Transcriber's Name: Crescendo Transcription Pvt. Ltd.
Design of Power Electronic Converters
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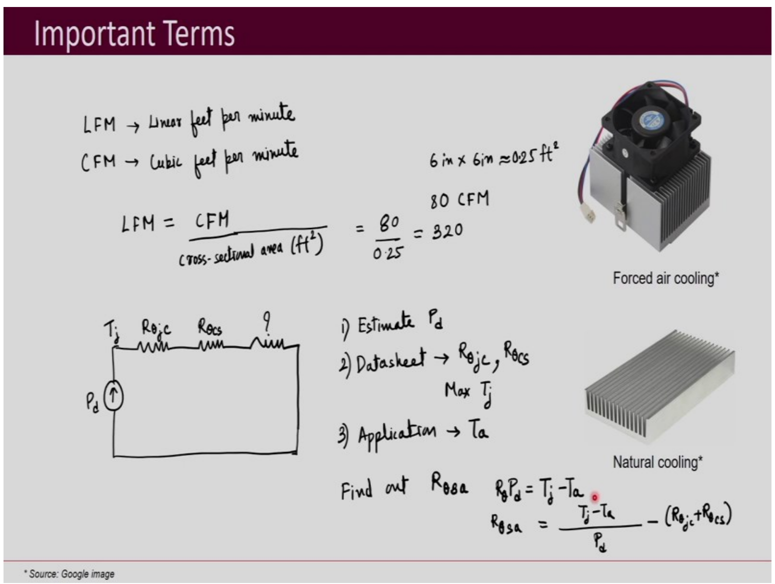
Lecture – 43
Choosing Heat Sink

Welcome to the course on Design of Power Electronic Converters. We were in the module of thermal design. Till now, we have seen the procedure to estimate the power losses. Then we also saw different types of heat sinks. Then we further saw simple models of thermal design. We saw steady state response, transient response and we also saw how devices can be modelled in very simple networks. Now, let us look into the procedure to choose the heat sink for thermal design, that means actually the procedure to do the thermal design.



So, thermal design means that basically you have to cool down the device and you have to choose the heat sinks and you have to choose the cooling method, that means in forced air cooling or liquid cooling or natural cooling you want to choose cooling type and a good heat sink, which you can use, and it will be able to cool down the devices and the entire power electronic converter. Then, we will be able to maintain the temperatures below the maximum limits.

So, now, we have to then be familiar with the terms which are important for heat sink selection. Now, we have already discussed some of the terms like the thermal resistances, impedances, the time constants. So, those terms are important. Apart from that you should be knowing the common terms related to the fan. Because if you are using forced air cooling, you should know about the way for that specified fan for thermal design.

Now, there are two terms associated there, one is LFM that is linear feet per minute and second is CFM which is cubic feet per minute. Now, this linear feet per minute is basically in terms of heat sink, and it is the volume of the air which is flowing through a certain point or a certain part.

But usually the fan manufacturers provide air velocity information in terms of cubic feet per minute. It is a volumetric air flow term, which is cubic feet per minute. So, we can relate these two. They can be converted. So, linear feet per minute (LFM) is equal to CFM by cross sectional area of the fan and it has to be in feet square.

So, let us say the fan is *6* in into *6* in. The cross sectional area of it is written as equal $0.25\ ft^2$. If the manufacturer provides you the information that it is an *80* CFM fan, you can substitute here and it is *80* by *0.25*. So, that will give you *320*.

$$LFM = \frac{CFM}{cross - sectional\ area\ (ft^2)} = \frac{80}{0.25} = 320$$

So, that means *320* in LFM is equal to *80* CFM. Now, we saw that there are different types of foster network, cauer network and then transient and then you can also use the very simple steady state equivalent circuit for choosing the heat sink. Now, most of the people go by the simplest one which means the simple electrical equivalent circuit that we have discussed before. That means, you calculate or you estimate the total power dissipation (P_d).

