Electronics Enclosures Thermal Issues
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Lecture – 11
Mounting of packages

Let me continue from the place where I had left last, the source material as I said is important and then I acknowledge fully both crc process and a rinse bergs a contribution and we should understand that as a one of my colleagues has explained over so many years these things have been formulated and then in cases where it is fully analyzed it is very much what you call possible to calculate things. So, most manufacturers will directly give you from the whatever the source the junction, all the way up to the case and in where the specification of the small heat spreader is given a little to the next level.

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Consult individual data sheets for product-specific values or requirements.

1. These values are offered for general reference use.
2. High effective thermal conductivity board (JEDEC 4 layer) was used for the calculations.
3. DFN and QFN package type dimensions are in millimeter.
4. All QFN/QFN are Cu lead frames.
5. The values for Plastic Packages are for copper material and non-fused type unless otherwise shown in STYLE LEAD COUNT column.
6. Construction variations, such as die size, material, leads fused internally to Die Attach Pad, and PCB copper layout, significantly influence thermal performance.
7. For θ jc (Theta JC) calculation on e-pad packages, the heat sink applies to package bottom exposed pad only.
8. Cu = Copper; A42 = Alloy 42.
   * 3-Lead Versions, metal can.

So, if you see if you come to this end, I will go if you click go through these and tell you a little about. If you check these for example, there is a, what you call an institution called the JEDEC, sorry for my accented pronunciation probably you can make out it is this JEDEC stands for joint electronic devices engineering council. So, this engineering council over maybe I am not very clear, but over 50 or 60 years I have standardized various types of packages and most packages you have a way of going back and you can always ask them know saying can I become a member and you are welcome to become the member of it.

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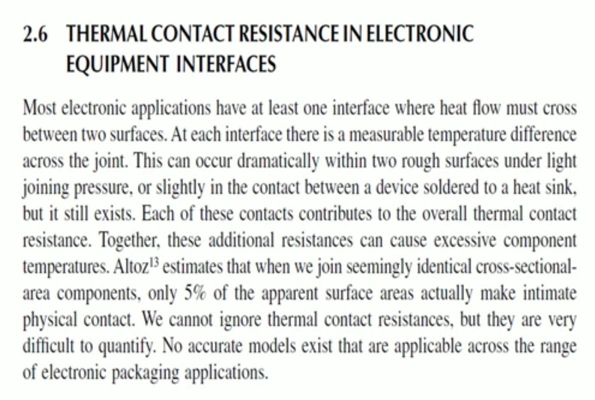

2.6 THERMAL CONTACT RESISTANCE IN ELECTRONIC EQUIPMENT INTERFACES

Most electronic applications have at least one interface where heat flow must cross between two surfaces. At each interface there is a measurable temperature difference across the joint. This can occur dramatically within two rough surfaces under light joining pressure, or slightly in the contact between a device soldered to a heat sink, but it still exists. Each of these contacts contributes to the overall thermal contact resistance. Together, these additional resistances can cause excessive component temperatures. Altoz[13] estimates that when we join seemingly identical cross-sectional-area components, only 5% of the apparent surface areas actually make intimate physical contact. We cannot ignore thermal contact resistances, but they are very difficult to quantify. No accurate models exist that are applicable across the range of electronic packaging applications.

Now, you see here if I go you can you are allowed to become a member and you can also add any new package which you have done with various other type of things, having said that at that point and then I will try to show you..

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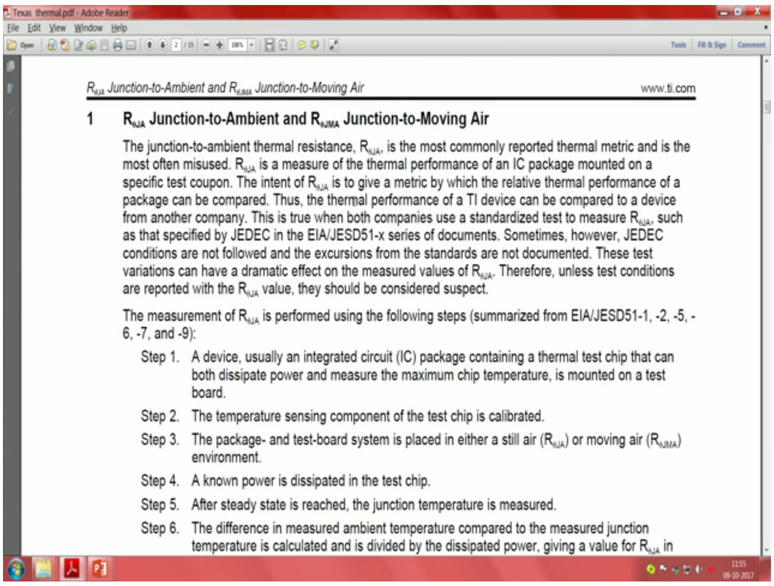

$R_{\theta JA}$ Junction-to-Ambient and $R_{\theta JMA}$ Junction-to-Moving Air www.ti.com

1 $R_{\theta JA}$ Junction-to-Ambient and $R_{\theta JMA}$ Junction-to-Moving Air

The junction-to-ambient thermal resistance, $R_{\theta JA}$, is the most commonly reported thermal metric and is the most often misused. $R_{\theta JA}$ is a measure of the thermal performance of an IC package mounted on a specific test coupon. The intent of $R_{\theta JA}$ is to give a metric by which the relative thermal performance of a package can be compared. Thus, the thermal performance of a TI device can be compared to a device from another company. This is true when both companies use a standardized test to measure $R_{\theta JA}$, such as that specified by JEDEC in the EIA/JESD51-x series of documents. Sometimes, however, JEDEC conditions are not followed and the excursions from the standards are not documented. These test variations can have a dramatic effect on the measured values of $R_{\theta JA}$. Therefore, unless test conditions are reported with the $R_{\theta JA}$ value, they should be considered suspect.

