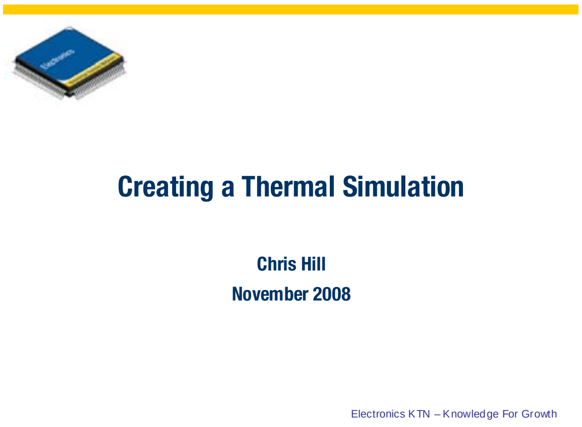
Creating a Thermal Simulation



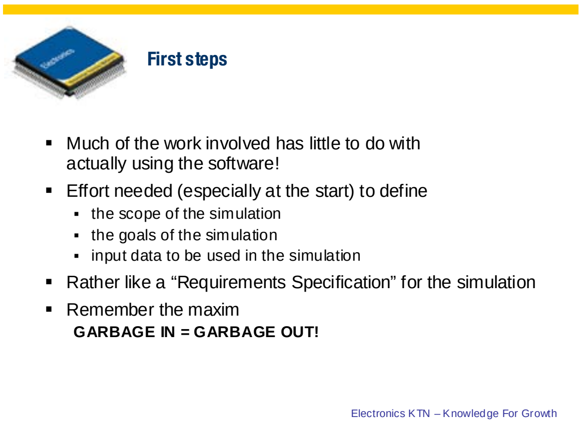
Creating a Thermal Simulation

Chris Hill
November 2008

Electronics KTN – Knowledge For Growth

This presentation will describe the steps taken in order to create a typical thermal simulation.

The presentation will use the “Flotherm” thermal simulation package as an example, although the method described will be equally applicable to any thermal simulation software.



First steps

- Much of the work involved has little to do with actually using the software!
- Effort needed (especially at the start) to define
  - the scope of the simulation
  - the goals of the simulation
  - input data to be used in the simulation
- Rather like a “Requirements Specification” for the simulation
- Remember the maxim
  GARBAGE IN = GARBAGE OUT!

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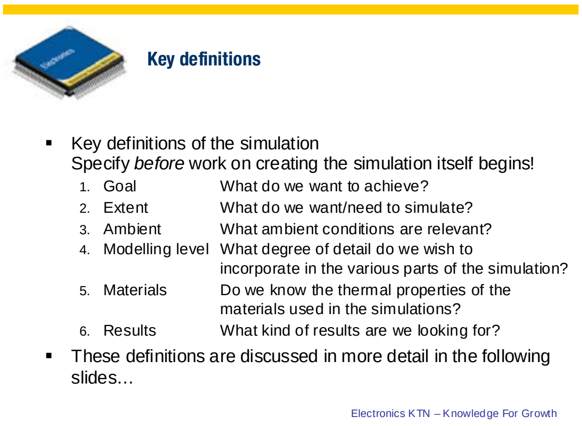
Much of the work involved in creating a successful thermal simulation has little to do with the actual use of the software itself. Rather, a degree of effort must be expended (especially at the start of the project) in defining the scope of the simulation, the goals of the simulation, and the input data to be used in the simulation.

This is rather like defining a “Requirements Specification” for the simulation. And remember the venerable computer maxim: garbage in = garbage out!



Key definitions

- Key definitions of the simulation
  Specify *before* work on creating the simulation itself begins!

1.	Goal	What do we want to achieve?
2.	Extent	What do we want/need to simulate?
3.	Ambient	What ambient conditions are relevant?
4.	Modelling level	What degree of detail do we wish to incorporate in the various parts of the simulation?
5.	Materials	Do we know the thermal properties of the materials used in the simulations?
6.	Results	What kind of results are we looking for?

- These definitions are discussed in more detail in the following slides…

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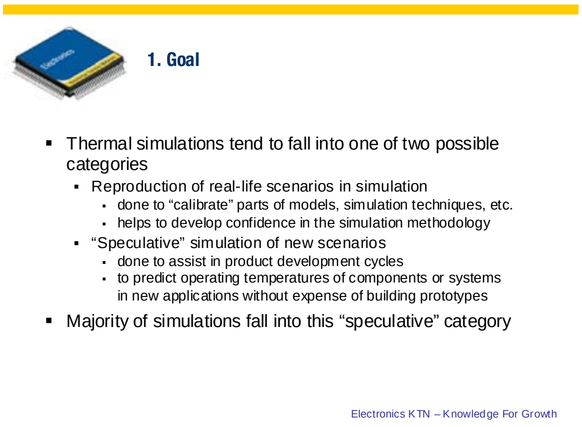
The following are key definitions of the simulation which should be specified before work on creating the simulation itself begins:

- First, the goal: What do we actually want to achieve?
- Second, the extent: What do we want or need to simulate?
- Thirdly, the ambient conditions: What ambient conditions are actually relevant?
- Fourth, the modelling level: What degree of detail do we wish to incorporate in the various parts of the simulation?
- Fifthly the materials: Do we know the thermal properties of the materials used in the simulations?
- And finally the results: What kind of results are we looking for?

These definitions are discussed in more detail in the following slides…



1. Goal

- Thermal simulations tend to fall into one of two possible categories
    - Reproduction of real-life scenarios in simulation
        - done to “calibrate” parts of models, simulation techniques, etc.
        - helps to develop confidence in the simulation methodology
    - “Speculative” simulation of new scenarios
        - done to assist in product development cycles
        - to predict operating temperatures of components or systems in new applications without expense of building prototypes
- Majority of simulations fall into this “speculative” category

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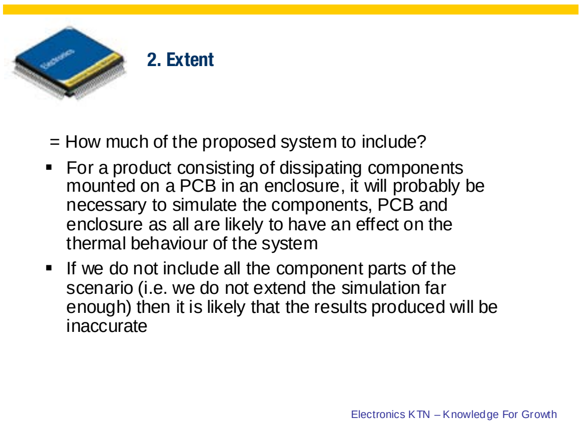
In my experience, thermal simulations tend to fall into one of two possible categories:

- The first category is that of reproduction of real-life scenarios. This is usually done in order to “calibrate” parts of models, simulation techniques, and so on, and helps to develop a degree of confidence in the simulation methodology.
- Secondly, we have “speculative” simulation of new scenarios. This is done in order to assist in product development cycles, where we wish to predict the operating temperatures of components or systems in new applications without the expense of building real-life prototypes.

It is likely that the majority of simulations fall into the second “speculative” category.



2. Extent

= How much of the proposed system to include?

- For a product consisting of dissipating components mounted on a PCB in an enclosure, it will probably be necessary to simulate the components, PCB and enclosure as all are likely to have an effect on the thermal behaviour of the system
- If we do not include all the component parts of the scenario (i.e. we do not extend the simulation far enough) then it is likely that the results produced will be inaccurate

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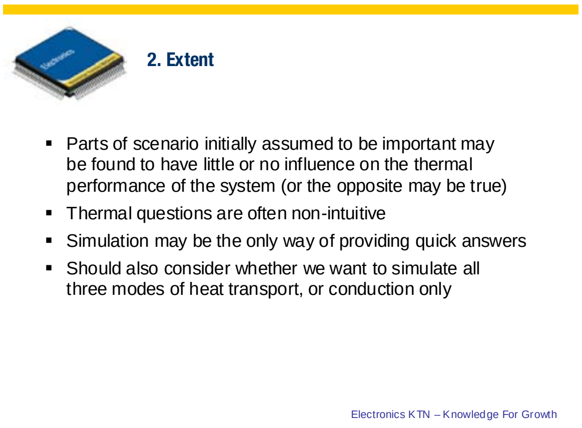
When considering the “extent” of the simulation we are defining how much of the proposed system we actually intend to include in the simulation.

For example, for an electronic product consisting of dissipating components mounted on a PCB in an enclosure, it will probably be necessary to simulate the components, PCB and enclosure, as all are likely to have an effect on the thermal behaviour of the system.

If we do not include all the component parts of the scenario (i.e. we do not extend the simulation far enough), then it is likely that the results produced will be inaccurate.