You find out the different thermal resistances that are provided and you find out the maximum junction temperature. So, you look for estimate the P_d, the total power dissipation. Then you go to the datasheet of the device which you are using and from there you look for the information of $R_{\theta jc}$.

So, you look for that information. Then you will also find out the typical value of case to sink. This is also mostly given in the datasheet of devices or depending on thermal pads that you may be using or the type of thermal paste, which you may be applying to the power semiconductor modules base. So, from their data sheets also you can find out the typical value of case to sink thermal resistance.

So, you find out these and then you also find out the allowed maximum junction temperature (T_j). Then based on the application, you find out the ambient temperature. It may not be a fixed ambient temperature, or it may be a range of ambient temperature. So, you can find out the most likely ambient temperature. It is a room temperature or is it higher than that *50°C*, *60°C*. It is around room temperature *20- 25°C*, which is the ambient temperature for the application.

So, once you have found out these things, then you find out $R_{\theta sa}$. So, this is the one that you find out. So, we write using simple equations that is

$$R_\theta P_d = T_j - T_a$$

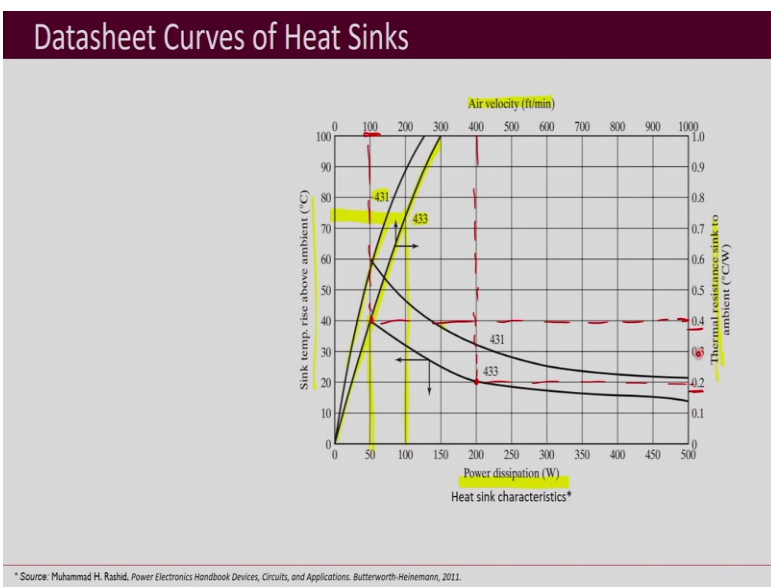
So, based on that you can find out this $R_{\theta sa}$.

$$R_{\theta sa} = \frac{T_j - T_a}{P_d} - (R_{\theta jc} + R_{\theta cs})$$

Then you go to the data sheets of different manufacturers of heat sinks. You try to find out a heat sink which has got a thermal resistance similar to this. Now, this equation over here is for natural cooling. Natural cooling means that you are just using the heat sink and you are not providing anything additional, and you are not giving any fan there, also you are not doing forced air cooling.

Now, here we are not discussing liquid cooling. We are skipping it, we are taking only the simple things. So, this equation is valid for natural cooling. So, you go into the data sheets of heat sinks and there you see for natural cooling, the thermal resistance that is provided and you have to find out a heat sink which is having a thermal resistance and which is close to this value of $R_{\theta sa}$ that you have obtained here.

If you are using forced air cooling, then you have to use these terms also and you have to also look into further information related to decrease in the thermal resistance with the value of this increase in air velocity. That is LFM value versus thermal resistance graph, which will also be provided into the data sheets of heat sinks.



So, kind of graphs or curves given by heatsink manufacturer look similar to this. So, two types of graphs are given on the same graph and it is usually to save space. They give both the graphs on the same inside one graph. There actually they give two graphs. So, the first one here is power dissipation, the P_d value versus the rise in temperature, the rise above ambient.

So, rise in temperature of the heat sink is based on the power dissipation. So, these are the graphs, which are given. So, you can see that the loss is 50. The rise in temperature will be *40°C*. This is actually over here, and it has given the information regarding the graphs for two of the heat sinks together. So, that's why you see two graphs here. One is having some number *431* and another is *433*.