The measurement of $R_{\theta JA}$ is performed using the following steps (summarized from EIA/JESD51-1, -2, -5, -6, -7, and -9):

Step 1. A device, usually an integrated circuit (IC) package containing a thermal test chip that can both dissipate power and measure the maximum chip temperature, is mounted on a test board.

Step 2. The temperature sensing component of the test chip is calibrated.

Step 3. The package- and test-board system is placed in either a still air ($R_{\theta JA}$) or moving air ($R_{\theta JMA}$) environment.

Step 4. A known power is dissipated in the test chip.

Step 5. After steady state is reached, the junction temperature is measured.

Step 6. The difference in measured ambient temperature compared to the measured junction temperature is calculated and is divided by the dissipated power, giving a value for $R_{\theta JA}$ in

We have this beautiful, what you call data directly given by the manufacturer, one of the simplest thing is if you have a package like typically your integrated circuit and so on very rarely we attach a big heat spreader on top of it, except in the case of well known devices.

So, they have given when theta junction to ambient such as specified by JEDECS and then they have given this is engineering association series of documents. So, we have what you call a literally from the horses.

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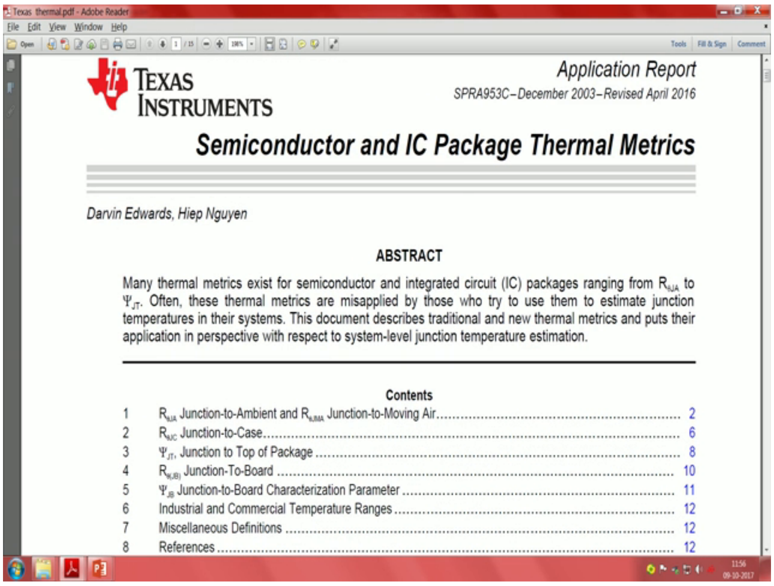
Texas Instruments

Application Report

SPRA953C–December 2003–Revised April 2016

Semiconductor and IC Package Thermal Metrics

Darvin Edwards, Hiep Nguyen

ABSTRACT

Many thermal metrics exist for semiconductor and integrated circuit (IC) packages ranging from $R_{θJA}$ to $Ψ_{JT}$. Often, these thermal metrics are misapplied by those who try to use them to estimate junction temperatures in their systems. This document describes traditional and new thermal metrics and puts their application in perspective with respect to system-level junction temperature estimation.

Contents

On a lot of this stuff about, thermal metrics for semiconductor integrated circuit packages ranging from to the sink matrix are misapplied by those who try to use them to estimate junction temperatures. This document described traditional and new thermal matrix to put their application in perspective with respect to system level junction temperature estimate. You see here original thing has been prepared early 2000 and we are late you know 2010.

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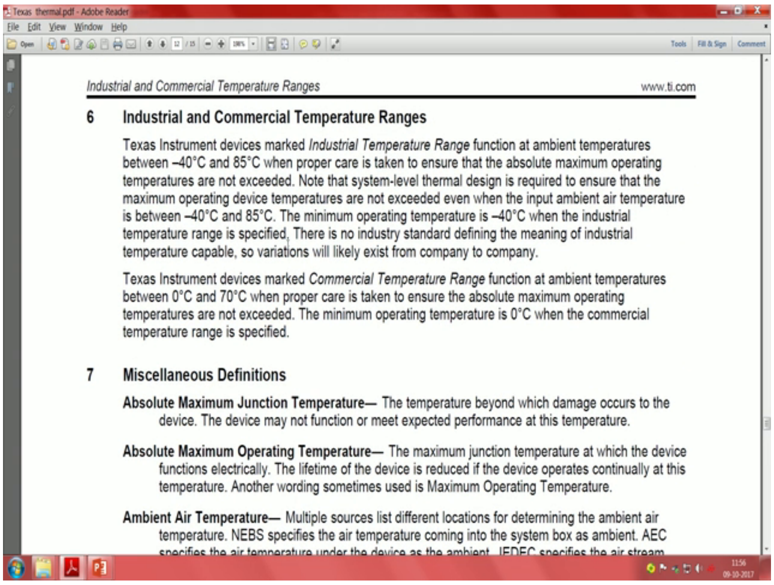

