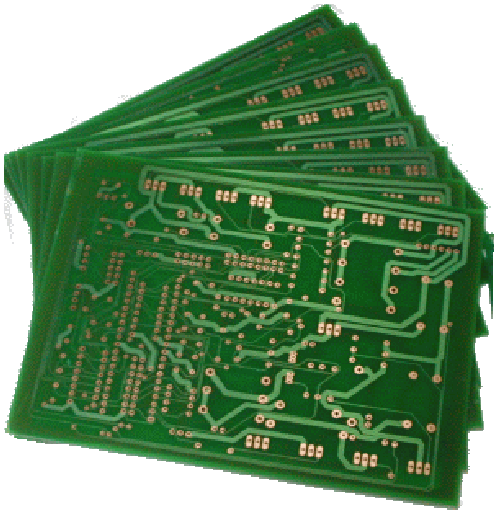
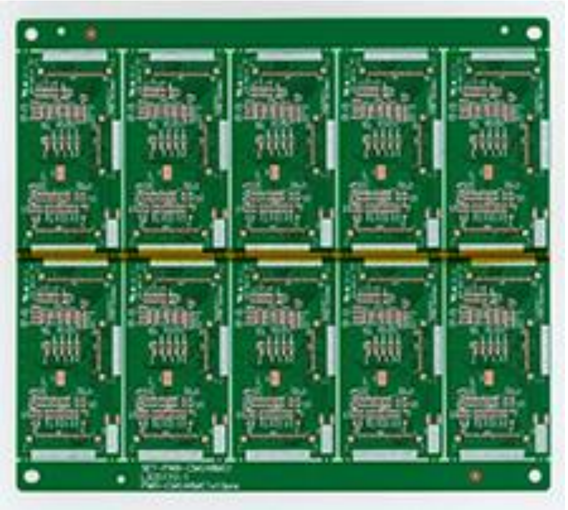
Automotive Electronics Council
Component Technical Committee

Recommendations for Specification & Qualification of Automotive Grade Rigid Printed Circuit Boards





James McLeish

16th Annual
Automotive Electronic Council
Reliability Workshop
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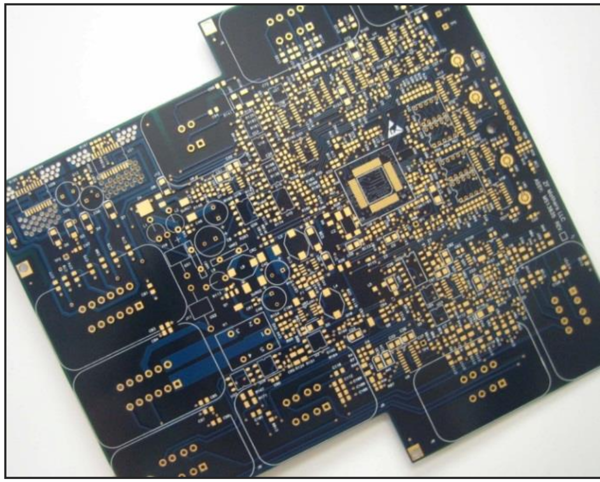
DfR Solutions

Printed Circuit Boards

- PCBs are the foundation that electronics assemblies are built upon, providing the structure that holds circuit components together physically & electrically.
- Originally a low tech commodity, PCBs have evolved into high precision & tight tolerance products to keep pace with the ever increasing capabilities & shrinking size and higher power loads of modern electronics.



- PCB fabrication is highly complex, requiring large equipment investments and over 50 process steps despite consistent of only four (4) basic elements:
  - The reinforcement mesh,
  - The resin system and
  - The conductive circuit traces, pads & through hole vias
  - The solder mask
- Since circuit boards are used in many different applications, a wide range of PCB base material, architectures and design rules are used to achieve various levels of performance versus cost.

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How Problems Can be Prevented
- Good Circuit Boards Requirement Specifications

- Circuit boards are the "Least Standardized" Items in Electronics.
  - Various types of Glass Fibers, Weave Patterns, Resins Formulations, Plating Techniques, Copper Finishes, Layer Thicknesses as well as Fabricator Process Differences Provide Flexibility for Customization.
  - Allows PCBs to be *"Specifically Engineered for Specific Applications"*
  - But expertise is required to select the right PCB material & design for an application.