2. Extent

- Parts of scenario initially assumed to be important may be found to have little or no influence on the thermal performance of the system (or the opposite may be true)
- Thermal questions are often non-intuitive
- Simulation may be the only way of providing quick answers
- Should also consider whether we want to simulate all three modes of heat transport, or conduction only

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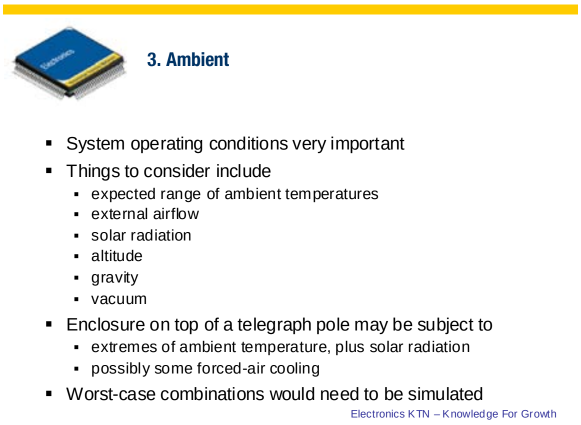
We may also find that parts of the scenario which we initially assumed to be important are found to have little or no influence on the thermal performance of the system
(or indeed the opposite may be true).

Thermal questions are often non-intuitive, and simulation may be the only way of providing quick answers to this question.

Also under “extent”, we should consider whether we want to simulate all three modes of heat transport (i.e. conduction, convection and radiation) or, for special cases, conduction only.



3. Ambient

- System operating conditions very important
- Things to consider include
  - expected range of ambient temperatures
  - external airflow
  - solar radiation
  - altitude
  - gravity
  - vacuum
- Enclosure on top of a telegraph pole may be subject to
  - extremes of ambient temperature, plus solar radiation
  - possibly some forced-air cooling
- Worst-case combinations would need to be simulated

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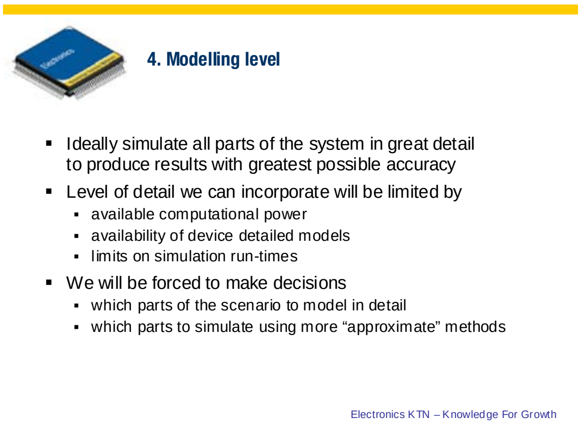
The ambient conditions in which the system is intended to operate are very important. Things to consider include:

- The expected range of ambient temperatures. What are the high and low extremes?
- External airflow – will there be any? how much? and can we rely on its presence?
- Solar radiation – will the system be exposed to sunlight?
- Altitude – does the system have to function on a mountain top? This has implications for convection cooling.
- Gravity – a system intended for use in outer space will not be subject to gravity, and this also has implications for convection cooling. As indeed does that fact that a system may be intended for use in a vacuum and therefore will rely on conduction and radiation cooling only.

So, a system which is mounted in an enclosure at the top of a telegraph pole may be subject to extremes of ambient temperature, plus solar radiation and possibly some forced-air cooling. The worst-case combinations of ambient conditions would need to be simulated in this case.



4. Modelling level

- Ideally simulate all parts of the system in great detail to produce results with greatest possible accuracy
- Level of detail we can incorporate will be limited by
  - available computational power
  - availability of device detailed models
  - limits on simulation run-times
- We will be forced to make decisions
  - which parts of the scenario to model in detail
  - which parts to simulate using more “approximate” methods

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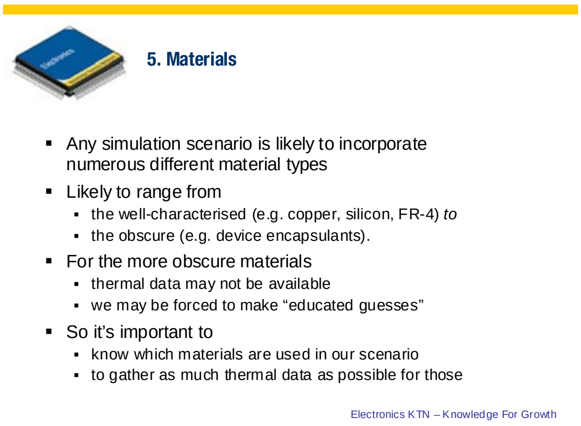
Ideally we would simulate all parts of the system in great detail in the hope of producing results with the greatest possible accuracy.

Unfortunately, the level of detail we can incorporate will be limited by available computational power, availability of device detailed models, and limits on simulation run-times.

So we will be forced to make decisions as to which parts of the scenario we wish to model in detail and which parts will be simulated using more “approximate” methods.



5. Materials

- Any simulation scenario is likely to incorporate numerous different material types
- Likely to range from
  - the well-characterised (e.g. copper, silicon, FR-4) *to*
  - the obscure (e.g. device encapsulants).
- For the more obscure materials
  - thermal data may not be available
  - we may be forced to make “educated guesses”
- So it’s important to
  - know which materials are used in our scenario
  - to gather as much thermal data as possible for those

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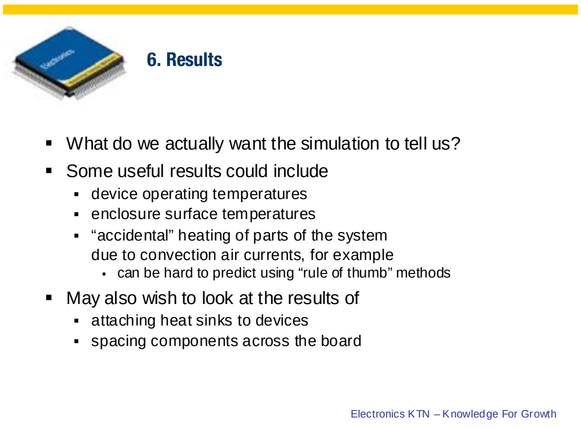
Any simulation scenario is likely to incorporate numerous different material types.

These are likely to range from the well-characterised (such as copper, silicon, and FR-4) to the obscure (for instance, some of the plastics used as device encapsulants).

For the more obscure materials, thermal data such as conductivity, specific heat, and so on, may not be available and so we may be forced to make “educated guesses”.

It is important, therefore, that we are know which materials are used in our scenario, and that we gather as much thermal data as possible for those materials.



6. Results

- What do we actually want the simulation to tell us?
- Some useful results could include
  - device operating temperatures
  - enclosure surface temperatures
  - “accidental” heating of parts of the system due to convection air currents, for example
    - can be hard to predict using “rule of thumb” methods
- May also wish to look at the results of
  - attaching heat sinks to devices
  - spacing components across the board

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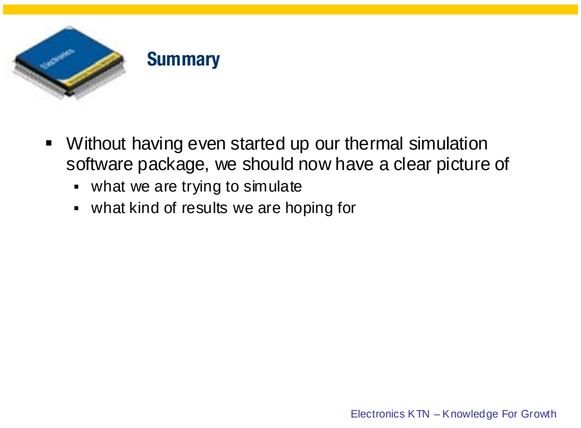
It is important that we define exactly what we want the simulation to tell us. Some useful results could include:

- Device operating temperatures – are we likely to exceed specified operating limits?
  - Enclosure surface temperatures – a possible safety concern for surfaces which may come into contact with human skin.
  - And the “accidental” heating of parts of the system due to, for example, convection air currents, and this can be very hard to predict using “rule of thumb” methods.
- We may also wish to look at the results of, say, attaching heat sinks to devices, or the spacing of components across a PCB.