So, here if we follow this 433 graph, then you can see this. If it is 100°, power dissipation of 100 W is happening. So, the temperature rise will be something in between 70, 80 and close to 75 is the temperature rise that is going to take place. Now, we observe there another graph that is air velocity versus thermal resistance. So, with respect to the air velocity in LFM, that is feet per minute, and these graphs are given.

So, *100* is the air velocity. So, there you can see that the thermal resistance is *433* for this heat sink and that is around *0.4°C/W*. If the air velocity becomes *400*, you can see that the thermal resistance reduces to *0.2°C/W*. We can mark from here and here also we can mark and you can observe this. So, like that you can see for other points also.

So, as we increase the air velocity that means forced air cooling is increased, the thermal resistance is going to go down. This graph that is provided that is the rise in temperature versus power dissipation and it is for natural cooling. That means when no forced air cooling is provided, no fan is attached, that time how the temperatures are going to rise based on power dissipation that is provided here.

So, you can obtain the thermal resistance for natural cooling using this graph. So, how do you do that? So, basically you have this rise in temperature and you also have the power dissipation. You simply divide, and 40 is the rise in temperature here corresponding to 50 W. So, 40/50, so that is 4/5 is the thermal resistance at this point.

This is not exactly a straight line. So that means thermal resistance is also not going to be completely a cost in value, it depends on power dissipation at operating point. You can obtain the thermal resistance from there for natural cooling. Then if you see for forced air cooling, how much the thermal resistance is reducing, then using this thermal resistance multiplying with the power dissipation that is happening in the application, you can obtain the rising temperature for that particular heat sink. So, let us now look into datasheet of a heat sink.

AAVID THERMAL DIVISION OF BOYD CORPORATION

DATASHEET

Board Level Cooling – Square Skived Fin

RoHS Compliant

BOARD LEVEL COOLING – Square Skived Fin

Square skived fin is a series of square skived fin board level heat sinks designed to cool BGA and FPGA devices. Representative image only.

ORDERING INFORMATION

Part Number	Device Type
342940	BGA, FPGA
342941	BGA, FPGA
342942	BGA, FPGA
342943	BGA, FPGA
342945	BGA, FPGA
342946	BGA, FPGA
342947	BGA, FPGA
342948	BGA, FPGA
342949	BGA, FPGA
342950	BGA, FPGA

HEAT SINK DETAILS

Property	Details
Material	Copper
Finish	AavSHIELD 3C
Device Attachment Options	Push Pin

Property	Details
Thermal Interface Material	Laird TPCM 585
Heat Sink Mounting Direction	Horizontal

MECHANICAL & PERFORMANCE

Drawing dimensions are shown in mm, (in)

Part Number	"T" Dim	"H" Dim	"W" Dim	"L" Dim
342940	2.80 (0.110)	14.00	38.50	37.58
342941	2.80 (0.110)	13.50	40.00	40.50
342942	2.80 (0.110)	22.50	45.00	44.00
342943	2.80 (0.110)	14.00	50.00	50.00
342945	2.80 (0.110)	14.00	60.00	60.00
342946	2.80 (0.110)	22.00	60.00	60.00
342947	2.80 (0.110)	11.00	57.90	59.00
342948	2.80 (0.110)	14.00	70.00	69.00
342949	2.30 (0.091)	12.00	80.00	80.00
342950	2.30 (0.091)	10.00	90.00	90.00

