DELPHI COMPACT THERMAL MODEL GUIDELINE

(From JEDEC Board Ballot JC-15-04-288A, formulated under the cognizance of the JC-15.1 Committee on Thermal Characterization.)

Contents

1 Scope

This guideline specifies the definition and lists acceptable approaches for constructing a compact thermal model (CTM) based on the DELPHI methodology.

The purpose of this document is twofold. First, it aims to provide clear guidance to those seeking to create DELPHI compact models of packages. Second, it aims to provide users with an understanding of the methodology by which they are created and validated, and the issues associated with their use.

The scope of this document is limited to single-die packages that can be effectively represented by a single junction temperature.

The scope of the current document is also limited to steady state compact models. Dynamic compact models (which are necessary for simulating time-dependent behavior) are not covered.

Boundary condition independence is a measure of the predictive capabilities of the model in application-specific environments.

2 Normative references

The following normative documents contain provisions that, through reference in this text, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

1. JESD51, *Methodology for the Thermal Measurement of Component Packages (Single Semiconductor Device)*, Dec. 1995.
2. JESD51-2, *Integrated Circuits Thermal Test Method Environmental Conditions – Natural Convection (Still Air)*, Dec. 1995.
3. JESD51-3, *Low Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages,* Aug. 1996.
4. JESD51-5, *Extension of Thermal Test Board Standards For Packages With Direct Thermal Attachment Mechanisms,* Feb. 1996.
5. JESD51-6, *Integrated Circuit Thermal Test Method Environmental Conditions - Forced Convection (Moving Air)*, March 1999.
6. JESD51-7, *High Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages*, Feb. 1999.
7. JESD51-8, *Integrated Circuit Thermal Test Method Environmental Conditions – Junction-to-Board*, Oct. 1999.
8. JESD51-9, *Test Boards for Area Array Surface Mount Package Thermal Measurements,* July 2000.

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11. JESD15, *Thermal Modeling Overview* [1)].
12. JESD15-1, *Compact Thermal Modeling Overview* [1)].
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3 Definition of the DELPHI compact model

3.1 Overview

The DELPHI methodology was developed by the DELPHI Research Consortium, which completed a 3-year research project from 1993 to 1996. The project was partially funded by the European Community under ESPRIT III Contract # 9197. The results of the Consortium's investigation into compact package models is non-proprietary and in the public domain. The consortium proposed a methodology for the generation of compact models with a high degree of boundary condition independence. This methodology is documented in a comprehensive report published by the consortium as well as a number of technical journals and conference proceedings that are available in the literature (see Bibliography).

The fundamental vision that underlies compact thermal models is the principle of division of responsibility. It is the responsibility of the CTM supplier to characterize the part, whereas the end-user must specify the environment that defines the application. Thus the CTM supplier then becomes responsible for supplying a properly characterized model of the component.

The concept of "a properly characterized model" is tied to a metric of boundary condition independence (BCI). This metric is defined as the BCI Index. A discussion of the BCI concept is available. An additional metric is also defined for the accuracy of a CTM over sub-ranges of boundary conditions relevant to specific application environments. This metric is known as the boundary condition subset (BCS) Index.

3.2 General criteria for compact thermal models

A compact thermal model should fulfill the following criteria.

- It should be of limited complexity. In today's technology, this equates to tens of nodes. It is conceivable that this number could increase over time with improvements in computer calculating power and the sophistication of CTM techniques.
- It should satisfy appropriate levels of boundary condition independence (BCI). BCI is a property of a CTM whereby it accurately calculates a chip temperature in a variety of application environments, which, in essence, impose different boundary conditions on the component. It is a goal of the CTM standardization effort that CTMs should demonstrate a high level of BCI.

[1)] To be published.

- It should be vendor and software neutral.
- A CTM generation technique should be adaptable to standard conduction codes for performing a package-level thermal analysis.
- The CTM should be capable of insertion into standard numerical codes for system-level analysis.
- It should be fully documented and non-proprietary.

3.3 The DELPHI methodology

The following are the key features of the DELPHI methodology.

- The compact model is generated from analysis, and not testing. Experiments are relevant for validation purposes only.
- The starting point for the process is the availability of an experimentally validated detailed thermal model (see 4.2).
- The analytical procedure used to derive the compact model involves a statistical process of optimization.
- The model does not contain any artifacts from the environment.
- Error estimate is an intrinsic part of the model generation process.
- Like the other compact model approaches, the DELPHI approach masks data about the package that the CTM supplier may regard as proprietary.

3.4 The DELPHI compact model

A DELPHI compact model is a thermal resistance network.

The DELPHI thermal resistance network is comprised of a limited number of nodes connected to each other by thermal resistor[2)] links (see Figure 1). In effect, the complex 3D heat flow within a real package is represented by a series of links.

Network nodes are, by definition, each associated with a single temperature only. The nodes can be either surface or internal. Surface nodes are associated with a physical region of the package surface defining the area of the node. In such a case, the nodal temperature represents the average temperature of the area allocated to the node in the actual package. Also, surface nodes must always have a direct one-to-one association with the corresponding physical areas on the actual package. Therefore, it is critical that they communicate with the environment in the same manner as the package.