Summary

- Without having even started up our thermal simulation software package, we should now have a clear picture of
  - what we are trying to simulate
  - what kind of results we are hoping for

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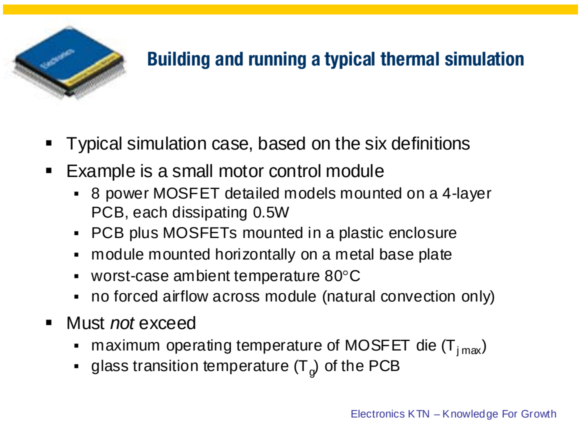
So, without having even started up our thermal simulation software package, we should now have a clear picture of what we are trying to simulate and what kind of results we are hoping for.



Building and running a typical thermal simulation

- Typical simulation case, based on the six definitions
- Example is a small motor control module
  - 8 power MOSFET detailed models mounted on a 4-layer PCB, each dissipating 0.5W
  - PCB plus MOSFETs mounted in a plastic enclosure
  - module mounted horizontally on a metal base plate
  - worst-case ambient temperature 80°C
  - no forced airflow across module (natural convection only)
- Must *not* exceed
  - maximum operating temperature of MOSFET die ($T_{j\,max}$)
  - glass transition temperature (T_g) of the PCB

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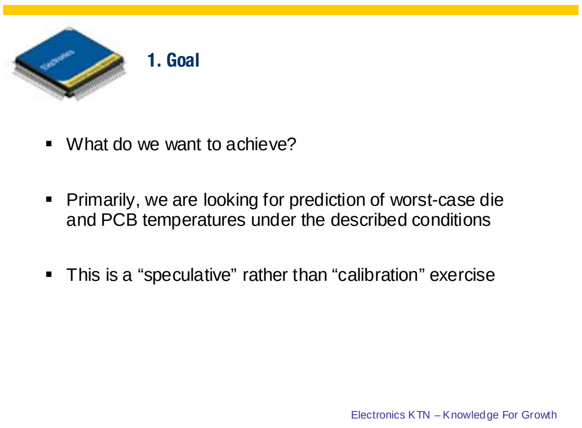
This section of the presentation will describe how a typical simulation case is built and run, based on the six definitions detailed in Part 1.

As an example we will simulate a small motor control module described as follows:

- 8 power MOSFET detailed models mounted on a 4-layer PCB, each dissipating 0.5W
- the PCB plus MOSFETs is mounted in a plastic enclosure
- the module is mounted horizontally on a metal base plate
- worst-case ambient temperature is 80°C
- there is no forced airflow across the module i.e. natural convection only

It is essential that we do not exceed either the maximum operating temperatures of the MOSFET die or the glass transition temperature of the PCB.

Creating a Thermal Simulation



1. Goal

- What do we want to achieve?
- Primarily, we are looking for prediction of worst-case die and PCB temperatures under the described conditions
- This is a “speculative” rather than “calibration” exercise

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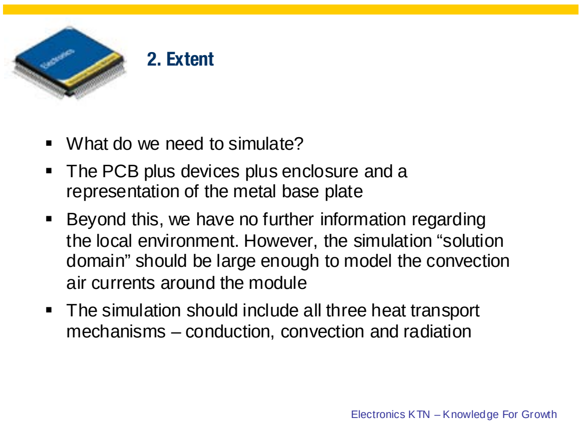

2. Extent

- What do we need to simulate?
- The PCB plus devices plus enclosure and a representation of the metal base plate
- Beyond this, we have no further information regarding the local environment. However, the simulation “solution domain” should be large enough to model the convection air currents around the module
- The simulation should include all three heat transport mechanisms – conduction, convection and radiation

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What do we need to simulate?

Clearly this is the PCB plus devices plus enclosure and a representation of the metal base plate.

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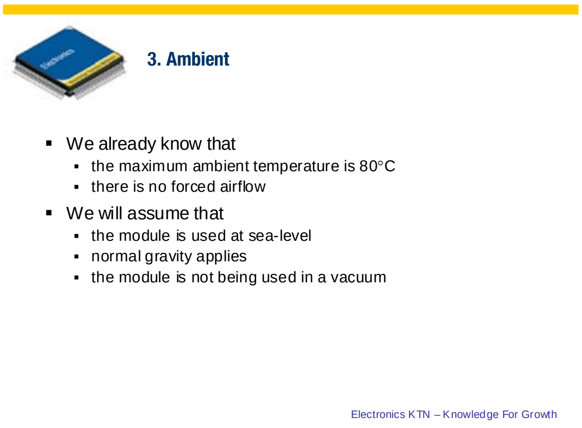

3. Ambient

- We already know that
  - the maximum ambient temperature is 80°C
  - there is no forced airflow
- We will assume that
  - the module is used at sea-level
  - normal gravity applies
  - the module is not being used in a vacuum

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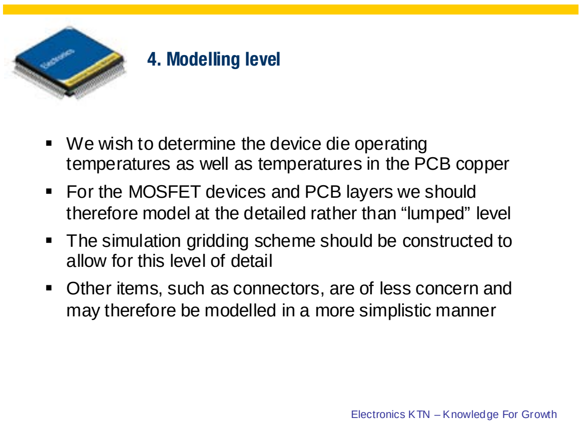
We already know that the maximum ambient temperature is 80°C, and that there is no forced airflow.

We will also assume that the module is used at sea-level, normal gravity applies, and the module is not being used in a vacuum.



4. Modelling level

- We wish to determine the device die operating temperatures as well as temperatures in the PCB copper
- For the MOSFET devices and PCB layers we should therefore model at the detailed rather than “lumped” level
- The simulation gridding scheme should be constructed to allow for this level of detail
- Other items, such as connectors, are of less concern and may therefore be modelled in a more simplistic manner

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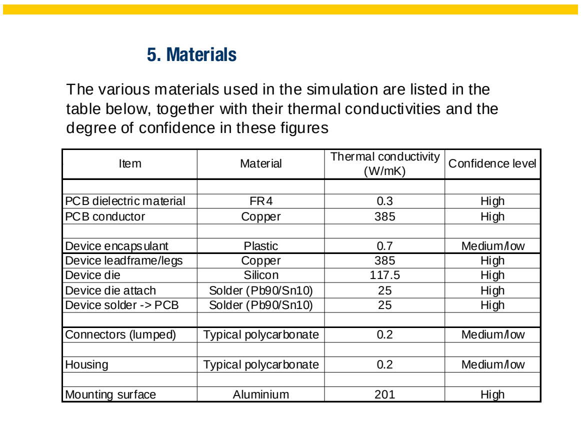

5. Materials

The various materials used in the simulation are listed in the table below, together with their thermal conductivities and the degree of confidence in these figures

Item	Material	Thermal conductivity (W/mK)	Confidence level
PCB dielectric material	FR4	0.3	High
PCB conductor	Copper	385	High
Device encapsulant	Plastic	0.7	Medium/low
Device leadframe/legs	Copper	385	High
Device die	Silicon	117.5	High
Device die attach	Solder (Pb90/Sn10)	25	High
Device solder -> PCB	Solder (Pb90/Sn10)	25	High
Connectors (lumped)	Typical polycarbonate	0.2	Medium/low
Housing	Typical polycarbonate	0.2	Medium/low
Mounting surface	Aluminium	201	High

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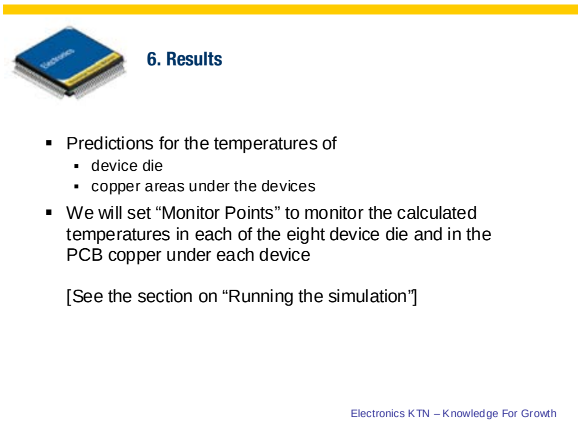

6. Results

- Predictions for the temperatures of
  - device die
  - copper areas under the devices
- We will set “Monitor Points” to monitor the calculated temperatures in each of the eight device die and in the PCB copper under each device

  [See the section on “Running the simulation”]

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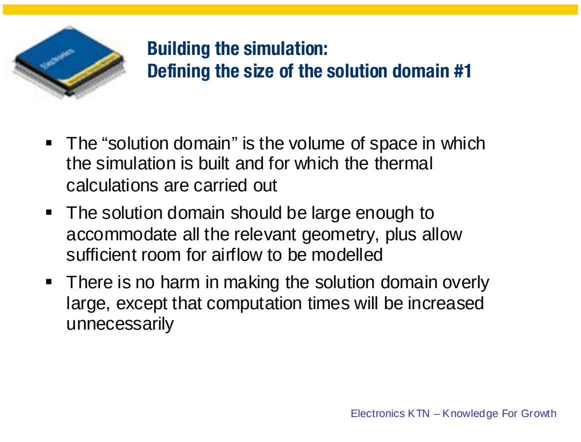
From this simulation we are looking for the temperatures of device die and copper areas under the devices.

