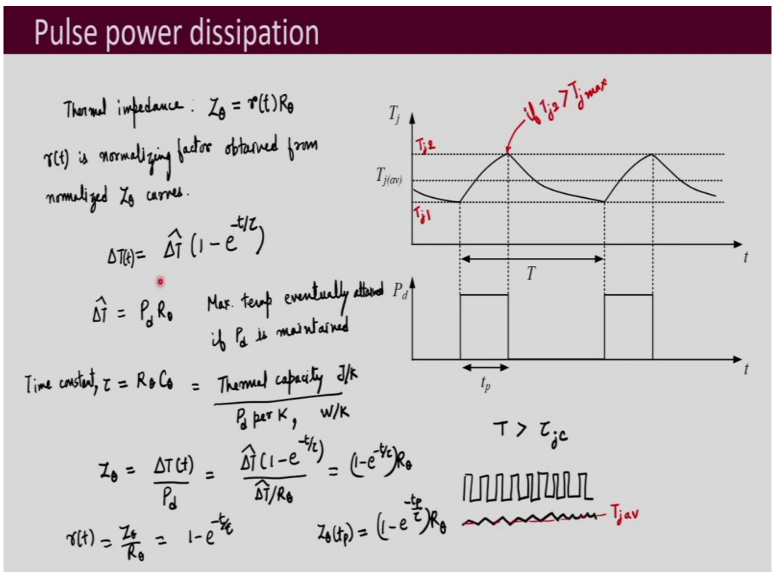
Transcriber's Name: Crescendo Transcription Pvt. Ltd.
Design of Power Electronic Converters
Professor Doctor Shabari Nath
Department of Electronics and Electrical Engineering
Indian Institute of Technology, Guwahati
Lecture – 41
Thermal Modelling 2

Welcome back to the course on Design of Power Electronic converters. We were discussing Thermal Design. In last lecture, we saw the electrical equivalent circuit, which can be used for choice of heat sinks, when we can use the steady state response. Now, in this lecture let us look into the transient response.



This graph shows that the power dissipation is in the form of pulses and the frequency of these pulses is small enough. This time period T is much large as compared to the time constant of the junction to case material. Let us say that the temperature was over here initially before this power dissipation pulse. So, as the power dissipation (P_d) takes place, the junction temperature increases and it reaches to another temperature.

T_{j2} and T_{j1} are mentioned in the figure given in the slide-1. So, T_{j1} increases to this temperature of T_{j2} and then after that this time period of the pulse (t_p) gets over and again there is no dissipation taking place. So, the temperature tends to reduce and it goes back to the original temperature of T_{j1}. Further, when this next power dissipation (P_d) comes in, then again this temperature increases and decreases in the usual manner.

As, I just told you that this time period (T) of the pulse is much larger than the time constant (τ_{jc}) of the junction to case. The chip is being used whatever semiconductor device material is there. In that case this is relevant as compared to last lecture, where we saw that the pulse density is very high or the frequency at which it is taking place is very high.

So, the junction then responds to the average that means it increases and decreases very small such that it is almost like a steady state temperature or like an average junction temperature where average power dissipation is there, to which the junction is responding. So, at that time this was not valid. The time period of this entire cycle was not large as compared to the time constant of the junction to case area.

So, in that case this steady state model is not valid. We have to take into account the transient response. So, in that case the simple thermal resistance, $R_{\theta jc}$ is not applicable. Instead of that the thermal impedance or the transient thermal impedance is used, and this is denoted by Z_θ, which is written as

$$Z_\theta = r(t)R_\theta$$

Now, this *r(t)* is a normalizing factor, which is obtained from normalized Z_θ curves. Now here the problem is that, if T_{j2} becomes greater than the maximum junction temperature that is written in the datasheet of the semiconductor device, then the device may get damaged. So, the device is now going to respond to the instantaneous temperatures or the peak, to that the device is going to respond.

So, the average temperature or the steady state temperature is not important. The important is that how instantaneously the temperatures are rising or falling and whether it is reaching to a value which is greater than the maximum junction temperature permissible for that device. So, we have to use that transient model and find out if this temperature to which it reaches, is greater than the maximum junction temperature.

