INTEGRATED APPROACH TO TECHNOLOGY/PRODUCT DEVELOPMENT

- A Packaging Perspective -

Presented by
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Abstract - This presentation gives a systematic method to link technical power packaging issues to user requirements as the basis for developing a product or technology roadmap. The framework goes further to give individual designers a means to better understand, evaluate and communicate technical needs for integration of electro-physical power electronic circuits.

The framework uses a four-dimensional coordinate of User Requirements, Levels of Packaging, and Technical Issues, all cross-cut by Forms of Energy. Examples assist the reader in understanding the framework and appreciating the potential for application in future developments of power electronics packaging. – Dr. Doug Hopkins, Jan 2003

Quandary —

A high frequency magnetic core couples to a copper PWB conductor causing eddy current heating. This increases conductor resistance causing further heating. Mechanical stresses between the conductor and PWB lead to early failure.

Who should notice the problem first?

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Quandary — (con'd)

Who should notice the problem first?

- The electrical designer through circuit loss measurements,
- The thermal designer through a thermograph of that specific spot, or --
- The packaging engineer who first noticed conductors lifting off the board and assumes conductor adhesion from faulty chemistry?

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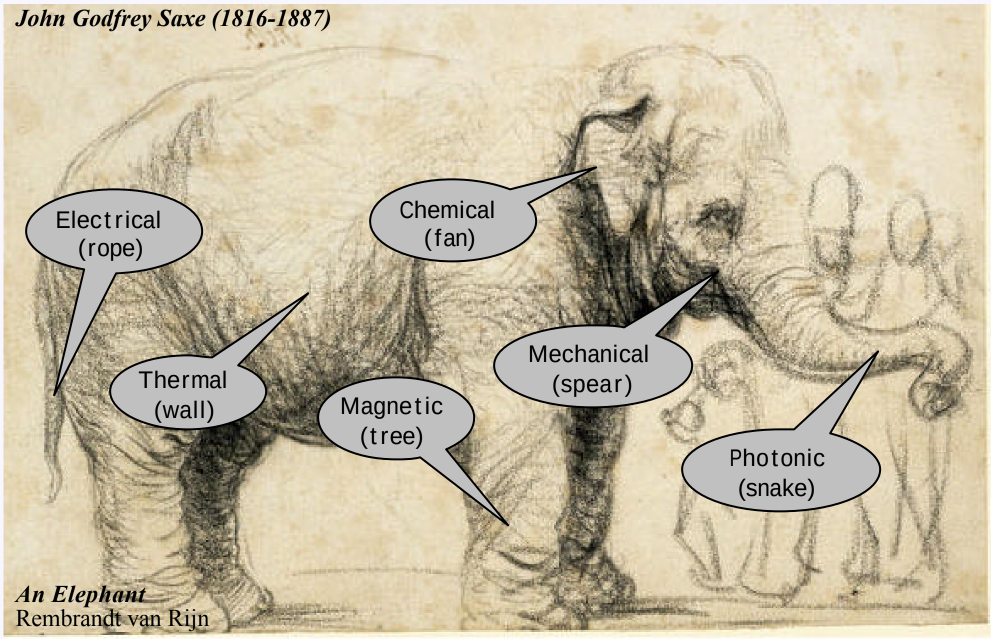
Packaging is Multidisciplinary



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A parable of the Six Blind Men & the Elephant by John Goeffery Saxe is appropriate for to show the difficulty of one engineer uncovering all the problems in electrophysical design. This seminar helps to identify the issues and provide a common understanding of what might be, but not what is.

Six Blind Men & the Elephant
from John Godfrey Saxe (1816-1887)
A Hindu Parable

It was six men of Indostan
To learning much inclined,
Who went to see the Elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind.

The First approached the Elephant,
And happening to fall
Against his broad and sturdy side,
At once began to bawl:
"God bless me! but the Elephant
Is very like a wall!"

The Second, feeling of the tusk
Cried, "Ho! what have we here,
So very round and smooth and sharp?
To me 'tis mighty clear
This wonder of an Elephant
Is very like a spear!"

