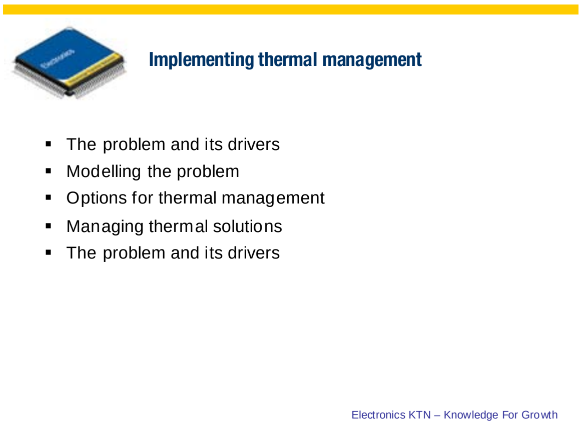
Implementing thermal management

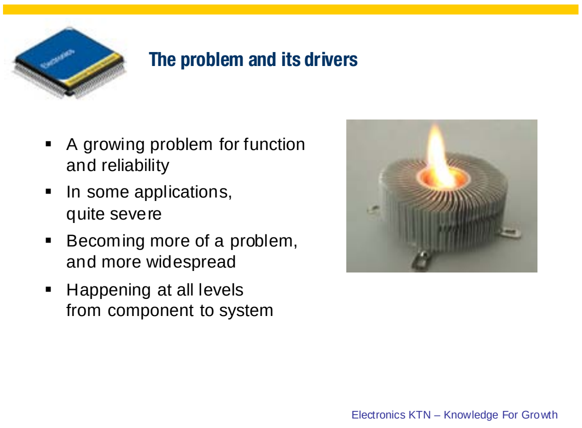


Implementing thermal management

- The problem and its drivers
- Modelling the problem
- Options for thermal management
- Managing thermal solutions
- The problem and its drivers

Electronics KTN – Knowledge For Growth

In this brief review of the whole of this EKTN material we will be drawing on many of the concepts explained earlier, and even quickly repeating some of the slides by way of a reminder. We are reviewing where the problem comes from, how it's modelled, and how designers can select from the many options available to manage their thermal problem, and then we'll be trying to scope the problem of implementing thermal management in an effective way.



The problem and its drivers

- A growing problem for function and reliability
- In some applications, quite severe
- Becoming more of a problem, and more widespread
- Happening at all levels from component to system

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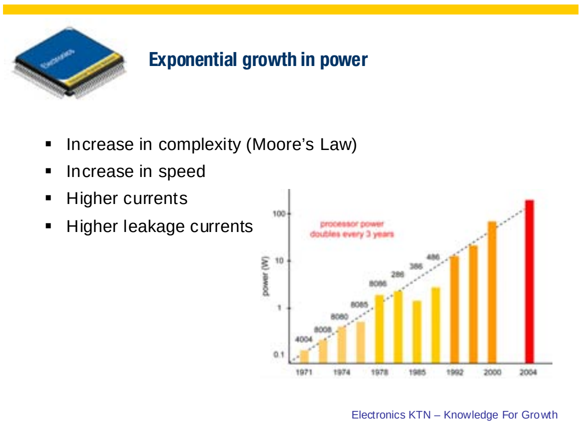
We have seen that increasing thermal dissipation gives problems in terms of equipment functionality and reliability, and that thermal dissipation is becoming more of a problem and more widespread, and is happening at all levels from component to system.



Exponential growth in power

- Increase in complexity (Moore's Law)
- Increase in speed
- Higher currents
- Higher leakage currents

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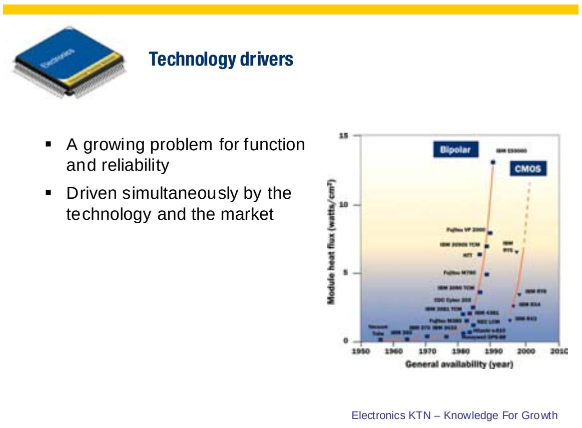
Much of this growth in recent years has been explained by the continuing increases in complexity of silicon, with more functionality, more components, and higher speeds, all leading to greater power requirements.



Technology drivers

- A growing problem for function and reliability
- Driven simultaneously by the technology and the market

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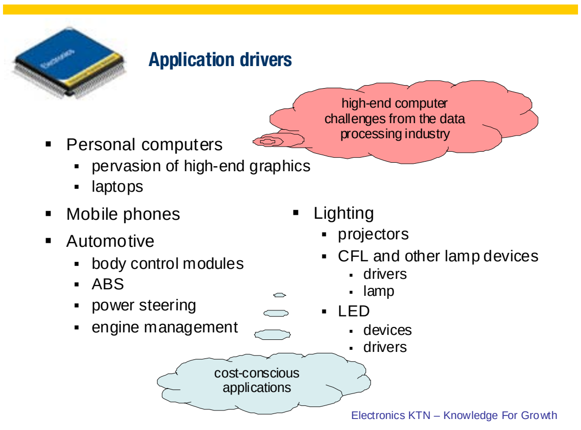
True there was a similar growth in power with previous technologies, and the thermal problems then were circumvented by moving from bipolar technology to CMOS. But today we have no such magic solution until such time as biological computers come along! So we are stuck with higher power, driven by both technology and the market-place.



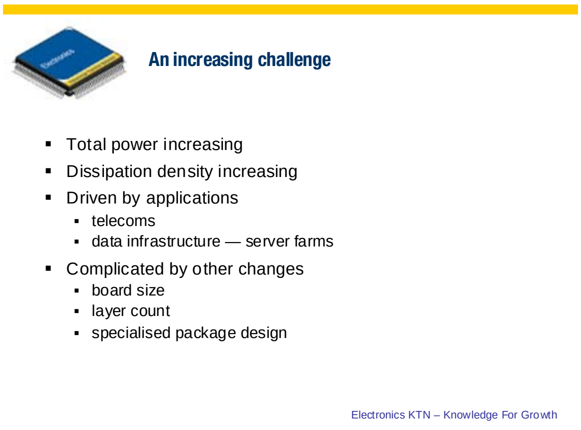
Application drivers

high-end computer challenges from the data processing industry

- Personal computers
  - pervasion of high-end graphics
  - laptops
- Mobile phones
- Automotive
  - body control modules
  - ABS
  - power steering
  - engine management
- Lighting
  - projectors
  - CFL and other lamp devices
    - drivers
    - lamp
  - LED
    - devices
    - drivers

cost-conscious applications

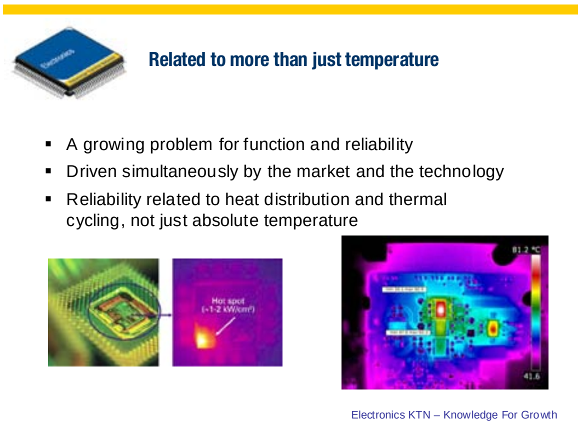
Particular applications driving the trend to higher power are computers of different kinds, and not just personal computers. What this slide originally didn't say was how many high-end thermal challenges are presented by the data processing industry. Cloud processing is fine for the individual user, but somebody somewhere has to provide the brute computing power! At the other end of the spectrum are solutions for cost-conscious individual applications in the automotive and lighting industry.