So, then this is written as the temperature rise

$$\Delta T(t) = \widehat{\Delta T}(1 - e^{-t/\tau}).$$

Now this equation is similar to the transient equations that you have written for electrical circuits. For the RC circuits the way you have written the transient equations, is similar to this equation. The peak temperature rise is denoted by

$$\widehat{\Delta T}$$

τ is the time constant of the circuit where it will be governed by to the thermal resistance (R_θ) and the thermal capacitance (C_θ).

t is the time, for that it takes place. Eventually if the power dissipation is maintained everything, in that case it has to reach the steady state. But if it does not happen, and if again the state changes, then we have to apply this equation and see that how much is the temperature. Now,

$$\widehat{\Delta T} = P_d R_\theta$$

This is the maximum temperature which eventually is going to be attained if P_d is maintained.

It means if you continuously keep apply P_d , then in steady state the temperature rise will take place that is

$$\widehat{\Delta T} = P_d R_\theta$$

As, I already told you this time constant (τ) this is given as

$$\tau = R_\theta C_\theta$$

or

$$\tau = R_\theta C_\theta = \frac{Thermal\ Capacity \quad J/k}{P_d\ per\ k, \qquad W/k}.$$

Now, let me write it as a function of time because the change in the temperature is a function of time. Here, ΔT is as a function of time and it is divided by (P_d) the thermal impedance. So, this will be given as

$$Z_\theta = \frac{\Delta T(t)}{P_d} = \frac{\widehat{\Delta T}(1-e^{-t/\tau})}{\widehat{\Delta T}/R_\theta} = \left(1 - e^{-t/\tau}\right)R_\theta$$

So, this normalized part that means,

$$r(t) = \frac{Z_\theta}{R_\theta} = 1 - e^{-t/\tau}$$

.

Now, this thermal impedance is a function of time. So, it is going to vary with time and it depends on this time constant (τ) that means, it is equal to R_θ into multiplication of C_θ and of course, we can normalize it dividing by the thermal resistance (R_θ).

Many times instead of T people apply this t_p that means, what is written as

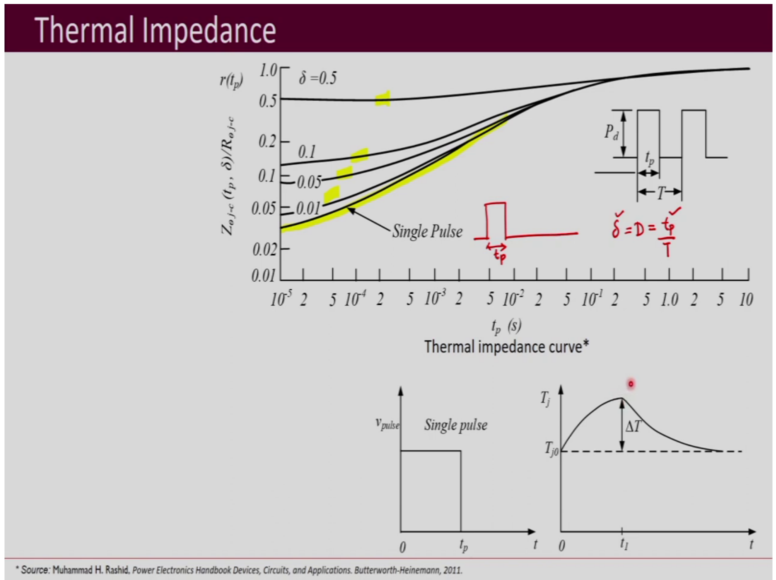
$$Z_\theta(t_p) = \left(1 - e^{-t_p/\tau}\right)R_\theta$$

After t_p no dissipation is going to take place. So, we are mostly interested in finding out the temperature to which it is reaching finally. We are most interested in T_{j2}.

So, this t_p time is that where we have to find out the thermal impedance, and at this point temperatures are rising. Now, this equation is written over here. This is assuming that it is a homogeneous material and it is uniform heat flow. The path of the flow of heat is very uniform and there is only a single point where power dissipation is taking place.