Internal nodes lie within the package body and may or may not correspond to a physical region within the package. The predicted node temperature has no physical meaning for those internal nodes that do not correspond to actual regions within a package.

[2)] The thermal resistors in a DELPHI model are mathematical constructs. They have the units of ºC/W, but the presence of a thermal resistance between any two surface nodes in the thermal network does not necessarily imply that this corresponds to the actual physical resistance between those two points in the package.

Surface nodes communicate with internal nodes as well as the surrounding environment. Internal nodes do not communicate with the environment directly; however they may have a heat source associated with them.

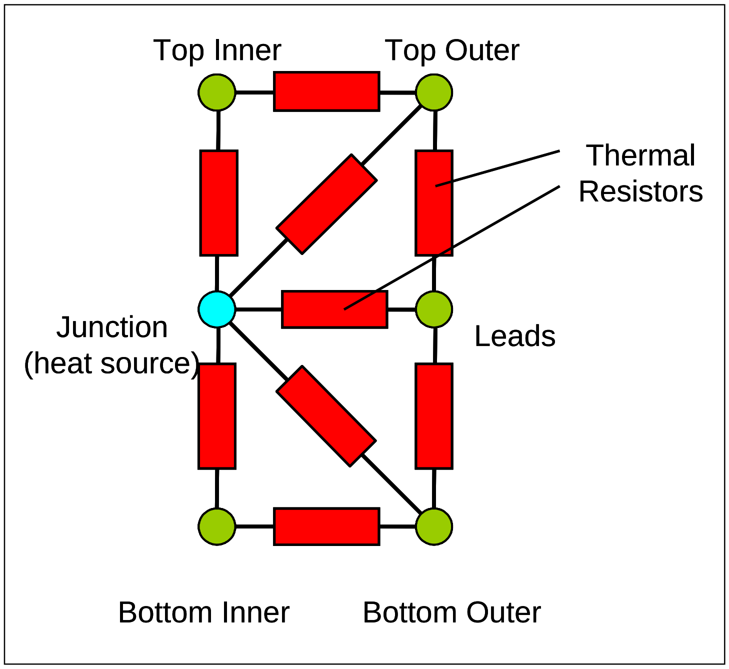

Figure 1 — Network Compact Model

4 Generating a DELPHI compact model

4.1 Summary of salient steps in the model generation process

The various steps that comprise the DELPHI compact model generation methodology are outlined in more detail below, and in Figure 2.

Step 1: Ensure that a validated detailed model is available.

Step 2: Define the objective function that is to be minimized during the optimization.

Step 3: Define training and test boundary conditions sets in terms of heat transfer coefficient values.

Step 4: Define number and locations of surface and internal nodes.

Step 5: Simulate detailed model under training and test boundary conditions to generate heat flux and temperature data.

Step 6: Choose appropriate statistical optimization technique.

Step 7: Execute optimization using training boundary condition set.

Step 8: Define error estimation method.

Step 9: Generate error estimate (backfit) using test boundary condition set.

Step 10: Make compact model available for dissemination in neutral file format.