- PCB Performance Specification Involve:
  - Mechanical, Thermal, Electrical, Dimensional and Chemical Criteria
    - To endure assembly soldering thermal stresses
    - To properly perform and endure in the service application
  - Individual companies have developed their internal PCB specs
    - Some are good, others are lacking

- A Good, (up to date) Industry Standard to Define Automotive Grade PCBs for various vehicle applications (Passenger Compartment, Under hood, Chassis, High-Low Complexity . . .) Does Not Exists.

Examples of Insufficient PCB Requirements
A Concern for High Reliability E/E Applications.

- The circuit board material shall be FR-4 (and nothing more).
  - FR-4 Simply denotes that a PCB material uses
    - Epoxy resin,
    - Over woven glass fiber reinforcements
    - That meets Grade 4 Flame Resistance per National Electrical Manufacturers Association Standard NEMA LI 1-1198 - Industrial Laminated Thermosetting Products
      - A standard that provides generic category recognition of Laminated Thermosetting grades based on their construction, reinforcement, & resin
      - Other vital PCB performance properties for thermal, humidity, electrical and mechanical performance are not addressed
      - Thus FR-4 by itself is insufficient for adequately specifying all of the needed characteristics of a PCB for High Reliability-Harsh Environment applications.

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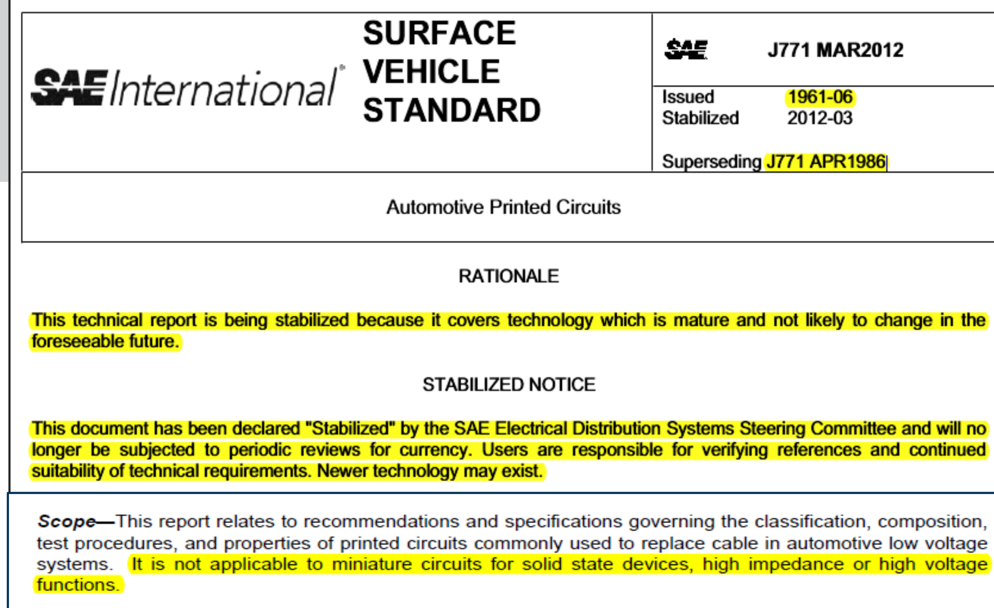
SAE J771 - Automotive Printed Circuits

- SAE J771 1st published in 1961 and Reaffirmed in 1986.
  - Covers aspects of PCB materials, design & testing of PWBs (i.e. wiring replacement Boards) that do not hold E/E components)