Industrial and Commercial Temperature Ranges www.ti.com

6 Industrial and Commercial Temperature Ranges

Texas Instrument devices marked *Industrial Temperature Range* function at ambient temperatures between –40°C and 85°C when proper care is taken to ensure that the absolute maximum operating temperatures are not exceeded. Note that system-level thermal design is required to ensure that the maximum operating device temperatures are not exceeded even when the input ambient air temperature is between –40°C and 85°C. The minimum operating temperature is –40°C when the industrial temperature range is specified. There is no industry standard defining the meaning of industrial temperature capable, so variations will likely exist from company to company.

Texas Instrument devices marked *Commercial Temperature Range* function at ambient temperatures between 0°C and 70°C when proper care is taken to ensure the absolute maximum operating temperatures are not exceeded. The minimum operating temperature is 0°C when the commercial temperature range is specified.

7 Miscellaneous Definitions

Absolute Maximum Junction Temperature— The temperature beyond which damage occurs to the device. The device may not function or meet expected performance at this temperature.

Absolute Maximum Operating Temperature— The maximum junction temperature at which the device functions electrically. The lifetime of the device is reduced if the device operates continually at this temperature. Another wording sometimes used is Maximum Operating Temperature.

Ambient Air Temperature— Multiple sources list different locations for determining the ambient air temperature. NEBS specifies the air temperature coming into the system box as ambient. AEC

So, various things you know including junction to moving air and industrial and commercial temperature ranges and large number of these things are already listed here, which it is very what you call encouraging, industrial temperature ranges it looks like minus 40 to plus 85 degrees centigrade is used occasionally. So, do we are we likely to face a 85 yes, maybe as you said directly if you go into the automobile and then inside the automobile we have the engine control unit ecu.

So, it is quite hot it is hot under the hood. So, they have given system level thermal design is required to ensure that the maximum operator and device temperature not excitedly, even when the input ambient air temperature is between minus 40 and 85 degrees centigrade. Now, coming back again to this they have the other thing saying commercial temperature ranges, commercial temperature range function at ambient temperatures of 0 to 70 which by our standards is very benign, quite benign because 0 is a something maybe you know external freezing.

And then 70 is what we are likely to face most of the times, even at homes inside if you have a closed box take for example, a microwave oven or that new clothes washers and dishwashers, some of the clothes washers use 90 degree centigrade hot water and the inlet is often from the hot water that is available for a room heating. You have a centralized huge boiler sometimes it is depending on where you are very rarely that main thing is electrical, it is based on a furnace oil or some oil which is used basically there are oil fired boilers and then hot water is available and that hot water you know is usually 70 to 80 degrees centigrade which is there.

And now currently solar water heaters are available, rooftop water heaters once you have a solar rooftop water heater and in a semi commercial or a group establishment like a hostel which are likely to be familiar with our, in case you have a home slightly remote and not stuck up in an urban jungle. You have vast area of rooftop available and then using a normal what you call rooftop not pv, when we talk about generally about a solar water heaters it is not a pv water heater. It is a simple static the second occasionally pumping may not may or may not be there, but generally it is a just an inclined plate, encased in a greenhouse tank and then depending on the radiation and we in India we come under the zone 2.

Zone 2 is not really hot; it is a little hot and not very very hot, not like zone one which is probably in the desert areas. So, even here 60 to 70 degrees centigrade hot water is available. So, if that is fed into the either you have dishwasher or the clothes washer, all electronics must be capable of dealing with the 70 degrees centigrade, that is way it is and when proper care is taken to ensure this things. So, we see here the manufacturer know invariably gives us various details about how to measure various temperatures and this.

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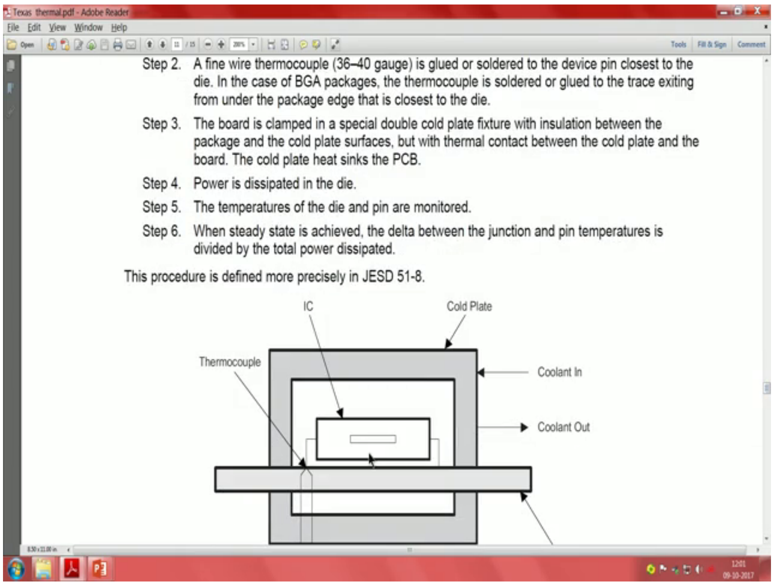

You see here very beautiful thing we have a cold plate outset coolant in to maintain the temperature in which you know we maintain it and you see here there is a nice thermocouple. Advantage with thermocouple is it is a very small contact area and then not much of a heat load is placed on that.