We will set “Monitor Points” to monitor the calculated temperatures in each of the eight device die and in the PCB copper under each device.

[See the section on “Running the simulation”]



Building the simulation: Defining the size of the solution domain #1

- The “solution domain” is the volume of space in which the simulation is built and for which the thermal calculations are carried out
- The solution domain should be large enough to accommodate all the relevant geometry, plus allow sufficient room for airflow to be modelled
- There is no harm in making the solution domain overly large, except that computation times will be increased unnecessarily

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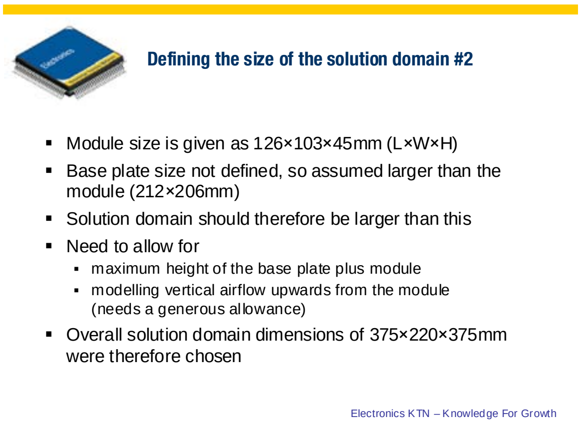

Defining the size of the solution domain #2

- Module size is given as 126×103×45mm (L×W×H)
- Base plate size not defined, so assumed larger than the module (212×206mm)
- Solution domain should therefore be larger than this
- Need to allow for
  - maximum height of the base plate plus module
  - modelling vertical airflow upwards from the module (needs a generous allowance)
- Overall solution domain dimensions of 375×220×375mm were therefore chosen

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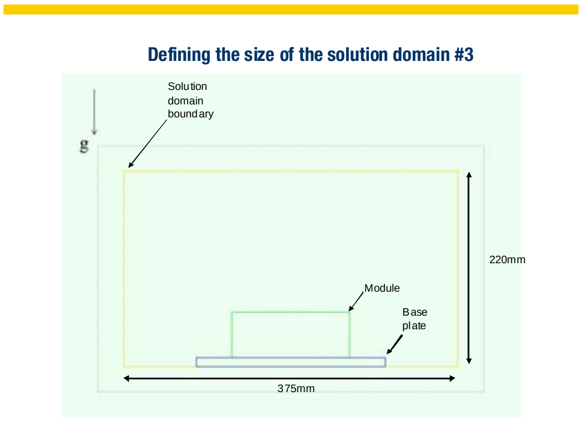
The size of the module is given as 126×103×45mm (length by width by height).

The metal base plate size is not defined, so we will assume it is somewhat larger than the module i.e. 212×206mm. The solution domain should therefore be larger than this.

In terms of height, we obviously need to allow for the maximum height of the base plate plus module, as well as a generous allowance in order to model vertical airflow upwards from the module.

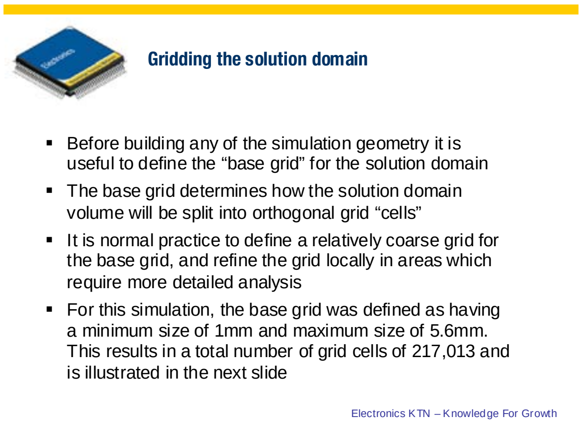
Overall solution domain dimensions of 375×220×375mm were therefore chosen.

Creating a Thermal Simulation



Defining the size of the solution domain #3

Overall solution domain dimensions of 375×220×375mm were therefore chosen.



Gridding the solution domain

- Before building any of the simulation geometry it is useful to define the "base grid" for the solution domain
- The base grid determines how the solution domain volume will be split into orthogonal grid "cells"
- It is normal practice to define a relatively coarse grid for the base grid, and refine the grid locally in areas which require more detailed analysis
- For this simulation, the base grid was defined as having a minimum size of 1mm and maximum size of 5.6mm. This results in a total number of grid cells of 217,013 and is illustrated in the next slide

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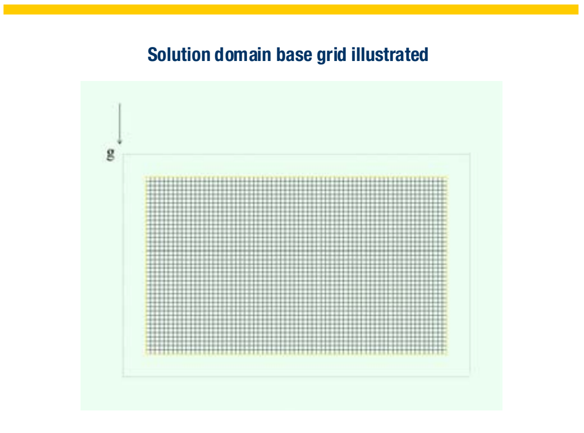
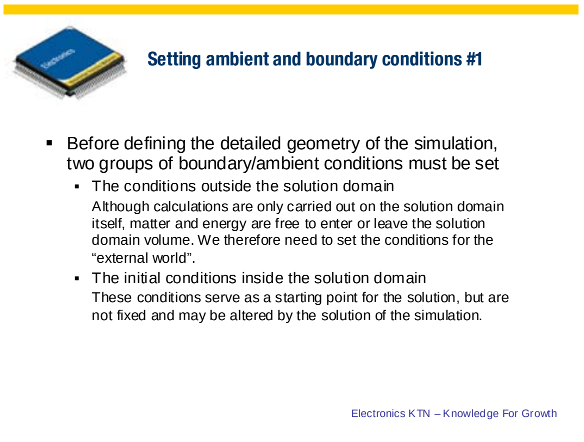


Solution domain base grid illustrated

For this simulation, the base grid was defined as having a minimum size of 1mm and maximum size of 5.6mm. This results in a total number of grid cells of 217k.



Setting ambient and boundary conditions #1

- Before defining the detailed geometry of the simulation, two groups of boundary/ambient conditions must be set
  - The conditions outside the solution domain
    Although calculations are only carried out on the solution domain itself, matter and energy are free to enter or leave the solution domain volume. We therefore need to set the conditions for the "external world".
  - The initial conditions inside the solution domain
    These conditions serve as a starting point for the solution, but are not fixed and may be altered by the solution of the simulation.

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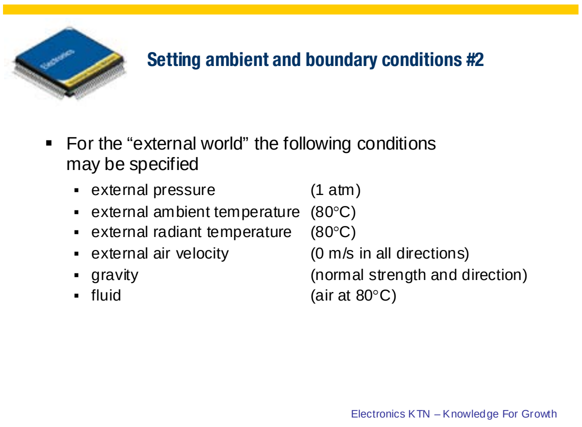
Before defining the detailed geometry of the simulation, there are two groups of boundary/ambient conditions which must be set.