SAE International® SURFACE VEHICLE STANDARD

SAE J771 MAR2012

Issued 1961-06
Stabilized 2012-03

Superseding J771 APR1986

Automotive Printed Circuits

RATIONALE

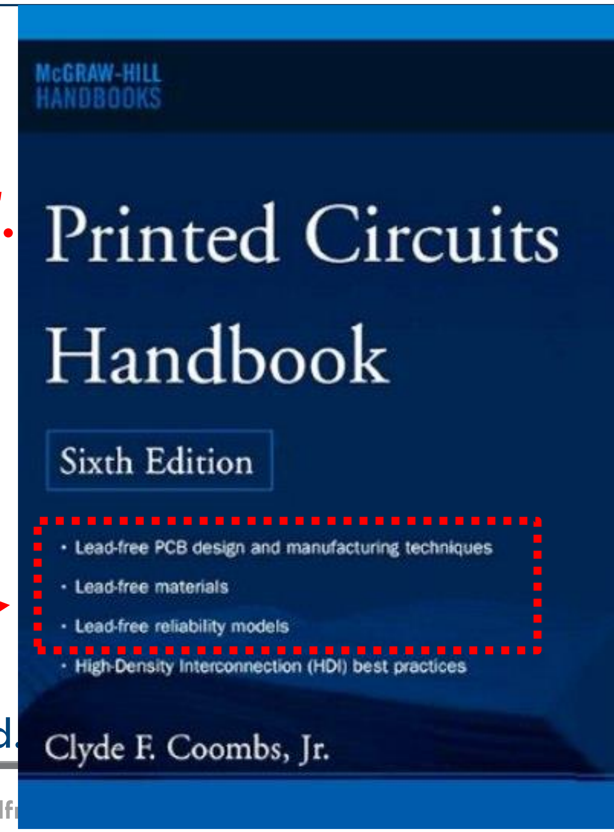
This technical report is being stabilized because it covers technology which is mature and not likely to change in the foreseeable future.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE Electrical Distribution Systems Steering Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

Scope—This report relates to recommendations and specifications governing the classification, composition, test procedures, and properties of printed circuits commonly used to replace cable in automotive low voltage systems. It is not applicable to miniature circuits for solid state devices, high impedance or high voltage functions.

- Was "stabilized" in 2012 by SAE as *"technology which is mature and not likely to change in the foreseeable future".*
  - *HOW WAS THIS DECISION MADE? !!!!!!!!!!!*
    - A revolution in new PCB materials & specifications has been under way since 2006 to meet Global RoHS/Lead Free/Green requirements.
      - The Printed Circuit Handbook has grown to 67 Chapters & >1000 pages because of RoHS regulation
      - Criteria not covered in SAE J771
      - SAE J771 is grossly out of date and should be obsoleted.



Examples of Insufficient PCB Requirements Concerns for High Reliability Applications.

- The circuit board shall meet the requirements of IPC-4101 "Specification for Base Materials for Rigid and Multilayer Printed Boards".
  - IPC-4101 was originally developed to replace MIL-S-13949,
  - Defines numerous PCB properties intended to cover various classes of boards.
    - But a specific set of requirements are needed to define a specific PCB.
  - Includes a appendix of "slash (/) sheets that define general classes of PCBs.

  - But "Min. or Max Requirements" instead of "Ranges" or Values with Tolerances are defined for each class.
  - PCB material suppliers seek to certify their PCB materials to as many slash sheet classes as possible - each class recognizes a wide range of PCB materials.
    - **Some of may be suitable for an application and other may not.**
    - **Specifying an IPC-4101/ slash sheet allows, PCB fabricators to use/switch to any of the specific material certified to that slash sheet throughout the production life cycle**
      - **May use the best performing material to develop and validate a product.**
      - **But switch to the cheapest/less reliable material for production.**

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IPC 4101 "/" Slash Sheets - Organization by Reinforcement & Resin Type