An increasing challenge

- Total power increasing
- Dissipation density increasing
- Driven by applications
  - telecoms
  - data infrastructure — server farms
- Complicated by other changes
  - board size
  - layer count
  - specialised package design

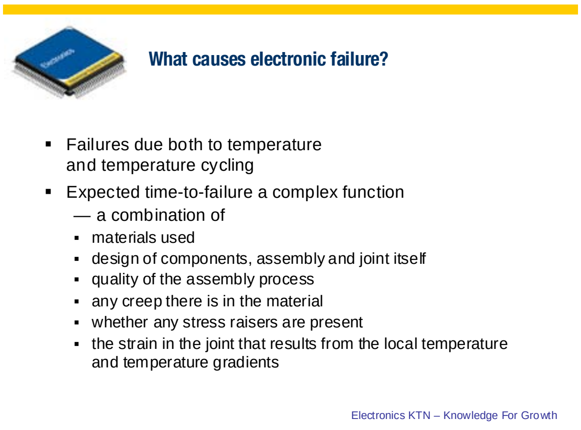
So total power is increasing, and dissipation density is increasing, both driven by applications, but of course complicated by other technology trends.



Related to more than just temperature

- A growing problem for function and reliability
- Driven simultaneously by the market and the technology
- Reliability related to heat distribution and thermal cycling, not just absolute temperature

The growing problem is not just that things get too hot, because often the problem relates to heat distribution and thermal cycling rather than high temperature itself. For example, there may be thermal hot spots at the semiconductor device level, or at the board level, and we shouldn't forget that deficiencies in airflow can also give problems within cabinets.



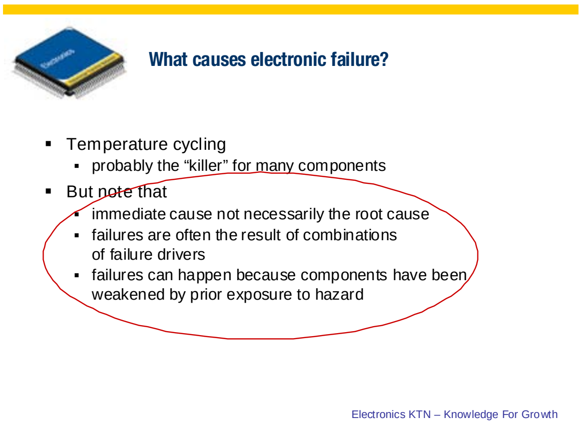
What causes electronic failure?

- Failures due both to temperature and temperature cycling
- Expected time-to-failure a complex function — a combination of
  - materials used
  - design of components, assembly and joint itself
  - quality of the assembly process
  - any creep there is in the material
  - whether any stress raisers are present
  - the strain in the joint that results from the local temperature and temperature gradients

The failures that we get will be due both to temperature, and the temperature cycling that this causes when systems are power cycled.

The time-to-failure is a complex function of many materials, design and quality aspects …

Implementing thermal management



What causes electronic failure?

- Temperature cycling
  - probably the “killer” for many components
- But note that
  - immediate cause not necessarily the root cause
  - failures are often the result of combinations of failure drivers
  - failures can happen because components have been weakened by prior exposure to hazard

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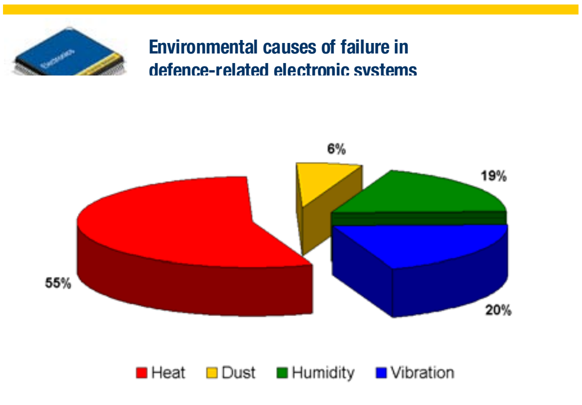
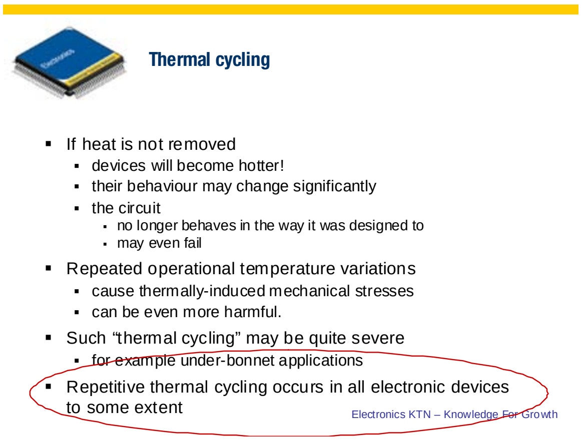
… and the causes of failure may be combinational, with one root cause for the problem initiation which is, so to speak, “developed” by other factors. Remember the case of thermal cycling creating cracks which led to failure on drop test.



Environmental causes of failure in defence-related electronic systems

🟥 Heat 🟨 Dust 🟩 Humidity 🟦 Vibration

Although one can debate the percentages, what is certain is that a very considerable proportion of equipment failures are related in some way to heat, and in particular to thermal cycling.



Thermal cycling

- If heat is not removed
  - devices will become hotter!
  - their behaviour may change significantly
  - the circuit
    - no longer behaves in the way it was designed to
    - may even fail
- Repeated operational temperature variations
  - cause thermally-induced mechanical stresses
  - can be even more harmful.
- Such “thermal cycling” may be quite severe
  - for example under-bonnet applications
- Repetitive thermal cycling occurs in all electronic devices to some extent

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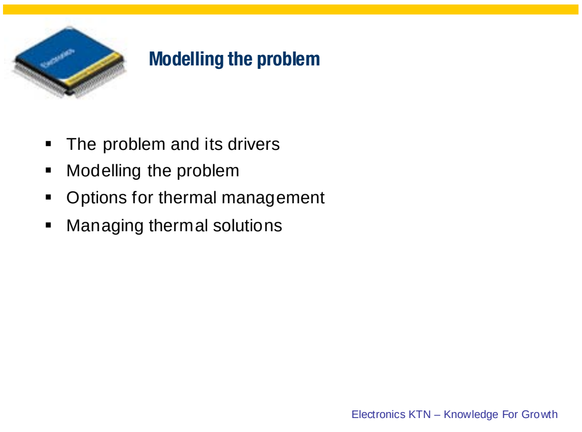
As we say in this slide, repetitive thermal cycling occurs in almost every electronic application, and it is generally the case that the level of thermal cycling strain can be reduced by reducing the operating temperature. Having said that, over-cooling makes no economic sense, and may even give rise to problems.