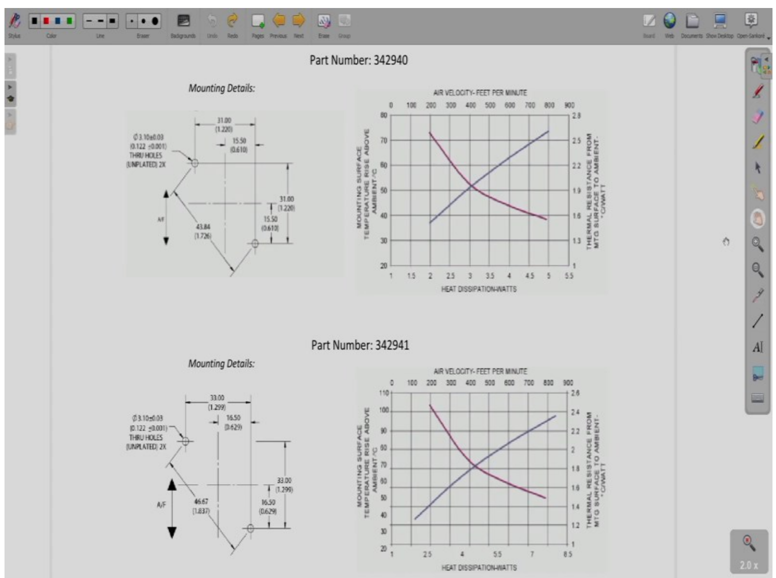
This is datasheet of a heat sink by the manufacturer AAVID and here, this is actually not a datasheet of only one heat sink, but a series of heat sinks. So, you can see that these are in series that is written here. Now, it is like the same geometry, but the dimensions may be somewhat different where you get a series.

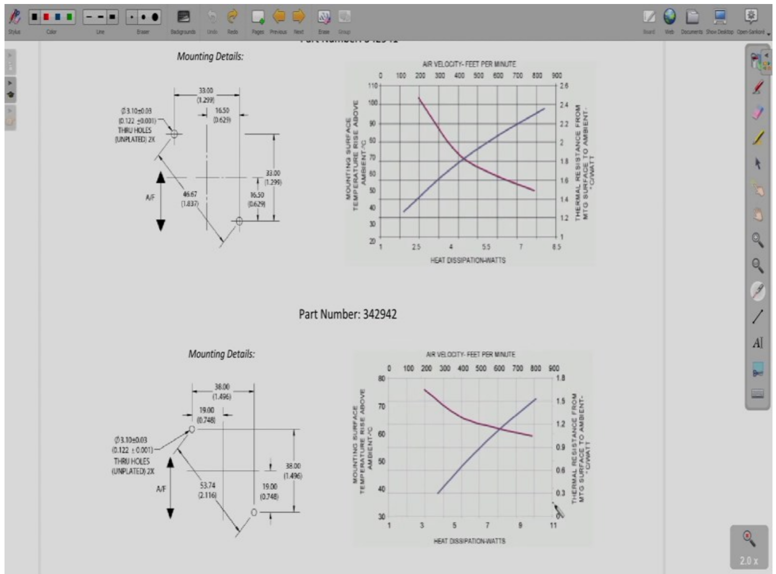
So, you can see here the geometry of the heating that it is shown over here. So, you have got the screws on the side. It means some holes are there and then you can put screws here and then fix it wherever you want to fix the heat sink. Then this is a very simple heat sink. This is a plate that you can see below.

Then further you can see that these are different fins that are put. Some of the fins and their lengths are little smaller where the screw is placed. Other fins are little longer. What is the material that is used? You can see here the material written is copper. Further other information details of the heat sink are also provided here.

It is also written that the mounting direction of the heat sink that is horizontal. It means you have to put the heat sink on this module, and you have to put it on the plate and not on the fins. Then we further see here, that this is one part number and for this entire series the dimensions are given and you can see that this dimension is same for many of them, for these two they are different.

What is this *T* dimension? You can see that this *T* is the thickness that is provided. So, they all have that same thickness plate we can see. We observe here, only two of them have different. Then what is *H*? *H* is the height of the heat sink. You can see here the height of the heat sink that is provided or you can say the height of the fins that is also given but that is varying and then that is the width of the heat sink that is also provided here. Then the length of the heat sink is also given. So, the length is also varying for different of them. Then the fin dimensions that means the thickness of the fin is also given over here. So, these are the different dimensions of the heat sinks that are provided for you.

