Electronics Enclosures Thermal Issues
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Lecture – 06
Text book theory

This lecture I wanted to sort of read it you to read along with me the original you know Ransburg book in which I feel things are written very authentically and instead of just sort of you know making it into a mathematical or you know analytical approach I have also brought along a few samples with me. So, you will see here I think on a white background it shows better can you see this very tiny.

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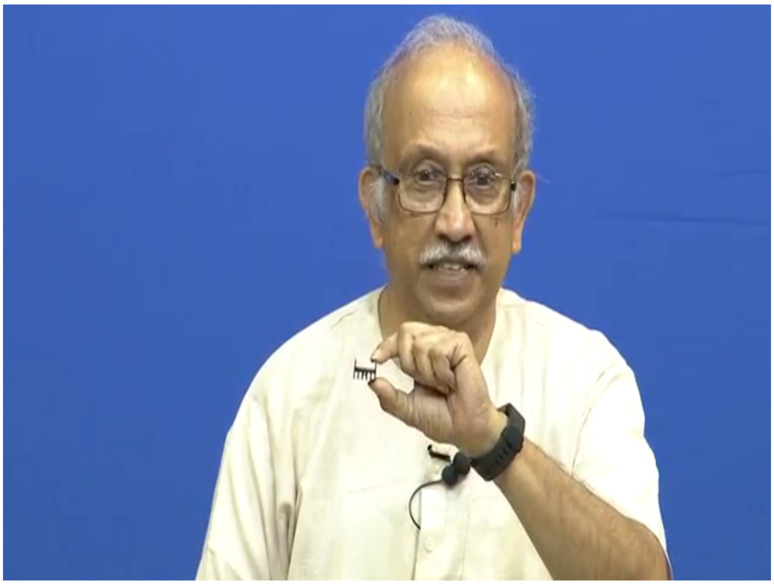

Tiny teeny weeny eeny heat sink you can see by this also know loosely we call the word heat sink and the other extreme we have this monster.

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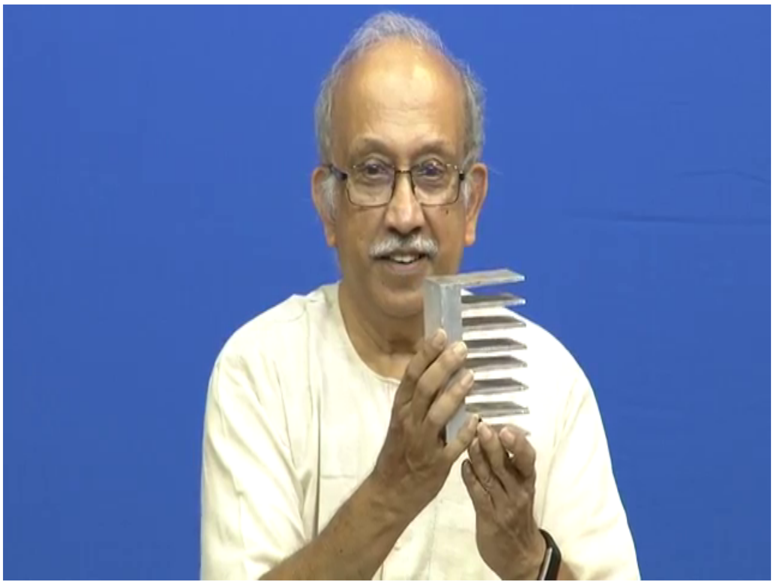

This I will show again see blue background so, that you can say it you have seen this absolutely this I mean monstrosity it is not as if there is some what you call.

By mistake or somebody wanted to sell things by weight. So, both of them we have here both of them have their own function how these have a come about is going to be part of this lecture and for good effect I will also show you these things.