Modelling the problem

- The problem and its drivers
- Modelling the problem
- Options for thermal management
- Managing thermal solutions

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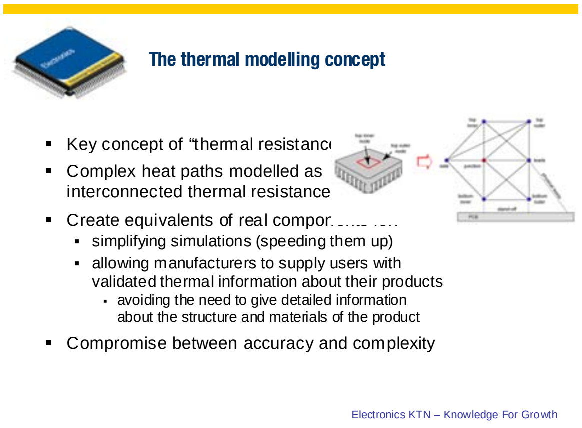
Our model will look at the whole system, operating successively at component, board and equipment levels, and be based on thermal models of components as our attempt to simplify the real world.

Implementing thermal management



The thermal modelling concept

- Key concept of “thermal resistanc
- Complex heat paths modelled as interconnected thermal resistance
- Create equivalents of real compor
  - simplifying simulations (speeding them up)
  - allowing manufacturers to supply users with validated thermal information about their products
    - avoiding the need to give detailed information about the structure and materials of the product
- Compromise between accuracy and complexity

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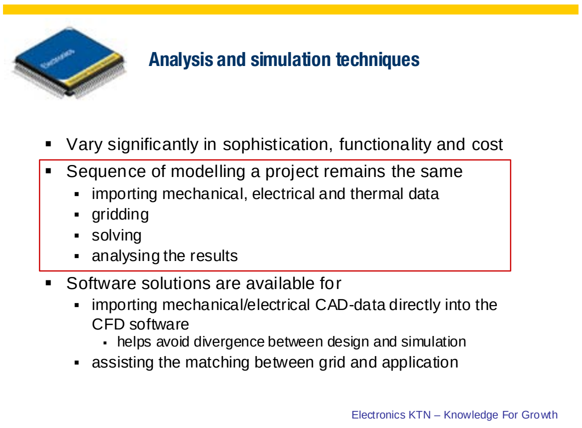
We’ve seen that thermal resistance is a useful concept, which can be used to model heat paths, and we have also seen its value in creating equivalents of real components to simplify and speed up simulations and to allow information on packages to be shared between manufacturers and users.

But we have also seen that these models have differing degrees of accuracy, and care needs to be taken in their use.



Analysis and simulation techniques

- Vary significantly in sophistication, functionality and cost
- Sequence of modelling a project remains the same
  - importing mechanical, electrical and thermal data
  - gridding
  - solving
  - analysing the results
- Software solutions are available for
  - importing mechanical/electrical CAD-data directly into the CFD software
    - helps avoid divergence between design and simulation
  - assisting the matching between grid and application

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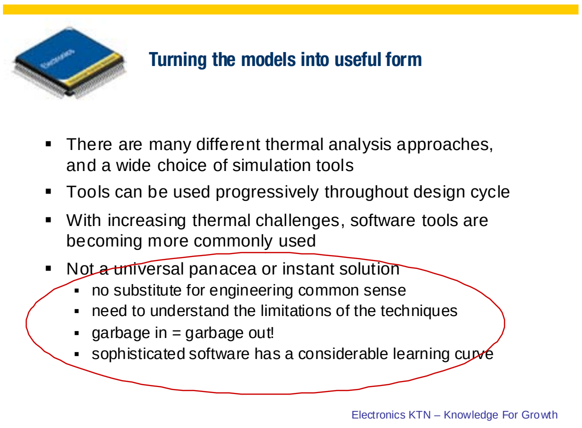
We have also seen that those models can be used in a number of analysis and simulation techniques that vary significantly in their sophistication, their functionality and their cost, though the sequence of modelling remains broadly the same, which is first to import mechanical, electrical and thermal data, then to “grid” the model of the structure, then to solve the very many partial differential equations using numerical methods, and finally to analyse the results.



Turning the models into useful form

- There are many different thermal analysis approaches, and a wide choice of simulation tools
- Tools can be used progressively throughout design cycle
- With increasing thermal challenges, software tools are becoming more commonly used
- Not a universal panacea or instant solution
  - no substitute for engineering common sense
  - need to understand the limitations of the techniques
  - garbage in = garbage out!
  - sophisticated software has a considerable learning curve

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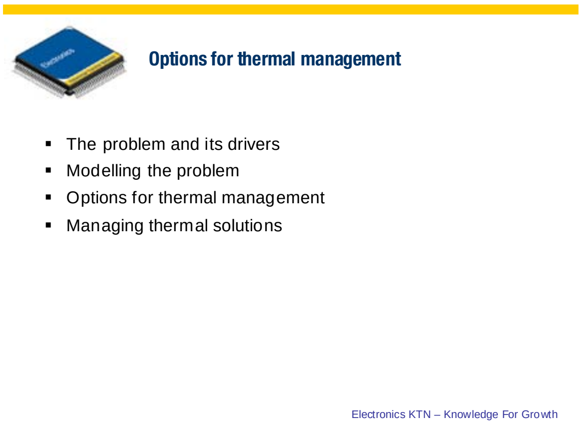
And we’ve issued dire warnings that there is still no substitute for engineering commonsense, and users need:

- to understand the limitations of the techniques
- to remember that bad data leads to bad simulations and bad conclusions, and
- to bear in mind that sophisticated software has a considerable learning curve



Options for thermal management

- The problem and its drivers
- Modelling the problem
- Options for thermal management
- Managing thermal solutions

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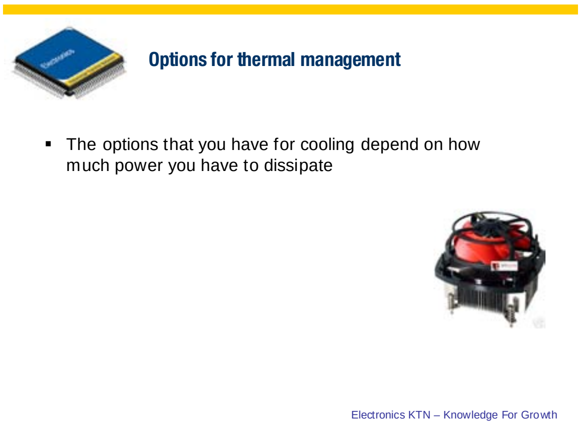
Having modelled the problem, we can proceed to evaluate different options for thermal management.



Options for thermal management

- The options that you have for cooling depend on how much power you have to dissipate

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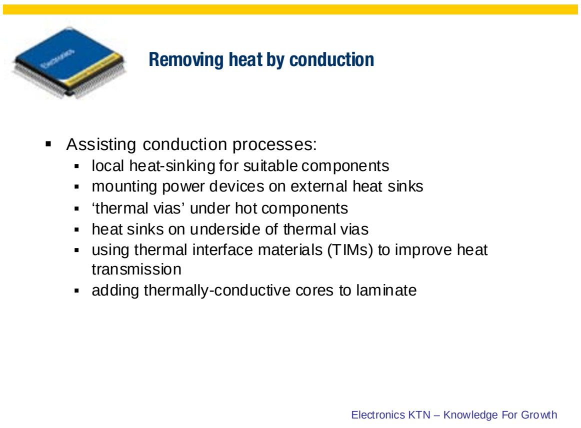
It has rightly been said that the options you have for cooling depend on how much power you have to dissipate. For many purposes a simple heat sink with or without a fan will give a “cheap and cheerful” solution, but there are many strategies beyond that.



