Transducers For Instrumentation
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Lecture - 36
Mechanical and Thermal Issues

Hello, welcome to the course Transducers for Instrumentation. Today we will discuss some mechanical and thermal aspects of sensor design. These are the topics which are most of the time not given enough considerations while designing our sensors and systems. For example, thermal issues and the associated physics to that. We all know that electronic circuits or electronic devices. They are all very sensitive to thermal variation or the temperature variation. If the temperature of a device changes or it increases, then the performance of this device goes down and accordingly the speed of operation and all other reliability issues comes into picture.

So, these are the aspects when we need to consider when the temperature of a system goes high and we need to do certain corrections in our design or we involve certain other type of things, for example, heat sinks in our design to incorporate these kind of issues. These thermal issues are always there in all the system design and day by day they are again becoming more and more challenging because in the earlier technology the heat dissipation was not a very big issue but going forward to lower and lower technology nodes the heat dissipation by the device itself is so high that the total heat dissipation within a unit area is going high because of so many devices are actually fabricated within a single chip. So the heat dissipation is going high accordingly the temperature will go high so we need to remove this heat energy from the chip so that the chip can work in its limited range of temperature and removing this heat from a very confined area to the outside environment is very critical and is going to be more and more challenging day by day and today we are going to discuss what are the challenges about removing this heat from the IC and how we can improve on the heat removal of these systems. So today we are going to discuss some thermal aspects or the mechanical and thermal aspects of system design. So for example if we focus on thermal aspects so the physics of semiconductors, heat sinks, is an important aspect of semiconductor device cooling. In earlier days a simple metallic piece was good enough. to carry away the excessive heat. However, the continuous more demand and more demanding interest in the heat to be vacated on the electronic devices brought up the newer types of heat sinks.

So, for example, specially designed forced convection. along the short fins and guided directed air flux down the longitudinal fins. So we need to understand the heat sinks and how heat sink actually perform the remove the heat from the electronic devices and give it to the outside environment. So we need to understand the physics of heat sink which is an important aspect of semiconductor device cooling which is a very important topic for reliability point of view. Earlier days however the heat generated by the electronic devices was not very high. So, a simple piece of metal was good enough if we take a small piece of metal and put it on the electronic device or the chip. So that was good enough to remove the heat from the IC because the power density of that semiconductor chip was not very high. So, a simple metallic piece can dissipate that much of heat. However, as the technology is growing we want more and more devices to be fabricated on a unit area. So each device is dissipating some heat.

So overall in a unit area the number of devices are high. Accordingly the power density which is the power dissipated within that area is also very high compared to the earlier technologies. So, this heat need to be removed quickly otherwise the performance of the device which are working there in that area that performance goes down because of the elevation in temperature. So, day by day this challenge is becoming more and more critical. So, there are continuous demand to how to evacuate this heat from the electronic devices and there are newer and newer type of heat sinks are coming up.

For example, there is a specially designed forced convection. So earlier we just had a metallic sheet which can dissipate the heat but now we have started using forced convection along the short fins. So, these fins has these heat sinks has small fins and we force the air through those short fins to cool down or to dissipate the energy to outside environment or guided directed air flux down the longitudinal fins. So, this is also another type of heat sinks. So let us discuss a little bit about these heat sinks.

These are the heat sinks nothing but the piece of metal and these metal has little bit of fins placed on top of it so that it increases the overall area of these heat sinks. So, something like this. This is just a piece of metal, and these are fins. So, this is conventional heat sink. The second one is the forced convection with short fins. In this type of design, we have let us say a complete PCB and on this PCB there is a heat sink which has very short fins and that is in circular in nature and in between we can place a fan which can force the air through these fins. So, in this type of arrangement this air will be forced through these fins and by convection this heat will be removed from these fins. This is forced convection and let us say the third one is the guided air flux. So in this type of heat sink application, we have a PCB where all the electronic circuits are there and we need to remove the heat from them. So, the heat sink is on the one side, and we place a fan on one side and this whole assembly is now placed such that the air is actually guided in this direction.

This air flux is actually guided through the fins of this heat sink, and this is how the heat is being removed from the system. So, this is the third type where we have guided air flux down the longitudinal fins, and this is the third type. So, there are certain considerations which we need to see while we are designing these heat sinks for better removal of heat from the electronic circuits. So, these are like thermal conductivity and cooling surface area must be compared with material and manufacturing cost. Most heat sinks are made from aluminum because of its low thermal resistance light weight and low cost. Cover is also sometime used for heat sinks although lower in thermal resistance. Then aluminum its cost and higher weight. So aluminum is less desirable for certain applications. So we have heat sink which need to be designed. So before designing we need to consider certain aspects for example the thermal conductivity of the material.