- Provides Little Insight into Application Suitability & QRD

IPC Spec.	Reinforcement	Resin System	ID Ref.	Tg C° min.	Dk @ 1Mhz
IPC-4101B/00	Cellulose Paper	Phenolic	NEMA XPC, UL/ANSI XPC	N/A	5.6
IPC-4101B/01	Cellulose Paper	Modified Phenolic	NEMA XXXPC, UL/ANSI XXXPC	N/A	4.8
IPC-4101B/02	Cellulose Paper	Phenolic, Flame Resistant	NEMA FR1, UL/ANSI FR1	N/A	6.0
IPC-4101B/03	Cellulose Paper	Phenolic, Flame Resistant	NEMA FR2, UL/ANSI FR1	N/A	5.0
IPC-4101B/04	Cellulose Paper	Modified Epoxy, Flame Resistant	NEMA FR3, UL/ANSI FR3	N/A	4.8
IPC-4101B/05	Cellulose Paper	Phenolic, Flame Resistant	UL/ANSI FR2	N/A	N/A
IPC-4101B/10	Woven E-Glass Surface, Cellulose Paper Core	Epoxy (1), Phenolic (2), Flame Resistant	NEMA CEM-1, UL/ANSI CEM-1	100°	5.4
IPC-4101B/11	Woven E-Glass Surface, Nonwoven E-Glass Core	Polyester, Flame Resistant	NEMA CRM-5, ANSI CRM-5/11	N/A	4.1
IPC-4101B/12	Woven E-Glass Surface, Nonwoven E-Glass Core	Epoxy, Flame Resistant	NEMA CEM-3, UL/ANSI CEM-3	N/A	5.4
IPC-4101B/13	Woven E-Glass	Polyester (1), Vinyl Ester (2), Flame Resistant	ANSI 4101/13	N/A	N/A
IPC-4101B/14	Woven E-Glass Surface, Nonwoven E-Glass Core	Epoxy, Flame Resistant	UL/ANSI CEM-3	N/A	5.4
IPC-4101B/20	Woven E-Glass	Epoxy, Non Flame Resistant	NEMA G10, UL/ANSI G-10, MIL-S-13949/03 GE/GEN	100°	5.4
IPC-4101B/21	Woven E-Glass	Difunctional Epoxy (1) Multifunctional Epoxy (2), Flame Resistant	NEMA FR4, UL/ANSI FR-4/21, MIL-S-13949/04 GF/GFN/GFK/GFP/GFM	110°	5.4
IPC-4101B/22	Woven E-Glass	Epoxy, Hot Strength Retention, Non Flame Resistant	NEMA G11 – GB, UL/ANSI G-11, MIL-S-13949/02 GB/GBN/GP	135-175°	5.4
IPC-4101B/23	Woven E-Glass	Epoxy, Hot Strength Retention, Flame Resistant	NEMA FR5, UL/ANSI FR-5, MIL-S-13949/05 GH/GHN/GHP	135-185°	5.4
IPC-4101B/24	Woven E-Glass	Epoxy (1), Multifunctional Epoxy (2), Flame Resistant	NEMA FR4, UL/ANSI FR-4/24, MIL-S-13949/04 GF/GFG/GFN	150°	5.4
IPC-4101B/25	Woven E-Glass	Epoxy (1), Polyphenylene oxide (2), Flame Resistant	NEMA FR4, ANSI 4101/25, MIL-S-13949/04 GF/GFG/GFN	150-200°	4.4
IPC-4101B/26	Woven E-Glass	Epoxy (1), Multifunctional Epoxy (2), Flame Resistant	NEMA FR4, UL/ANSI FR-4/26, MIL-S-13949/04 GF/GFT	170°	5.4
IPC-4101B/27	Unidirectional E-Glass, Cross-plied	Epoxy (1), Multifunctional Epoxy (2), Flame Resistant	ANSI 4101/27	110°	5.4
IPC-4101B/28	Woven E-Glass	Epoxy (1), Non-Epoxy (2), Flame Resistant	ANSI 4101/28, MIL-S-13949/04 GN/GFT	170-220°	5.4
IPC-4101B/29	Woven E-Glass	Epoxy (1), Cyanate Ester (2), Flame Resistant	ANSI 4101/29, MIL-S-13949/04 GN/GFT	170-220°	4.4
IPC-4101B/30	Woven E-Glass	Bismaleimide/Triazine (BT) (1), Epoxy, (2), Flame Resistant	UL/ANSI GPY, MIL-S-13949/26 – GIT/GMT	170-220°	4.8
IPC-4101B/31	N/A	Epoxy (1), Multifunctional Epoxy (2),	N/A	90°	7
IPC-4101B/32	Woven E-Glass	Epoxy (1), Multifunctional Epoxy (2),	N/A	90°	7
IPC-4101B/33	N/A	Epoxy (1), Multifunctional Epoxy (2),	N/A	150°	7
IPC-4101B/40	Woven E-Glass	Polyimide	UL/ANSI GPY, MIL-S-13949/10 GI/GIN/GIJ/GIP/GIL	200°	5.4
IPC-4101B/41	Woven E-Glass	Polyimide	UL/ANSI GPY, MIL-S-13949/10 GIL/GIP	250°	5.4
IPC-4101B/42	Woven E-Glass	Polyimide (1), Epoxy (2),	UL/ANSI GPY, MIL-S-13949/10 GIJ	200°	5.4