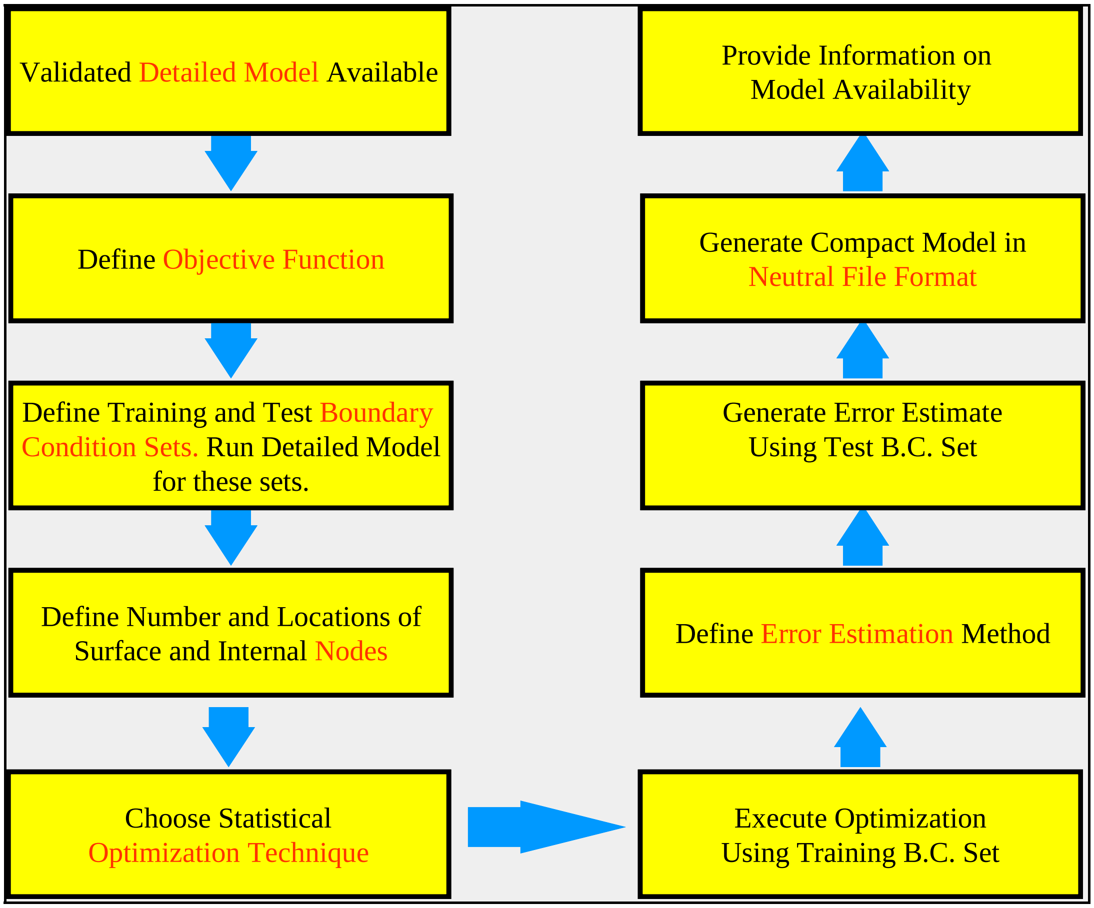

Figure 2 — The DELPHI Methodology

4.2 Validated detailed model

A detailed thermal model or detailed model of a package is a numerical model that attempts to reproduce the physical geometry and material properties of the package in as exact a manner as necessary in order to predict temperatures and fluxes to a sufficient degree of accuracy at any point within the package.

The methodology for the generation of a detailed model is outside the scope of this document. The generation of such models is partially dependent on the capabilities of the software environment available to the user and user preferences in modeling methodologies.

The DELPHI methodology assumes that a validated detailed model of the package is available, and has been validated under well-defined or “hard” boundary conditions, or otherwise, in a manner acceptable to the CTM supplier.

4.3 Defining the objective function

The objective function in this methodology is defined as the discrepancy between the detailed model and prediction from the compact model summed over both the training boundary condition set (see below) and a finite number of points of interest within the package. In effect, the objective function is the measure of the deviation of the compact model results from the detailed model results. Minimizing the objective function should result in a compact model with a low error.

An acceptable objective function can be constructed in several ways. However, it is strongly recommended that it include terms related to the heat flux from all the surface nodes and the rise in junction temperature. Although predicting the junction temperature is important to determine whether the package will meet performance criteria, the heat flux is also important as it influences the board temperature and the temperatures in neighbouring components. Thus an objective function that reflects the contribution of both will yield improved compact models.

It is recommended that the following formulation of the objective function be used:

$$F = \sum_{1}^{M}\left(W\left(\frac{T_{J,C} - T_{J,D}}{T_{J,D} - T_{Amb}}\right)^2 + \left(\frac{1-W}{N}\right)\sum_{i=1}^{i=N}\left(\frac{q_{i,C} - q_{i,D}}{Q}\right)^2 \right)$$

where:

F is the objective function,

M is the number of boundary condition sets,

W is the weight factor (varying between 0 and 1)[3],

N is the number of external nodes (inner and outer nodes treated separately),

$T_{J,C}$ is the junction temperature of the compact model,

$T_{J,D}$ is the junction temperature of the detailed model,

T_{Amb} is the ambient temperature,

$q_{i,C}$ is the flux leaving the i^{th} node in the compact model,

$q_{i,D}$ is the flux leaving the i^{th} node in the detailed model,

Q is the total power applied to the junction.

The CTM supplier must report the objective function used if it deviates from the formulation stated above.

4.4 Defining training boundary condition set

A DELPHI compact model must be derived using an optimization process over a “universal” boundary condition set, defined as the training set. Such a set should reflect the full spectrum of environmental conditions encountered by the package in typical electronics applications.

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3) The weight factor W represents the relative weighting given to the junction temperature term as compared to the flux term in the objective function. Thus assigning a value of 1 to W means that only the junction temperature discrepancies are minimized in the objective function, while a value of 0 implies that only the flux terms are taken into account. An intermediate value would indicate the extent to which each of the terms is weighted. A commonly used value is 0.5, which tends to balance the flux and temperature terms. The dependence of the model quality on W can be examined by plotting the error in junction temperatures and fluxes against W.

The DELPHI consortium proposed a set of 38 such boundary conditions, known as the *38 set*. Since then other sets have been proposed in the literature[18].

These sets are typically presented as a matrix containing heat transfer coefficients (h.t.c.'s). Each row corresponds to one boundary condition set, which represents a single simulation. The rows are typically grouped into environment categories which represent typical operating environments – for example, forced convection, natural convection, attached heat sink, etc.

Each column represents a particular class of boundary conditions, which in turn represents specific areas on the package surface on which the heat transfer coefficients are applied. Thus the column labelled "Top" is a set of h.t.c.'s that represent conditions typically encountered at the top surface of a package. A similar concept applies to the other classes.