The Third approached the animal,
And happening to take
The squirming trunk within his hands,
Thus boldly up he spake:
"I see," quoth he, "the Elephant
Is very like a snake!"

The Fourth reached out an eager hand,
And felt about the knee:
"What most this wondrous beast is like
Is mighty plain," quoth he;
"'Tis clear enough the Elephant
Is very like a tree!"

The Fifth, who chanced to touch the ear,
Said: "E'en the blindest man
Can tell what this resembles most;
Deny the fact who can,
This marvel of an Elephant
Is very like a fan!"

The Sixth no sooner had begun
About the beast to grope,
Than, seizing on the swinging tail
That fell within his scope.
"I see," quoth he, "the Elephant
Is very like a rope!"

And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
And all were in the wrong!

Moral:

So oft in theologic wars,
The disputants, I ween,
Rail on in utter ignorance
Of what each other mean,
And prate about an Elephant
Not one of them has seen.

What is Packaging?

- "Packaging is the arranging of components to provide a function or characteristic."
- "Packaging is a <u>design</u> function."
- "Manufacturing is the implementation of that design."

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The viewpoint in a power electronics design that 'if it is physical, it is packaging' lumps all non-electrical issues into one area and makes the understanding, evaluation and development of packaging designs difficult. The initial steps, then, must be to define packaging, delineate the areas of electro-physical design, and provide a set of common boundaries and terms for clear common understanding.

"*Packaging is the arranging of physical components to provide a function or characteristic that is compatible with external interfacing elements."*

This is the essence of *physical circuit* design. Manufacturing embodies the *processes* to fabricate that arrangement. Although packaging and manufacturing are strongly interrelated, they are not synonymous. (The IEEE Components, Packaging and Manufacturing Technology Society clearly delineates a difference just by its name.)

Objectives

- Provide a systematic method to link *technology development* with *user requirements*.
- Predict technology trends and provide a checklist of *technical issues*.
- Identify electro-physical design interrelationships for
  - forming interdisciplinary design teams
  - planning concurrent engineering.

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Corporate Deliverable

Electrical designers deliver schematics.

Companies deliver physical products.

- Systems integrators are typically electrical designers.
- Electrical designers directly or indirectly define the physical path.

Match the designer to the need.

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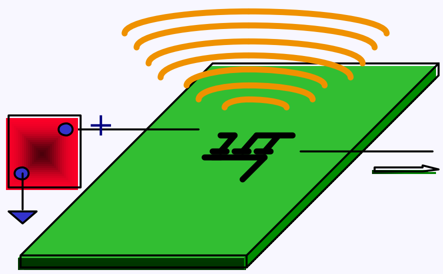
An example of a packaging problem relating the four energy forms of interest is: a high frequency magnetic core couples the radiated field into a copper conductor on a PCB. This causes eddy current heating and increasing the skin-effect resistance. Higher resistance loss further increases conductor heating which increases the mechanical stresses between the conductor and PCB leading to early failure.

Who would notice the problem first? The electrical designer through circuit loss measurements; The thermal designer through a thermograph of that specific spot, or the packaging engineer who first notices the conductors are lifting off the board and assumes the conductor adhesion is poor because of faulty chemistry? Match the designer to the need or form the appropriate team structure.

Energy Forms – the KEY

A power electronic CIRCUIT conditions and converts many energy forms.



There are many circuits:

Electric circuits

Thermal circuits

Mechanical circuits

Electromagnetic circuits

Etc.

Energy forms: electric, magnetic, electromagnetic /electrostatic, mechanical, thermal, chemical, photonic ...

Why do only electrical design?

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A continual endeavor in power electronics is to increase power density. During the last two decades circuit frequencies have increased, thus, requiring smaller dimensions to allow for the higher frequencies. The electrical and physical interaction has become so great that there no longer can be a separation between the electrical and physical design functions.

