Electronic Packaging and Manufacturing
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Lecture – 26
Thermal Management 5: Heat Sink Characterization

Welcome back to the course on Electronic Packaging and Manufacturing and today we will continue our discussion on thermal design analysis and Thermal Management. So, in the last class we discussed about what is the heat sink and what is a finned heat sink alright.

So, and we say that you know this occurrence of fins either in heat sinks or heat exchangers; these are very, these are omnipresent. I mean if you look at air conditioners car radiators you will see a lot of them and in electronics components also if you ever open your desktop tower; you will be able to see a fan with a fin heat sink ok.

So, it is very very common and probably the most common thermal solution that is available in a computing product. So, today what we will do is we are going to talk a little bit about heat sink design. Because as a thermal designer, it is essential to know how to do calculations and to come up with heat sink design. So, that is going to be our topic today we are going to talk about heat sink design the concepts covered today are going to be heat sink design.

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Followed by thermal analysis because what we will do is when we do calculations towards heat sink design; then what we need to do is we need to also know as to how to do those calculations So, what are the tools.

And here what we will see is we are going to do a little recap of heat transfer correlations. So, what is that? We will come to the details. So, let us start with heat sink design and what it is.

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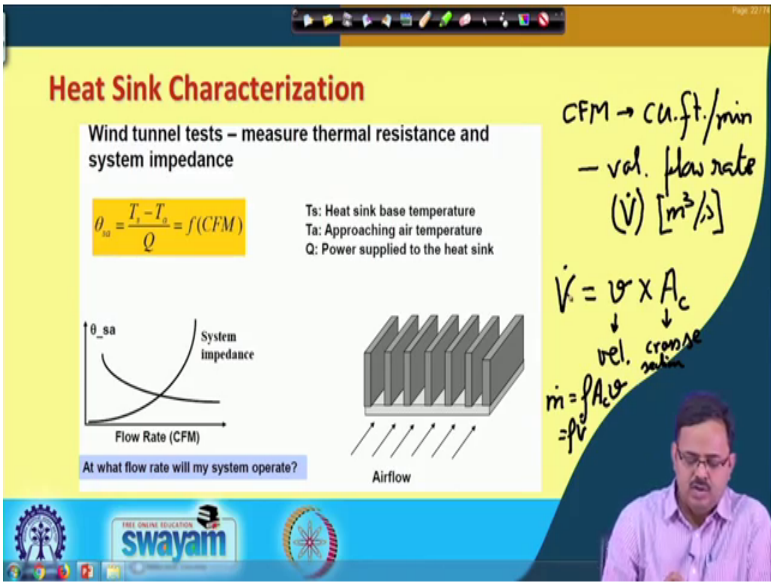

So, a heat sink we have seen this picture as well as photos of heat sinks and let us just consider a parallel plate fin heat sink like this. There is a base which is kept on the heated surface that I need to cool and then there is air flowing through and this is a flow through mode; this is not impingement mode, it is a flow through mode.

Now that being said there impingement mood heat transfer the basic design principle is not going to change. Of course, that formulae etcetera correlations that we are going to use that is going to be different depending on whether it is a flow through design or a impingement or an impingement design, but the basic philosophy remains the same.

So, what is it? Remember we discussed about theta sink to ambient ok; the thermal resistance from between the sink and ambient. So, which means that if I am supplying some power onto the base of this heat sink ok; then what happens to the temperature difference between the sink and the ambient; now needless to say that depending on the power this temperature difference or rather from the very basic theory of conduction convection that we know we know that this theta is going to be delta T over Q.

So, which means that if we increase the power input the delta T; which is the temperature difference between the heat sink and the ambient is going to go up proportionately ok; especially for force convection that is a very safe assumption alright. So, theta sa is theta sink minus T of ambient divided by Q which is the you know the rate of heat dissipation in watts. Now what is that going to be? Now, that is going to be a function of the flow rate. So, CFM is a loosely used term often used in the electronic industry CFM stands for Cubic Feet per Minute.

Essentially what it is; it is the volume flow rate of air through this heat sink. More importantly I would say it is going to depend on the velocity of the air that flows in between these passage; flows through these passages in between these adjacent fins. Now intuitively we can say that if we have more air flowing through or air flowing at a higher speed then my cooling will be better.