Removing heat by conduction

- Assisting conduction processes:
  - local heat-sinking for suitable components
  - mounting power devices on external heat sinks
  - ‘thermal vias’ under hot components
  - heat sinks on underside of thermal vias
  - using thermal interface materials (TIMs) to improve heat transmission
  - adding thermally-conductive cores to laminate

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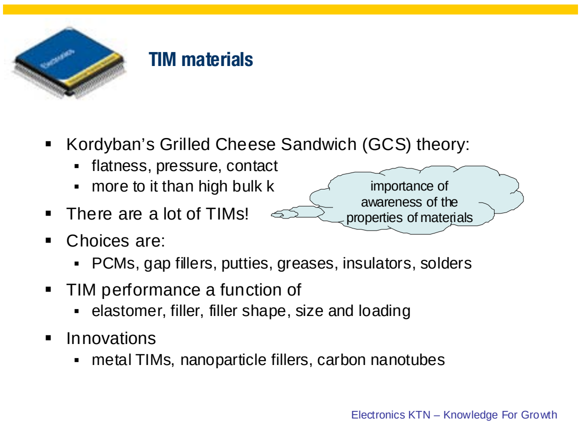
We recommend that you start right back at basics, by looking at the way in which one can assist natural conduction processes, by proper board design and choice of materials, and using heat sinks effectively.



TIM materials

- Kordyban’s Grilled Cheese Sandwich (GCS) theory:
  - flatness, pressure, contact
  - more to it than high bulk k
- There are a lot of TIMs!
- Choices are:
  - PCMs, gap fillers, putties, greases, insulators, solders
- TIM performance a function of
  - elastomer, filler, filler shape, size and loading
- Innovations
  - metal TIMs, nanoparticle fillers, carbon nanotubes

importance of awareness of the properties of materials

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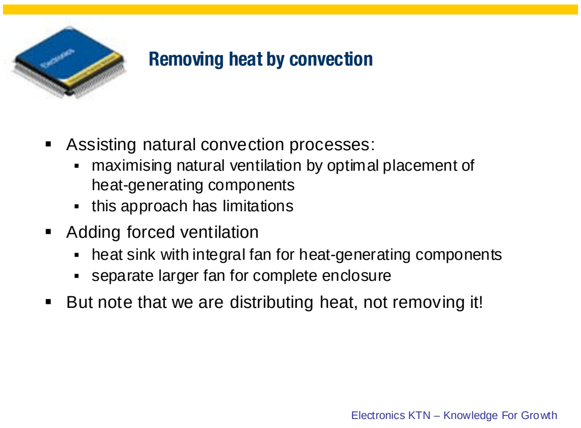
Inevitably this means doing some digging into the materials used, both for the heat sink and for the thermal interface material between device and heat sink. A major point to remember here is that most materials conduct heat very poorly, and it is the interfaces that provide much of the thermal resistance.



Removing heat by convection

- Assisting natural convection processes:
  - maximising natural ventilation by optimal placement of heat-generating components
  - this approach has limitations
- Adding forced ventilation
  - heat sink with integral fan for heat-generating components
  - separate larger fan for complete enclosure
- But note that we are distributing heat, not removing it!

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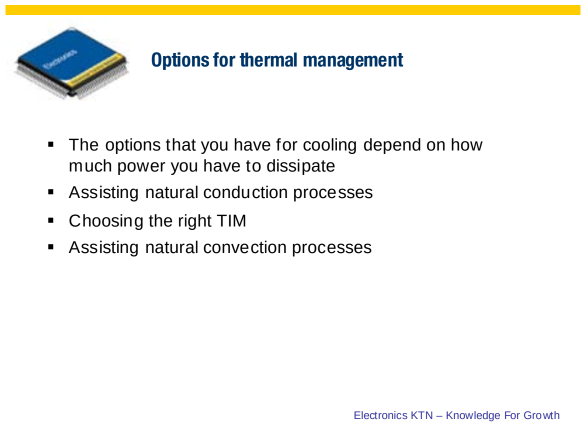
As well as assisting natural conduction processes, we can assist natural convection processes, but we will often need to add forced ventilation.

Implementing thermal management



Options for thermal management

- The options that you have for cooling depend on how much power you have to dissipate
- Assisting natural conduction processes
- Choosing the right TIM
- Assisting natural convection processes

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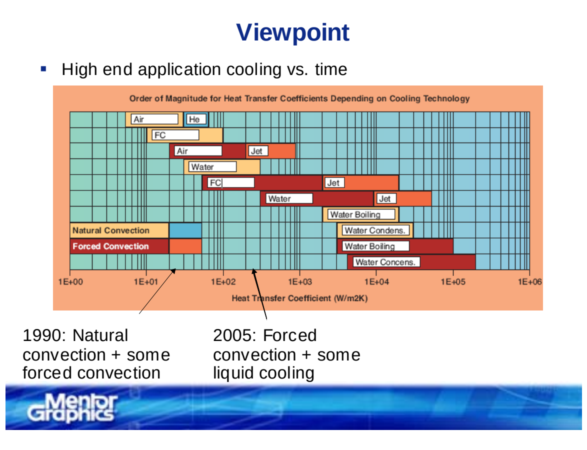
We saw in Section 4 that there are many different ways of tackling the problem, and our choice will depend to a large extent on the power that we need to dissipate.



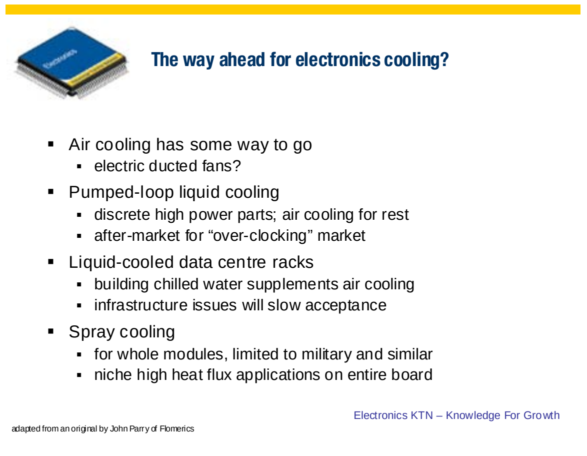
Viewpoint

- High end application cooling vs. time

1990: Natural convection + some forced convection

2005: Forced convection + some liquid cooling

This is certainly an area where there is continuing and considerable change in both the challenges and the solutions.



The way ahead for electronics cooling?

- Air cooling has some way to go
  - electric ducted fans?
- Pumped-loop liquid cooling
  - discrete high power parts; air cooling for rest
  - after-market for “over-clocking” market
- Liquid-cooled data centre racks
  - building chilled water supplements air cooling
  - infrastructure issues will slow acceptance
- Spray cooling
  - for whole modules, limited to military and similar
  - niche high heat flux applications on entire board

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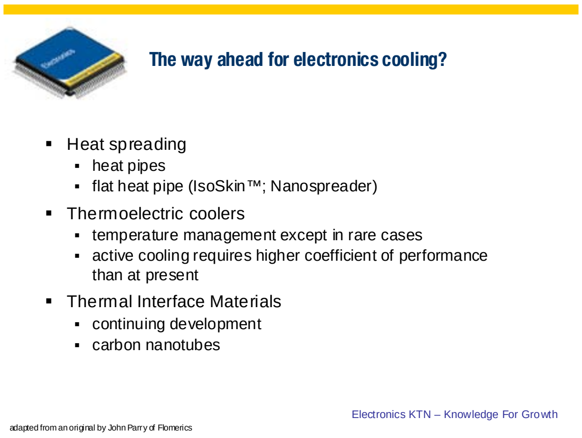
adapted from an original by John Parry of Flomerics

In this review of electronics cooling technology, John Parry of Flomerics offered the view that air cooling has some way to go, possibly using advances in fan technology. For discrete high power parts, air cooling will remain the primary method, supplemented by pumped-loop liquid cooling, and we will see more liquid cooling for “enthusiast applications” for high dissipation computing.

