
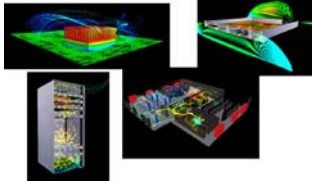



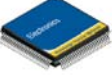








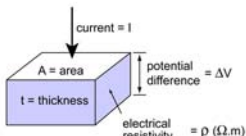
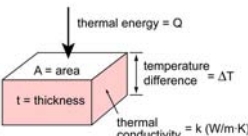
## Introductory concepts

 <h3>Introductory concepts</h3> <ul style="list-style-type: none"><li>▪ The thermal model<ul style="list-style-type: none"><li>▪ component level</li><li>▪ board level</li><li>▪ system level</li></ul></li><li>▪ The concept of thermal resistance</li></ul>  <p>Electronics KTN – Knowledge For Growth</p>	<p>Earlier parts of this material have dealt with the need for thermal management and the basics of heat transfer, and this main section tackles the central issue of building thermal models that we can use to predict thermal characteristics. In this first presentation we are looking at some underpinning ideas: first the idea of the thermal model itself, which can be applied all the way through from component level to the complete system, and then the concept of thermal resistance which we will find applied both in analytical methods of thermal problem-solving and in simulation.</p>
 <h3>The thermal model</h3> <ul style="list-style-type: none"><li>▪ A thermal model is a mathematical model that dynamically predicts the temperature of an object<ul style="list-style-type: none"><li>▪ analogies in electronics and mechanics</li></ul></li></ul> <p>Electronics KTN – Knowledge For Growth</p>	<p>Well, what is a thermal model? It's a mathematical model that we construct to try and predict the temperature of an object either in steady state or dynamically as a function of time, and so that we can assess the temperature distribution within the product and the effect of influences such as power cycling. Such modelling practice exists elsewhere within professional engineering – thermal models are comparable to electronic models produced to predict aspects such as output logic values or signal to noise ratio, or a structural model used to calculate stresses and strains.</p>
 <h3>The thermal model</h3> <ul style="list-style-type: none"><li>▪ A thermal model is a mathematical model that dynamically predicts the temperature of an object<ul style="list-style-type: none"><li>▪ analogies in electronics and mechanics</li></ul></li><li>▪ The primary function of thermal modelling is to improve reliability in the end product</li></ul> <p>Electronics KTN – Knowledge For Growth</p>	<p>The whole purpose of our thermal model is to improve the reliability of the end product by predicting the temperatures of key components, and avoiding reliability issues, where a product might work for a while after switch-on, but eventually blow up or break down because of thermal effects.</p>
 <h3>The thermal model</h3> <ul style="list-style-type: none"><li>▪ A thermal model is a mathematical model that dynamically predicts the temperature of an object<ul style="list-style-type: none"><li>▪ analogies in electronics and mechanics</li></ul></li><li>▪ The primary function of thermal modelling is to improve reliability in the end product</li><li>▪ The most commonly-used indicator of thermally-affected reliability is the component junction temperature (<math>T_j</math>)</li></ul> <p>Electronics KTN – Knowledge For Growth</p>	<p>Failure can often be linked to the internal temperatures within components, both their absolute values and the temperature cycling that accompanies power cycling. It is the <math>T_j</math>, the temperature of the junction at the very source of the heat within the integrated circuit or similar heat-generating component, that influences reliability, and this temperature will usually be considerably higher than that of the case or the environment</p> <p>For that reason, manufacturers' data sheets frequently quote the maximum junction temperature. Its value will vary widely, according to the construction, the function, and the intended application of the device, but a common feature is that operation above the recommended maximum <math>T_j</math> will adversely affect the life expectancy of the device.</p>





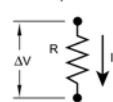
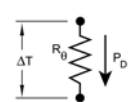
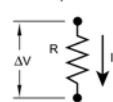
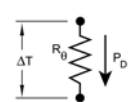
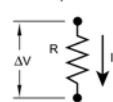
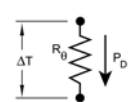
## Introductory concepts