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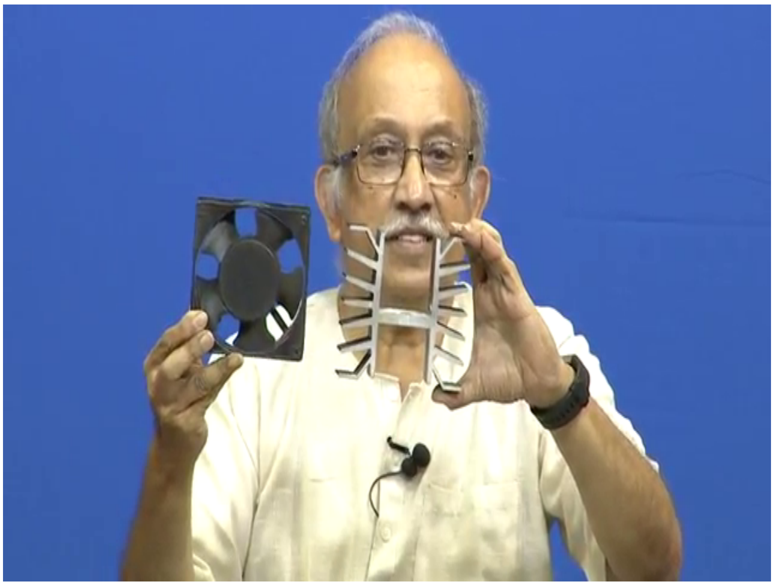

Very interesting thing you know. In fact, you can make scrap art with this maybe if I show you this fan.

Now, something will fall in place can you see have you notice something if you now keep it in front of it or in this case know let me keep at back of it. The fan has a particular flow pattern and these fins have been made such that they directly follow the flow pattern. This is slightly different from the chip coolers which I have shown in the earlier pictures which have radial flow and all that seen that so.

If you go back to this fan you see in the center portion there is not too much of airflow. So, if you are one of the arrow modellers you are even somebody who was a little thing must have heard of the word with spinner in front of a propeller usually you have a spinner. That spinner deflects the air and here we do not need such sort of things for various things about the amount of space now when you put these things together you will see that these fins are directly in the airflow and this area in this area has been reserved for components. You can mount power electronic components and further if you want you can create manifold such that the air from there comes here and not all the semiconductors have a base and they can all be mounted here.

But imagine you have other things like sometimes a toroid which if it is used as a transformer or as a simple what you call inductor will heat up. So, part of that air if you have a printed circuit board here, you will have those things all mounted here so, that they also get cold here same thing about some other devices which may need convective cooling having done said this I think I will now start with my actual semi theoretical lecture.

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1 Introduction to Thermal Design of Electronic Equipment

1.1 INTRODUCTION TO THE MODES OF HEAT TRANSFER IN ELECTRONIC EQUIPMENT

This has been directly taken from Ransburg book. You may be asking me why sir? What is it not yes it is true, first thing is a acknowledging that this is from the textbook.

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1.1 INTRODUCTION TO THE MODES OF HEAT TRANSFER IN ELECTRONIC EQUIPMENT

Electronic devices produce heat as a by-product of normal operation. When electrical current flows through a semiconductor or a passive device, a portion of the power is dissipated as heat energy. Besides the damage that excess heat can cause, it also increases the movement of free electrons in a semiconductor, which can cause an increase in signal noise. The primary focus of this book is to examine various ways to reduce the temperature of a semiconductor, or group of semiconductors. If we do not allow the heat to dissipate, the device junction temperature will exceed the maximum safe operating temperature specified by the manufacturer. When a device exceeds the specified temperature, semiconductor performance, life, and reliability are tremendously reduced, as shown in Figure 1.1. The basic objective, then, is to hold the junction temperature below the maximum temperature specified by the semiconductor manufacturer.

Nature transfers heat in three ways, convection, conduction, and radiation. We will explore these in greater detail in subsequent chapters, but a simple definition of each is appropriate at this stage.

Secondly you have full access to the textbook seen that now you have full access to the textbook unlike a tutorial class where somebody gives you a little bit of theory and a lot of questions and answers which are likely to come based on the theory and if you are like some of our what you call good students, you will probably read the theory a little in the beginning and then after going through all the questions and answers things will fall in place any future question and answer you have no doubt about it, but then only thing which we have mistake when we took up our education we did not have this system of coaching classes, tutorials are there which are very different from coaching classes and you have to read the original, you have no choice. I am proud that I have read the original.

So, I want you to get this book called you know electronic cooling and have a go at it so, I thought I will help you with these things. So, you have this saying introduction and modes of heat transfer and electronic equipment convection and all this.