Power electronic circuits condition or convert a multitude of energies. It is, therefore, unreasonable that design of a power electronic circuit be considered solely as an electrical design. An integrated, electro-physical approach should be used. However, the core of a power electronic system is, and will remain, electrical energy, even though other energy forms for sensing, actuation and isolation are included. Thus, the electrical designer will be the designer of choice for the future and will evolve with physical design becoming part of her or his knowledge base. To evolve this knowledge base a *packaging technology framework* should be put in place that all designers can use to understand the commonality and duality of electrical and physical design. The framework shows a logical progression from technical *user requirements* to the 'hard-core' technical issues in packaging.

It is equally important that the power electronics industry evolve in integrating electrical and physical systems. To guide the industry, a power electronics packaging roadmap is needed. To systematically and comprehensively develop a packaging roadmap a *technology framework* is also needed. The same framework applies to the evolution of the designer as to the evolution a product or industry.

Optimum Circuit (deliverable)

- All circuits have components.
  - e.g. resistors, heat sinks, fasteners, FeO cores
- All circuits have optimum topologies.
  - Optimum electrical topology
  - Optimum thermal topology
  - etc.
- The optimum deliverable circuit is a combination of non-optimum energy circuits.

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To better understand the correlation between electrical and physical circuits (and systems), consider the morphology of a generic circuit. A circuit has three partitions: components, topologies and controls. The components are active or passive. The topologies are the positioning of the components to provide a function. The controls provide a preferred set of rules for operation of those components. It is obvious to the power electronics designer how the domains apply to electric circuits.

Physical circuits have the same domains: components, such as heat sinks and PCBs (printed circuit boards); the topologies, such as the stack structure of silicon soldered on copper on ceramic; and, finally, controls (which is not as prevalent) can be found in thermo-electric coolers and active fluid cooling systems. Most of the interest in physical circuits lies with components and topologies.

To better define "physical," one should first define "electrical". "Electrical" identifies the form of energy being processed. Hence, "physical" represents the other forms of processed energies, such as mechanical, thermal, chemical, photonic, etc. This presentation is limited in discussion to four energy forms: electric, magnetic, mechanical and thermal. (Not included are secondary forms such as acoustic.) A common phrase to power electronics designers is the "… circuit," such as a "magnetic circuit". The phrase indicates a topology for processing magnetic energy. In education, equivalent electrical topologies are used to model thermal circuits. Hence, it can be concluded that "An electro-physical 'circuit' defines the circuits of multiple energy forms. All energy forms have components and all have optimum topologies to create a specified function."

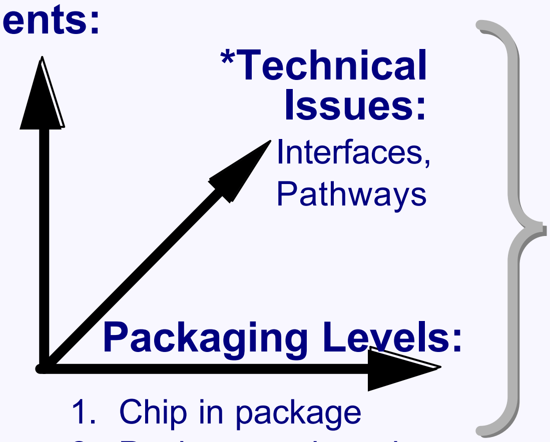
The foremost concern in power electronics continues to be the efficient processing of energy. Unlike the computer and telecom areas which process "information," the power electronics area processes energy. Therefore, use of energy as a foundation in the development of the framework should be expected.

The Framework

User Requirements:

Financial
*Technical
Environmental
Legal
Social

*Technical:
Taxonomies and Characteristics



***Technical Issues:**
Interfaces, Pathways

Packaging Levels:

1. Chip in package
2. Package on board
   1.5 Chip on board
3. Board in rack (box level)
4. Rack in cabinet, etc.

cross-cut by
Energy Forms

Electric
Magnetic
Thermal
Mechanical
Chemical
etc.