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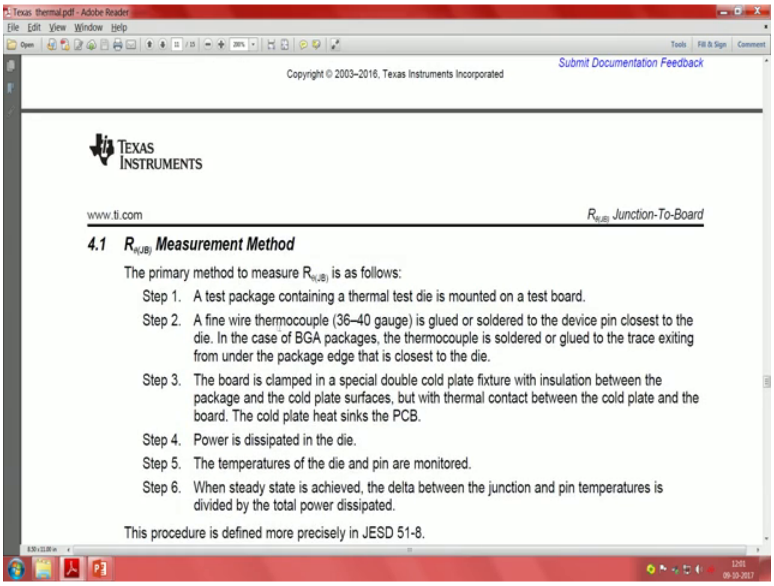

So, you have seen this fine wire thermocouple is glued or solder to the device pin closest to the die. So, it is possible for us to on a hot die.

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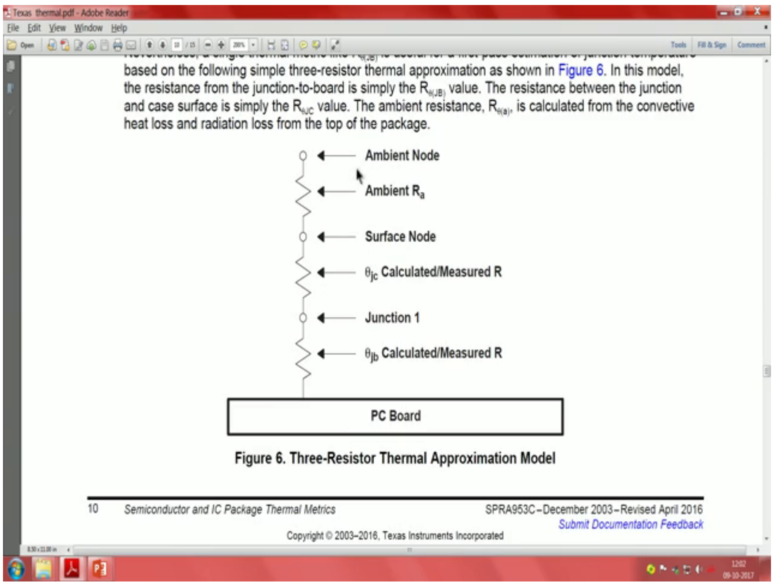

So, we have you know such a big, we have a board then we have calculated and they have an ambient node ambient what you call a resistant surface and then calculated measured and so on know. So, we have various way of calculating junction to board you know temperatures and so on so.

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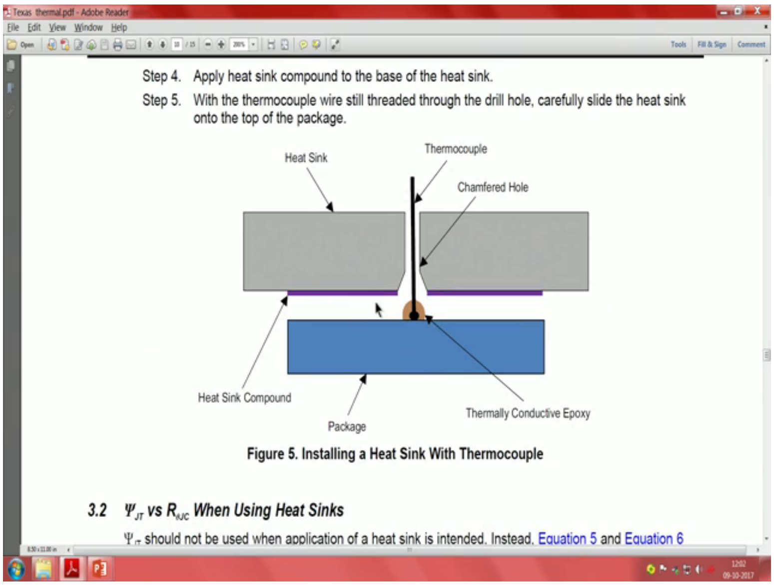

We have a heat sink thermally conductive epoxy, then there is a package how these things are you know mounted and so on.