 <p><b>The thermal model</b></p> <ul style="list-style-type: none"><li>▪ The accuracy of the model is a function of<ul style="list-style-type: none"><li>▪ the algorithm used</li><li>▪ the simplifications made</li></ul></li></ul> <p>Electronics KTN – Knowledge For Growth</p>	<p>Our thermal model is unlikely to be totally accurate, in part because of variation in both components and structures. But the model accuracy is also a function of how the algorithm used, that is the sequence of calculations that is applied to the model, and which (usually after a number of iterations) produces its “best estimate” of the values.</p> <p>The calculations are complex, and many simplifications are necessary in order to get a usable result in an acceptable time, so the accuracy of the model is also a function of the simplifications made. We will see more about this in the section on modelling heat generating elements.</p>
 <p><b>The thermal model</b></p> <ul style="list-style-type: none"><li>▪ The accuracy of the model is a function of<ul style="list-style-type: none"><li>▪ the algorithm used</li><li>▪ the simplifications made</li><li>▪ the accuracy of the input data!</li></ul></li></ul> <p>Electronics KTN – Knowledge For Growth</p>	<p>Perhaps most importantly the accuracy is a function of the accuracy of the input data, which may be information on basic materials, or conclusions drawn from the measurement of devices. One particularly important aspect is the accuracy of information on the dissipation of the different elements within the structure, which is a consequence of the electronic design. When it comes to it, it is all about I squared R heating.</p>
 <p><b>The thermal model</b></p> <ul style="list-style-type: none"><li>▪ The accuracy of the model is a function of<ul style="list-style-type: none"><li>▪ the algorithm used</li><li>▪ the simplifications made</li><li>▪ the accuracy of the input data!</li></ul></li><li>▪ Thermal models are a compromise between accuracy and complexity</li></ul> <p>Electronics KTN – Knowledge For Growth</p>	<p>Thermal models are a compromise between accuracy and complexity. It is possible to extract useful information from quite a simple model, but for other purposes you may need to invest a lot of time building a complex model. Effective modelling is about matching the detail of the model to the application, bearing in mind that models need a considerable amount of computation and sometimes many hours of processing.</p>
 <p><b>The thermal model</b></p> <ul style="list-style-type: none"><li>▪ The accuracy of the model is a function of<ul style="list-style-type: none"><li>▪ the algorithm used</li><li>▪ the simplifications made</li><li>▪ the accuracy of the input data!</li></ul></li><li>▪ Thermal models are a compromise between accuracy and complexity</li><li>▪ Traditional approach has been to start simply and add complexity as desired, as over-complication significantly increases computation time</li></ul> <p>Electronics KTN – Knowledge For Growth</p>	<p>This is why the traditional approach has been to start simply and add complexity as required. Of course, you can come at this from either end: you can look at the problem from the systems point of view, and gradually build in detail from the top down. Or you can start with individual chips, model them, then model the board assembly, model within an enclosure, and so on, simplifying each stage in order to give as accurate as possible a view of the overall system built from the bottom up. Both methods work, and we will be seeing both approaches in the case studies. It is important to remember, however, that using complicated models from the outset may not be the best way to go about it!</p>




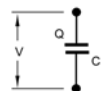
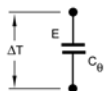
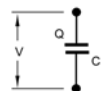
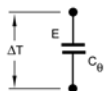
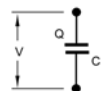
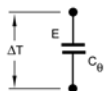