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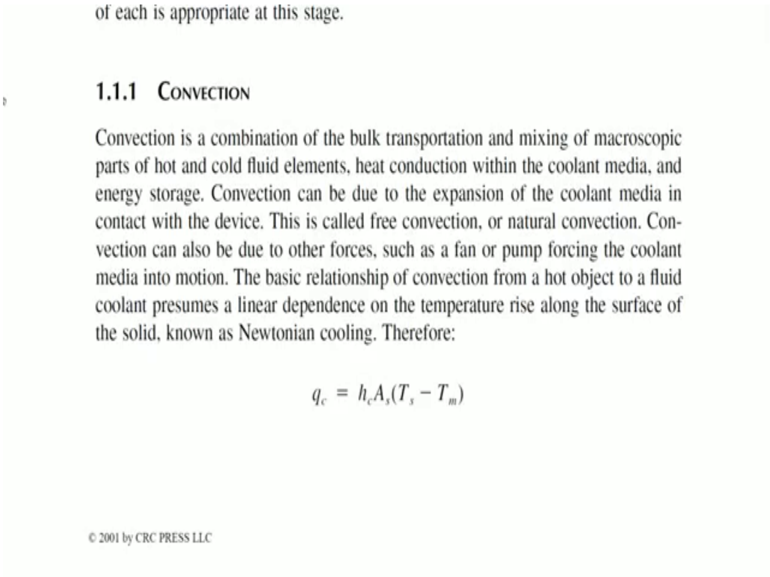

of each is appropriate at this stage.

1.1.1 CONVECTION

Convection is a combination of the bulk transportation and mixing of macroscopic parts of hot and cold fluid elements, heat conduction within the coolant media, and energy storage. Convection can be due to the expansion of the coolant media in contact with the device. This is called free convection, or natural convection. Convection can also be due to other forces, such as a fan or pump forcing the coolant media into motion. The basic relationship of convection from a hot object to a fluid coolant presumes a linear dependence on the temperature rise along the surface of the solid, known as Newtonian cooling. Therefore:

$$q_c = h_c A_s (T_s - T_m)$$

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I have directly and then I am acknowledging the copyright of CRC press limited in 2001 we are approximately 16, 17 I mean 16 years away. So, I am taking the liberty saying since you are also what you call knowledge seekers that you will learn from this book read the original and then part of the reading the original is you may need to procure it. Now allow me to go back to the power point presentation.

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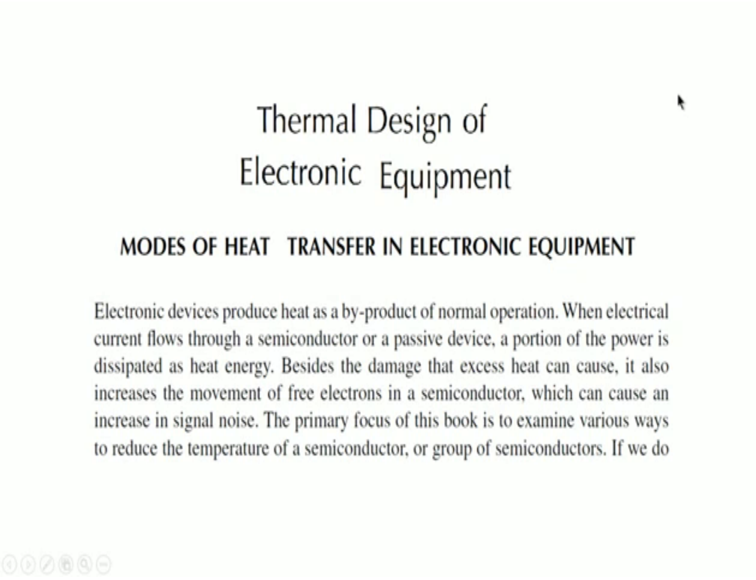

In case why is accented and it is monotonous you can just lower the voice and read along with me which I have been telling you all along say first of all electronic devices produce heat as a by product of normal operation. I have told you earlier also an ideal switch in the on condition has no voltage across is, but all the current the same ideal switch.

In the off condition we will have only voltage across it and no current. So, if you take the product of it total dissipation is zero; however, a practical switch has both of them, it has in the on condition a small voltage and a large current and in the off condition a large voltage and a small leakage current. In spite of the best switching semiconductor devices there is a rate of switching also is there how quickly it turns out off and on that little period required for it is too leads to heating. When electrical current flows through a semiconductor or a passive device a portion of the power is dissipated as heat energy this is real.

Besides the damage that excess heat can cause it also increases the movement in a semiconductor which cause an increase in signal noise seen that know, the noise floor at slightly elevated temperatures keeps rising. Primary focus of this book and in this case my lectures which by which no insist that you read the book is examined in various ways to reduce the temperature of a semiconductor group of semiconductors.