The 38 set proposed by the original DELPHI consortium is shown in Figure 3, and also tabulated in the Annex A.

Boundary Condition Class

Environment Category

Heat Transfer Coefficient

B.C. #	Top	Bottom	Leads	Sides	Environment Type
1	100	100	1000	100	
2	100	1	1000	100	
3	1	100	1000	100	
4	200	200	1000	200	
5	50	50	1000	50	
6	200	200	10000	200	
7	100	100	10000	100	
8	50	50	10000	50	***Forced Convection***
9	10	100	1000	10	
10	100	10	1000	10	
11	10	100	100	10	
12	100	10	100	10	
13	50	50	50	50	
14	100	100	100	100	
15	100	100	500	100	
16	10	10	10	10	
17	10	10	1000	10	
18	10	10	100	10	***Free Convection***
19	10	10	10000	10	
20	30	30	30	30	
21	500	10	1000	10	
22	1000	10	1000	10	
23	10	500	1000	10	
24	10	1000	1000	10	
25	500	10	100	10	***Heat Sink***
26	1000	10	100	10	
27	10	500	100	10	
28	10	1000	100	10	
29	10000	10	100	10	
30	10	10000	100	10	
31	10000	10	1000	10	
32	10	10000	1000	10	***Cold Plate***
33	1	10000	10000	1	
34	10000	1	10000	1	
35	1.00E+09	1.00E+09	1.00E+09	1.00E+09	
36	10000	10000	10000	10000	
37	1000	1000	1000	1000	***Fluid Bath***
38	500	500	500	500	

All Heat transfer coefficients have units of W/m^2K

Figure 3 — The 38 boundary condition set for a leaded package, as proposed by the original DELPHI consortium.

The manner of applying a training boundary condition set is a function of the package style in question. Two fundamental categories of packages can be distinguished - area array and leaded packages. Area array packages allow for two principal directions of heat transfer (top and bottom) whereas three principal directions need to be analyzed for leaded packages (top, bottom, and leads). This affects the manner of mapping the columns in the boundary condition set.

This guideline does not endorse any particular training boundary condition set over others, and leaves the choice to the user. However, the accuracy of the resultant compact model obtained from different training sets can be compared by exercising it against the standard test set (see 4.7).

4.5 Defining surface and internal nodes

The definition of nodes is a critical part of the DELPHI methodology. This is because it is important for the compact model (with its associated surface areas) to interact with its environment as identically as possible to the detailed model. Figure 4 demonstrates an example of a possible node definition for a plastic quad flat pack (PQFP) package.

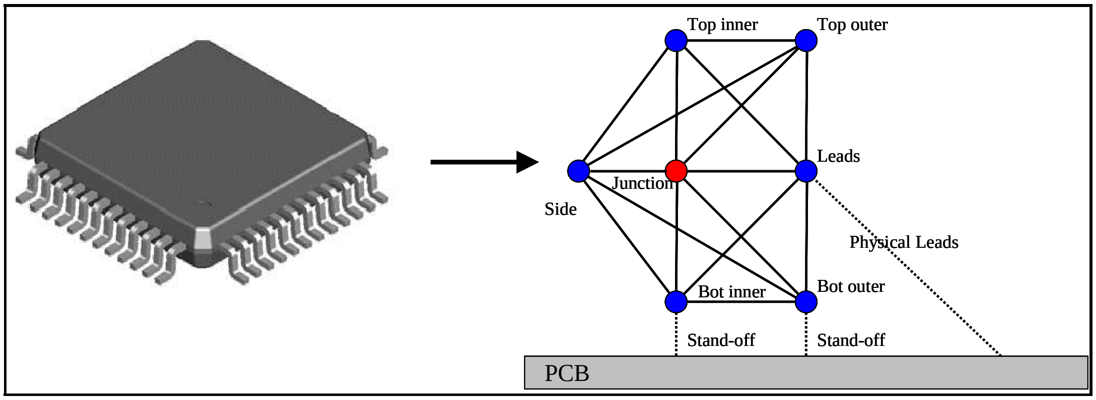

Figure 4 — Possible node topology for a PQFP package

This implies that the compact model nodes representing surface areas have a one-to-one correspondence with their corresponding areas in the detailed model. In other words, temperatures over discrete areas on the package (detailed model) surface are each represented by a single averaged nodal value in the compact model.

Because the package surface is usually significantly non-isothermal, it is important to sub-divide the package surface into several surface nodes. This is especially important when temperature gradients on a surface are particularly steep, as (for example) in the case of overmolded plastic packages.