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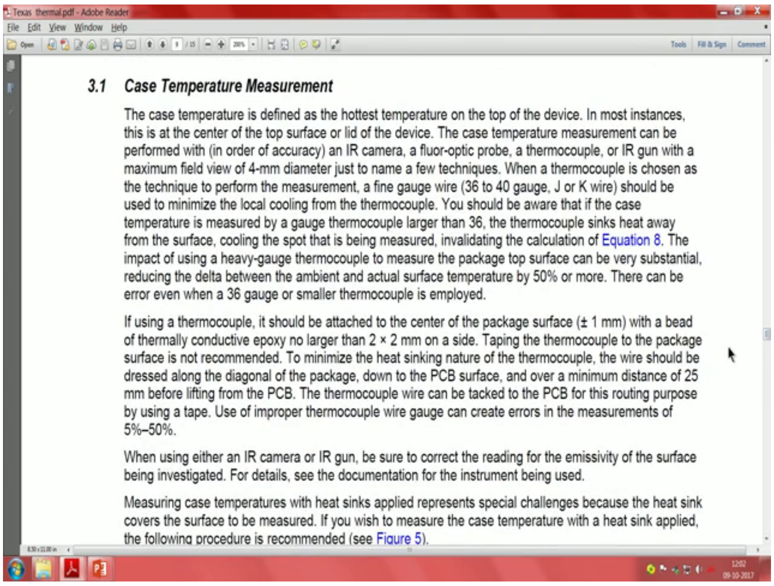

Using all this the manufacturers have made a lot of these data available to us designers to use it, they themselves probably use the modeling and the analytical methods which are described in the main lecture. So, if you just search around on the what you call in your on your internet and all the other things.

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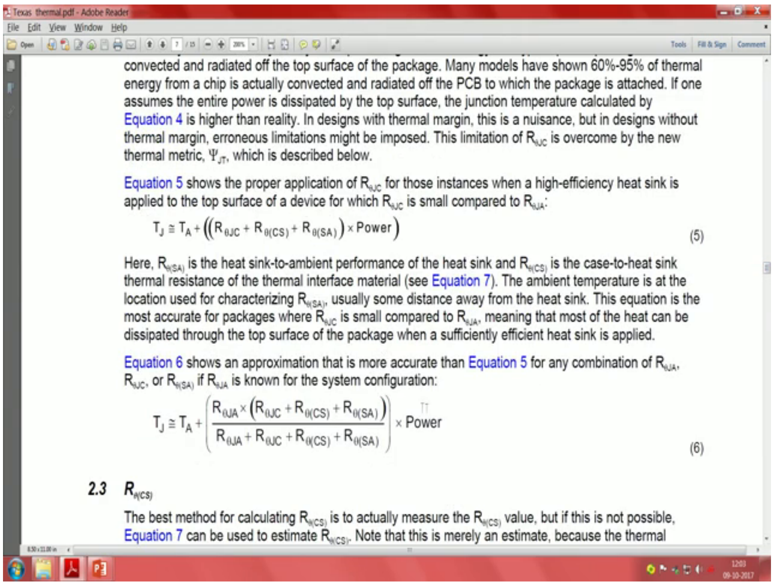
convected and radiated off the top surface of the package. Many models have shown 60%-95% of thermal energy from a chip is actually convected and radiated off the PCB to which the package is attached. If one assumes the entire power is dissipated by the top surface, the junction temperature calculated by Equation 4 is higher than reality. In designs with thermal margin, this is a nuisance, but in designs without thermal margin, erroneous limitations might be imposed. This limitation of $R_{\theta JC}$ is overcome by the new thermal metric, Ψ_{JT}, which is described below.

Equation 5 shows the proper application of $R_{\theta JC}$ for those instances when a high-efficiency heat sink is applied to the top surface of a device for which $R_{\theta JC}$ is small compared to $R_{\theta JA}$:

$$T_J \cong T_A + \left(\left(R_{\theta JC} + R_{\theta(CS)} + R_{\theta(SA)}\right) \times Power\right) \quad (5)$$

Here, $R_{\theta(SA)}$ is the heat sink-to-ambient performance of the heat sink and $R_{\theta(CS)}$ is the case-to-heat sink thermal resistance of the thermal interface material (see Equation 7). The ambient temperature is at the location used for characterizing $R_{\theta(SA)}$, usually some distance away from the heat sink. This equation is the most accurate for packages where $R_{\theta JC}$ is small compared to $R_{\theta JA}$, meaning that most of the heat can be dissipated through the top surface of the package when a sufficiently efficient heat sink is applied.