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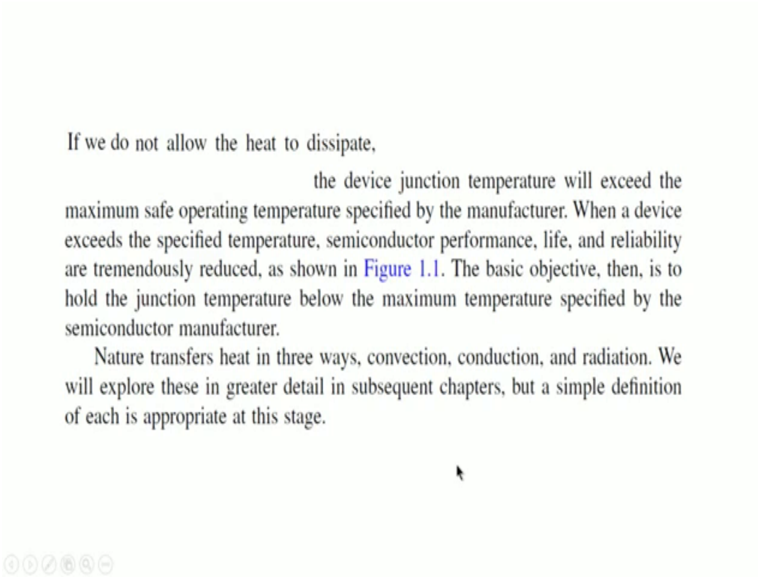
If we do not allow the heat to dissipate, the device junction temperature will exceed the maximum safe operating temperature specified by the manufacturer. When a device exceeds the specified temperature, semiconductor performance, life, and reliability are tremendously reduced, as shown in Figure 1.1. The basic objective, then, is to hold the junction temperature below the maximum temperature specified by the semiconductor manufacturer.

Nature transfers heat in three ways, convection, conduction, and radiation. We will explore these in greater detail in subsequent chapters, but a simple definition of each is appropriate at this stage.

So, you see here we do not allow the heat to dissipate the device junction temperature will exceed the maximum safe operating temperature specified by the manufacturer for a simplicity sake right now I will ignore transient or I will only talk of it as if it is steady state because transient are slightly different transient.

Because of the dv by dt and dv by dt other failures can happen though you may be in the safe operating area. When a device exceeds a specified temperature semiconductor performance life and reliability are reduced.

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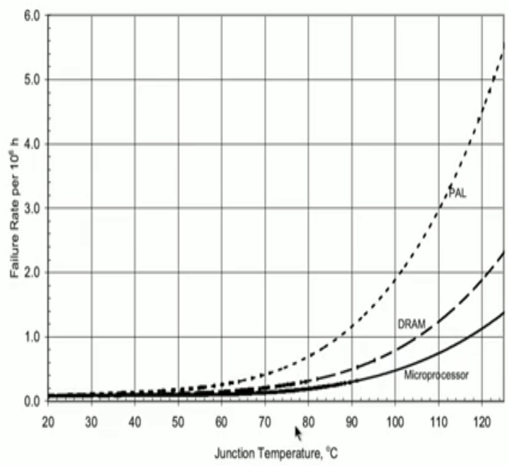

FIGURE 1.1 Component failure rates with temperature for Programmable Array Logic (PAL), 256K Dynamic Random Access Memory (DRAM), and Microprocessors. Data from MIL-HDBK-217.

Sir kindly show this slide as it is very obvious failure rate keeps on increasing as the junction temperature increases. So, we have what you call various types of there has what we call logic arrays and dynamic RAM's and then simple this thing this is all quite old and probably measured and proven by the mil standard people mil handbook 217.

Gives the various things like this in reality know they keep changing all the time. So, I will go back to the starting point nature transfers heat in 3 ways convection, conduction and the radiation. So, if you see all the heat sinks which I have been showing I will pick on one more heat sink so, you seen this all these fins.