## Introductory concepts

 <h3>The thermal model</h3> <ul style="list-style-type: none"> <li>Modelling may take place at             <ul style="list-style-type: none"> <li>system level</li> <li>board level</li> <li>component level</li> </ul> </li> <li>Thermal modelling of components is one of the most challenging issues in thermal design</li> <li>Work on thermal models of components started in the early 1990s</li> </ul> <p style="text-align: right; font-size: small;">Electronics KTN – Knowledge For Growth</p>	<p>Thermal modelling of components has certainly proven to be one of the most challenging issues in thermal design, and there is an enormous amount of discussion in the literature. Fortunately, improvements in understanding, accompanied by considerable enhancements in computing power, mean that we no longer have to work empirically, but can take advantage of the information resources that have built up since work on thermal models of components started in the early 1990s. The way in which that work developed can be seen in our next section on “Modelling heat-generating elements”.</p>
 <h3>The concept of thermal resistance</h3> <ul style="list-style-type: none"> <li>A key element in thermal modelling is the concept of “thermal resistance”</li> <li>This approach is based on similarities between the conduction of heat and the conduction of electricity</li> <li>Analogy is between resistance to the transfer of heat and electrical resistance to the passage of current</li> </ul> <p style="text-align: right; font-size: small;">Electronics KTN – Knowledge For Growth</p>	<p>A key element that we use in thermal modelling is the concept of thermal resistance, a way of expressing the way in which materials are less than perfect conductors of heat. The approach is based on similarities between the conduction of heat and the conduction of electricity, but that is not to say that good thermal conductors are always good electrical conductors. In fact there is no general correspondence, because the conduction mechanisms are different. Whilst metals perform well with both heat and electricity, electrical insulators such as ceramics conduct heat moderately well.</p> <p>However, a useful analogy can be drawn between resistance to the transfer of heat and electrical resistance to the passage of current. It’s not an absolute analogy in any sense, so has to be regarded more as a guideline, but it remains useful nonetheless, and is frequently referred to in the literature.</p>
 <h3>Material properties</h3> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>Electrical resistance</p>  <p><math>R = \text{electrical resistance } (\Omega)</math>  <math>R = \frac{l}{A} \rho</math>     <math>\Delta V = IR</math></p> </div> <div style="text-align: center;"> <p>The thermal resistance analogy</p>  <p><math>R_{\theta} = \text{thermal resistance } (^{\circ}\text{C/W})</math>  <math>R_{\theta} = \frac{l}{A} \times \frac{1}{k}</math>     <math>\Delta T = QR_{\theta}</math></p> </div> </div> <p style="text-align: right; font-size: small;">Electronics KTN – Knowledge For Growth</p>	<p>On the left of this slide we illustrate the equations for electrical resistance: the resistance to current depends on the thickness of the element and the resistivity of the material, and inversely on the area.</p> <p>Our thermal analogue shows temperature difference rather than potential difference, and thermal energy instead of current. The equation is slightly different, because we normally think in terms of thermal conductivity, rather than thermal resistivity. Otherwise, the forms of these equations are identical, and the outcome is a value of “thermal resistance” in °C per Watt, or more correctly in Kelvin per Watt.</p>