Liquid cooling will be used on a larger scale for data centre racks, where the thermal challenges are considerable, in particular systems that use chilled water supplied as a building service, though infrastructure considerations will slow acceptance of this technology. We will also see liquid used, this time sprayed, as part of phase change thermal management, but typically only for high-reliability applications with an adverse environment and significant thermal demand.



The way ahead for electronics cooling?

- Heat spreading
  - heat pipes
  - flat heat pipe (IsoSkin™; Nanospreader)
- Thermoelectric coolers
  - temperature management except in rare cases
  - active cooling requires higher coefficient of performance than at present
- Thermal Interface Materials
  - continuing development
  - carbon nanotubes

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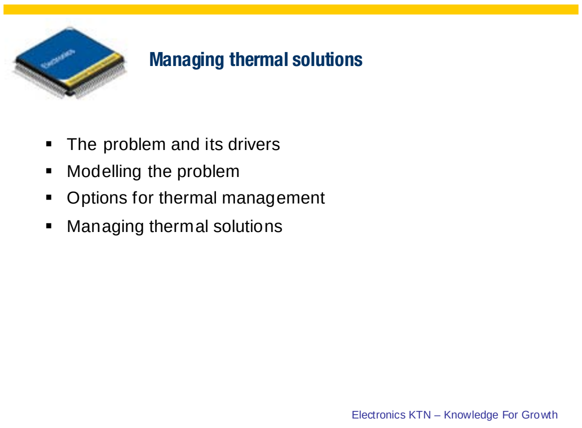
adapted from an original by John Parry of Flomerics

Heat spreading will continue to grow in importance, both using heat pipes to enhance conventional structures and using different types of flat heat pipe.

Except in rare cases thermoelectric coolers will find their application within temperature control for devices, as using them for active cooling requires a higher coefficient of performance than is currently available.

And for all these solutions we need to remember that thermal interface materials are extremely important, and attract continuing development efforts, the most promising of which involve carbon nanotubes. A case of “watch this space”!



Managing thermal solutions

- The problem and its drivers
- Modelling the problem
- Options for thermal management
- Managing thermal solutions

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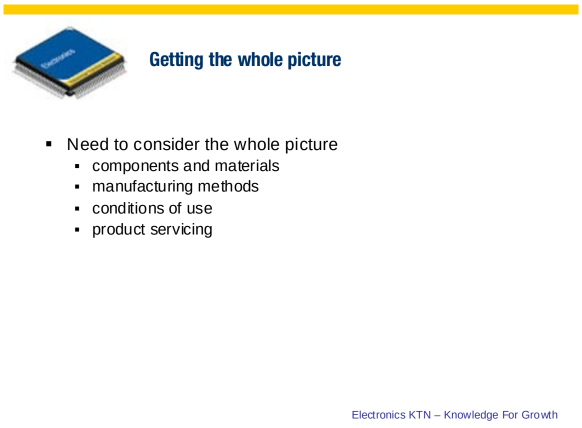
With so many options for thermal management available, having the right way to model the problem is essential as a means of selecting the best solution for a particular application. We would certainly recommend simulation as a structured way of tackling the selection process.

But how does one manage a thermal solution in the widest sense?



Getting the whole picture

- Need to consider the whole picture
  - components and materials
  - manufacturing methods
  - conditions of use
  - product servicing

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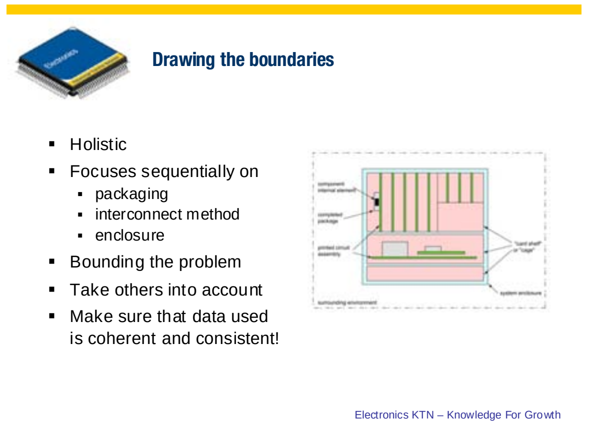
The first thing we need to remember is that thermal management has to be holistic – we need to consider the whole picture, so we will be thinking in terms of the components and materials that we buy, the manufacturing methods, and about how the product will be used and serviced throughout life.

Implementing thermal management



Drawing the boundaries

- Holistic
- Focuses sequentially on
  - packaging
  - interconnect method
  - enclosure
- Bounding the problem
- Take others into account
- Make sure that data used is coherent and consistent!

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We will be looking at different levels of the structure, starting with the package, and moving from board to enclosure. And in doing this we will be putting some boundary around the problem. Sometimes the boundary will be the enclosure, but often we will be modelling either at an individual module level or looking at the impact of design choices on a complete system.

Wherever we draw the boundary in a physical sense, we have to remember that the engineering boundary is wider than just thermal management, and we need to take others into account, and in particular to make sure that there is good feedback of the thermal issues to other members of the partnership and that design proceeds in parallel. It is particularly important that simulation should use the same data that is being worked on by electronic and enclosure design, so that the model built will be accurate.

The energy audit

- Need to consider the whole picture
- The energy audit
  - importance of reliable data

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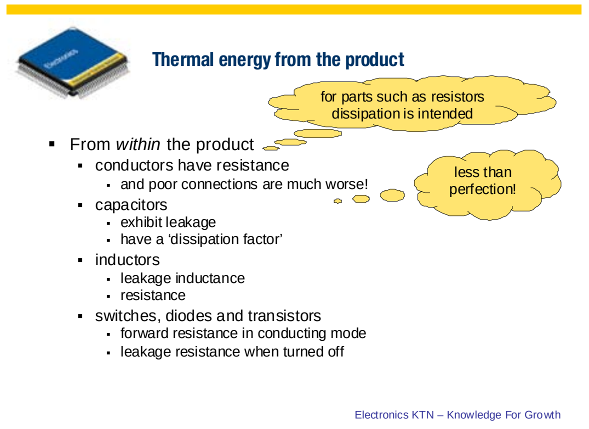
As part of our overall view, a key aspect is what might be described as an energy audit.



Thermal energy from the product

for parts such as resistors dissipation is intended

less than perfection!

- From *within* the product
  - conductors have resistance
    - and poor connections are much worse!
  - capacitors
    - exhibit leakage
    - have a 'dissipation factor'
  - inductors
    - leakage inductance
    - resistance
  - switches, diodes and transistors
    - forward resistance in conducting mode
    - leakage resistance when turned off

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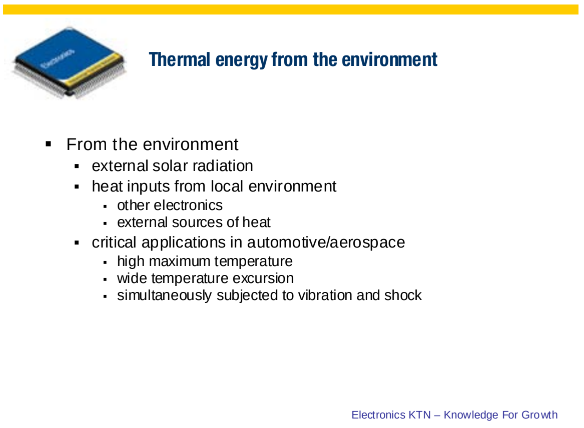
We know that most of the heat comes from within the product, both because components are not perfect, and as a result of intended dissipation …



Thermal energy from the environment

- From the environment
  - external solar radiation
  - heat inputs from local environment
    - other electronics
    - external sources of heat
  - critical applications in automotive/aerospace
    - high maximum temperature
    - wide temperature excursion
    - simultaneously subjected to vibration and shock

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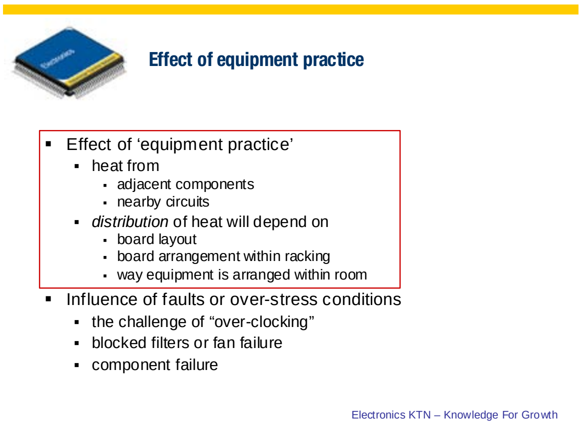
… but there may also be heat inputs from the environment, both from nearby heat dissipating sources and from heat sources outside the enclosure.