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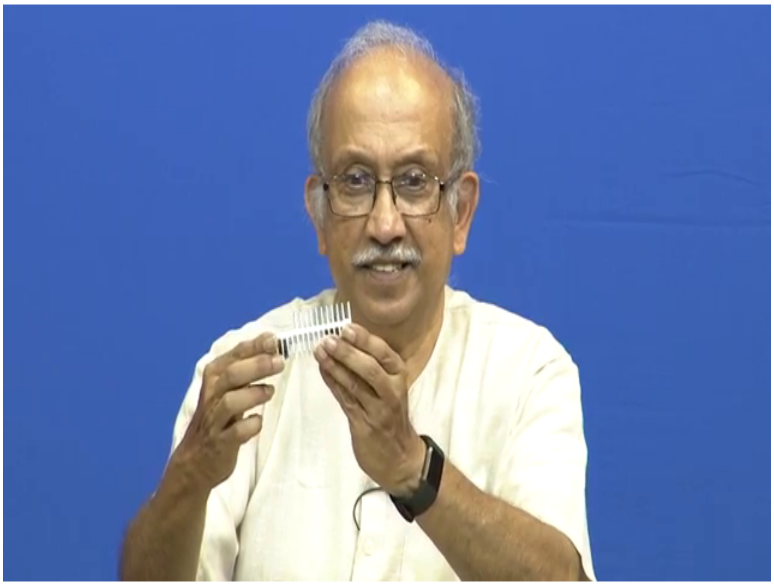

Obviously the way heat is transferred to the ambient is invariably by the most important thing is convection and no radiation, kindly remember this black colour it looks better on my shirt is incidental, it has no function in cooling this as compared to this.

However the coating which is not about the colour the coating meaning after analyzing and after you do sealing and if you put it and close all the pores and put it may have some other factors one of them is it will prevent digression from the environment. So, to that extent know the anodized it and you must seal it, when you seal it is convenient if you seal it with some chemicals other than water which will make which may aid a little in the other properties of it. So, main thing about a heat sink is not so much about very heavy not so much about conduction as much it is about convection. So, what whom I call authority on this starts with.

Unlike your conventional thing now starts with convection. So, we have convection and conduction which needs to be radiate we will explore these in subsequent chapters as he says.

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CONVECTION is a combination of the bulk transportation and mixing of macroscopic parts of hot and cold fluid elements, heat conduction within the coolant media, and energy storage. Convection can be due to the expansion of the coolant media in contact with the device. This is called free convection, or natural convection. Convection can also be due to other forces, such as a fan or pump forcing the coolant media into motion. The basic relationship of convection from a hot object to a fluid coolant presumes a linear dependence on the temperature rise along the surface of the solid, known as Newtonian cooling. Therefore:

$$q_c = h_c A_s (T_s - T_m)$$

Convection is a combination of the bulk transportation and mixing of microscopic parts of hot and cold fluid elements heat conduction within the coolant media and energy storage you have seen that know all 3 are very critical one of them is transportation that is where no mass transfer comes into place. So, a hot and cold fluid elements and from there know all the things which you have which is part of fluid mechanics saying how will a boundary layer is found how you have what you call turbulent flow.

And how heat is exchanged within the media comes under study in the initial part of this lecture I have said everything is reduced to analytical good theory avoids unnecessary experimentation which is what the I mean please look it up though I have the a reference here I wanted to look it up a good theory avoids unnecessary experimentation and probably speed to market. So, even if I think like what do you call mobile phone if somebody does quick small calculations we can make use of all what you call things and finally, you may have to end up with only one single prototype and next is a production or pilot run is possible.

If you understand the analytical portion of it and the analytical portion is used in simulation and simulation is based on physical verification up front in that case well I will not withdraw my comment in the earlier thing everything has it is place. I hope you agree with me now come back to my what I call this slide conviction can be due to the expansion of the coolant media in contact with the device this is called free convection or natural convection. So, what happens here is buoyancy is set up the moment something expands that the density comes down and immediately it will try to rise up; this is the basis of natural convection which is good my body gets what you call.

Naturally convicted like yours and if you are one of those people who check whether there are 2 more important parameters they keep defining other than the temperature and humidity that things like a real feel and feels like both of them real feel and feels like take the case of ambient conditions of the skin stand now and clothing what we wear. So, with light clothing and proper ambient things sometimes if it is cold outside it feels chillier than outside which is the wind chill factor understand know light clothes and then there is a wind blowing at the same temperature you have a wind chill factor and feels colder if ambient is or maybe it is a 10 degrees it may feel like 3 or 4 degrees lower the other end of it.

If you are clothed well and already the ambient is a little high especially if it is about 27 or 28 the moment you cover yourself it feels much hotter and the places where we live when the ambient temperature shows around 35 or 36 real feel may heat 40 and 42 it feels hot those winds which come about may or may not cool they may be heating. So, we have this issue of 2 things called natural convection and first convection in the case of natural convection the expansion is the one that aids it, but then by definition we have a little problem not problem the reality of natural convection is orientation of the fins is critical.