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Developing User Requirements [1]

Responsible Design is from Cradle to Grave

- Typically, User Requirements are derived through a polling process.
- This brings forward the highest-priority requirements, but are limited to personal experiences.
- A comprehensive approach uses a matrix of

Five Taxonomies
and
Three Characteristics

[1] QFD (Quality Functional Deployment) by Lawrence R. Guinta, Nancy C. Praizler, 1993

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Grouping User Requirements

Characteristic:

Unspoken Expectations

Articulated Needs

Unexpected Features

Taxonomy:

Financial

Technical

Environmental

Legal

Social

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Taxonomies in User Requirements

Financial requirements: represent cost and is base metric for other matrix entries.

Legal requirements: include intellectual property as a source of revenue, strategic positioning or enticement.

Social requirements: represent the corporate culture and image, global perceptions, and ethical conduct.

Environmental requirements: represent government regulations and broader global concerns.

Technical requirements: science based metrics related to 'energy forms' and provide the "specifications."

Characteristics of User Requirements

Unspoken Expectations: requirements for a product, process or service to be acceptable to all end users. May develop when a business has not kept up with the competition or market place, or may be basic requirements for entry into new markets.

Articulated Needs: typical, open and printed "specifications. " Discerns one user from another. There should be no question that these needs are requirements that must be met for each user.

Unexpected Features: exciters that make the product, process or service unique and readily distinguishable from the competition. (What the sales force lives for.) Features are speculative requirements.

Example User Requirements

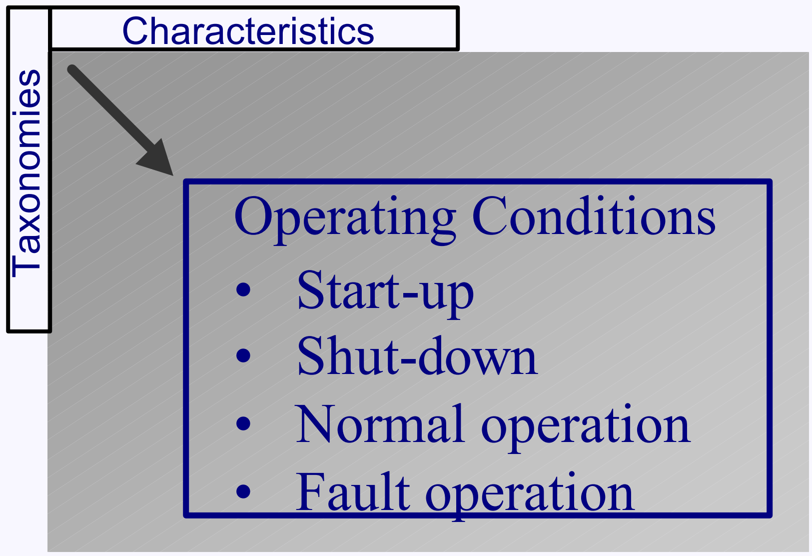
Unspoken *Environmental* Expectation: the product is not lethally hazardous to shippers

Articulated *Technical* Need: the products will operate from -40°C to +100°C.

Unexpected *Legal* Feature: the product can have exclusive patent protection.

Framework leading to specifications

Superimpose TIME on all specifications



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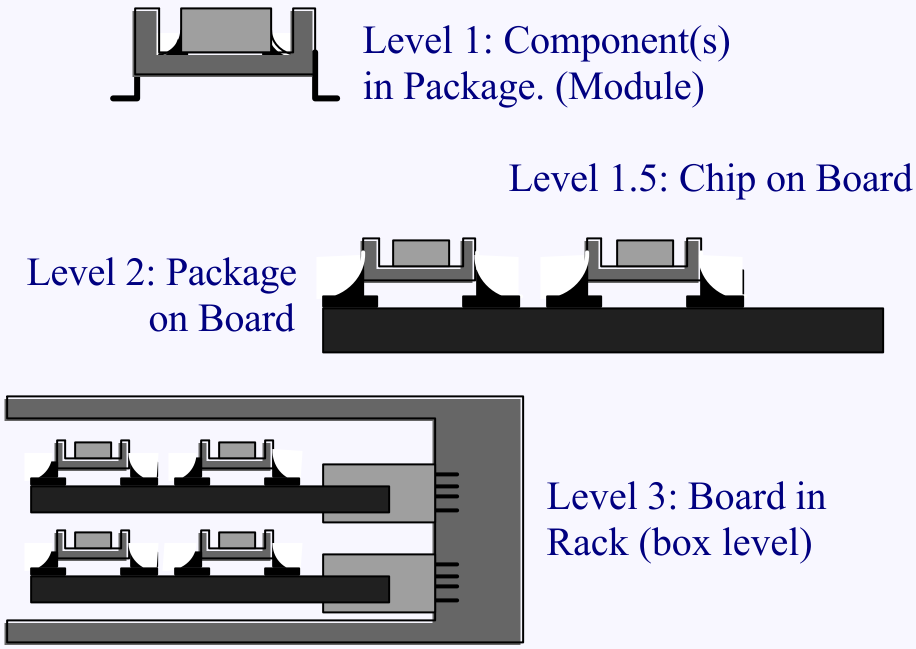
Levels of Packaging: 1-3 [1]