Equation 6 shows an approximation that is more accurate than Equation 5 for any combination of $R_{\theta JA}$, $R_{\theta JC}$, or $R_{\theta(SA)}$ if $R_{\theta JA}$ is known for the system configuration:

$$T_J \cong T_A + \left(\frac{R_{\theta JA} \times \left(R_{\theta JC} + R_{\theta(CS)} + R_{\theta(SA)}\right)}{R_{\theta JA} + R_{\theta JC} + R_{\theta(CS)} + R_{\theta(SA)}}\right) \times Power \quad (6)$$

2.3 $R_{\theta(CS)}$

The best method for calculating $R_{\theta(CS)}$ is to actually measure the $R_{\theta(CS)}$ value, but if this is not possible, Equation 7 can be used to estimate $R_{\theta(CS)}$. Note that this is merely an estimate, because the thermal

We have beautifully, you have seen this a beautiful correlation with which it is very much possible for us to knowing the correct conditions. If you know the power and if we can somehow estimate all these, what your say type of you know junction to ambient junction to case, the case to heat sink the sink to ambient all these things it is possible for you to get approximately I mean very close to the junction temperature, which is good absolutely which is very good.

And the manufacturers themselves, I will now try to minimize this and see..

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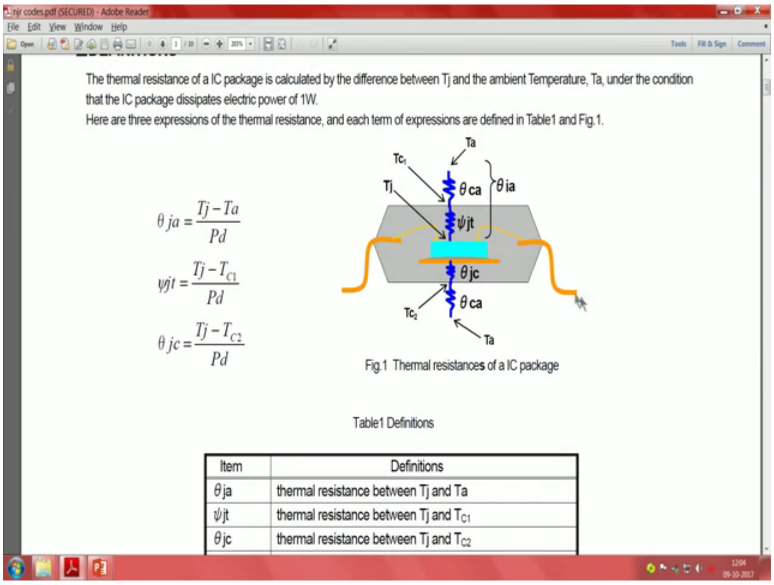

You have seen this here their conduction here, there is a conduction here and then there is conduction and directly to ambient and then you have something through the leads and we have a huge collection of, this is taken from one of the manufacturers catalog.

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TYPE	PACKAGE CODE	STYLE LEAD COUNT	THETA JC °C/W	THETA JA °C/W	PIN COMMON TO SUBSTRATE — BOARD TYPE
Metal Can	K	TO-3 2L	3	35	Case
		TO-3 4L	3	35	Case
Metal Can	H	TO-5	40	150	—
		TO-39	15	150	Pin 3*
		TO-46	80	440	Pin 3*
		TO-52	N/A	360	Pin 3*
CERDIP	J	J8	30	110	—

You see here we have a beauty saying the to 3 is the conventionally which I have you know what we are trying to explain to you earlier is the so called power transistor that case which was in use for a very long time.

So, it is about this much size, I am sure to some of you have seen it and if you are hobbies you would have seen these old power transistors including several switching transistors, if you have a audio amplifier it is possible if you are operating in a class d, get tremendous amount of power and then make it little more efficient. So, all of them invariably use this to 3 to 3 is a very nice what you call you have a beautiful base which is made of high conductivity material, often a variant of copper then in this also know you have 2 variants you have the 2 lead and a 4 lead.

Now, looking at the what you call the thing here you have seen this here junction to case is 3 degree centigrade per watt. So, if somehow the case can be kept around, let us say 40 or 50 degrees centigrade and you have 10 watts, you are still at inside the case the junction can be 3 into 10, 30 above the case. So, the case is at 40 you are still nicely you can get away with 70 watts and then a little going up higher and higher if you can tolerate around 100 degree centigrade of the junction and then, the I mean the case is at as I told you know I will take an example of 40. So, I still have 60 divided by 3 safely you know 20 watts can pass through it.

Now, the 20 watts refers to steady state after the temperature has stabilized over a measurement time, the right side figure shows you the actual directly junction to ambient if you do not have a heat spreader of any type. This one refers to junction to case and the case can be maintained at a given temperature, this is directly junction to ambient. So, if the ambient itself is again taking the told example of a 40 degrees and then you have this 35 degrees. So, now, the amount of a heat that can be allowed to be dissipated will become 10 times less, you understand know between 3 to 30 they are the 30 degree centigrade rise and here its only a 3 degree centigrade rise with a.

I will now start using the word heat sink with the heat sink what gets 3 degrees for a given what you call watt without the heat sink it can become so much, some of you would have seen the old transistors which come in a metal can well known to 5 package. So, you have seen here, if you put a small heat spreader you can come to 40 and then we do not have a heat spreader directly it becomes very very high..