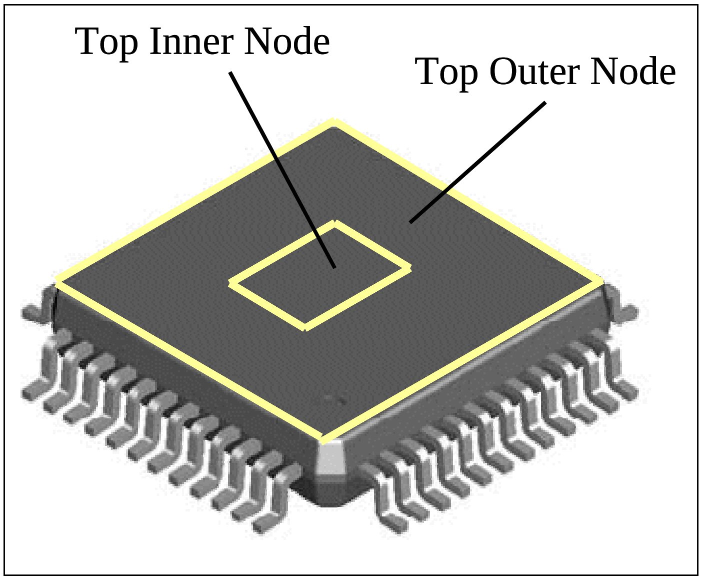

Figure 5 — Partitioning the top surface of a QFP into two surface nodes

In a large majority of cases, two surface nodes each on the top and bottom surfaces of the package provide sufficient granularity to resolve the temperature gradients. Figures 5 and 6 illustrate the partitioning of the top surface of a QFP and BGA package respectively into two top nodes: inner and outer. A similar approach can be adopted for the bottom surface.

It is important to note that the relative surface coverage of the inner and outer nodes can affect the quality of the model. CTM suppliers should determine the optimal area partitioning scheme which suits their needs best.

Nodes defined for the sides of the package can improve the model accuracy in some cases. In leaded packages, one or more lead nodes are necessary that represent the leads. For area array packages, the bottom surface is coincident with the lead surface, and additional lead nodes may or may not be needed. Some approaches for such packages remove the solder balls from the resistor extraction process and then reattach them as additional external resistors to the derived CTM. Other approaches include the solder balls in the CTM derivation step.

One issue of concern is the effect of asymmetric boundary conditions on the compact model accuracy. Application-specific boundary conditions are often asymmetric. If this asymmetry is severe, the assumption of isothermal leads (for example) can break down, as leads on different sides of the package are likely to have significantly different average surface temperatures.

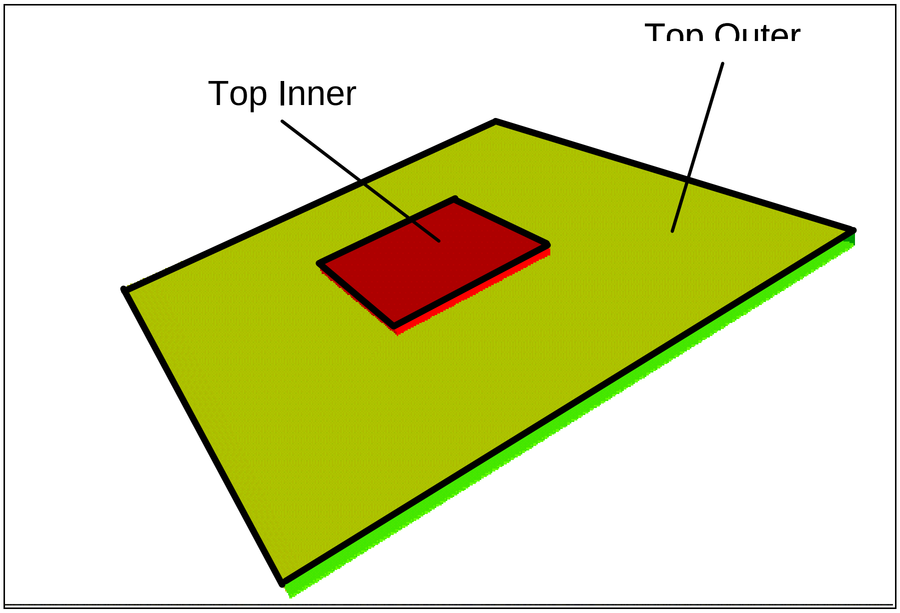

Figure 6 — Possible node partitioning of the top surface of a flip-chip BGA package (only substrate and die shown).

The recommended solution to this is to increase the number of surface nodes. In the case of the PQFP package example, four leads nodes could be defined – each corresponding to a particular side. Thus different temperatures are then allowed for leads on different sides of the package, and any boundary condition asymmetry is accounted for. Similarly, four side nodes can also be defined.