Effect of equipment practice

- Effect of ‘equipment practice’
  - heat from
    - adjacent components
    - nearby circuits
  - *distribution* of heat will depend on
    - board layout
    - board arrangement within racking
    - way equipment is arranged within room
- Influence of faults or over-stress conditions
  - the challenge of “over-clocking”
  - blocked filters or fan failure
  - component failure

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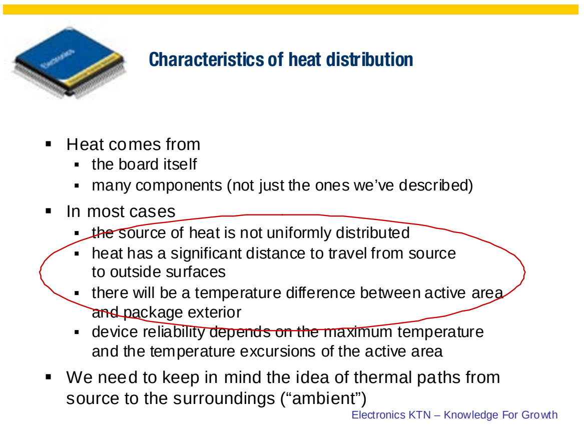
We have to keep in mind that the way that we organise the enclosure will affect its thermal performance, …



Characteristics of heat distribution

- Heat comes from
  - the board itself
  - many components (not just the ones we’ve described)
- In most cases
  - the source of heat is not uniformly distributed
  - heat has a significant distance to travel from source to outside surfaces
  - there will be a temperature difference between active area and package exterior
  - device reliability depends on the maximum temperature and the temperature excursions of the active area
- We need to keep in mind the idea of thermal paths from source to the surroundings (“ambient”)

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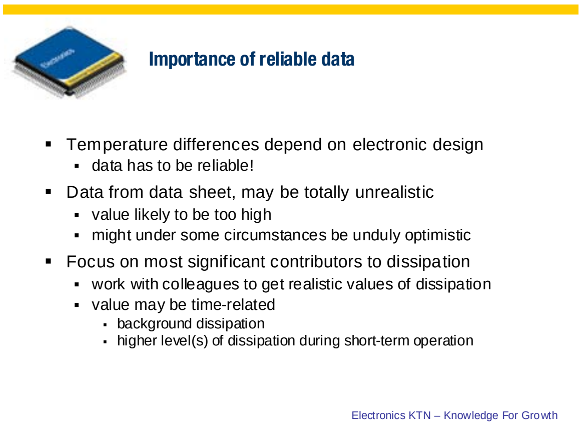
… and of course remember where the heat comes from. Key features in this slide refer to the fact that heat flow is neither uniform nor instantaneous, and that temperature differences will exist.



Importance of reliable data

- Temperature differences depend on electronic design
  - data has to be reliable!
- Data from data sheet, may be totally unrealistic
  - value likely to be too high
  - might under some circumstances be unduly optimistic
- Focus on most significant contributors to dissipation
  - work with colleagues to get realistic values of dissipation
  - value may be time-related
    - background dissipation
    - higher level(s) of dissipation during short-term operation

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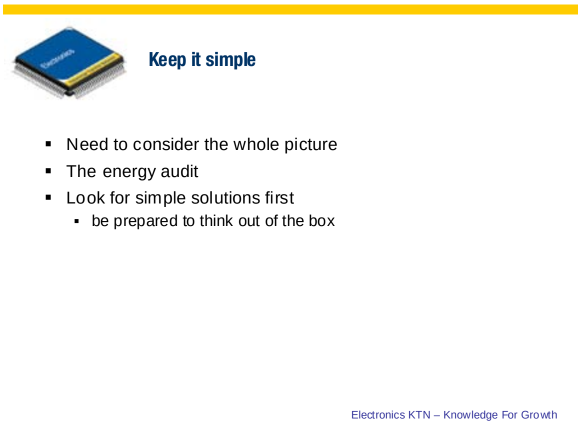
But what those temperature differences are will depend to a large extent on the electronic design, and we can’t stress too much the importance of collecting reliable data. If we use the data from the data sheet, this may give us a totally unrealistic value, which is likely to be too high, but might under some circumstances be unduly optimistic.

In an ideal world we collect information about every component: in the real world we will focus on the most significant contributors to dissipation, and work with colleagues in other departments to get realistic values of dissipation, bearing in mind that the real information may have a time-related component – for example, a background dissipation and one or more higher levels of dissipation during short-term operation.

Implementing thermal management



Keep it simple

- Need to consider the whole picture
- The energy audit
- Look for simple solutions first
  - be prepared to think out of the box

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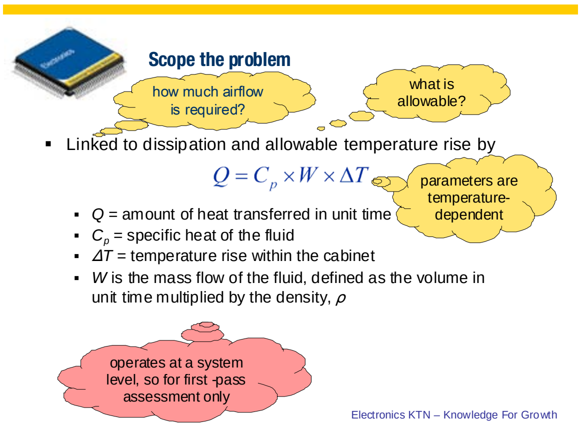
Once we know the scale of the problem, having carried out as accurate an energy audit as possible, we will look for solutions, and here we need to look for simple solutions first, both in terms of the way we model the problem, and in the way we solve it.



Scope the problem

how much airflow is required?

what is allowable?

- Linked to dissipation and allowable temperature rise by

$$Q = C_p \times W \times \Delta T$$

parameters are temperature-dependent

  - Q = amount of heat transferred in unit time
  - C_p = specific heat of the fluid
  - ΔT = temperature rise within the cabinet
  - W is the mass flow of the fluid, defined as the volume in unit time multiplied by the density, ρ

operates at a system level, so for first -pass assessment only

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Even if we need a more complex solution later, it is always worthwhile carrying out some simple calculations to see whether we have a milk saucepan boiling over or a young Vesuvius! This is where simulation really helps, because we can apply heat sinks and forced convection and get at least a preliminary assessment of the scale of the problem quite quickly.