IPC-TR-579 Comparison of 4 IPC-4104/24 PCB Materials for PTH Via Life & Reliability

- ISOLA IS410 (/24), ISOLA IS410 (/21,/24,/26,/121,/124, /129), ISOLA 370HR (/21,/24,/26,/98,/99,/101,/126) & Nelco N4000-29 (/24,/28,/98,/99,/129)

Stackup Properties

Based on the currently defined board outline and the stacku

Board Size: 139 x 117 mm [5.5 x 4.6 in]

Board Thickness: 62.8 mil

IS410

CTExy: 12.227 ppm/C — **12.2**

CTEz: 52.320 ppm/C — **53.3**

Exy: 48,410 MPa

Ez: 4,658 MPa

Stackup Layers

Double click any row to edit the properties for that layer or s button to replace all layers using a given PCB thickness an

Layer #	Type	Thickness	Material
1	SIGNAL	2.0 oz	COPPER (50%)
2	Laminate	10.0 mil	IS410
3	SIGNAL	2.0 oz	COPPER (50%)
4	Laminate	8.0 mil	IS410
5	SIGNAL	2.0 oz	COPPER (50%)
6	Laminate	10.0 mil	IS410
7	SIGNAL	2.0 oz	COPPER (50%)
8	Laminate	8.0 mil	IS410
9	SIGNAL	2.0 oz	COPPER (50%)
10	Laminate	10.0 mil	IS410
11	SIGNAL	2.0 oz	COPPER (50%)

Stackup Properties

Based on the currently defined board outline and the stack

Board Size: 139 x 117 mm [5.5 x 4.6 in]

Board Thickness: 62.8 mil

IS415

CTExy: 13.977 ppm/C — **13.9**

CTEz: 52.320 ppm/C — **50.4**

Exy: 50,417 MPa

Ez: 4,658 MPa

Stackup Layers

Double click any row to edit the properties for that layer or s button to replace all layers using a given PCB thickness ar

Layer #	Type	Thickness	Material
1	SIGNAL	2.0 oz	COPPER (50%)
2	Laminate	10.0 mil	IS415
3	SIGNAL	2.0 oz	COPPER (50%)
4	Laminate	8.0 mil	IS415
5	SIGNAL	2.0 oz	COPPER (50%)
6	Laminate	10.0 mil	IS415
7	SIGNAL	2.0 oz	COPPER (50%)
8	Laminate	8.0 mil	IS415
9	SIGNAL	2.0 oz	COPPER (50%)
10	Laminate	10.0 mil	IS415
11	SIGNAL	2.0 oz	COPPER (50%)

Stackup Properties

Based on the currently defined board outline and the stackup lay

Board Size: 139 x 117 mm [5.5 x 4.6 in]

Board Thickness: 62.8 mil

N4000-29

CTExy: 17.156 ppm/C — **17.1**

CTEz: 44.995 ppm/C — **48.4**

Exy: 48,410 MPa

Ez: 4,658 MPa

Stackup Layers

Double click any row to edit the properties for that layer or select button to replace all layers using a given PCB thickness and defa

Layer #	Type	Thickness	Material
1	SIGNAL	2.0 oz	COPPER (50%)
2	Laminate	10.0 mil	N4000-29
3	SIGNAL	2.0 oz	COPPER (50%)
4	Laminate	8.0 mil	N4000-29
5	SIGNAL	2.0 oz	COPPER (50%)
6	Laminate	10.0 mil	N4000-29
7	SIGNAL	2.0 oz	COPPER (50%)
8	Laminate	8.0 mil	N4000-29
9	SIGNAL	2.0 oz	COPPER (50%)
10	Laminate	10.0 mil	N4000-29
11	SIGNAL	2.0 oz	COPPER (50%)

Stackup Properties

Based on the currently defined board outline and the stack

Board Size: 139 x 117 mm [5.5 x 4.6 in]