[1] R. R. Tummala and E. J. Rymaszewski, Microelectronics Packaging Handbook, Van Nostrand Reinhold, New York, 1989.

The *Levels of Packaging* divides a system, top-down, into lower and lower subassemblies with the boundary drawn between assembly and subassemblies. Requirements, trends, and the roadmap are developed at each level based on

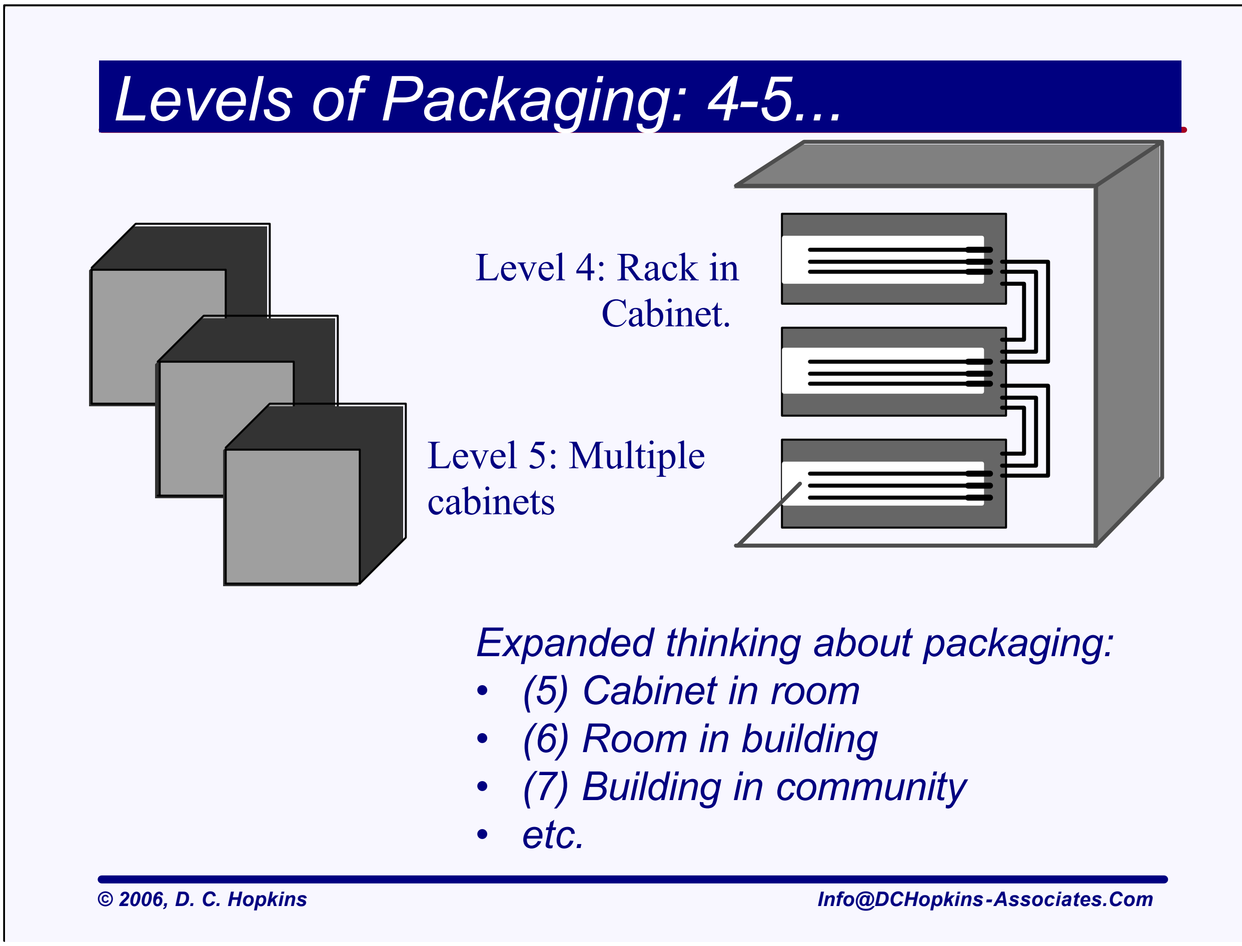
•The boundary conditions of electrical / mechanical / thermal performance characteristics within the level.