It should be in the same direction in which the things are I mean the fluid is flowing. Maybe in the next picture I will show you a picture of a printing head which moves in a printer you will notice that the that solenoid mechanism again dissipates heat and fins there are kept horizontally. So, as the printing heat moves as the especially if it is dot matrix printer the moment is horizontal. So, the fins invariably will be moving like this so that they cool better in contrast the ones you see normally heat sinks and all now we expect keep them here now these days it is fashionable rather fashionable or the thing which is coming back is so, called 3D printing.

And all of you must have seen the small devices which I build over by at home better known of it is maker board next time you see the print head of the maker board fins is there are horizontal, though it moves slowly for various reasons they have put it horizontal. One of the advantages in one and probably you can put a cooler or a fan maybe put another section one and all the time we have a forced convection which helps us like that. So, the important thing whenever you are talking about anything including natural convection or free convection is the orientation of the fins, in the case of forced convection we have a fan or pump forcing the coolant media into motion which is normally forced

Advantage of is you have some control about it disadvantage of it is lot of power is involved and for some reason if the pump or fan fails we are in deep soup. So, you end up with other hardware, one of the hardware is something to sense the temperature while you can build it directly into the chips or anything you still need to see to prevent damage the rate at which things rise you probably need something which has a flow sensor. So, you end up with a small anemometer or you may end up with curie sensors which see in the case the air flow falls some reason there may be a block head of the filters and so, on you need to take preventive action one of the simple thing is try to what I call reduce the operation of the devices.

So, that you can save power and now with the intelligent what you call things and possible is very much possible for you to make things much easier. So, you got it the advantage of natural convection is that no extra hardware involved and it is low and then things equalize as things equalize they will do there is no chance of failure even in case you have a filter the catastrophic failure chances rate of rise of heat is small and in the case of first convection we have the disadvantage thus in case of failure of one component in the forcing system everything freezes and unless you take what you call upfront action you may have problem.

So, coming back basic relationship of convection from a hot object to a fluid presumes a linear dependence on the temperature rise along the surface of solid as Newtonian cooling therefore, we have total quantity of heat in convection as in area temperature different between to the medium and the source into a heat transfer coefficient in convection.

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The basic relationship of convection from a hot object to a fluid coolant presumes a linear dependence on the temperature rise along the surface of the solid, known as Newtonian cooling. Therefore:

$$q_c = h_c A_s (T_s - T_m)$$

where:

q_c = convective heat flow rate from the surface (W)
A_s = surface area for heat transfer (m^2)
T_s = surface temperature (°C)
T_m = coolant media temperature (°C)
h_c = coefficient of convective heat transfer (W/m^2)

This equation is often rearranged to solve for ΔT, by which:

$$\Delta T = \frac{q_c}{h_c A_s}$$

The beauty here is convective heat flow rate from the surface inwards because it is been made very convenient surface area for heat transfer, surface temperature, coolant media, coefficient of convective heat transfer here we have to face reality without theory you cannot predict or you cannot without understanding a mechanism.

There is no way for predicting the heat transfer coefficient in convection and then without making an experiment that theory may not have started. So, both go hand in hand together you start with the experiment setup I mean make a setup and then later on see how well you can make things. So, just now my colleague told me you have a trick question why do not you show them the trick question next time when you have a chance taken a any heat sink take a large heat sink like this know, take this ugly monster or you take this cute I do not know I call it a cutie pie.

One thing you notice is when you have fins here you also have some small horizontal lines, it gives like a school bell and now you would have guessed what it is the main thing what it does is how to increase the area of interaction with the ambient you will have them in all these things how to increase the effect of surface area. One way is try to calculate all these areas another is if you take a simple I mean a device like this and try it out directly you can make a new heat transfer coefficient in conviction with the given rates.

On this thing and then if we just take the area you will be able to get it. I expect they are all car enthusiasts the moment you are a car enthusiast to you will end up with CD drag coefficient. So, they say given a surface area and this you can predict the drag coefficient.

So, I am not very sure of the numbers I expect that 0.6, 0.7, 0.1 and all are very much in demand and then I think you read it up is a little like that.