What material we are using for making these heat sinks that material should be chosen carefully and the thermal conductivity and the how much cooling surface area is that need to be compared before choosing a heat sink or before designing a heat sink and that also should be considered along with the material and the manufacturing cost of the heat sink. For example, most of the heat sinks nowadays are made up of aluminum which is a very light metal which is very light in weight and it has low thermal resistance which is good for heat sink application and the cost is also very low for aluminum based heat sinks. However sometimes we use copper also to make these heat sinks where we have lower thermal resistance just aluminum but the cost of the copper for the same amount of heat sink is high and its weight is also higher. Weight is also a critical factor because these heat sink which need to be placed on top of the package which is placed on a PCB. So if the weight is higher and because of the thermal vibration this extra weight can cause some problems.

So aluminum is lightweight so that is more preferable compared to copper heat sinks which are heavier in weight and the cost is also high for the copper, so this is less desirable in certain applications. Based on the construction of heat sinks we can have multiple type of heat sinks which are like this. So based upon geometrical structure we have stamped heat sink. These are made from a single sheet of metal worked and bent to desired thermal properties. The second is extruded heat sink. These are cost effective and provide good thermal performance. The third is bonded fins. These are made by bonding the fins separated from sheet metal. And the fourth one is the folded fin heat sink. In this type of heat sink folding the fins over themselves provide a large surface.

So, we have some geometrical structure based on that we can classify some heat sinks. The very first or the very easy one is the stamped heat sinks where we take a sheet of metal and we just cut the shape of heat sink using some die and we cut it out and bend this structure like a heat sink so that can act as a heat sink but the area is limited because whatever is the area of that sheet that is going to be the area of heat sink to dissipate the energy. This is very easy to make but the performance is not very high then we have extruded heat sinks which is more cost effective and this has very good thermal performance. Most of the time with heat sinks we have certain extra structures which come out of heat sink. These extra structures increase the surface area of heat sink very dramatically.

So, for example bonded fin heat sink we have a piece of metal and on top of it we bond certain fin like structure a wall sort of structure very short fins we bond them on the surface.

These fins has little volume but the surface area of these fins are very high so that they are in contact with so much of air and the air will take away the excessive heat from these fins. The fins are used to increase the surface area of heat sink and there are two types one is the bonded fin where we take the fin and bond on the piece of metal and this is called bonded fin heat sink. The other one is the folded fin heat sink where we have these fins and we fold again these fins again so that a single fin has now double the area of the earlier one. In this way we can increase the area the surface area of total heat sink and this can effectively evacuate the heat from the devices the electronic devices.

So let us see some geometrical and thermal design constraints. So, for example, we have a system where these heat sinks are encapsulated in this closed assembly this is a closed assembly where the air is flowing from the left to carry away the excessive heat. This is the direction of air flow and we are looking at the side view. In this assembly we have a package electronic package which is generating this high amount of heat and we need to place a heat sink on it. So, if we look at the side view the heat sink will look like this we will see a single fin here this is the fin and from side view we will see only one fin and the air is flowing from left to right. However, if we see the front view then we have the system where this chip is placed and from the side view we will see the heat sink like this. And the air is flowing going into the board from the front and this in the side view we see only a single fin however this heat sink has five fins this increases the total area which is in contact with air. So, this is the whole area which is now in contact with air and air can take away the excessive heat from all of this surface. So, because of this fins we can see that the area is very high compared to the volume of metal. So all of this area which is shaded blue here this is all in contact with air and air can take away the heat from this heat sink.

So, these are some of the design constraints if the air is flowing from left to right the fins of heat sink need to be aligned in such a way that more amount of air flows through the heat sink through the fins. So, the fins are fins should be aligned with the air flow direction. So, this is how we put heat sink in a system. We cannot put a heat sink where the air flow is from left to right and heat the fins are aligned in the perpendicular direction. So, these are some of the design constraints while we design a complete system for example a heat sensitive systems they need to be designed perfectly so that the air flow pattern is aligned with the direction of fins.

So in forced convection where we are forcing air through the fins the critical parameters for heat sink design include upstream air temperature which is let us say ta and the velocity. The cross-section area details such as width and height also play important role in heat sink design. So, here we see that the heat sink is actually very well aligned with the direction of air flow so that maximum amount of air is in contact with fin while the air is flowing. To design these heat sink in the forced convection case forced convection is the case where we put a local fan very close to the heat sink and this fan is pushing the air through the fins. So, in this kind of arrangement where we have forced air flow the critical parameters to design the heat sinks these are the incoming air temperature what is the temperature of air which comes in which is generally the room temperature.