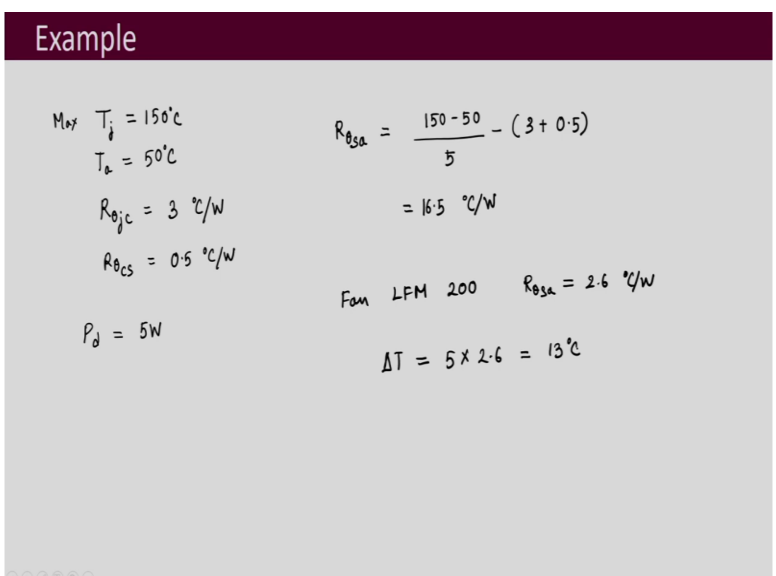


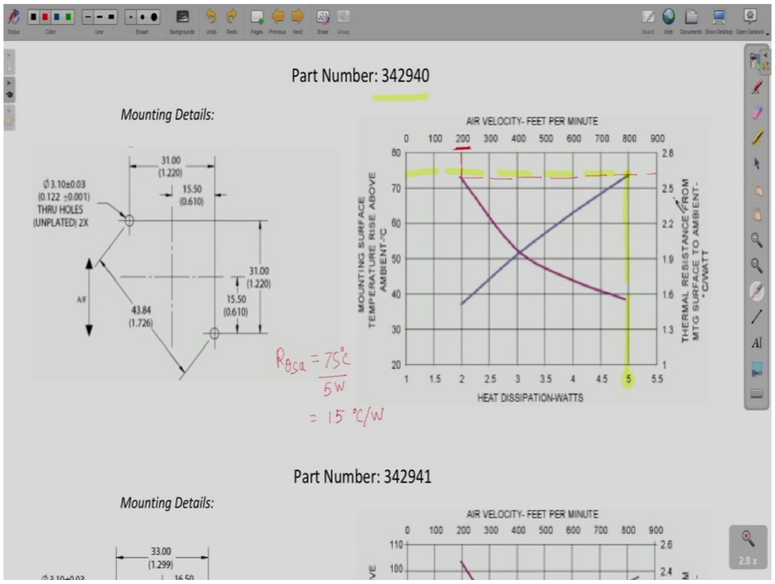


Now, we observe that further, that is the graph over here which we just saw and it means the rise in temperature versus the heat dissipation or power dissipation and this one is the air velocity (LFM) versus the thermal resistance in *ºC/W* that is provided. This is provided for this part number *342940* and similar graphs are provided for all the other rest of the part numbers.

So, you can see here. This is the second graph that is provided for this part number and then there is another one which is provided here. For this part number *342942* similar graphs are provided. On this side you observe here these mounting details that also is provided. Now this is actually associated with mounting the heat sink and mounting the device, also its orientation, and the torque which you should be providing while fixing the screws.

So, those information are also given in the data sheets. Now, let us take a simple example oof the procedure to use these data sheets for heat sink design or thermal design.





Let us say you chose some power semiconductor device for power electronic converter, where the maximum T_j is given as 150°C. So, this is the max that is allowed. For the particular application, the ambient temperature was given as equal to 50°C. Further, you saw in the data sheet that the thermal resistance from junction to case is given as *3°C/W*.