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		(TO-92)			(By Device)
Plastic TO	T	TO-220 3L	11	34	Pin 2
	T	TO-220 5L	11	34	Pin 3
	T7	TO-220 7L	11	34	Pin 4
Plastic DD	M	DD Pak 3L	11	34	Pin 2
	Q	DD Pak 5L	11	34	Pin 3
	R	DD Pak 7L	11	34	Pin 4
Plastic PDIP 300mil	N8	N8	45	100	Cu, 4 layer
		N8	50	150	A42, 4 layer
Plastic PDIP 300mil	N	N14, Cu	33	70	4 Layer
		N16, Cu	34	70	4 Layer
		N18, Cu	29	65	4 Layer
		N20, Cu	28	62	4 Layer
		N24, Cu	27	60	4 Layer
		N28, Cu	30	59	4 Layer
Plastic SC70	SC6	SC6, 2 pin fused	-	270	Cu, Multilayer
	SC8	SC8, 3 pin fused		270	Cu, Multilayer
Plastic SOT/TSOT	S3	S3	100	202	A42, 4 layer, pin 2
	S5	S5	50	215	Cu, 4 layer, Pin 2
	S6	S6	51	192	Cu, 4 layer, Pin 2
	TS8	TS8	47	195	Cu, 4 layer, Pin 2
Plastic	ST	SOT-223	15	60 (est.)	Pin 2

So, it is not possible for you to, next die I would like to point out these things when I get back to the power point projection again try to show you these things again. You see here at the top I am sure some several of you must have come across is TO 220 packages, TO 220 instead of the old TO 3 the same what you call a die and a chip is mounted in a plastic case, you understand know the plastic with a small heat sinking what you call base attached to it.

So, what was 3, it is like it is suddenly becomes know 4 times as much because the amount of area available for contact is much less. So, you have 3 lead a 5 lead and so on know. Typically all of them are same, once again we end up with the same condition if you were not to use any heat sink it as good as that same old To 3 package and then as we go on so many of them know have been, so many new packages have come about.

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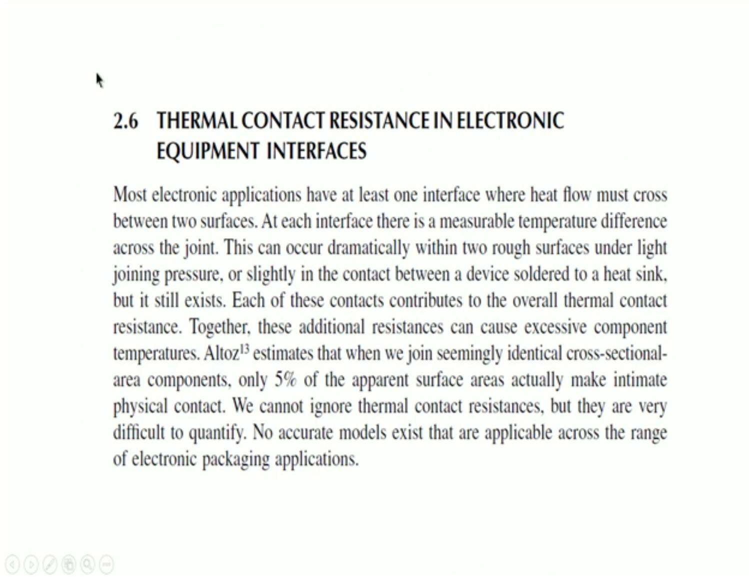

2.6 THERMAL CONTACT RESISTANCE IN ELECTRONIC EQUIPMENT INTERFACES

Most electronic applications have at least one interface where heat flow must cross between two surfaces. At each interface there is a measurable temperature difference across the joint. This can occur dramatically within two rough surfaces under light joining pressure, or slightly in the contact between a device soldered to a heat sink, but it still exists. Each of these contacts contributes to the overall thermal contact resistance. Together, these additional resistances can cause excessive component temperatures. Altoz[13] estimates that when we join seemingly identical cross-sectional-area components, only 5% of the apparent surface areas actually make intimate physical contact. We cannot ignore thermal contact resistances, but they are very difficult to quantify. No accurate models exist that are applicable across the range of electronic packaging applications.

So, we have this sot packages and all that which is not intended for power applications and all the time manufacturers are coming back with more and more newer type of packages all the time.

Now, I will start with the little bit of a, allow me to get back to the what you call background material. So, this typically here you will see that you have seen this know, there is at least one interface where heat flow must cross between 2 surfaces very rarely things are directly built into it, except maybe a heater or these our what you call electronic lamps where there is an arc lamp and so on were directly the final you know effect. The gas heating and all it occurs directly by various electrical and heat phenomena, in this case in all other cases normal electronic thing we must have an interface where heat flow crosses 2 surfaces.

At each interface there is a measurable temperature difference across the joint, this is the boon this where we can work completely understand know there is a this thing. This can occur dramatically with into rough surfaces under light joining pressure or slightly in the contact between device soldered to the heat sink you understood know, but it still exists even if you have to directly take a electronic device the base and use some way of as a soldering. Soldering usually has an interface material, the other is directly welding you can have a contact welding that is you can have a electrical resistance welding other than that you have also sometimes the same thing is called brazing or hydrogen brazing, you put it in a not gas and then pass another this thing in the whole thing know they get fused to much better.