## Introductory concepts

<div style="text-align: center;">  <p><b>The concept of thermal resistance</b></p> </div> <ul style="list-style-type: none"> <li>▪ Heat (= power) is substituted for current, temperature for voltage, and thermal resistance for resistance           <ul style="list-style-type: none"> <li>▪ potential difference = current x resistance (<math>V=IR</math>)</li> <li>▪ temperature difference = heat x thermal resistance</li> <li>▪ thermal resistance = temperature difference/heat</li> </ul> </li> </ul> <p style="text-align: right; font-size: small;">Electronics KTN – Knowledge For Growth</p>	<p>In our analogy, we substitute heat for power, temperature for voltage, and thermal resistance for electrical resistance, and we can derive a number of equations, broadly equivalent to Ohm's Law for electricity. So we have an equivalent for Ohm's Law expressed as temperature difference in terms of heat and thermal resistance, rather than voltage in terms of current and resistance.</p>		
<div style="text-align: center;">  <p><b>The concept of thermal resistance</b></p> </div> <ul style="list-style-type: none"> <li>▪ Heat (= power) is substituted for current, temperature for voltage, and thermal resistance for resistance           <ul style="list-style-type: none"> <li>▪ potential difference = current x resistance (<math>V=IR</math>)</li> <li>▪ temperature difference = heat x thermal resistance</li> <li>▪ thermal resistance = temperature difference/heat</li> </ul> </li> <li>▪ The product of power input and thermal resistance is a temperature rise</li> </ul> <p style="text-align: right; font-size: small;">Electronics KTN – Knowledge For Growth</p>	<p>If we turn the equation round, we can see that the product of power dissipation (or input, or generated power) and the thermal resistance is the temperature rise. So the larger the thermal resistance, the greater will be the difference of temperature. If we consider the thermal resistance between the junction and the environment for a typical semiconductor device, increasing the thermal resistance for a given power input or power dissipation is going to increase the temperature difference, and thus the temperature at the junction. So what we are generally trying to do is to reduce the thermal resistance between the source of the heat and the external environment, where the heat generated will end up.</p>		
<div style="text-align: center;">  <p><b>The concept of thermal resistance</b></p> </div> <ul style="list-style-type: none"> <li>▪ The thermal resistance of a heat path is the temperature difference that will cause 1W of energy to flow along it</li> <li>▪ The symbol commonly used for thermal resistance is <math>R_{\theta}</math> (R-sub-theta), or <math>R_{th}</math></li> <li>▪ The unit of thermal resistance is K/W (or °C per watt)</li> </ul> <p style="text-align: right; font-size: small;">Electronics KTN – Knowledge For Growth</p>	<p>In summary, we can say that the thermal resistance of a heat path is the temperature difference that will cause 1W of energy to flow along it, which is the analogue for one form of Ohm's Law <math>R = V/I</math>. The symbol commonly used for thermal resistance is <math>R_{\theta}</math> (R-sub-theta), or <math>R_{th}</math> and the unit of thermal resistance is Kelvin per watt (or °C per watt).</p>		
<div style="text-align: center;">  <p><b>The concept of thermal resistance</b></p> </div> <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top;"> <p style="text-align: center; font-size: small;">Electrical parameters</p>  <p style="text-align: center; font-size: small;"><math>\Delta V = I \times R</math></p> <p style="font-size: x-small;">R = electrical resistance (<math>\Omega</math>)  <math>\Delta V</math> = potential difference (V)            I = current (A)</p> </td> <td style="width: 50%; vertical-align: top;"> <p style="text-align: center; font-size: small;">The thermal resistance analogy</p>  <p style="text-align: center; font-size: small;"><math>\Delta T = P_D \times R_{\theta}</math></p> <p style="font-size: x-small;"><math>R_{\theta}</math> = thermal resistance (<math>^{\circ}\text{C}/\text{W}</math>)  <math>\Delta T</math> = temperature difference (<math>^{\circ}\text{C}</math>)  <math>P_D</math> = power dissipated (W)</p> </td> </tr> </table> <p style="text-align: right; font-size: small;">Electronics KTN – Knowledge For Growth</p>	<p style="text-align: center; font-size: small;">Electrical parameters</p>  <p style="text-align: center; font-size: small;"><math>\Delta V = I \times R</math></p> <p style="font-size: x-small;">R = electrical resistance (<math>\Omega</math>)  <math>\Delta V</math> = potential difference (V)            I = current (A)</p>	<p style="text-align: center; font-size: small;">The thermal resistance analogy</p>  <p style="text-align: center; font-size: small;"><math>\Delta T = P_D \times R_{\theta}</math></p> <p style="font-size: x-small;"><math>R_{\theta}</math> = thermal resistance (<math>^{\circ}\text{C}/\text{W}</math>)  <math>\Delta T</math> = temperature difference (<math>^{\circ}\text{C}</math>)  <math>P_D</math> = power dissipated (W)</p>	<p>This slide summarises the Ohm's Law expression in its electrical form, and the thermal resistance analogy. As we've said, this is a useful concept, rather than one that should constrain our thinking. It's particularly important, as we will see in a couple of slides time, to keep in mind that the flow of heat takes many different paths, in contrast to the electrical circuit, where unintended conduction paths are rare.</p>
<p style="text-align: center; font-size: small;">Electrical parameters</p>  <p style="text-align: center; font-size: small;"><math>\Delta V = I \times R</math></p> <p style="font-size: x-small;">R = electrical resistance (<math>\Omega</math>)  <math>\Delta V</math> = potential difference (V)            I = current (A)</p>	<p style="text-align: center; font-size: small;">The thermal resistance analogy</p>  <p style="text-align: center; font-size: small;"><math>\Delta T = P_D \times R_{\theta}</math></p> <p style="font-size: x-small;"><math>R_{\theta}</math> = thermal resistance (<math>^{\circ}\text{C}/\text{W}</math>)  <math>\Delta T</math> = temperature difference (<math>^{\circ}\text{C}</math>)  <math>P_D</math> = power dissipated (W)</p>		