So, the temperature of environment or the temperature of air which is coming in that is a critical parameter as well as the velocity by which the air is flowing. So that depends on the performance of fan what fan we are putting if that fan is very strong that can push more air so the velocity of air will be very high and it can take more amount of heat from the fins. So, temperature of air and the velocity these are critical parameters while designing these heat sinks in forced convection case as well as along with this the casing dimensions for example the cross section area of the casing where we are putting the heat sink that also plays an important role while designing these heat sinks. So there are certain simulators available where you can plug in all these details and find out the air flow pattern in the assembly accordingly we can design the heat sink for that application. So let us see what are the critical parameters to design the heat sinks.

The important factor for the air flow is the maximum volume the heat sink can occupy which is nothing, but the width of heat sink multiplied by the length of heat sink multiplied by the height of heat sink. The design must accommodate the component specifications such as power dissipation and the maximum junction temperature. Jmax. Also play a critical role in the design. And another critical factor is the overall cost of thermal solution. So, these are some of the factors which we considered during the heat sink design the very first one is how much is the volume available or how much is the space available in the assembly to put the heat sink which is nothing but the maximum width, maximum length, and the maximum height of heat sink. So this is the volume which our heat sink can occupy to remove the heat efficiently. The design while we are designing these heat sinks these also accommodate the component specifications. For example, the chip set which is sitting beneath the heat sink what is the specification of that chip set how much is the power it dissipates for example this is a 1 watt of power which is generated in the chip set or it is 2 watt or it is 5 watt depending upon that power dissipation we need to design the heat sink. If the power dissipated more we need bigger and bigger heat sinks to remove the heat and we also should know the junction temperature the maximum junction temperature which is allowed in that chip set.

Most of these devices the electronic devices the performance degrades with the temperature. So, there is a certain junction temperature which is specified for those devices above those temperature we cannot operate that chip set. So that critical junction temperature or the maximum junction temperature we should know so that we need to keep the temperature of chip set well below that maximum junction temperature. So in that way we need to design the heat sink. The weight of heat sink is also important because these chip sets these are placed on the board using a very small pins or small balls under solder balls. So, if the weight of heat sink is very high and we put this heavy weight heat sink on top of chip set this can damage the pins or the chip set. So the weight of the heat sink is also very important while designing and the overall cost of the heating solution is also a key parameter while designing these thermal solutions. The overall cost includes the heat sink as well as we put extra fans or motors so to for the forced convection of air. So that also comes in the thermal solution cost. So that also we need to consider while designing these heat sinks. So, for example we have a heat sink. So, this is a typical heat sink. And there are certain parameters, for example this is the width of heat sink in the perpendicular direction this is the length of heat sink, and this is distance is b from here to here and the air is flown in this direction inside the fins. The spacing between the fins is s and this the fin thickness is let us say delta. And this heat sink is now placed on a casing or the chip set. This chip set is at a temperature T case or T casing and there is a resistance in between this T case and heat sink which is let us say R internal.

This is the temperature of base of heat sink that is a T base. So, these are some of the parameters we have assumed for this heat sink. To select a proper heat sink we should consider following things. To do this it is necessary to know T case. Also, the power dissipation which is Q of module. This is the first point we need to measure this is the second and the third one is we need to know the thermal resistance at the casing and heat sink interface. Which is R internal. So, when we know all these three parameters we can calculate the heat sink temperature. So, maximum allowed temperature at the surface of heat sink can be calculated. E base is equal to T case minus Q mode into R in. So, this is the formula to calculate the temperature at the surface of heat sink. So here we see a heat sink which has certain fins the width is W length is L and this heat sink is placed on top of a casing or module. This module is generating the heat which is the in terms of heat dissipation the power dissipation. This we need to know to design a proper heat sink and for example this is Q which is the power dissipation dissipated by this module. And the temperature of this module is let us say T case which is easy to measure.

Now we need to calculate the R in which is the thermal resistance between this T case this the chip set and the heat sink there is a certain amount of epoxy or paste is generally put based on that there is a certain thermal resistance that is R in that we need to know and T case we know by measurement. So, if we know all these parameters, we can easily calculate the T base which is the temperature at the base of heat sink. This is the maximum allowable temperature at the heat sink. We need to put this temperature always below T base which is our critical parameter. So, we need to design our heat sink in such a way that this temperature T base is always remain the temperature actual temperature at the heat sink always remain lesser than the T base temperature.

So, heat sinks can be designed by using computer modeling and other softwares we can design these heat sinks, and this is a very simple structure but we can play around with the B with S with delta there are many parameters which we can play around to calculate the thermal resistance of heat sink and accordingly we can design a proper heat sink.

So, this is all for today.

Thank you.