Board Thickness: 62.8 mil

370HR

CTExy: 13.977 ppm/C — **13.9**

CTEz: 37.670 ppm/C — **37.6**

Exy: 49,407 MPa

Ez: 4,658 MPa

Stackup Layers

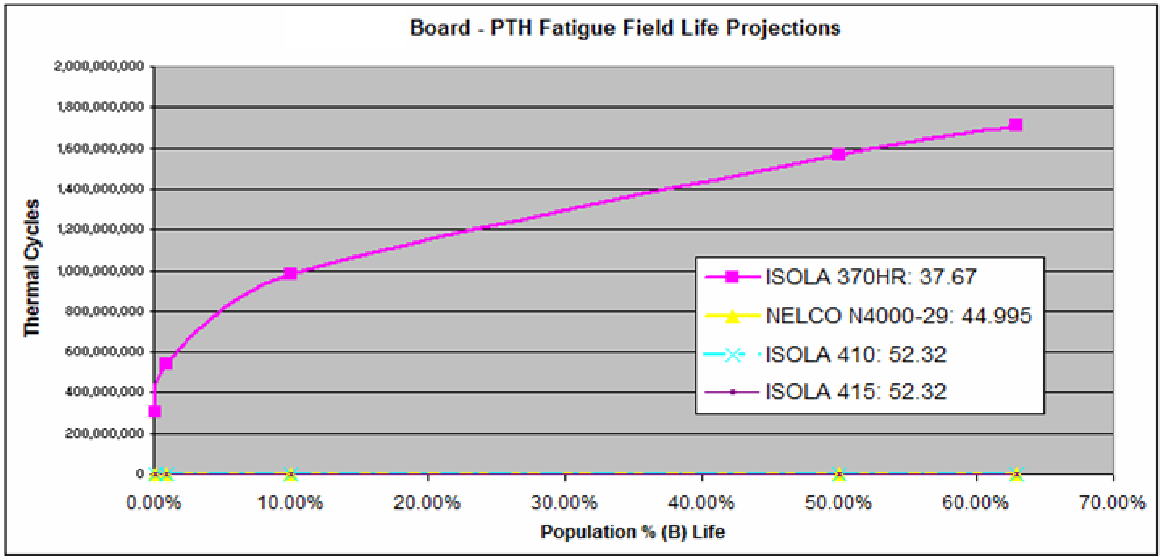
Double click any row to edit the properties for that layer or s button to replace all layers using a given PCB thickness an

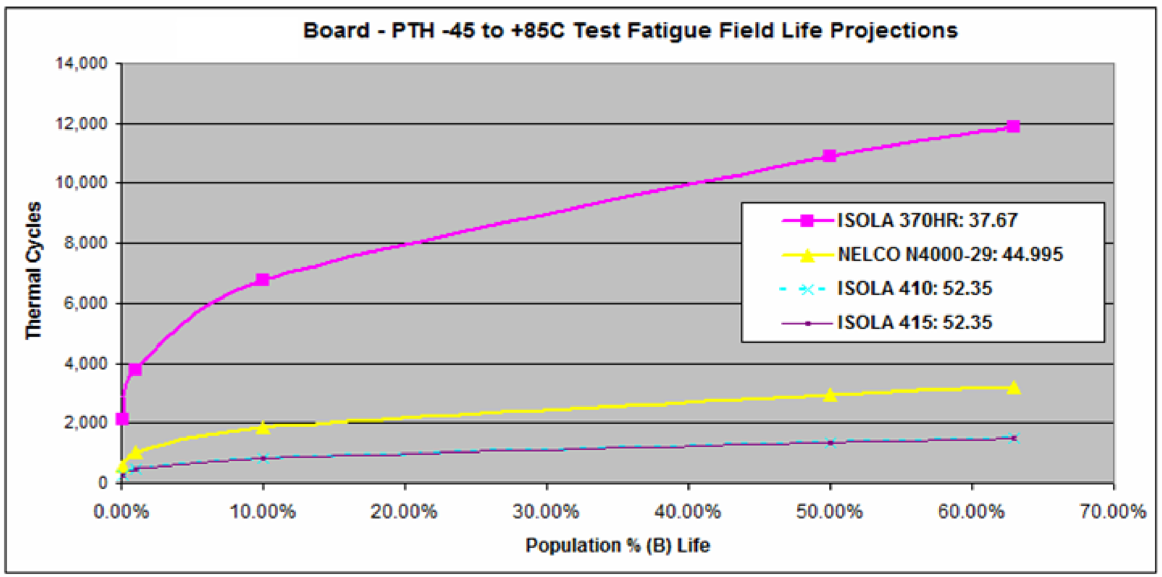
Layer #	Type	Thickness	Material
1	SIGNAL	2.0 oz	COPPER (50%)
2	Laminate	10.0 mil	370HR
3	SIGNAL	2.0 oz	COPPER (50%)
4	Laminate	8.0 mil	370HR
5	SIGNAL	2.0 oz	COPPER (50%)
6	Laminate	10.0 mil	370HR
7	SIGNAL	2.0 oz	COPPER (50%)
8	Laminate	8.0 mil	370HR
9	SIGNAL	2.0 oz	COPPER (50%)
10	Laminate	10.0 mil	370HR
11	SIGNAL	2.0 oz	COPPER (50%)