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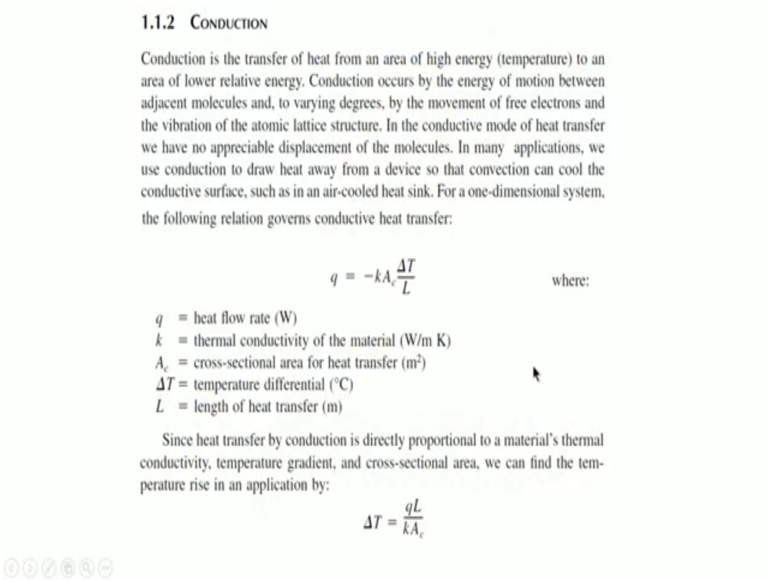

1.1.2 CONDUCTION

Conduction is the transfer of heat from an area of high energy (temperature) to an area of lower relative energy. Conduction occurs by the energy of motion between adjacent molecules and, to varying degrees, by the movement of free electrons and the vibration of the atomic lattice structure. In the conductive mode of heat transfer we have no appreciable displacement of the molecules. In many applications, we use conduction to draw heat away from a device so that convection can cool the conductive surface, such as in an air-cooled heat sink. For a one-dimensional system, the following relation governs conductive heat transfer:

$$q = -kA_c\frac{\Delta T}{L}$$

where:

q = heat flow rate (W)
k = thermal conductivity of the material (W/m K)
A_c = cross-sectional area for heat transfer (m^2)
ΔT = temperature differential (°C)
L = length of heat transfer (m)

Since heat transfer by conduction is directly proportional to a material's thermal conductivity, temperature gradient, and cross-sectional area, we can find the temperature rise in an application by:

$$\Delta T = \frac{qL}{kA_c}$$

Next slide comes to the most important part the conduction is a transfer of heat from an area of high energy to an area of lower relative energy. You have seen this here know heat is not treated as a fluid that passes through because there is no passing there in a heated mass transfer we have a fluid in there here it is only energy in transition. So, something with a high energy to lower energy in transition is what makes conduction occurs by the energy of motion between molecules.

By the movement of free electrons and so, on and so, on in the convective mode of heat transfer we have no appreciable displacement of the molecules. So, he is being a little more precise saying there is no appreciable this thing the reality is there is no measurable unless you got a very special thing as it is a solid remains a solid and it is vibration of the lattice structure within the vibration. So, we need not in the convictive mode of heat transfer we use conduction to draw heat away from a device so that the convection cool the conductive surface which is an air cooled heat sink after a long time know we are slowly coming into the saying heat sinks invariably have to be cooled by another medium.

So, by definition it is just a heat spreader, it is not infinitely it will not sink the heat if you insulate it which is one of the experiments have made a box there and then I will show you I do not know whether you are familiar with this one is a small heater from this is taken.

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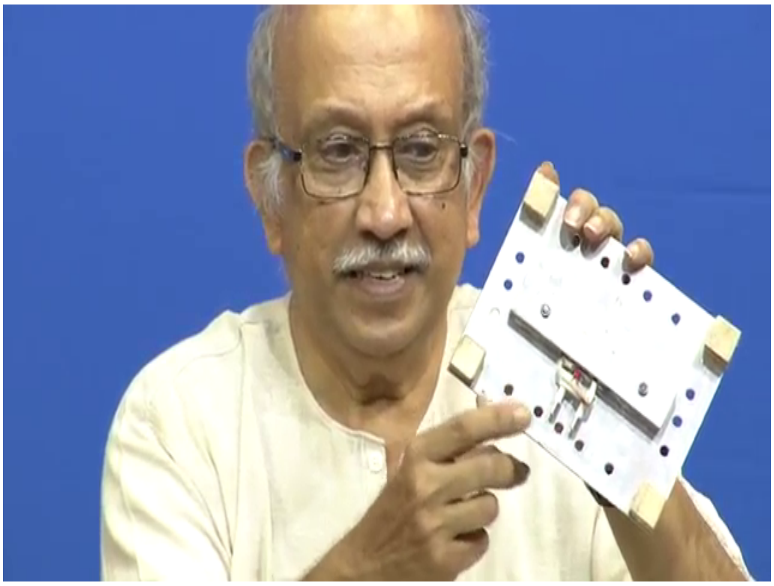