•The electrical / mechanical / thermal interconnection between each level.

Each level is defined and numbered, bottom-up, in a micro to macro manner. There are five traditional levels in electronic packaging also applicable to power packaging. Note that Levels are not easily defined. Some packages may be categorized in either of two levels depending on the application.

•Level-1: Component(s) in Package. This is basic component packaging. Examples include mount-down and lead attach of a component or semiconductor in a discrete package, or multiple components in a module. Traditional 'chip and wire' hybrid circuits mounted in a housing (often hermetic) are Level-1 packages. The package provides a 'self contained environment' that allows the components to be tested, transported and used at the next higher level of packaging while buffering electrical, mechanical and chemical discontinuities from the next level. This package becomes a subassembly to the next higher level.

•Level-2: Package on Board. These boards carry mixed-technology components (capacitors, resistors, inductors and packaged discretes) that are usually coated and terminated with a connector. Examples are PCB, IMS (insulated metal substrate) and SMT boards. They differ from Level-1 in the lesser sophistication in fabrication. The board provides a functional partition and is a subassembly to the next packaging level.



•Level-1.5 *(half-level)*: Chip on Board (COB). This mounts 'chip and wire' semiconductors directly to a PCB or on IMS. A driver in packaging is to combine levels. An objective of the road map will be the development of a direction to combine levels.

•Level-3: Board in Rack or Sub-Assembly Level. At this level the rack or case is considered. Each board or module is a subassembly with a back connector interfacing to the rack back plane connectors. Another example is the sub-modules in a power supply such as the output module sub-assembly where there might be several for a multi-output power supply or the PFC module sub-assembly. Each of these sub-assembles connect to the overall power supply main assembly. The sub-module approach is being utilized where flexibility and fast assembly time are both required to serve a certain market..

•Level-4: Rack in Cabinet or Sub-Cabinet Level. A single cabinet is sub-divided for assembly purposes. A rack is a common cabinet sub-division. Functional assemblies with common dimensions are stacked the full cabinet width. In this arrangement, common signals and power bussing can be routed quite easily.

•Level-5: Cabinet in Room or Multiple Cabinet Level. Here the entire cabinet is considered. Usually requires floor space availability and compatibility with adjoining cabinets, room interconnect facilities, and allowable room ambient conditions that include impact on operator interference (sound, heat, etc.). At this level, the power supply is usually a sub-assembly within the cabinet or is perhaps a rack level component serving a restricted section of the cabinet. Many system designs end at this level as the system is self contained in a single cabinet.

Module vs Partition

- Modularization is subdividing circuit functionality for repeated use in multiple products.

- Circuit Partitioning is subdividing circuit fabrication along packaging levels to improve manufacturability.