Ways to make improvements

- Conclusions by Intel
  - improvements in one single area alone will not be able to satisfy the thermal budget requirements
  - focus needs on packaging materials and technologies to reduce interfacial resistance and improve heat spreading
  - pay attention to layout of high- and medium-power devices
  - focus on optimising the airflow and the amount of preheating from other components in the equipment

"The desired outcome would be to drive design and technology development concurrently at silicon, package, motherboard and system-level packaging to ensure that thermal solutions can support the need for increasing computing and communication needs"

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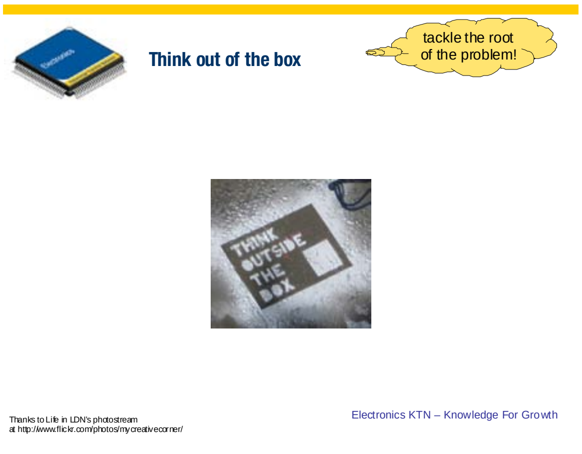
Of course the problem may need to be tackled on several fronts. The authors of one seminal Intel paper concluded that:

- Improvements in one single area alone will not be able to satisfy the thermal budget requirements.
- The focus needs to be on packaging materials and technologies to reduce interfacial resistance and improve heat spreading.
- Board layout designers need to pay attention to the layout of high- and medium-power devices.
- System designers need to focus on optimising the airflow and the amount of preheating that comes from other components in the equipment.

And they finish with the statement: "The desired outcome would be to drive design and technology development concurrently at silicon, package, motherboard and system-level packaging to ensure that thermal solutions can support the need for increasing computing and communication needs".

Implementing thermal management



Think out of the box

tackle the root of the problem!

Thanks to Life in LDN's photostream at http://www.flickr.com/photos/mycreativecorner/

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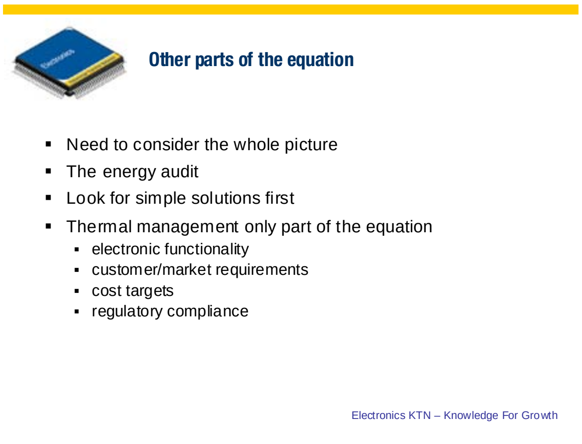
In the same way as we should look for simple solutions first, we should be prepared to think out of the box, even to the extent of challenging the constraints of the design. Does it need to have this level of dissipation? Are the size and format of the enclosure carved in tablets of stone?



Other parts of the equation

- Need to consider the whole picture
- The energy audit
- Look for simple solutions first
- Thermal management only part of the equation
  - electronic functionality
  - customer/market requirements
  - cost targets
  - regulatory compliance

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While we are carrying out the energy audit, trying to get the best possible information, and looking for a range of solutions to choose from, we have to keep in mind that thermal management is only part of the equation. We have to consider electronic functionality, any requirements of the customer and the market, and any resulting cost targets.

At the same time, we have to bear in mind the need for compliance with appropriate regulations, whether these relate to safety, electromagnetic compatibility, the safe use of materials, eventual disposal of the product, or whatever else is thrown at us by an increasingly bureaucratic world.

Need for a safety margin

- Mechanical constraints
- Operating environment
  - humidity considerations
  - vibration and vibration testing
  - mechanical testing and impact testing
  - chemical and biological hostility
- Resistance to water in the environment
- Appropriate thermal management
- Need for a safety margin
- Three levels of requirement
  - safety; functionality; **reliability**

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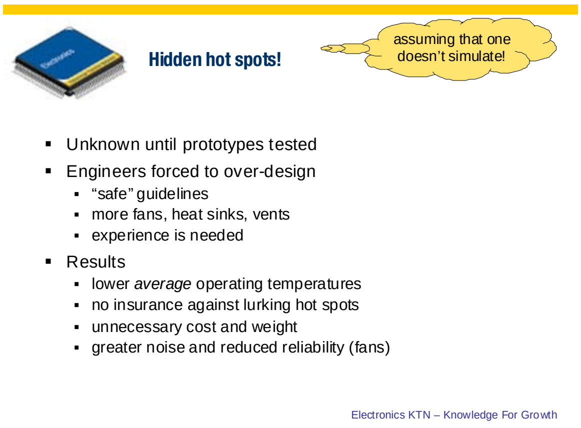
As part of this we will develop a specification, and our specification is going to be similar to that which we presented earlier as the elements of the specification for the enclosure.

But as we concluded there, a key aspect of the “appropriate thermal management” is that there should be some margin of safety. If you recall, we identified three levels of requirement, of which the most basic was safety: Is the equipment going to burn up on me? Will it pass its UL test in terms of the materials used? And the second level is about functionality: Will the equipment work, not just in the factory, but also in the field under the expected range of environmental conditions?

And of course there is that final requirement for reliability, the target we are aiming at, which is to make the product managed from a thermal perspective in such a way that the product is totally reliable.



Hidden hot spots!

assuming that one doesn't simulate!

- Unknown until prototypes tested
- Engineers forced to over-design
    - “safe” guidelines
    - more fans, heat sinks, vents
    - experience is needed
- Results
    - lower *average* operating temperatures
    - no insurance against lurking hot spots
    - unnecessary cost and weight
    - greater noise and reduced reliability (fans)

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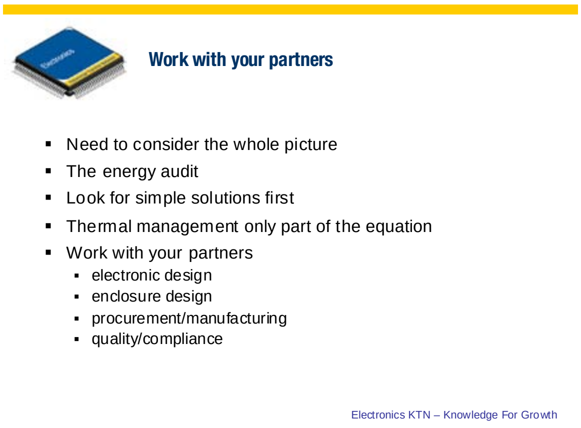
And this is where simulation followed by verification really helps. If you are doing things without simulation, as this slide said earlier, you are probably going to over design the cooling, but you might well end up with hidden hotspots, despite the extra costs that you have incurred.



Work with your partners

- Need to consider the whole picture
- The energy audit
- Look for simple solutions first
- Thermal management only part of the equation
- Work with your partners
    - electronic design
    - enclosure design
    - procurement/manufacturing
    - quality/compliance

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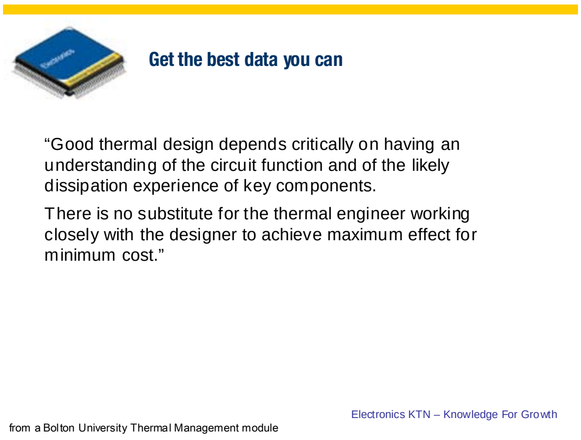
So you have done all the right things, and you have kept looking at the broader picture as well as dealing in detail with some of the challenges. But have you really taken into account the other partners in the chain?