So, which means my thermal resistance from the sink to ambient is going to be lower [FL] ok. Let me here just write down a small formula for you know this CFM which is a volume flow rate. So, CFM sorry let me go back; so CFM which is cubic feet per minute is actually what? Volume flow rate and often denoted by capital V dot ok; sometimes it is also denoted by capital Q.

But here since we are using Q as the heat input then; so I am I am writing V dot. Now what is that going to be? What is the unit? Unit is going to be CFM is one meter cube per second is another alright. Now think about it, if it is flow through a passage, flow through a channel of whatever cross section what is V dot going to be?

See V dot is going to be the velocity of the air small v which I am writing as velocity times the area of the cross section; clear, cross section; the area of the cross section. Similarly, we also write sometimes we write mass flow rate and that is actually rho A c times v which is volume flow rate times the density.

I am sorry this is a little cluttered, but I hope you understand what I mean. So, this air flow rate which is V dot is going to determine what is the thermal resistance between the sink to ambient. So, if you have more air flowing through the thermal resistance is going to be lower. Think of and if you have less air flow thermal resistance will go up and think of an extreme situation, where you have no air flow; then thermal resistance is going to be high because the only mode of cooling at that point; the convective mode of cooling is going to be natural convection.

So, typically if you think of; if you know if you plot the thermal resistance as a function of flow rate, this is how it is going to look like. The theta s a is going to come down; it is going to be high at low flow rates very high at 0 flow rate and then it is going to come down like this. And beyond a flow rate of course, the rate of decrease as a function of flow rate is going to go down and beyond a point you will see that the rate of decrease is not as much as it used to be at the beginning.

It is called point of diminishing return that is true for many dependencies that we see in engineering and science. So, here this is also one of those where this is the plot of theta; the thermal resistance as a function of flow rate is like this ok. Now, nothing comes for free; if you need to blow air through these passages and I need to blow it at a higher flow rate then of course, I have to do something right I mean and what is that? I need to put in more power right.

So, let us say pumping power; so the energy that I have to spend per unit time to have the high flow rate is going to be higher. And why is that? That is because as the air flows through these channels or let us say a pipe, there is flow resistance that it faces and that flow resistance it can be shown, is proportional especially at some higher values of flow rate. It is proportionate has a quadratic dependence; the flow resistance is measured in terms of the pressure loss or pressure drop.

So, air as it flows through a pipe it has high pressure and then as it goes to the other end the pressure is lower. Why? Because it has lost energy in overcoming the resistance to flow; so therefore, the flow resistance is often measured in terms of the pressure drop across the length of flow; there is a channel where there is a pipe to the weather is a channel between two adjacent fins as shown here. So, in other words if I look at the top view.

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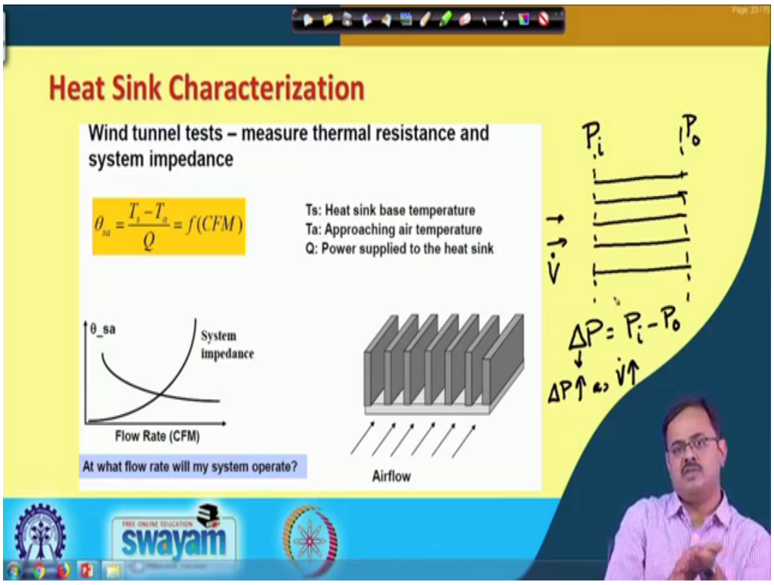

These are my adjacent fins and I am having an airflow at V dot. So, if I take a cross section here, I will measure a pressure P i which is an inlet pressure. And if I do the same over here I will measure a pressure P naught and delta P which is a pressure drop is going to be P i minus P naught. And this delta P increases as V dot increases ok; now why does this pressure drop happen?