Now, that model in practice does not work for most of the practical devices components that we use. That model is not applicable and the path is not uniform. We may not be having a single point at which the power distribution may be taking place. The material may not be homogeneous and several other non-idealities may be there. So, this equation that is written over here, cannot be used to find out the thermal impedance.

So, instead of that the manufacturers perform experiments and they measure temperatures by giving the pulses of different durations and then they obtain curves and those curves are provided which can be then used for a purpose where transient model is applicable and we have to use this kind of transient equations to find out the rise in the temperature.



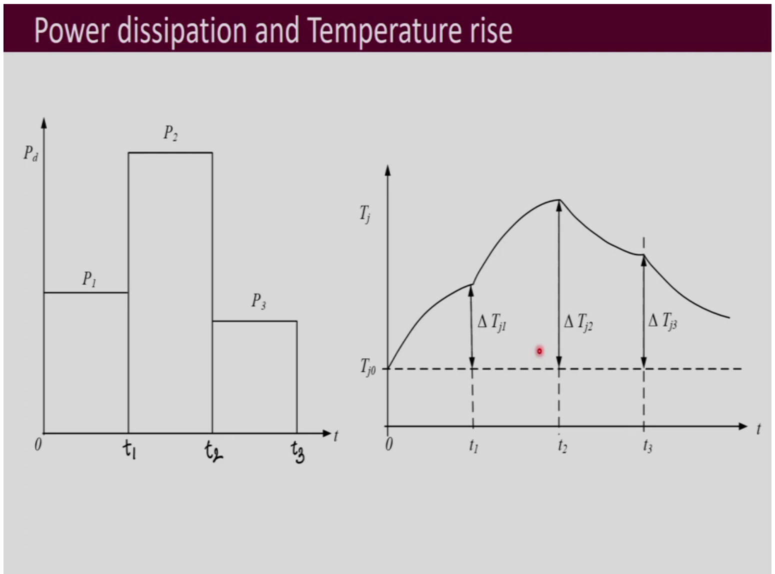
So, this is the nature of those graphs which are provided by manufacturers. So, here you can see that this one is the thermal impedance normalized and it is divided by the thermal resistance that means, this is the curve of $r(t_p)$. Over here this is the x axis, where the duration of the pulse t_p is given. Then, the thermal impedance for different values of t_p is provided over here.

Now, this first curve is for a single pulse. So, this one is for a single pulse and here more curves are given. The other four curves are for nature of pulses which are repetitive. The single pulse means that the pulse is there and then after that there is no pulse. So, that is the single pulse, which is of duration t_p. Here in this case, we have repetitive pulses, which are the pulse duration of t_p.

The time period or the frequency is decided by this period T and P_d is the power dissipation that is taking place. This power dissipation means the height of this pulse. So, then we can write the duty ratio, which is denoted by δ. D is the notation of duty ratio which we have used earlier. So, that is t_p by T. So, if we know this duty ratio and t_p, then we will be also able to find out T.

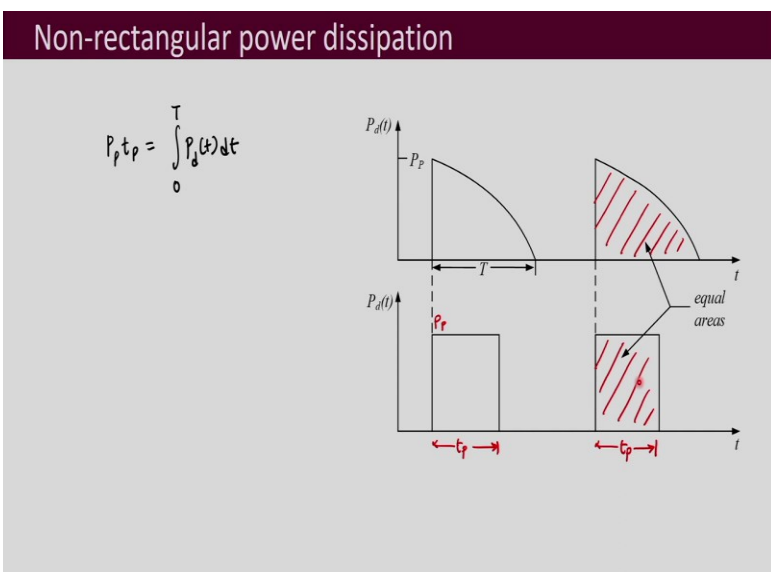
So, with respect to different values of this duty ratio and t_p, these plots are provided for the thermal impedances. So, from here, the transient response is going to be more valid or important for a particular purpose where the power distribution is taking place. So, in that case, we can use these kind of graphs. From there, you can find out the thermal impedance and you can find out the power dissipation and you can find out the rise in the temperature.