Firstly, the conditions outside the solution domain. Although calculations are only carried out on the solution domain itself, matter and energy are free to enter or leave the solution domain volume. We therefore need to set the conditions for this external environment.

Secondly, the initial conditions inside the solution domain. These conditions serve as a starting point for the solution, but are not fixed and may be altered by the solution of the simulation.



Setting ambient and boundary conditions #2

- For the “external world” the following conditions may be specified
  - external pressure (1 atm)
  - external ambient temperature (80°C)
  - external radiant temperature (80°C)
  - external air velocity (0 m/s in all directions)
  - gravity (normal strength and direction)
  - fluid (air at 80°C)

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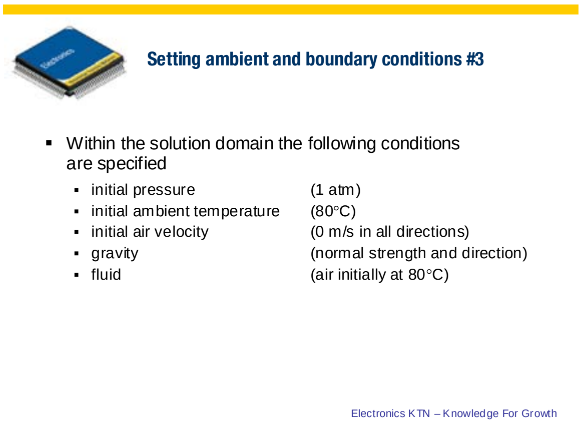
For the external environment, the following conditions are specified: external pressure, 1 atm; external ambient temperature, 80°C; external radiant temperature, also 80°C; external air velocity, 0 m/s in all directions; gravity, normal strength and direction; and fluid is air at 80°C.



Setting ambient and boundary conditions #3

- Within the solution domain the following conditions are specified
  - initial pressure (1 atm)
  - initial ambient temperature (80°C)
  - initial air velocity (0 m/s in all directions)
  - gravity (normal strength and direction)
  - fluid (air initially at 80°C)

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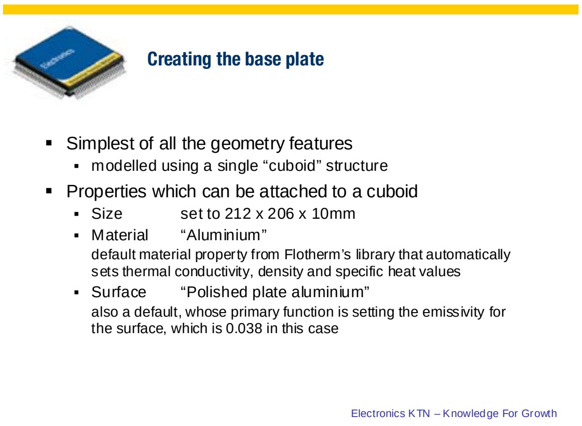
Within the solution domain the following initial conditions are specified: initial pressure, 1 atm; initial ambient temperature, 80°C; initial air velocity, 0 m/s in all directions; gravity, normal strength and direction; fluid, air initially at 80°C.



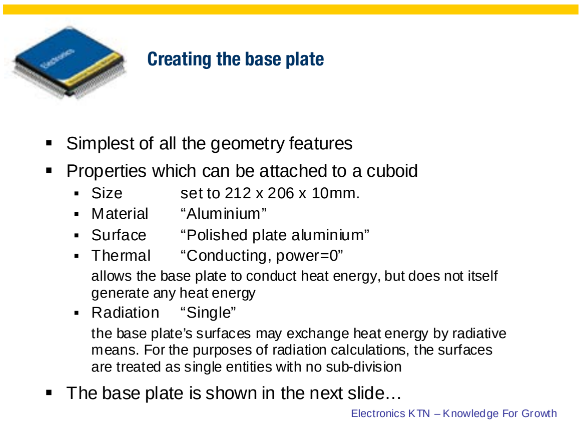
Creating the base plate

- Simplest of all the geometry features
  - modelled using a single “cuboid” structure
- Properties which can be attached to a cuboid
  - Size set to 212 x 206 x 10mm
  - Material “Aluminium”
    default material property from Flotherm’s library that automatically sets thermal conductivity, density and specific heat values
  - Surface “Polished plate aluminium”
    also a default, whose primary function is setting the emissivity for the surface, which is 0.038 in this case

Electronics KTN – Knowledge For Growth

The base plate is the simplest of all the geometry features, and is modelled using a single “cuboid” structure. The base plate provides a good example of the properties which can be attached to a cuboid. These are:

- Firstly, Size: in this case set to 212×206×10mm.
- Secondly, Material: in this case “Aluminium”. This is a default material property from Flotherm's library which automatically sets thermal conductivity, density and specific heat values.
- Third, Surface: “Polished plate aluminium”. This is also a default, whose primary function is setting the emissivity for the surface, which is 0.038 in this case.



Creating the base plate

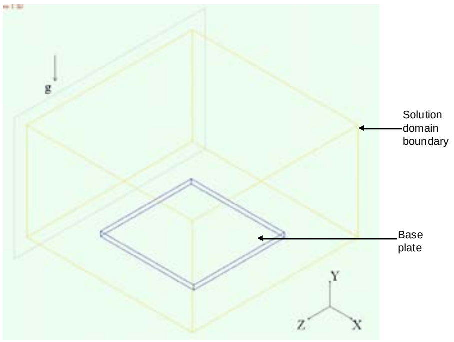
- Simplest of all the geometry features
- Properties which can be attached to a cuboid
  - Size set to 212 x 206 x 10mm.
  - Material “Aluminium”
  - Surface “Polished plate aluminium”
  - Thermal “Conducting, power=0”
    allows the base plate to conduct heat energy, but does not itself generate any heat energy
  - Radiation “Single”
    the base plate’s surfaces may exchange heat energy by radiative means. For the purposes of radiation calculations, the surfaces are treated as single entities with no sub-division
- The base plate is shown in the next slide…

Electronics KTN – Knowledge For Growth

- Fourthly, Thermal: “Conducting, power=0”. This allows the base plate to conduct heat energy, but does not itself generate any heat energy.
- Fifth, Radiation. The base plate's surfaces may exchange heat energy by radiative means. For the purposes of radiation calculations, the surfaces are treated as single entities, with no sub-division.

The base plate is shown in the next slide…

The base plate



Creating the module housing

- The next simplest part of the simulation geometry
  - a hollow box with two small cut-outs for module connectors
- Housing structure can be created from individual cuboids
  - a “Smartpart” structure is available within Flotherm which simplifies the creation of such structures

Electronics KTN – Knowledge For Growth

The module housing is the next simplest part of the simulation geometry, and is a hollow box with two small cut-outs for the module connectors.

It would be possible to create the housing structure from individual cuboids. However a “Smartpart” is available within Flotherm which simplifies the creation of such structures.

Creating the module housing

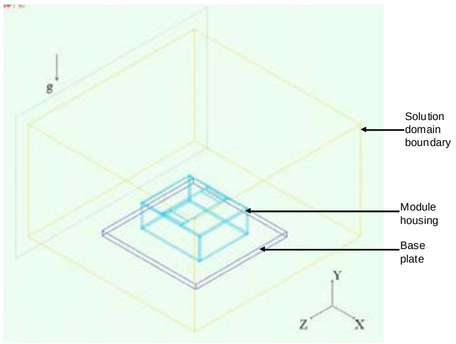
- The next simplest part of the simulation geometry
- Housing structure can be created from individual cuboids
  - “Smartpart” structure simplifies creation of such structures
- “Enclosure” Smartpart allows the user to define
  - internal and external dimensions
  - wall thickness and size and location of cut-outs
  - all the other properties already described for the base plate

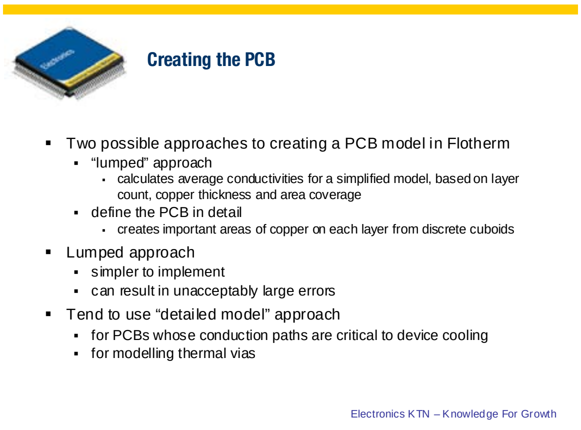
Size	126 x 103 x 45mm (external)
Material	Polycarbonate
Surface	Soft rubber
Thermal	Conducting, power=0
Radiation	Single

Electronics KTN – Knowledge For Growth

The “Enclosure” Smartpart allows the user to define internal and external dimensions, wall thicknesses and the size and location of cut-outs, as well as all the other properties already described for the base plate. These are size, 126×103×45mm; material, polycarbonate; surface, soft rubber; thermal, conducting, power=0; and radiation, single.