Now, that goes into a little bit into the details or into the flow physics. This is because of frictional resistance at the walls because it is a viscous fluid. Whenever a viscous fluid flows over a surface; it is called a no slip boundary condition especially at macro scale where the velocity is 0 at the wall and then it goes up.

And it can be shown that there is a flow resistance and the shear force or force the shear force per unit area; the shear stress is given by the viscosity times that velocity gradient which is 0 at the surface; to some other value at the surface at right next to the surface.

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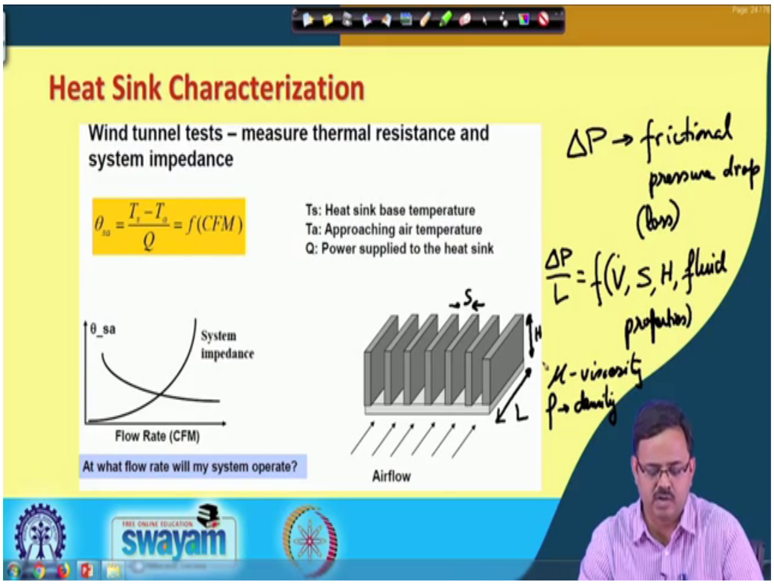

So, that is a little bit into the details, but what I am trying to say is this delta P is typically for flow through a channel; it is a frictional pressure drop. Sometimes it is also called the frictional loss alright; so that is why the delta P go increases you see this increase.

So, the system impedance increases with flow rate. So, as I am saying is, as I was mentioning I think in the last class also that any most problems in science and technology or I would say most reliance in life is an optimization problem. If something goes better you pay a penalty in sum in terms of something else ok; it is an optimization problem.

So, therefore what do I do here? So, the next question is I know this; this advantage disadvantage part, but think about a practical design I take a heat sink, I take a fan and I place them and use the fan. Let us say I put a voltage across the fan or run the fan at 5 volts or whatever is it; at its rating; in such a case what is going to be the airflow through this heat sink ok? What is going to be the airflow through this heat sink right?

So, before we go to the next slide if we just do a thought experiment; what do you think is going to happen to the system impedance ok? If you keep bringing the fins close to or even before that let us take a step back, what is this delta P going to depend on? For a given velocity of course, this is going to be a function of flow rate or velocity; what else? It is going to depend on; if I say that the spacing between the fins is S; it is going to depend on S. If I say the height of the fin is H; it is going to depend on H.

And it is going to depend on the fluid properties; what are those fluid properties? Namely mu which is viscosity, rho which is density; yeah and one more thing it is going to depend on; obviously or I would say delta P over the pressure gradient delta P over L; if this is L it is going to depend on all of these; so, the pressure drop is also going to depend on L.

Think about flow through a pipe or you know it is very again similar here also except that there is no concept of I mean think, see we saw this analogy between flow and sorry between heat transfer and electrical current. There the driving force was temperature radiant and what was flowing was heat or thermal energy. In electrical circuit, the driving force is the voltage difference or the potential difference and what flows is current. Here also the driving force is the pressure gradient or in this case the pressure loss and what flows is fluid, volume flow rate.

Now, if I have to have a fan and blow air at a certain flow rate through this heat sink then I need to pressurize that air at the inlet to a value such that it is able to overcome this pressure loss a pressure frictional pressure drop; clear? Just like an EMF source should give enough voltage rise or potential difference in potential difference so that the electric current can overcome the resistance of the load through which it is flowing alright.