## Introductory concepts

<div style="border-bottom: 2px solid yellow; padding-bottom: 5px;">  <h3 style="margin: 0;">Making use of the idea</h3> <ul style="list-style-type: none"> <li>▪ Typically there will be a number of complex heat paths between an element generating heat and its surroundings</li> <li>▪ We can model the segments of these heat paths as interconnected thermal resistances               <ul style="list-style-type: none"> <li>▪ where these are in <i>series</i>, we can add thermal resistances in the same way as with electrical resistances</li> <li>▪ similarly, where these are in <i>parallel</i>, we can add thermal conductances</li> </ul> </li> </ul> <p style="text-align: right; font-size: small; margin-top: 20px;">Electronics KTN – Knowledge For Growth</p> </div>	<p>Electrical resistances don't occur in isolation. Nor do thermal resistances, and particularly with thermal situations there will typically be a number of complex heat paths between the elements that generate the heat and their surroundings. But we can use the concept of thermal resistance to model the segments of these heat paths as interconnected thermal resistances. Where they are in series we can add thermal resistances in the same way as we would with resistors. Similarly, where the thermal resistance elements are in parallel, we can add thermal conductances.</p>										
<div style="border-bottom: 2px solid yellow; padding-bottom: 5px;">  <h3 style="margin: 0;">Making use of the idea</h3> <ul style="list-style-type: none"> <li>▪ Typically there will be a number of complex heat paths between an element generating heat and its surroundings</li> <li>▪ We can model the segments of these heat paths as interconnected thermal resistances</li> <li>▪ We can use an equivalent to Kirchhoff's Current Law (total heat flux towards/away from a point will be zero)</li> <li>▪ Elements of the heat path are also associated with thermal mass – they can store heat in the same way as a capacitor stores charge</li> </ul> <p style="text-align: right; font-size: small; margin-top: 20px;">Electronics KTN – Knowledge For Growth</p> </div>	<p>We can also create a thermal equivalent of Kirchhoff's Current Law, as the total of the heat flux flowing towards and away from any point will be zero. Of course, if we are looking at a thermal path that has significant heat capacity, that statement will only be true in steady state – where the heat flux is varying, the sum may be non-zero, and the path element will heat or cool accordingly.</p>										
<div style="border-bottom: 2px solid yellow; padding-bottom: 5px;">  <h3 style="margin: 0;">Extending the idea to thermal capacitance</h3> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left; width: 50%; font-size: small;">Electrical parameters</th> <th style="text-align: left; width: 50%; font-size: small;">The thermal capacitance analogy</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">  </td> <td style="text-align: center;">  </td> </tr> <tr> <td style="text-align: center;"> <math display="block">C = \frac{Q}{V} = \frac{It}{V}</math> </td> <td style="text-align: center;"> <math display="block">C_{\theta} = \frac{E}{\Delta T} = \frac{P_D t}{V}</math> </td> </tr> <tr> <td style="text-align: center;"> <math display="block">i(t) = C \frac{dV}{dt}</math> </td> <td style="text-align: center;"> <math display="block">P_D(t) = C_{\theta} \frac{dT}{dt}</math> </td> </tr> <tr> <td style="font-size: x-small;">           C = capacitance units F = A.sec/V         </td> <td style="font-size: x-small;">           C<sub>θ</sub> = thermal capacitance units Joules/K = W.s/K         </td> </tr> </tbody> </table> <p style="text-align: right; font-size: small; margin-top: 10px;">Electronics KTN – Knowledge For Growth</p> </div>	Electrical parameters	The thermal capacitance analogy			$C = \frac{Q}{V} = \frac{It}{V}$	$C_{\theta} = \frac{E}{\Delta T} = \frac{P_D t}{V}$	$i(t) = C \frac{dV}{dt}$	$P_D(t) = C_{\theta} \frac{dT}{dt}$	C = capacitance units F = A.sec/V	C <sub>θ</sub> = thermal capacitance units Joules/K = W.s/K	<p>So there is a further electrical analogy, between thermal mass and capacitance, the thermal mass storing heat in the same way as a capacitor stores charge, and this is shown diagrammatically here. The voltage depends on the charge, and the current into the capacitor depends on the rate of change of voltage. In the same way, with the thermal capacitance analogy, the temperature difference depends on the overall energy input to the system.</p>
Electrical parameters	The thermal capacitance analogy										
											
$C = \frac{Q}{V} = \frac{It}{V}$	$C_{\theta} = \frac{E}{\Delta T} = \frac{P_D t}{V}$										
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C = capacitance units F = A.sec/V	C <sub>θ</sub> = thermal capacitance units Joules/K = W.s/K										
<div style="border-bottom: 2px solid yellow; padding-bottom: 5px;">  <h3 style="margin: 0;">Don't press the analogy too far!</h3> <ul style="list-style-type: none"> <li>▪ Clemens Lasance "Thermal resistance: an oxymoron"</li> <li>▪ Different ratios of insulator : conductor resistance               <ul style="list-style-type: none"> <li>▪ electrical conduction &gt;10<sup>12</sup>: 1</li> <li>▪ thermal conduction 10<sup>3</sup>: 1</li> </ul> </li> </ul> <p style="text-align: right; font-size: small; margin-top: 20px;">Electronics KTN – Knowledge For Growth</p> <p style="font-size: x-small; margin-top: 5px;"> <a href="http://electronics-coding.com/articles/1997/may/brick2.php">http://electronics-coding.com/articles/1997/may/brick2.php</a> </p> </div>	<p>Thermal resistance is a useful analogy, but Clemens Lasance warns in his paper "Thermal resistance is an oxymoron" that we shouldn't press the analogy too far. The root cause is that electrical conductors and insulators have vastly different characteristics – conductors have resistance in milliohms, whereas an insulator may be thousands of megohms, with the result that almost all the current flows through the intended conductor paths. By contrast, however, even the best thermal conductors are not very conductive, and conversely thermal insulation still conducts a considerable amount of heat. In consequence, heat tends to flow through paths other than those of least resistance.</p>										