The base plate plus module housing





Creating the PCB

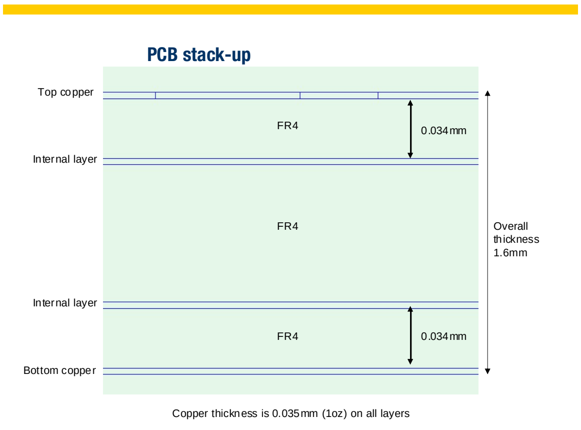
- Two possible approaches to creating a PCB model in Flotherm
  - “lumped” approach
    - calculates average conductivities for a simplified model, based on layer count, copper thickness and area coverage
  - define the PCB in detail
    - creates important areas of copper on each layer from discrete cuboids
- Lumped approach
  - simpler to implement
  - can result in unacceptably large errors
- Tend to use “detailed model” approach
  - for PCBs whose conduction paths are critical to device cooling
  - for modelling thermal vias

Electronics KTN – Knowledge For Growth

There are two possible approaches to creating a PCB model in Flotherm. Firstly we can use a “lumped” approach which calculates average conductivities for a simplified model, based on layer count, copper thickness and area coverage. Or we can define the PCB in detail, creating the important areas of copper on each layer from discrete cuboid elements.

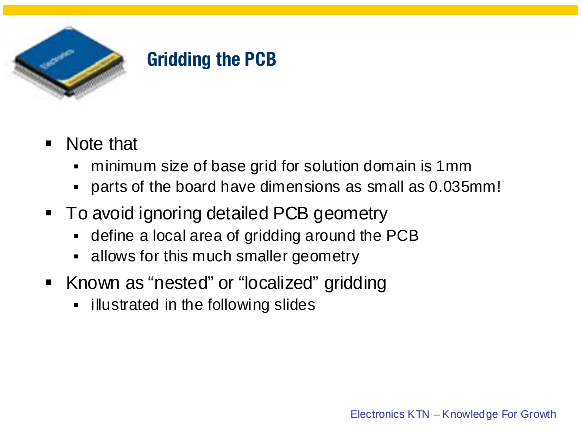
Whilst the lumped approach is much simpler to implement, for situations where the PCB is used as a heat sink, the degree of approximation can result in unacceptably large errors in simulation results.

We therefore tend to use a “detailed model” approach for PCBs whose conduction paths are critical to device cooling. Thermal vias are also modelled using the same approach.



PCB stack-up

Copper thickness is 0.035mm (1oz) on all layers



Gridding the PCB

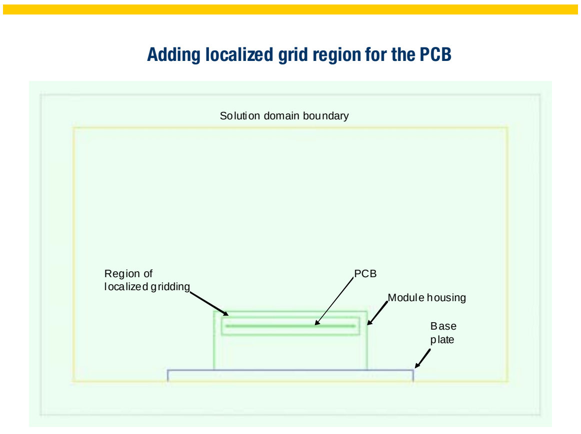
- Note that
  - minimum size of base grid for solution domain is 1mm
  - parts of the board have dimensions as small as 0.035mm!
- To avoid ignoring detailed PCB geometry
  - define a local area of gridding around the PCB
  - allows for this much smaller geometry
- Known as “nested” or “localized” gridding
  - illustrated in the following slides

Electronics KTN – Knowledge For Growth

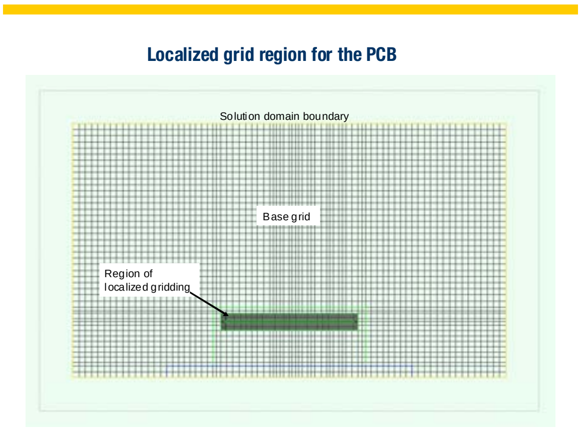
It will be recalled that the minimum size of base grid for the solution domain is 1mm, whilst parts of the PCB geometry have dimensions as small as 0.035mm.

In order that the detailed geometry of the PCB is not ignored, we must define a local area of gridding around the PCB which allows for this much smaller geometry.

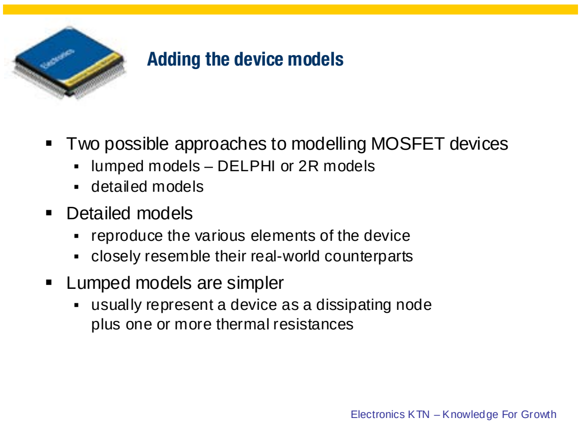
This is known as “nested” or “localized” gridding, and is illustrated in the following slides.



Adding localized grid region for the PCB



Localized grid region for the PCB



Adding the device models

- Two possible approaches to modelling MOSFET devices
  - lumped models – DELPHI or 2R models
  - detailed models
- Detailed models
  - reproduce the various elements of the device
  - closely resemble their real-world counterparts
- Lumped models are simpler
  - usually represent a device as a dissipating node plus one or more thermal resistances

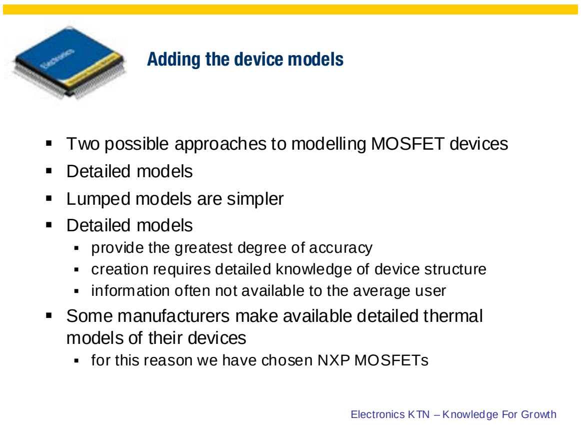
Electronics KTN – Knowledge For Growth

As for the PCB, there are two possible approaches to modelling the MOSFET devices;

- By lumped models – often referred to as DELPHI or 2R models
- By detailed models

Detailed models reproduce the various elements of the device (die, lead-frame, etc.) and closely resemble their real-world counterparts.

Lumped models are simpler and usually represent a device as a dissipating node plus one or more thermal resistances.