Levels of Packaging - Strategy

- Each level has components and topologies.
- Design groups, component manufacturing and companies are aligned along packaging levels and energy forms.
  - e.g. heat sink and back plane manufacturers.
- Strategy - combine levels downward for
  - decreased: cost, thermal resistance, stress
  - Increased: density, reliability, manufacturability

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Producers and suppliers have business thrusts aligned along one or more packaging levels. Thus, this axis of a technology or Product roadmap can be an important guide to business growth strategies. Combining levels, as done with Levels 1 and 2, is of great advantage in terms of many requirements, such as cost, reliability and manufacturability. A business can develop a niche market or gain product leverage by crossing or combining levels. A product line of heat sinks is a *thermal component* in *Level-2* packaging. A *cabinet fan* is a *thermal component* in *Level-3* packaging. Should fans be placed on boards?

Technical issues (I&P)

All technical issues are about energy flow at
INTERFACES and PATHWAYS

- Interface issues:
  energy transfer between levels.
  (flow from lower level ‘component’ (subassembly) to upper level)
- Pathway issues:
  energy transfer within a level.
  (flow from point-to-point within the subassembly)

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The last dimension completes the Framework and formulates the fundamental technical issues. *All technical issues can be reduced to issues of Energy Flow either at an Interface or along a Pathway.* This is comprehensive in that it represents the *inter-connection* and *intra-connection*, within and between levels.

Applying I&P to different Levels of Packaging is straight forward: Assume the component/sub-assembly from the next lower packaging level is characterized. The *Technical Issues* pertinent to *energy flow of* are then sought. Specifically, for each Level,

LEVEL-1 - The interface issues are of chip to a package and the pathway issues are of energy flow within the package.

LEVEL 2 - The interface issues are of package to the board and the pathway issues are of energy flow within the board.

LEVEL 3 - The interface issues are of board to a rack and the pathway issues are of energy flow within the rack. (ETC.)

Again, the forms of energy cross-cut both the I&P and Levels. An example of thermal issues would address the flow of heat from a chip package through the solder attach into the board, and then the conduction and spreading through the board. Electrical and mechanical issues arise.

Technical issues

Example for SOT: *Interface* for *Level-2* (package to board)

I&P	ISSUES
Electrical	solder impedance at leads
Magnetic	proximity of adjacent core
Mechanical	component attach (solder)
Thermal	under fill to heat sink

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This Example cites issues of placing multiple boards in a rack. Hot-swap issues would be identified by applying the procedure to a host of operational circumstances.

I&P		ISSUES
Interface (Energy flow from board to rack)		
	Electrical	connector resistance
	Magnetic	board to rack cross-coupling noise
	Mechanical	rigidity of guide slides
	Thermal	cold plate attach
Pathway (Energy flow through the rack)		
	Electrical	back plane wiring resistance
	Magnetic	EMI shielding
	Mechanical	vibration
	Thermal	rack aerodynamics

Technical issues

Example for FR-4 *Pathway* (within a level)
Level-2 (package on board)

I&P	ISSUES
Electrical	board trace resistance
Magnetic	lead and trace inductance
Mechanical	rigidity and vibration suppression
Thermal	hot spots and board aerodynamics

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Framework strategies

- Solve problems in different energy form.
  - use *electrical* (resonant switching) to reduce peak (*thermal)* temperatures.
  - reduce *thermal* gradients to reduce mechanical stress from CTE mismatch.
- Broaden product or technology
  - extend along an axis,
    - e.g. increased integration of chip-on-board (levels).
  - extend to new axes intersection.
- Develop a checklist for
  - concurrent concerns for design reviews.
  - interdisciplinary team development.

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When *User Requirements* are not met with available technology, the Framework can structure a decision tree for technology innovation? Innovation can be sought within one Level of packaging, e.g. better board level thermal and EMI management. Another "roadway" would use advanced technology to combine levels, i.e. the continual move toward higher integration. A third roadway cross-couples energy forms, i.e. decrease the problems occurring in one energy form by making changes in another form. As the roadmap develops, many roadways become evident.

Final Thoughts

Beyond a technology framework, this integrated approach is a tool to provide designers insight into the interdisciplinary nature of electronic packaging. The framework assists designers in forming teams in a common dialog to produce an optimized systems-level solution and facilitates the development of a common knowledge base.

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