fin that I have added I have drawn over here. Sorry please excuse my drawing it is very bad I know, but this pen I am not very very comfortable with this. So, it shakes, but I hope you get the idea. So, now, and finally, base plate thickness fin density how close are these that depends that that actually has a very very important role in actually determining what is the heat transfer coefficient.

When you place fins very close to each other then the heat transfer coefficient may go down or the pressure drop may go up for a given flow rate pressure drop may go up or for a given pumping power velocity may go down if its force convection ok, but and the heat transfer coefficient as a result may go down we will see all these later.

But then you have more number of pin fins means more surface area. So, what is good higher h ok that is one higher A is the other when you have to dense fins effective heat transfer coefficient may come down area may go up. Now which one goes comes down and goes up by what amount will determine whether the final heat dissipation which is h times A times delta T the heat dissipation rate whether it increases or reduces or remains the same. So, these are all important.

So, fin density is very important and material of course, if you if its copper or a very good or aluminum you will see that for most geometries the fin efficiency is going to be very high 90 percent or higher sometimes very close to 1 for copper. But if you use plastic fins fin efficiency will be very low because the conduction through the fin is going to be very inefficient and most of its going to be lost by convection very close to the base itself.

So, the tip temperature is going to be very very much lower compared to the base temperature. So, fin efficiency therefore, is going to be low and therefore, the total area effective area is also going to be low because a total was a base plus fin efficiency times the fin area times the number of fins ok.

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So, let us look at some heat sink types. So, these are heat sinks you see several configurations I am showing these pictures I want to acknowledge Intel corporation my first employer from whom I got these pictures from where I got these pictures I would say and you see these are fin (Refer Time: 21:25) sinks.

So, the actually the base this is a circular base which sits on the CPU or the heat spreader and then your fan that blows the air radially outwards through these fins this is the configuration. Look at this one, this is like a typical parallel plate longitudinal fin heat sink right, you have the fan on the top that fan blows the air in the downward direction and the air once it comes down impinges on the base and then comes out from both sides through the of the fins from this side as well as from the other side ok.

So, the air comes down and then goes out from either side. Same over here except what you see is this fins are curved just like many people called skived fins instead of rising straight it is curved, how does it help us. If your total height the space available in the vertical direction is limited then, if you curve the fin a little bit in the way it is shown in this picture you imagine the effective length of each fin is higher and therefore, effective surface area is also higher. Effective surface area our total surface a total effective surface area of the heat sink is higher right ok.

So, these are these are called active fins why because these come integrated with the fans and the, at is active because a fan has to be powered on you have to supply power hence it is active.

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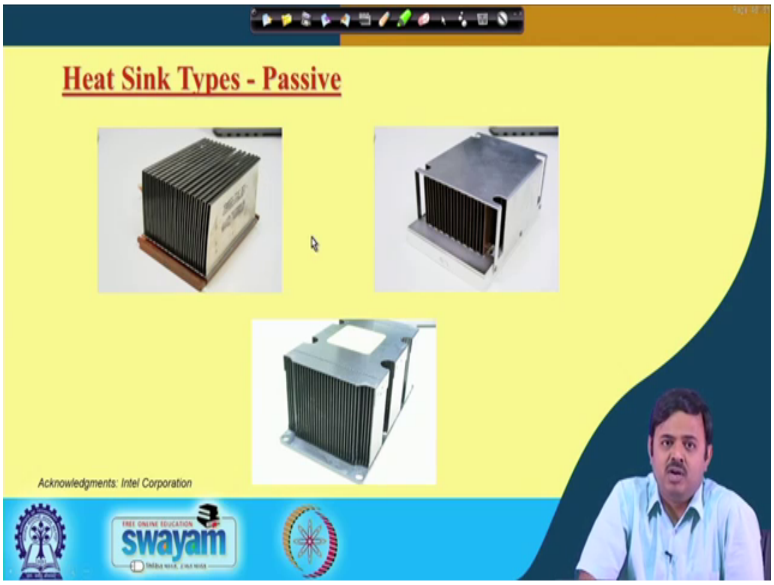

If there is no fan attached and its just a heat sink it is called passive heat sink and you see some examples over here as well the heat sink by itself comes as a passive device. Then you can either just put it and you will only have natural convection or you can have a fan externally attached to this heat sink either blowing directly into the base which is called impingement mode, which is what we saw over here or you can have a fan placed at one end which is blowing the air from one end to the other along the channel which is many a times called the flow through mode.

This one you say this is called a folded fin, the fin is like this as you can see goes up gets folded at the top comes down and then it is attached to the base somehow. This one the flow is channelized the top is for actually for both of these you have you know cover at the top so, that the flow is channelized.

So, if there is a flow through this it does not enter and then escape from the top it will be forced to flow like a channel covered on all four sides ok. Whereas, you know this picture that I was showing as the air comes it has the it may end up flowing through the channel from this end to that end, but part of it may also escape from the top if I do not cover it clear. So, a lot of lot of variations possible a lot of things possible ok.

So, that is what I wanted to cover here I wanted to give you in this lecture a feel of what a heat sink is and how a heat sink is designed what is the fin, how does it help and why a finned heat sink is so popular? See we are talking about only in as heat sinks in electronics cooling, but these fins you can see it in a multitude of applications everywhere, the most common one is your car radiator. Look at the car radiator you have this fins where next place right next to each other and except that you do not have a heated base instead what you have is you have these tubes through which the coolant is passed or the fluid is passed ok.

You open your air conditioner if it is a a wind if its a split AC you know with the with the evaporator inside that the inside indoor unit if you just open the lid which is very easy to open actually there are 2 press points at the sides if you open the front lead goes up. If you ever seen a service technician you will see this and inside you will see all these pipes and these fins attached to the pipe, these are called finned heat exchangers.

Through the pipe is what your refrigerant flows the refrigerant vapor and the air actually flows through the passages between the fins and as it flows over the tubes through these fin passages it loses heat to the refrigerant and that is flowing through the tubes. And therefore, what we get in indoors what we get inside the room is cooled air or chilled air and the same thing is on the other side which is called the condenser side all right where you have a fan blowing ambient air and which actually takes the heat away from the refrigerant and throws it if I may call it.

So, colloquy using the or rather more technically dissipates it to the ambient. So, fined heat sink or fin heat exchangers or the concept of fins as extended surfaces for enhanced heat transfer is extremely popular and used I think if you just look around you will see examples of fin heat sinks or heat exchangers and our application of electronic packaging and electronic cooling is no different ok. But many a times what we will see is that heat sink just a fan heat sink combination may not be enough we have to do something else and especially at the location weather where you may not have adequate space to put a heat sink and fan of the required size.

So, all these so, all these constraints do come and we will see examples of those in some of the subsequent lectures ok. So, thank you very much that is all I had and in the next lecture we will continue our discussion on fin heat sink and we will primarily look at that given an application, how do I determine what is going to be the performance of a fin heat sink.

Thank you very much.