So, this is also similar a fan pressurizes the air or a pump pressurizes a liquid so that it can overcome this frictional resistance ok; such that the frictional pressure drop during its flow is less than or equal to the pressure to which it was elevated alright; one more analogy. So, now, what is the energy that is spent or the power that is spent? It is volume flow rate times pressure drop; you do the units you will see it comes to watts. This volume flow rate times the pressure drop; what is the energy lost for flow of current through a voltage drop of delta V is delta V times i clear or V i. So, it is the potential times the flow in both cases; delta P times V dot or voltage drop times current alright.

So, now; so with this much of introduction and probably I hope I did not; let us recap again; what we say it is for a heat sink the system impedance goes up with flow rate the thermal resistance comes down. And the system impedance is a function of a variety of things which includes if it is a fin heat sink if into the fin spacing the fin height, the length, the fluid properties, the flow rate. So, now the next question is I have a fan which

I am running at a certain voltage; what is going to be my; what is going to be my flow rate at what flow rate is it going to flow through.

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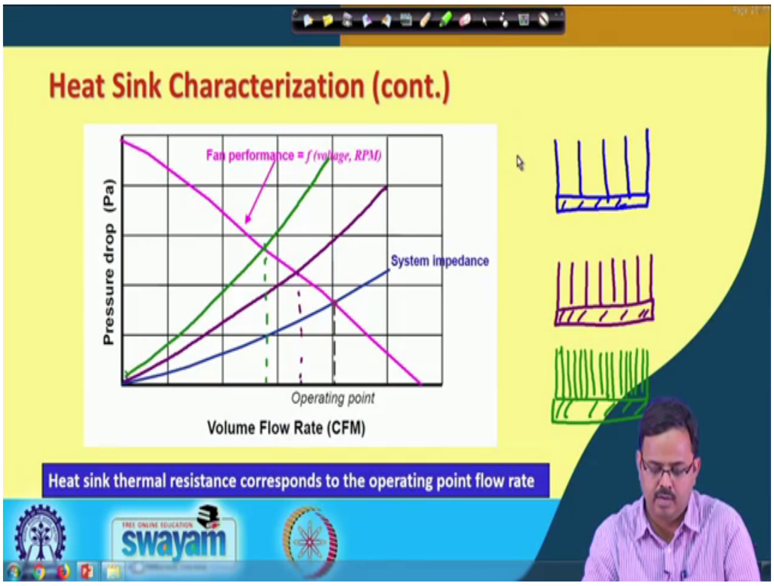

So, this one is a very important concept; a fan when you buy a fan what we get is something called a fan performance curve given by this pink line; it is pressure drop or in this case a pressure rise.

So, what kind of pressure rise can the fan give as a function of flow rate? So, this is the fan performance curve; this pink line and if you take a certain heat sink that will have an impedance curve depending on the fin spacing fin height, length, fluid properties, flow rate. And that is given by this blue line; the point of intersection of the fan performance curve and the system impedance curve is the operating point.

So, the heat sink and the fan combination is going to operate at a flow rate corresponding to this operating point. So, therefore if I give you a heat sink; the first thing we have to do is I have to get the system impedance curve and there are ways to do that we will come to that. Next what we will do is; we will get a fan performance curve and from the point of intersection, we will get the operating point and the flow rate corresponding to that operating point.

Next what we will do is; now that I know the operating point flow rate I will go back to the previous slide and calculate what is going to be the sink to ambient thermal resistance at that flow rate corresponding to that operating point. So, that is how the heat sink characterization works ok; now that being said sorry. If I now tell you that well I am going to change the heat sink.

This is not good enough; I will change the heat sink and I will probably come up with a different you know; I change the heat sink such that my thermal resistance is not good enough; I need to go lower. So, what do we know? If I have to go lower in the thermal resistance I need to have more surface area that is one way. So, that is better heat transfer; thermal resistance will go down fine. So, more surface area means more number of fins.

So, which means for a given space that I have got a given width of the heat sink that I have I need to pack more and more fins ok. So, if initially I had a heat sink like this; now I will go for a heat sink, same this is the base these are the end fins. But now I will go to denser fins and maybe even more I take one more right. So, what happens for a given flow rate the pressure drop of the blue one is going to be lowest followed by this purple one, followed by the green one.