Get the best data you can

“Good thermal design depends critically on having an understanding of the circuit function and of the likely dissipation experience of key components.

There is no substitute for the thermal engineer working closely with the designer to achieve maximum effect for minimum cost.”

from a Bolton University Thermal Management module

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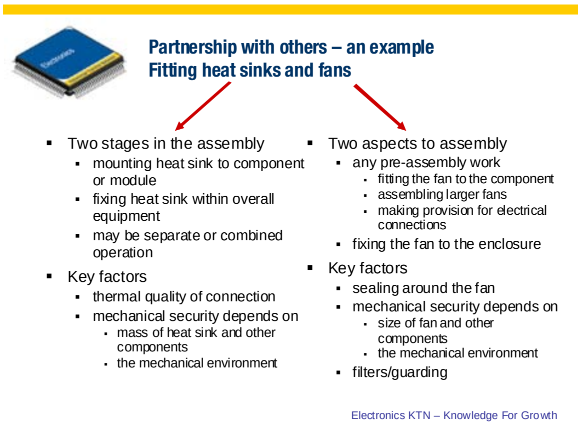
Some of these will be in electronic design, where a collaborative effort will help get the best data. As one of the Bolton MSc modules puts it: “Good thermal design depends critically on having an understanding of the circuit function and of the likely dissipation experience of key components. There is no substitute for the thermal engineer working closely with the designer to achieve maximum effect for minimum cost.”



Partnership with others – an example
Fitting heat sinks and fans

- Two stages in the assembly
    - mounting heat sink to component or module
    - fixing heat sink within overall equipment
    - may be separate or combined operation
- Key factors
    - thermal quality of connection
    - mechanical security depends on
        - mass of heat sink and other components
        - the mechanical environment

- Two aspects to assembly
    - any pre-assembly work
        - fitting the fan to the component
        - assembling larger fans
        - making provision for electrical connections
    - fixing the fan to the enclosure
- Key factors
    - sealing around the fan
    - mechanical security depends on
        - size of fan and other components
        - the mechanical environment
    - filters/guarding

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Others will be involved in the design of the enclosure, hopefully working closely together with procurement and manufacturing. As we said when considering fitting both heat sinks and fans, you need to think not only of the requirements of the application, but of the practicalities of implementing any pre-assembly work …

Implementing thermal management

Partnership with others – an example
Fitting heat sinks and fans

- Primary methods of assembly
  - nuts/washers/bolts
  - self-tapping screws
  - rivets
  - spring clips
  - adhesives
- Choice of method will depend on
  - the requirement for rework
  - the application life
  - the preferences of the assembler
  - the equipment available

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… the actual assembly methods themselves, and any subsequent rectification or servicing, and the methods you select will need to be in line with the preferences of your assembly and service partners and the equipment available to them.

Importance of specifications

- "Unfortunately, good, workable thermal requirements are a rare commodity"

  Wendy Luiten in *Sense and nonsense thermal requirements*
- Safety standards (e.g. UL6500; IEC60065)
  - describe the limits + applicable circumstances
  - outside these limits, the situation is potentially unsafe
- What happens in the event of failure?
  - will the system shut itself down? or catch fire?
  - will lack of functionality result in consequential damage?

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Finally you need to work with colleagues in quality and compliance. Specifications are important here, but as Wendy Luiten puts it, "Unfortunately, good, workable thermal requirements are a rare commodity".

Her paper was the source of our earlier comments on reliability, functionality and safety, and it is perhaps worth thinking of safety issues from the viewpoint of standards such as UL6500 and IEC60065, which describe the limits, the circumstances for which they are applicable, and suggest measuring methods. Outside these safety limits, the situation is potentially unsafe.

So we have to think about what happens in the event of failure – will the system shut itself down? Or catch fire? Will the lack of functionality and failure result in consequential damage?

Managing thermal risk

- Place of thermal analysis in electronic design
  - managing thermal risk
  - thermal design strategies
- Implementing thermal analysis in product development
  - a thermal design methodology
  - concept development phase
  - detailed design phase
  - hardware test phase
  - risk management

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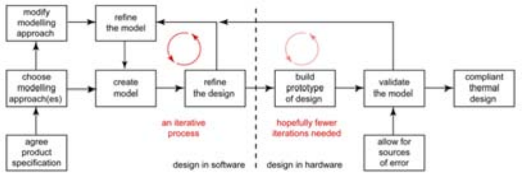
After all, as we said at the outset, risk management is one of the key functions of thermal analysis, which is why we try and use it throughout the development process, taking care to keep the thermal design synchronised with electronic design.

Rework the simulation, not the hardware!



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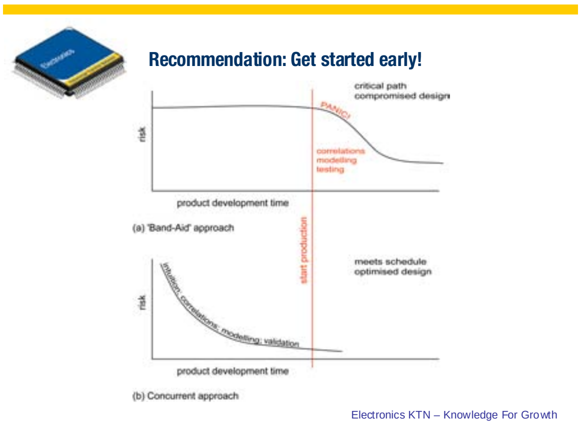
Inevitably the modelling that we do, which will include "what if" simulations, discussion with problem owners, and change imposed on the project from outside, that modelling will involve a degree of iteration. Although simulation gives us quick results, rarely will the first pass give us more than an indication of the way forward. However, provided that care has been taken, we will end up with a design that is thermally compliant with relatively little reworking needed at the expensive hardware design phase.

Implementing thermal management



Recommendation: Get started early!

(a) 'Band-Aid' approach

(b) Concurrent approach

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As was stressed in an earlier presentation, a key for success is involving thermal management early in the process in order to minimise the risk. We can't remove every element of risk, but we can ensure that the product is designed for correct function both during normal life and during life events that we might reasonably anticipate.

Use thermal engineering resources to the full

- New design concept
  - package changes
  - material improvements
- Start early during the design
  - assess the extent of the problem
  - model thermally as well as build electrical prototype
- Thermal engineer brings
  - personal experience
  - experience of others
  - full thermal management armoury

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Thermal design will start with the very first glimpse of that new design concept, and suggest ways in which the product can be improved, in both design and materials. And the thermal modelling will proceed in parallel with the electrical prototype.

The thermal engineer will bring to the party not only his or her experience but also draw on the experience of others, and on a range of techniques from the thermal management armoury, ranging from calculations on the back of the proverbial fag packet, to full simulation.

Managing thermal solutions

- Need to consider the whole picture
- The energy audit
  - importance of reliable data
- Look for simple solutions first
  - be prepared to think out of the box
- Thermal management only part of the equation
- Work with your partners

think
thermal!

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Managing thermal solutions is all about the whole picture, getting reliable information, and looking for the most cost-effective solutions. But it is only part of the overall scenario, and the thermal engineer is only one member in the partnership. So our final recommendation is that everyone in that partnership should "think thermal".