But even then there is some temperature drop and some resistance each of these contacts contribute to the overall thermal contact resistance, additional resistance and cause excessive component temperatures this is where it is. Estimate that when you join seemingly identical cross sectional area components, this is a very very critical thing 5 percent of the apparent surface actually make intimate physical contact. You seen that know in the very early beginning of the lecture I told you even the so called metal to metal that is if you take a, let us say 10 mm by 20 mm to 20 back of it and then try to attach it to another 10 mm by 20 mm what you call a copper rod and try to conduct a very little effect. In fact, this is a to me it feels threatening I first time I thought it could be 50 percent.

If we just lightly just touch it each other know only 5 percent of it is actual contact, remaining there is always some other medium in between subsequent slides explain to you. We cannot take ignore thermal contact resistances, but they are very difficult to quantify, no accurate models exist that are you a clip applicable across the range of packaging applications. So, when they talk about packaging applications latest is you would have seen all these new high power diodes if we take a so called 3 watt white led, 3 watts is a lot of wattage and then they actually light emitting area of that chip, chip led may be less than one millimeter square.

Now, if you go and examine Lucian star led by either Philips or (Refer Time: 21:46) or any of these people who make LEDs you see that all of them know and one of them well known thing is called golden dragon G D Hilary's and all that you notice that it already comes pre mounted on a chip. I am sorry on a small octagonal or hexagonal heat sink area, understand know that is somebody has braised it alternate if you buy the chip led and then the way they put it in your commercial things they give how the pad should be, how a slug be in the center should form its thing, how the whole thing has to be used in the application noted.

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2.6.1 Simplified Contact Resistance Model

Consider that heat flows from a microprocessor into a heat sink, both of which are in intimate contact. We assume that heat flow occurs in the axial direction, x, only. Heat flows through the microprocessor according to Fourier's law.

In a real interface, the surfaces are not perfectly smooth. As heat flows from the microprocessor into the heat sink, the heat transfer area seems constant—we call this the apparent contact area, A_a. We call the temperature difference caused by the thermal resistance at the interface the thermal contact resistance, ΔT_c. We call the interface coefficient h_i. The apparent contact area is composed of the cross-sectional area where we make actual hard contact, A_c, and a void area where contact does not occur, A_v. The apparent area of contact, A_a, then, is the sum of both the actual contact area A_c and the void area A_v. A magnified view of the thermal interface is shown in Figure 2.24.

Again coming back to this thing, no accurate models and so on, next thing is instead can we have a simplified contact resistance, consist that heat flows from a microprocessor into heat sink both of which are intimate contact. We assume that heat flow occurs in the axial direction x only heat flows through the microprocessor according to Fourier's law, this I said is what was made 200 years back what he has found out is if you increase temperature more heat flows and then a lot of heat is related to the area and then we have a proportionality constant.

And then the inverse of the proportionality constant, we use a directly as a thermal resistance where the advantage if we can add up these things. In a real interface surfaces are not perfectly smooth, as heat flows from the microprocessor into the heat sink the heat transfer area seems constant we call that the apparent contact area. We call the temperature difference caused by the this thermal contact resistance, we call the interface coefficient hi apparent contact area is composed of the cross sectional area where we make actual hard contact and a wide area of a contact does not occur.

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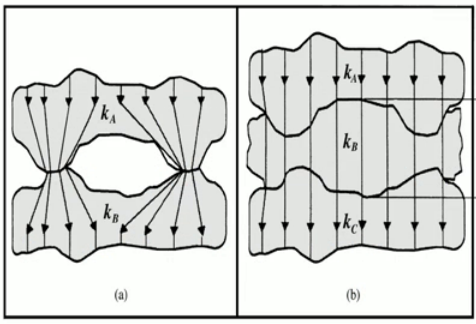

FIGURE 2.24 Heat flow across contacting surfaces: (a) without interstitial material, (b) with interstitial material. The interstitial material greatly increases the contact area available for heat transfer.

Heat flow across the thermal interface is quite complex. Conduction in the interface is parallel and three-dimensional as the heat appears to "squeeze" through the points of contact. Heat flow also occurs by radiation and by conduction through the interface material, which might be air. We can show that convection in the void fluid is insignificant if the Rayleigh number is <1700, which is almost always the case.

The apparent area of contact then is a sum of both actual and the wide area, magnified view is given in this model as in this. So, we have a material a, material b and then in between know is there something we can do to ensure the isothermal lines getting here. All this the chair know has no practical what you call thermal conductivity without interstitial material with interstitial, the interstitial material greatly increases the contact area available for heat transfer. In a lecture few lectures earlier I had given you the heat conductivity of both air, water and so called heat sink compound, usually they have that related paste. It is not very high it is still while if you take one for I mean some a two hundred for copper this comes nearly you know point two or something a 1000 say a 1000 times less. So, if you can somehow make this 0 and then do something else subsequent lectures know will give you, I will come back you see here.