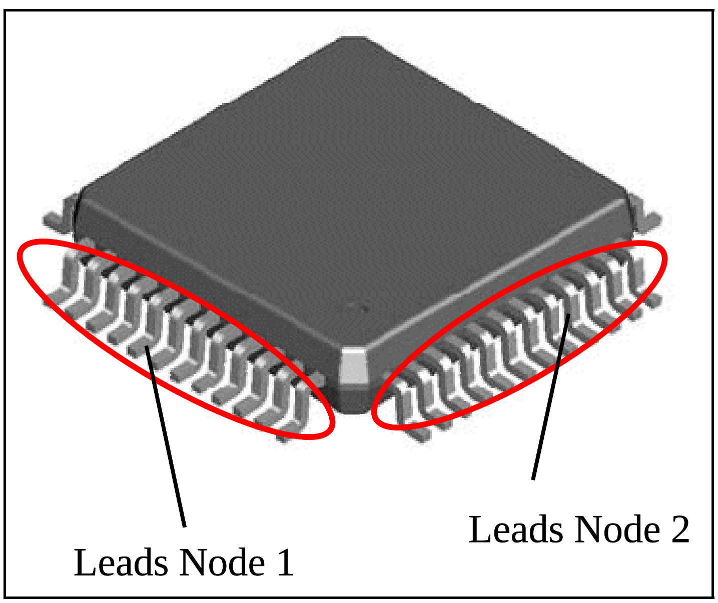

Figure 7 — Subdividing the leads node to handle asymmetric application environments.

Once the surface nodes are defined, then the topology can, in principle, allow for as many internal nodes as desired. Of course, there must be at least one internal node corresponding to the junction[4)]. Additional internal nodes can also be included in the nodal scheme. This allows additional degrees of freedom in the network, which can result in a higher quality compact model.

4.6 Choice of optimization technique

Once the objective function and training boundary condition set are defined and the node scheme decided upon, the next step is to choose a suitable optimization scheme. The fundamental requirement is that the objective function be minimized. Since there are a large number of optimization schemes to choose from – ranging from the simpler least-squares type approaches to more complex non-linear techniques – the precise choice of the scheme is left to the user. However, it should be noted that some optimization techniques will yield more accurate models than others.

The generalized least-squares method in N_d dimensions is similar to the classical least-squares regression technique in two variables. The idea is to derive a resistor network that minimizes the sum of the "shortest distances" (in the Euclidean sense) between the predicted trendline and the detailed model data points. This implies that the first derivative of the objective function with respect to each of the coefficients of the "trendline" (i.e., each resistor value) be zero, which would indicate a minimum. By applying this constraint for each resistor in the network, we obtain a set of linear equations which can be solved by standard matrix inversion techniques.

4.7 Error estimate

An important component of the DELPHI methodology is its inherent ability to generate a measure of the quality of the compact model. This measure of quality is central to the advantages afforded by the DELPHI approach.

The error estimate is obtained by exercising the compact network against the test boundary condition set. The predicted results for the fluxes and/or junction temperatures for the compact model can then be compared against the detailed model data for each of these test boundary conditions, and the error reported.

A standardized test set that can be used for estimating the error, and therefore the boundary condition independence, of the model is available in a separate guideline. This guideline also defines the boundary condition independence (BCI) index. The BCI index is a measure of the boundary condition independence of the compact thermal model. An equivalent measure is also defined for specific sub-classes of boundary conditions corresponding to particular environments, and is known as the boundary condition bubset (BCS) index.

Once the network compact model is generated and the error reported, the network must be made available in a vendor-neutral file format. This marks the formal completion of the DELPHI process.

[4)] The scope of this document is limited to packages that effectively have a single junction temperature of interest. Multiple-die packages (or single-die packages with more than a single major hot-spot) would necessitate a separate junction node corresponding to each temperature of interest.

However, the network must then be implemented in the user-specific software environment. This is where application issues must be considered, and forms the focus of the next section of this document.

5 Application considerations

5.1 Overview

The DELPHI compact model can be used in simulation tools that either directly support such a model, or provide building blocks from which the model can be built. The simulation tool could be in either of the following classes:

- thermal network calculator, or
- three-dimensional simulation tool.

This document will concentrate on the application of the DELPHI compact model in a three-dimensional simulation tool.

For a network calculator, the network links (resistors) are introduced as a part of the overall system network. The surface nodes are linked to appropriate nodes in the environment. A more detailed description of applying a compact model network within a network calculator tool can be found in JEDEC Standard JESD15-3 (Two-Resistor Compact Thermal Model Guideline).

It is important to keep in mind that the availability of the DELPHI compact model does not eliminate the need for understanding the application in which the package is to be used. In other words, it is the user's responsibility to take into account the environment surrounding the package. The environmental conditions for the relevant application must be applied at the surface nodes as boundary conditions.

5.2 Three-dimensional modeling and simulation tools

5.2.1 Overview

This class of software tools solves the constitutive equations governing heat transfer in a 3D domain using numerical discretization schemes. Thus, solving for the junction temperature does not involve the solution of a network-type equation for the environment, but rather a set of simultaneous differential equations.

In most practical applications, the numerical simulation also involves discretizing the solution domain, which is achieved by a process known as gridding (or meshing). The accuracy of the solution is affected by the grid density. The grid density is sufficiently high when any additional increase in grid has only a small effect on the results.

In addition to account for radiation heat transfer, in some tools, the surfaces that participate in radiation exchange to a significant degree need to be identified and appropriate emissivities assigned to all external surfaces. The emissivity of a surface is dependent on the material as well as the degree of smoothness or polish of a surface. The more polished a surface, the lower is the emissivity. Radiation view factors associated with the geometry of the problem are often calculated automatically by most tools.