Heater from a mosquito what you call pad on the box it is marked as 230 volts into 7 volts and then elaborate arrangements have been made to clamp it. I have clamped something on top something at the bottom and then you can see this here there is a small ceramic thing it is actually nothing, but a thermistor with 2 what you call rates of.

That you know temperature coefficient there are 2 slopes like this with this it has a self regulating property as things heater it will start it will allow large current to flow when the temperature is below a certain what you call set temperature limit it allows a large current to flow. Once the temperature has reached that may be 60 or 70 degrees it will sort of reduce the heat flow and maintain intent that I just wanted to show I have mounted it on an aluminium plate and put it in a what you call polystyrene PS foam expanded DPS foam box to show you that this whole play it will reach a temperature of 52 degree centigrade.

Which normally if you keep the small thing in the air it will not reach 2 things, heat laws second thing is the conduction, but you see here the main thing the whole thing here is to make it by conduction and there no fins and all attached to it because I wanted to make a hot plate which can be used for other purposes. One of them is I mean you can keep tea hot I think you are a scene the he was be tea cup holders if you keep hot tea in that it will not cool down because the temperature is maintained at about what you call temperature I was telling you can put an insulator all around. In fact, you can put the whole USB catheter into a box leave it there for maybe half an hour or.

So, if possible with a kitchen thermometer in notice that the temperature not does rise, but if you keep it outside it does not rise much and in fact, unless you close it you would not find it there conduction plays a large thing and then the moment you insulated it behaves in the case of a heat sink we will come back to the saying we use conduction to draw heat away from a device. So, that the convection can cool the surface I have shown you earlier dry out taken from a DC motor drive there it has a PWM control in spite of it the mounting plate gets hot and then they have given a provision such that we can mount it outside on a heat sink and then have all the power drawn out.

For a one dimensional system the following relation governs conductive heat transfer which I have already told you about it, heat flow rate inverts is proportional to temperature divided by all these things and I will get back to this what you call minus k at that later on cross sectional area of heat transfer, temperature difference, lengths of heat transfer.

Since heat transfer by conduction is proportional to a material thermal conductivity temperature gradient cross sectional area we can find the temperature rise and application by this. So, well that is what you call this thing the whole thing has been reduced and now I will get back the other thing saying that minus is not what it suppose to be you just shown as a proportionality thing.

So, we have this problem of if we want to know the temperature difference we need to have the geometrical parameters of it.

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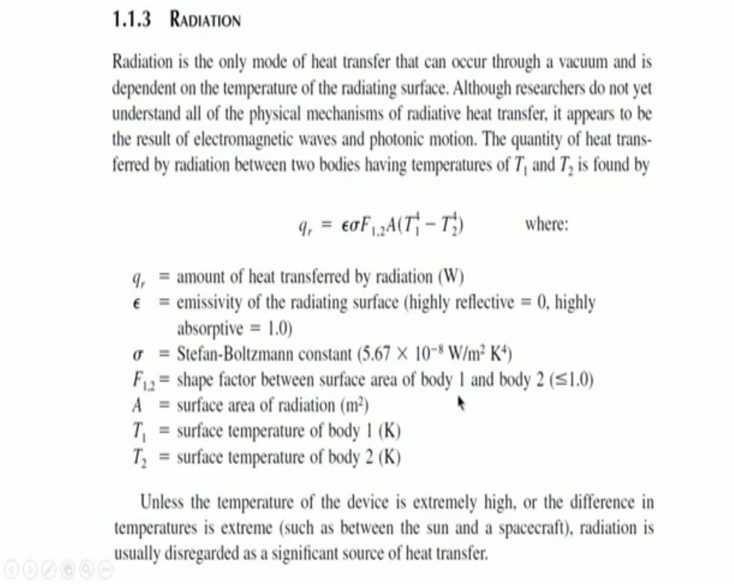

1.1.3 Radiation

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

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

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.

Finally we come to what you call the radiation you will notice here that so, far what we have talked about are 2 things real I will see if I can go back to the.