So, that is single pulse which is shown here. Here is the rise in the temperature and then after that the temperature just goes down and reaches to a particular value and this is the temperature which is very important that means instantaneously attained temperature is more important than the average temperature rise.



Now, power dissipation always need not be in form of just pulse, single pulse or repetitive pulse. It may be having different shapes. In these kind of different pulses for various values of power dissipation here, the power dissipation is assumed by P_1. The time duration is t_1, then till time t_2 the power dissipation level changes and it has the value of P_2. Then further for another time up till t_3 the power dissipation that takes place is P_3.

So, in that case, the changing phenomenon of temperatures has to be reached first and it is assumed that the change in temperature is ΔT_{j1}, then further it reaches to another temperature level that is delta T_{j2} plus this initial temperature which is denoted by T_{j0}. Then at point t_3 it reaches to this level, that is ΔT_{j3} plus T_{j0}. Then it finally decreases. So, they are also the same equations and those are transient thermal impedance graphs, which can be used to determine to what value the temperature has reached.



Now always it may not be in the form of rectangular pulses. The power dissipation may be of various different types of the shape. The power dissipation, you can plot and what you obtain may be very different. For example, it is shown here. Let us say the power dissipation is of this form which is taking place for this time period T and the peak is P_P and then it slowly reduces in this nature.

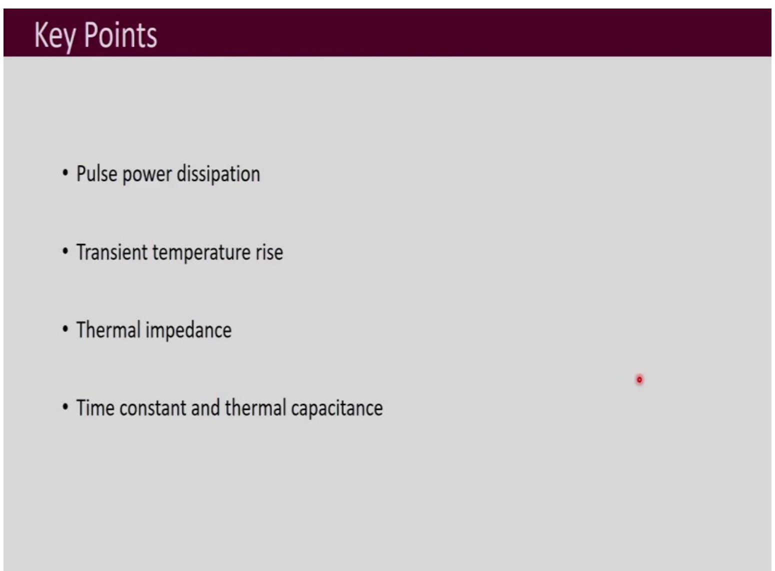
Now, whatever equations that we had written and whatever graphs that are given by manufacturers they are for rectangular pulses. So, then how do we convert this non-rectangular power distribution to rectangular? So, for that we can find out an equivalent rectangular power dissipation P_d where usually they maintain this peak power, mentioned by P_P.

These two areas are equated such that during this time period (t_p) it is

$$P_p t_p = \int_0^T P_d(t)dt.$$

So, what we observe here is the peak (P_P) which is retained and this time period (t_p) has to be decided such that the area of these two are equal.

So, in this way we can convert non rectangular power dissipation to rectangular power dissipation and then use the thermal transient thermal impedance graphs for finding out the terrorizing temperature.



So, the key points of this lecture are that the pulsed power dissipation in that case is depending on the frequency. If the frequency is low, then the transient model is applicable and temperature rise is transient and thermal impedance is used to there instead of thermal resistance and in the thermal impedance the time constant plays a very important role. Thank you.