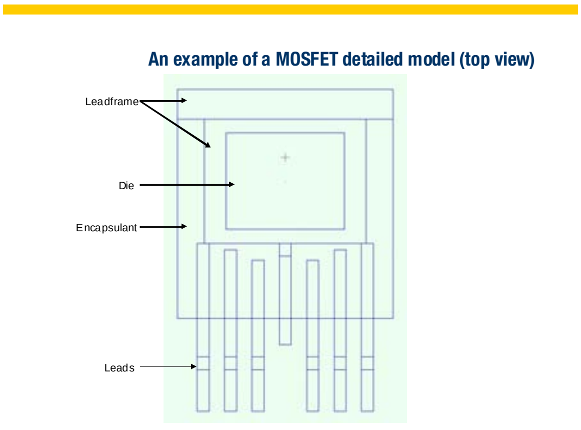
Adding the device models

- Two possible approaches to modelling MOSFET devices
- Detailed models
- Lumped models are simpler
- Detailed models
  - provide the greatest degree of accuracy
  - creation requires detailed knowledge of device structure
  - information often not available to the average user
- Some manufacturers make available detailed thermal models of their devices
  - for this reason we have chosen NXP MOSFETs

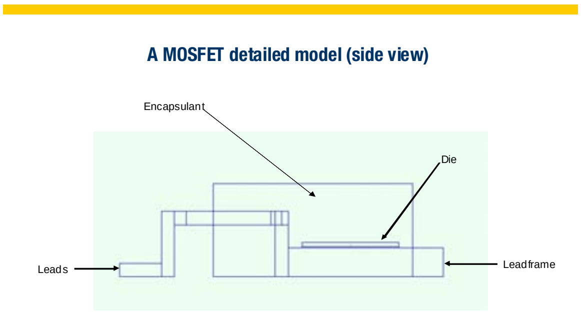
Electronics KTN – Knowledge For Growth

Although detailed models provide the greatest degree of accuracy, their creation depends on a detailed knowledge of the device structure – information which is often not available to the average user.

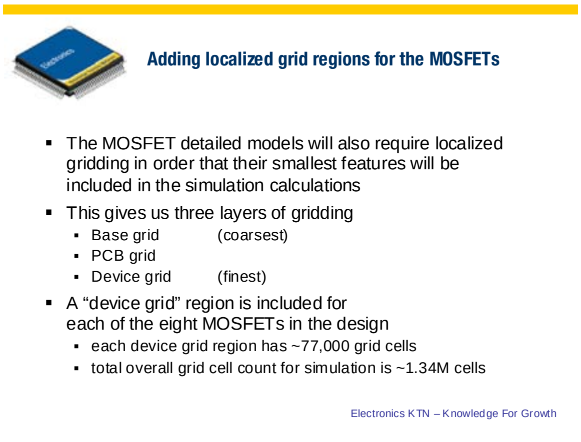
Some manufacturers make available detailed thermal models of their devices, and for this reason we have chosen NXP MOSFETs for use in this exercise.



An example of a MOSFET detailed model (top view)



A MOSFET detailed model (side view)



Adding localized grid regions for the MOSFETs

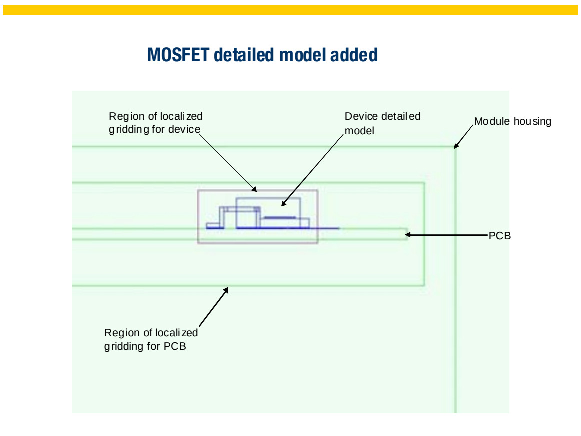
- The MOSFET detailed models will also require localized gridding in order that their smallest features will be included in the simulation calculations
- This gives us three layers of gridding
  - Base grid (coarsest)
  - PCB grid
  - Device grid (finest)
- A “device grid” region is included for each of the eight MOSFETs in the design
  - each device grid region has ~77,000 grid cells
  - total overall grid cell count for simulation is ~1.34M cells

Electronics KTN – Knowledge For Growth

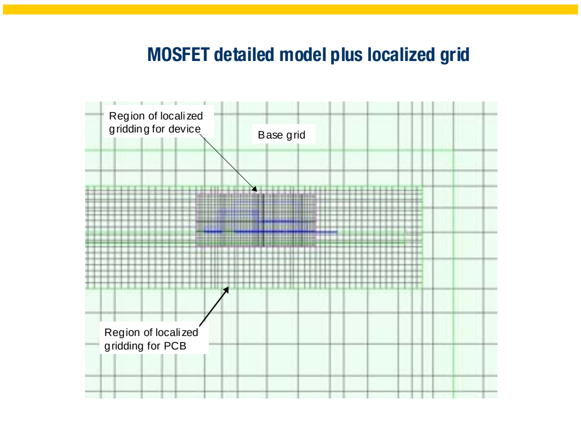
The MOSFET detailed models will also require localized gridding in order that their smallest features will be included in the simulation calculations.

This gives us three layers of gridding: base grid (coarsest); PCB grid; device grid (finest)

A “device grid” region is included for each of the eight MOSFETs in the design. Each device grid region has approximately 77k grid cells. The total overall grid cell count for the simulation is approximately 1.34M cells.

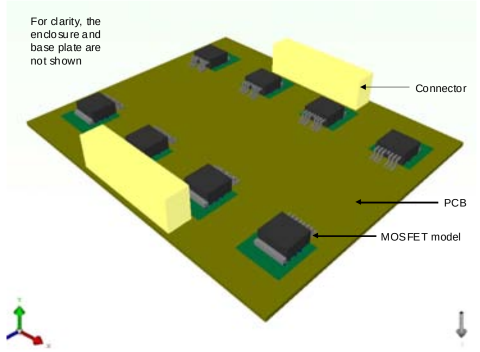


MOSFET detailed model added



MOSFET detailed model plus localized grid

The completed PCB model



For clarity, the enclosure and base plate are not shown

Connector

PCB

MOSFET model

Running the simulation and viewing results

- Having defined model geometry, ambient conditions, etc., it is time to run the simulation!
- No further intervention is required
  - can observe solution progress through “Profiles” window.
- From temperature plots in “Profiles”
  - we can determine at an early stage whether a gross error has been made [this is indicated by temperatures tending towards levels much higher or lower than expected]

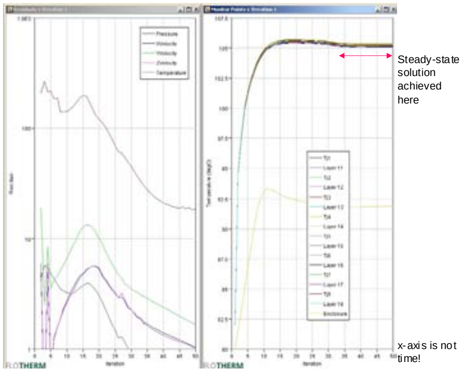
Electronics KTN – Knowledge For Growth

Having satisfactorily defined the model geometry, ambient conditions, etc., it is time to run the simulation. In Flotherm this is achieved by pressing the green “GO” button.

No further intervention is required whilst we are waiting for the software to “solve” the simulation, although we can observe the solution progress through Flotherm’s “Profiles” window.

By observing the temperature plots in Profiles we can also determine at an early stage in the solution process whether a gross error has been made in setting up the solution – this would be indicated by temperatures tending towards levels much higher or lower than expected.

Profiles plot showing successful solution of the simulation



Steady-state solution achieved here

x-axis is not time!

Notes on the Profiles window

- The Profiles window has two panes
  - the left-hand “Residuals v Iteration” pane shows the residual error after each calculation (iteration). [Reducing residual errors below a certain level is part of the process of determining convergence]
  - the right-hand “Monitor Points v Iteration” pane shows the resulting monitor point calculations after each iteration. [Stability of monitor points is also used to determine convergence]
- In the example shown, convergence has been judged to have been reached when
  - all residual errors are below 100 (left pane).
  - the variance in monitor point temperature is less than 0.5°C for at least 30 iterations

Electronics KTN – Knowledge For Growth

The Profiles window has two panes;

The left-hand “Residuals v Iteration” pane shows the residual error after each calculation (iteration). Reducing residual errors below a certain level is part of the process of determining convergence.