A three-dimensional representation of the compact model is required. In using the model the impact of its representation on the thermal environment surrounding the package (which generally involves complex three dimensional heat transfer and/or fluid flow) must be taken into account. Thus the outer physical geometry of the package should be represented as accurately as feasible to calculate the correct interaction between the package and surrounding environment.

Broadly speaking, such tools fall into two categories:

- conduction modeling (non-CFD) simulation tools;
- computational fluid dynamics (CFD) simulation tools.

5.2.2 Conduction modeling tools

Conduction modeling tools solve the governing equations for conduction heat transfer (and often radiation) within the solid portions of the system. The effects of the airflow are not solved for directly, but are instead represented at the solid-air interface in the form of equivalent heat transfer coefficients. In the case of a DELPHI compact model, appropriate heat transfer coefficients need to be applied at top and side surfaces of the model. The heat transfer coefficients are attached to the compact model at those surface nodes exposed to the air only. The surfaces in contact with the PCB and/or heat sink are handled within the conduction heat transfer calculation.

5.2.3 Computational fluid dynamics (CFD) tools

CFD tools solve both the solid and air portions of the system directly. This is achieved by solving the Navier-Stokes equations, which govern fluid flow and heat transfer, on the air side. In the solid portions, equations governing conduction heat transfer are solved. Nearly all CFD tools available also solve for radiation heat transfer. Since CFD tools explicitly model the air flow (convection) in addition to doing so for conduction and radiation modes of heat transfer, it is not necessary for heat transfer coefficients to be applied to the model.

In a CFD tool, attention should be paid to the representation of the external physical geometry of the package to ensure the correct interaction between the package and surrounding air flow. In other words, the DELPHI compact model should produce the same effect on the outer flow as the actual package. This means that the compact model must ideally result in the same flow resistance (i.e., pressure drop) as the detailed model. It must also provide a similar thermal interaction with this environment. Thus, in plan view, the size of the model should match the outline of the package body. The height of the model should also match the overall height of the package when mounted.

Surface emissivity is applied to the exposed surfaces, usually as a surface attachment, in order to account for radiation heat transfer.

5.2.4 Representing a DELPHI compact model in 3D space

There are several viable approaches to representing the DELPHI compact model in 3D space, which is required for both conduction-modeling and CFD tools. Essentially the problem involves representing a thermal resistor network (similar to that shown in Figure 1) in three-dimensional space.

Some constraints are common to all representations, such as:

- The surface nodes of the DELPHI compact model are, by definition, associated with a single temperature.

- The surface nodes of the compact model should have a direct correspondence with the scheme of sub-dividing the areas (Figure 5) adopted during the compact model generation process.
- The DELPHI compact model must closely approximate the effect on the environment of the actual package.
- The surfaces of attachment of the model to the PCB and/or heat sink should be as identical as feasible to the actual package.
- As the internal nodes in the network do not interface directly with the environment, their representation is not restricted as long as it conforms to the overall constraints stated above.

The most viable approach to represent a DELPHI compact model in three-dimensional space utilizes what may be called a “network object” (see Figure 8) to represent the compact network. Such an object has a three-dimensional external shape in order to model the obstruction caused by the package to the outer flow and the heat transfer to the environment. A resistor network solver is directly linked to the inputs from the surface nodes of this blockage.

Figure 9 demonstrates a viable approach to representing the compact model for a leaded package. The example shows a quad flat pack (QFP). Its salient features are as follows.

- The shape and form factor of the compact model are very close to the actual package.
- The surface nodes are isothermal surfaces in direct contact with the external environment and.
- The actual network is effectively embedded “inside” the compact model geometry (Figure 8).