So, therefore, now if I plot the system resistance curves how will it look? It is going to look something like this and for the green one something like this. So, see what is happening? My operating point is shifting to the left. So, therefore, I need to be careful because the operating point of the denser fin; the heat sink corresponds to a lower flow rate. So therefore if I now go back here; so therefore the same thing will apply; so that was my green one.

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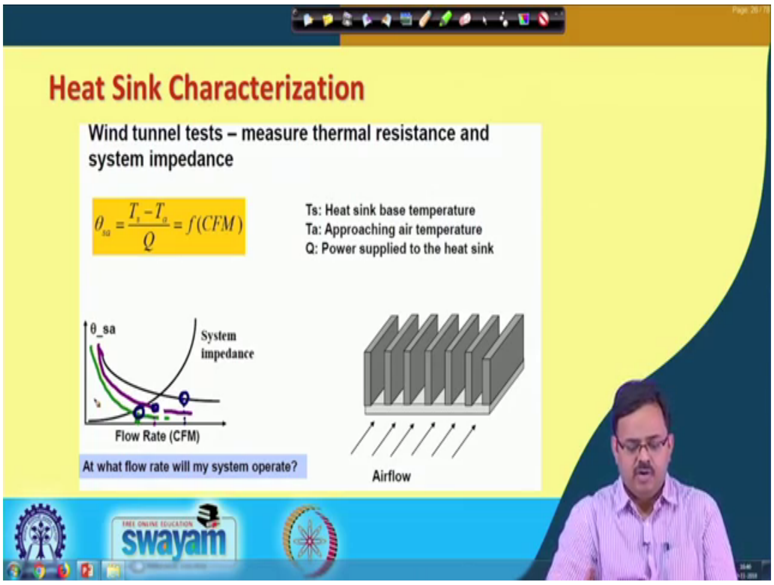

This is my purple; so that was my blue one; this is my purple, this is my green. Yes at a given flow rate if I take a given flow rate of course, the green has the lowest thermal resistance. But then we may find, but the corresponding operating point for the green is probably here. For the red is probably here and for the blue which unfortunately is denoted by black here is this yeah.

So, I need to compare the thermal resistance at here; this one and this one and then is it really low yeah, I can still say that it is lower. But it may so happen if; if my at this point instead of here corresponding to a much lower flow rate then I would not have had any advantage yeah. So, therefore as I was saying that this is how we design heat sink ok.

Think about a very extreme case you have so many fins that it is now a solid block; no air can move ok. System impedance is going to be infinite, it is probably going to just go like this and it is going to probably just graze this y axis. So, this is how heat sink design happens. So, I think I gave a lot more details than what is there on the slides, but what is there in the slide is something that you must know. The rest also is important if you are doing thermal design, but that is more of the design principle. So, again I got to end this lecture by doing a recap; if you take a heat sink the heat sink of the thermal resistance which reduces with flow rate. It has a system impedance due to frictional pressure drop which rises with flow rate.

So, then the question is that if I use a fan and a heat sink and then a sorry before that and a fan is characterized by something called a fan characteristic curve which gives you the rise in pressure; which is what a fan is supposed to do to pressurize the air or the gas as a function of flow rate. So, the question is if I use this fan with a heat sink which has its own in fan curve and impedance curve; what is the flow rate at which it this combination is going to operate?

And that is where we saw; that it is going to operate over here, the point of intersection of the system impedance curve and the fan curve gives you the operating point. And this operating point is going to be very very important; that is where this fan heat sink combination is going to work. So, then the heat sink thermal resistance corresponds to this operating point flow rate.

So, they can again go back and look at this thermal resistance as a function of flow rate and corresponding to that flow rate see what is the thermal resistance and that is going to be my performance of the heat sink for that geometry; for that along with that fan. Is that good enough? That is what we have to see clear alright.

So, I think with that we will end this lecture and when we come back in the next class what we will do is; we are going to work on or look at how do we; so, here we are saying this is theta I say this is system impedance. How do I get these curves? The fan characteristic curve is going to be given to you by the fan manufacturer. Sometimes take it with a pinch of salt do your own test, but the other two how do I characterize?

And similarly if it is not a heat sink; if it is something else etcetera how do we do that? So, what we will do in the next lecture; we are going to look at what is called heat transfer correlations. We will deviate a little bit away from electronics for some time, we will keep referring to it and we will only revisit the heat transfer correlations ok.

Thank you very much.