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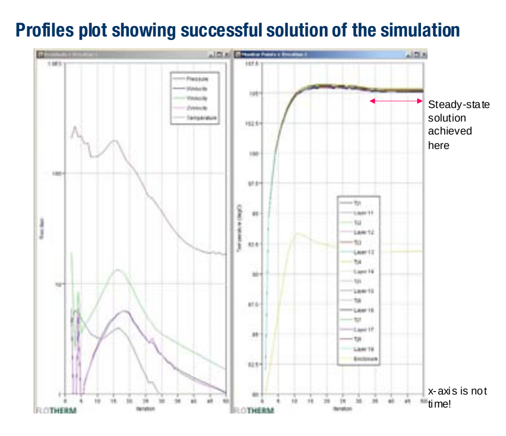
Creating a Thermal Simulation



Profiles plot showing successful solution of the simulation

Steady-state solution achieved here

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In the example shown, convergence has been judged to have been reached when;

- All residual errors are below 100 (left pane)
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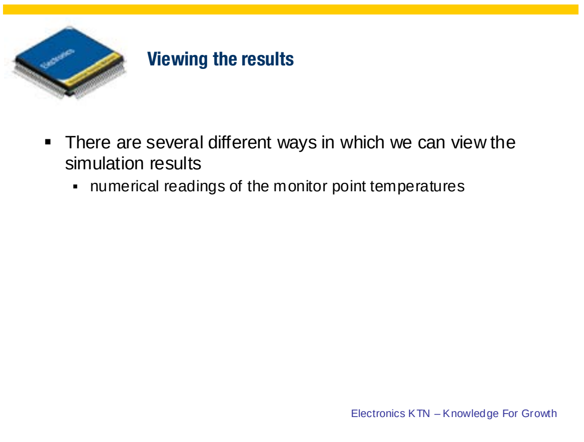


Viewing the results

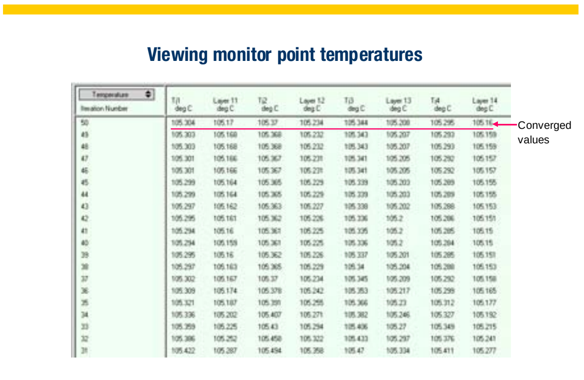
- There are several different ways in which we can view the simulation results
    - numerical readings of the monitor point temperatures

Electronics KTN – Knowledge For Growth

There are several different ways in which we can view the simulation results

- Numerical readings of the monitor point temperatures.
- Surface temperature plots of the PCB, devices, enclosure, etc.
- or as plots of the airflow pattern around the PCB, enclosure, etc.

Surface temperature plots are particularly useful for “getting the feel” of the thermal behaviour of a system, whilst airflow plots may reveal unexpected thermal “cross-coupling” effects!

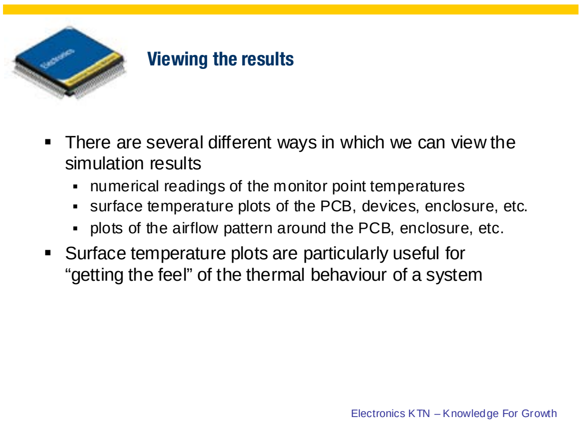


Viewing monitor point temperatures

Temperature Iteration Number	Tj1 deg C	Layer 11 deg C	Tj2 deg C	Layer 12 deg C	Tj3 deg C	Layer 13 deg C	Tj4 deg C	Layer 14 deg C
50	105.304	105.17	105.37	105.234	105.344	105.208	105.295	105.16
49	105.303	105.168	105.368	105.232	105.343	105.207	105.293	105.159
48	105.303	105.168	105.368	105.232	105.343	105.207	105.293	105.159
47	105.301	105.166	105.367	105.231	105.341	105.205	105.292	105.157
46	105.301	105.166	105.367	105.231	105.341	105.205	105.292	105.157
45	105.299	105.164	105.365	105.229	105.339	105.203	105.289	105.155
44	105.299	105.164	105.365	105.229	105.339	105.203	105.289	105.155
43	105.297	105.162	105.363	105.227	105.338	105.202	105.288	105.153
42	105.295	105.161	105.362	105.226	105.336	105.2	105.286	105.151
41	105.294	105.16	105.361	105.225	105.335	105.2	105.285	105.15
40	105.294	105.159	105.361	105.225	105.336	105.2	105.284	105.15
39	105.295	105.16	105.362	105.226	105.337	105.201	105.285	105.151
38	105.297	105.163	105.365	105.229	105.34	105.204	105.288	105.153
37	105.302	105.167	105.37	105.234	105.345	105.209	105.292	105.158
36	105.309	105.174	105.378	105.242	105.353	105.217	105.299	105.165
35	105.321	105.187	105.391	105.255	105.366	105.23	105.312	105.177
34	105.336	105.202	105.407	105.271	105.382	105.246	105.327	105.192
33	105.359	105.225	105.43	105.294	105.406	105.27	105.349	105.215
32	105.386	105.252	105.458	105.322	105.433	105.297	105.376	105.241
31	105.422	105.287	105.494	105.358	105.47	105.334	105.411	105.277

Converged values

Numerical readings of the monitor point temperatures.



Viewing the results

- There are several different ways in which we can view the simulation results
    - numerical readings of the monitor point temperatures
    - surface temperature plots of the PCB, devices, enclosure, etc.
    - plots of the airflow pattern around the PCB, enclosure, etc.
- Surface temperature plots are particularly useful for “getting the feel” of the thermal behaviour of a system

Electronics KTN – Knowledge For Growth

There are several different ways in which we can view the simulation results

- Numerical readings of the monitor point temperatures.
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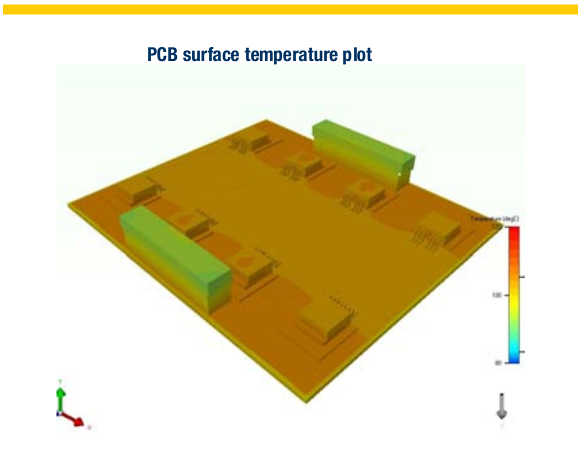
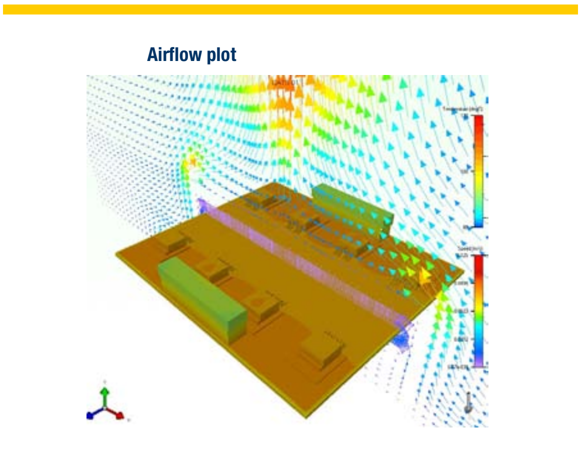
Surface temperature plots are particularly useful for “getting the feel” of the thermal behaviour of a system, whilst airflow plots may reveal unexpected thermal “cross-coupling” effects!

 **PCB surface temperature plot**	Surface temperature plots of the PCB, devices, enclosure, etc. Surface temperature plots are particularly useful for “getting the feel” of the thermal behaviour of a system.
Viewing the results ▪ There are several different ways in which we can view the simulation results ▪ numerical readings of the monitor point temperatures ▪ surface temperature plots of the PCB, devices, enclosure, etc. ▪ plots of the airflow pattern around the PCB, enclosure, etc. ▪ Surface temperature plots are particularly useful for “getting the feel” of the thermal behaviour of a system ▪ Airflow plots may reveal unexpected thermal “cross-coupling” effects! Electronics KTN – Knowledge For Growth	There are several different ways in which we can view the simulation results • Numerical readings of the monitor point temperatures. • Surface temperature plots of the PCB, devices, enclosure, etc. • or as plots of the airflow pattern around the PCB, enclosure, etc. Surface temperature plots are particularly useful for “getting the feel” of the thermal behaviour of a system, whilst airflow plots may reveal unexpected thermal “cross-coupling” effects!
 **Airflow plot**	Plots of the airflow pattern around the PCB, enclosure, etc. Airflow plots may reveal unexpected thermal “cross-coupling” effects!