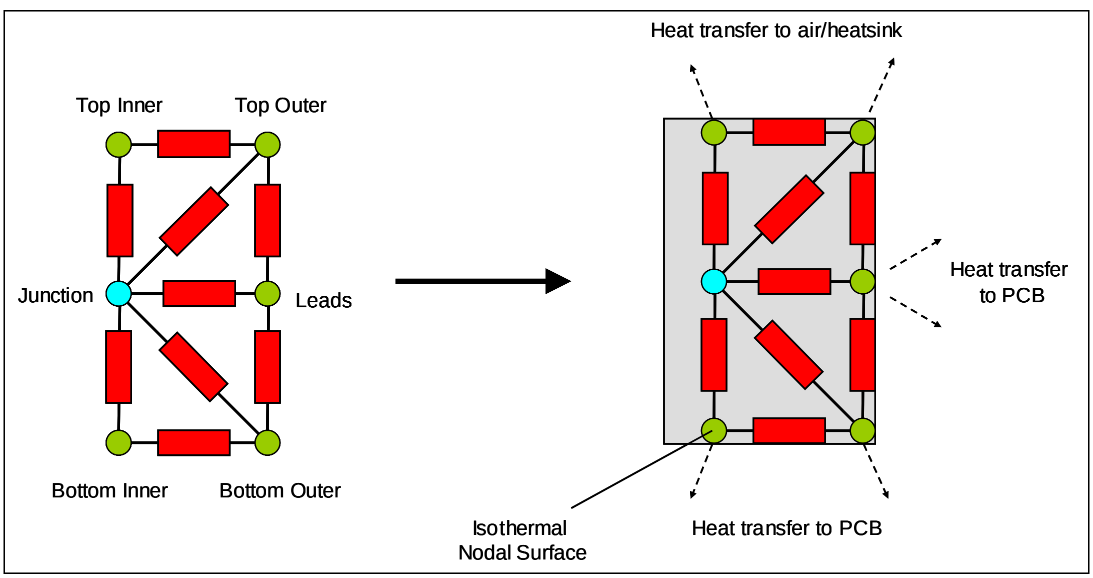

Figure 8 — Embedded DELPHI network

It is the responsibility of an end-user to apply the environmental conditions for the application environment at the surface nodes of the compact model. This can be done either by modelling the environment in detail or by prescribing effective boundary conditions (in terms of heat transfer coefficients). This will be constrained by the class of software tools available to the end-user. Some tools may allow a more precise description of the boundary conditions than others.

Real-life application environments are almost always asymmetric in nature. If the asymmetry is not severe, assumptions of symmetry in generating the model are often acceptable. However in some cases asymmetry must be taken into account while generating the model. When in doubt, it is safest to assume that asymmetry is relevant.

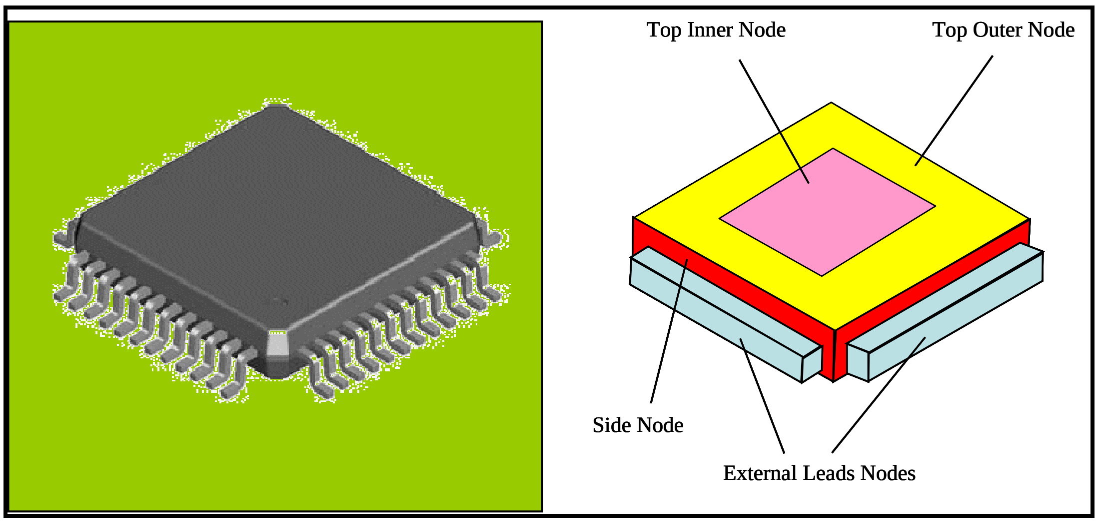

Figure 9 — Possible compact representation of a leaded package

6 Distribution and availability

The compact model should be made available in a vendor-neutral, standardized data format so that it is accessible by any design environment.

Annex A

The example 38 boundary condition set is presented in Table A.

Table 1 — 38 boundary condition set.

B.C. #	Top	Bottom	Leads	Sides	Environment Type
1	100	100	1000	100	
2	100	1	1000	100	
3	1	100	1000	100	
4	200	200	1000	200	
5	50	50	1000	50	
6	200	200	10000	200	
7	100	100	10000	100	
8	50	50	10000	50	***Forced Convection***
9	10	100	1000	10	
10	100	10	1000	10	
11	10	100	100	10	
12	100	10	100	10	
13	50	50	50	50	
14	100	100	100	100	
15	100	100	500	100	
16	10	10	10	10	
17	10	10	1000	10	
18	10	10	100	10	***Free Convection***
19	10	10	10000	10	
20	30	30	30	30	
21	500	10	1000	10	
22	1000	10	1000	10	
23	10	500	1000	10	
24	10	1000	1000	10	
25	500	10	100	10	***Heat Sink***
26	1000	10	100	10	
27	10	500	100	10	
28	10	1000	100	10	
29	10000	10	100	10	
30	10	10000	100	10	
31	10000	10	1000	10	
32	10	10000	1000	10	***Cold Plate***
33	1	10000	10000	1	
34	10000	1	10000	1	
35	1.00E+09	1.00E+09	1.00E+09	1.00E+09	
36	10000	10000	10000	10000	
37	1000	1000	1000	1000	***Fluid Bath***
38	500	500	500	500	
All Heat transfer coefficients have units of W/m^2 K					

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