## Introductory concepts

 <h3>Don't press the analogy too far!</h3> <ul style="list-style-type: none"><li>▪ Clemens Lasance "Thermal resistance: an oxymoron"</li><li>▪ Different ratios of insulator : conductor resistance<ul style="list-style-type: none"><li>▪ electrical conduction <math>&gt;10^{12}:1</math></li><li>▪ thermal conduction <math>10^3:1</math></li></ul></li><li>▪ Cannot treat thermal conduction<ul style="list-style-type: none"><li>▪ in isolation from its surroundings</li><li>▪ in just two dimensions</li></ul></li></ul> <p><small>http://electronics-coding.com/articles/1997/may/article2.php</small></p> <p><small>Electronics KTN – Knowledge For Growth</small></p>	<p>So we can't treat thermal conduction in a material in isolation from its surroundings – heat will flow everywhere, and not just along preferred paths. Similarly, we need to consider three dimensions, and all round heat source in those dimensions, rather than simplify conduction to just two dimensions.</p>
 <h3>Dealing with the convection element</h3> <ul style="list-style-type: none"><li>▪ So far the analogy has been applied implicitly just to heat transfer by conduction</li><li>▪ However, from Newton's Law of Cooling<math display="block">q = hA(T_s - T_f) = hA\Delta T</math>we can derive a thermal resistance due to convection as<math display="block">R_{\theta} = \frac{\Delta T}{Q} = \frac{1}{hA}</math></li><li>▪ The challenge is to choose a realistic estimate for <math>h</math></li></ul> <p><small>Electronics KTN – Knowledge For Growth</small></p>	<p>So far we have only applied the analogy to heat transfer by conduction. However, we know from Newton's Law of Cooling that the rate of heat transfer depends on area, temperature difference, and the convection coefficient <math>h</math>. From this we can derive a thermal resistance due to convection, which will allow us to model heat flow due to convection from the surface. The challenge is to choose a realistic estimate for <math>h</math>! The heat transfer coefficient may be expected to vary considerably, depending on the local airflow conditions, but a value of 10 has often been cited as appropriate for many natural convection conditions.</p>
 <h3>Where the concepts are used</h3> <ul style="list-style-type: none"><li>▪ For analysing heat-generating elements and heat paths</li><li>▪ As a basis for analytical methods of estimating temperature distribution in a structure</li></ul> <p><small>Electronics KTN – Knowledge For Growth</small></p>	<p>The thermal resistance concept is used for analysing heat generating elements and heat paths, and also as the basis for analytical methods of estimating temperature distribution in a structure. As we can see in the section on "Turning the models into useful form", useful work can be done with something as simple as a spreadsheet, building a model using the ideas of thermal resistance.</p>
 <h3>Where the concepts are used</h3> <ul style="list-style-type: none"><li>▪ For analysing heat-generating elements and heat paths</li><li>▪ As a basis for analytical methods of estimating temperature distribution in a structure</li><li>▪ For creating equivalents of real components that can be used to:<ul style="list-style-type: none"><li>▪ simplify simulations (speeding them up)</li><li>▪ allow manufacturers to supply users with validated thermal information about their products<ul style="list-style-type: none"><li>▪ avoiding the need to give detailed information about the structure and materials of the product</li></ul></li></ul></li></ul> <p><small>Electronics KTN – Knowledge For Growth</small></p>	<p>At a more sophisticated level, the thermal resistance concept is used for creating equivalents of real components that can be used to simplify and speed up simulations of complex systems. Thermal resistance is also the basis of the modelling that allows manufacturers to supply users with validated thermal information about their products, which properly reflects the structure and materials of the product without needing to publish detailed or confidential information about these aspects of the design.</p>