Typical thermal resistance from case to sink was given as equal to *0.5°C/W*. Let us say that the power dissipation that was happening in the device was equal to *5 W*. So, now,

$$R_{\theta sa} = \frac{150-50}{5} - (3 + 0.5)$$

$$= 16.5\ ^\circ\mathrm{C/W}$$

That means, you have to choose a heat sink whose thermal resistance is close to this or somewhat below this. In this way you have to choose the heat sink. So, now, let us go back to the data sheets. Now, if we look into this datasheet for this part number *342940*, for *5 W* power dissipation you can see here the temperature rise is about *75°C*. So, thermal resistance $R_{\theta sa}$ will be equal to *75°C* by *5 W*.

So, *15°C/W* will be the $R_{\theta sa}$. We needed something close to *16.5* or somewhat below that. So, we observe here that, we can choose this heat sink and we can use it. But we see here that for *5 W* the rise in temperature is *75°C,* which is a very huge temperature change that you can observe.

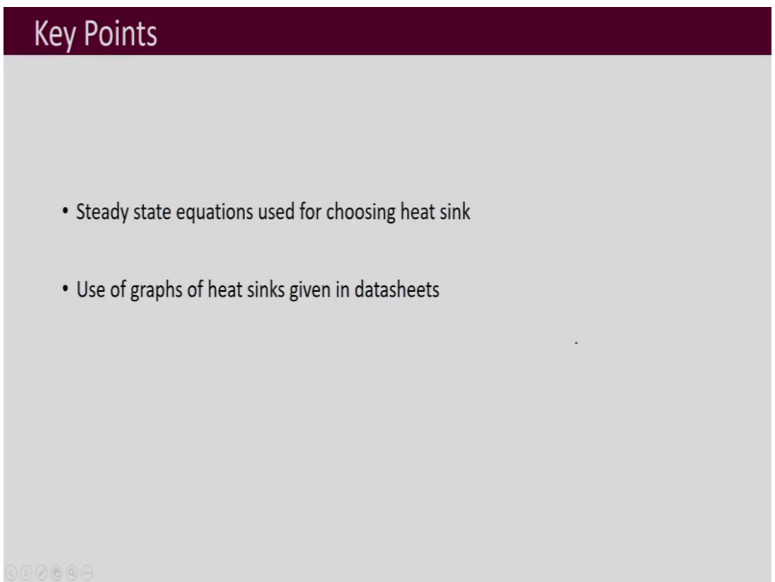
Now, what happens if you are going to use the forced air cooling that means you use a fan there, now you decided to go for a fan where the air velocity that means LFM is *200*. *200* is the LFM when you choose the fan. Correspondingly you can find out CFM of the fan by converting and the cross sectional area of the fan. So, LFM of the fan turns out to be *200*.

So, then, you can observe here that for *200,* this thermal resistance you find out that this is almost equal to *2.6* over here. The thermal resistances are between *2.5* and *2.8*. We can approximately say that the thermal resistance turns out to be *2.6*. So, in that case if you have the fan whose LFM equal to *200* and we saw that $R_{\theta sa}$ for that particular heat sink was equal to *2.6°C/W*.

So, then the change in temperature

$$\Delta T = 5 \times 2.6 = 13\ ^{\circ}\mathrm{C}$$

So, that much is the difference when you go for forced air cooling. So, now, using the same heat sink then more power dissipation can also be allowed based on the maximum temperature difference between T_j and T_a that is allowed. So, in this way you can use the information that is given in the data sheets of heat sinks and choose the heat sink that will be suitable for your purpose.



So, the key points of this lecture are that most of the time the steady state equations used for choosing the heat sink are the simple equations and there are graphs given by manufacturers of heat sink. Then you can use those graphs to find out the thermal resistance of the heat sink versus for different power dissipation and temperature rise using that information and if the heating is meant for forced air cooling, how much is the reduction in the thermal resistance as air velocity is increased? Those graphs are also provided by the manufacturer. So, using that you can then choose the thermal design, that means how much is the forced air cooling if you needed, how much of air velocity is required, or what should be the thermal resistance of the heat sink that is needed. So, you can perform these kinds of calculations and select the thermal design. Thank you.