Plated Through Hole Fatigue Life Projections Per IPC-TR-579 Model

CTEz Laminate	Delta T	Laminate	CTEz PCB Stack	Calculated Results - Cycle to Failure at Life Point: 0.10%	1%	10%	50%	63%	Test to Field Correlation
	Field								
45	25 - 75	ISOLA 370HR:	37.67	305,339,412	543,592,804	978,133,260	1,566,516,307	1,714,362,676	144,021
55	25 - 75	NELCO N4000-29:	44.995	522,431	930,079	1,673,571	2,680,286	2,933,249	910
65	25 - 75	ISOLA 410:	52.32	27,707	49,327	88,759	142,150	155,566	104
65	25 - 75	ISOLA 415:	52.32	27,707	49,327	88,759	142,150	155,566	104
	Test								
45	-45 - +85	ISOLA 370HR:	37.67	2,120	3,774	6,792	10,877	11,904	
55	-45 - +85	NELCO N4000-29:	44.995	574	1,022	1,839	2,945	3,223	
65	-45 - +85	ISOLA 410:	52.35	266	473	852	1,364	1,493	
65	-45 - +85	ISOLA 415:	52.35	266	473	852	1,364	1,493	

Comparison of 4 IPC-4104/24 PCB Materials – PHT Via, Life & Reliability - ISOLA IS410, ISOLA IS415, ISOLA 370HR & Nelco N4000-29



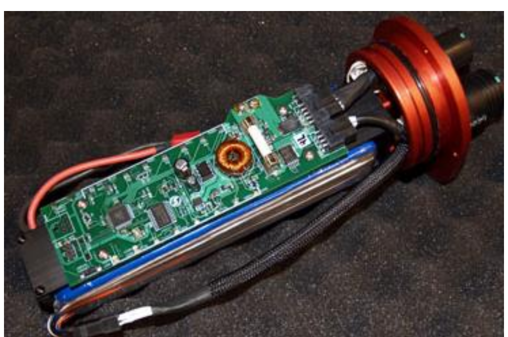
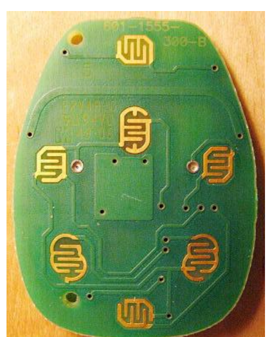


DfR Solutions

Proposed Scope of an Automotive PCB Spec

- PCBs are used is a Wide & Growing Range of Vehicle Functions
  - From Complex Vehicle Modules for:
    - Vehicle Controls & Safety Functions, Displays, Infotainment Systems, Hybrid Electric Vehicle Power Modules, Connections Boards in Fuse/Relay Center . . . etc.


  - To Simple Carriers in Sensors, Switches & Lamp Assemblies
    - Applying Complex PCB specs to a simple PCB could needless increase costs.


Proposed Scope of an Automotive PCB Spec

- Large Complex PCBs must accommodate many different EE part types & sizes & may be thicker with more conductive layers.
  - Need to be able to endure more soldering passes, at hotter temperatures.
    - IPC Definition of Peak PCB Assembly Conditions for Lead Free Soldering (Use to set objectives for PCB Material Properties):
      - Peak Temperatures Up To 260°C (increase from Peak of 220°C (of SnPb Solders)
      - Exposure to Up To 6 Soldering Processes

        - Original Assembly: Top Side Reflow, Bottom Side Reflow & Bottom Side Wave Soldering

        - Rework/Repair: Top Side Reflow, Bottom Side Reflow & Bottom Side Wave Soldering

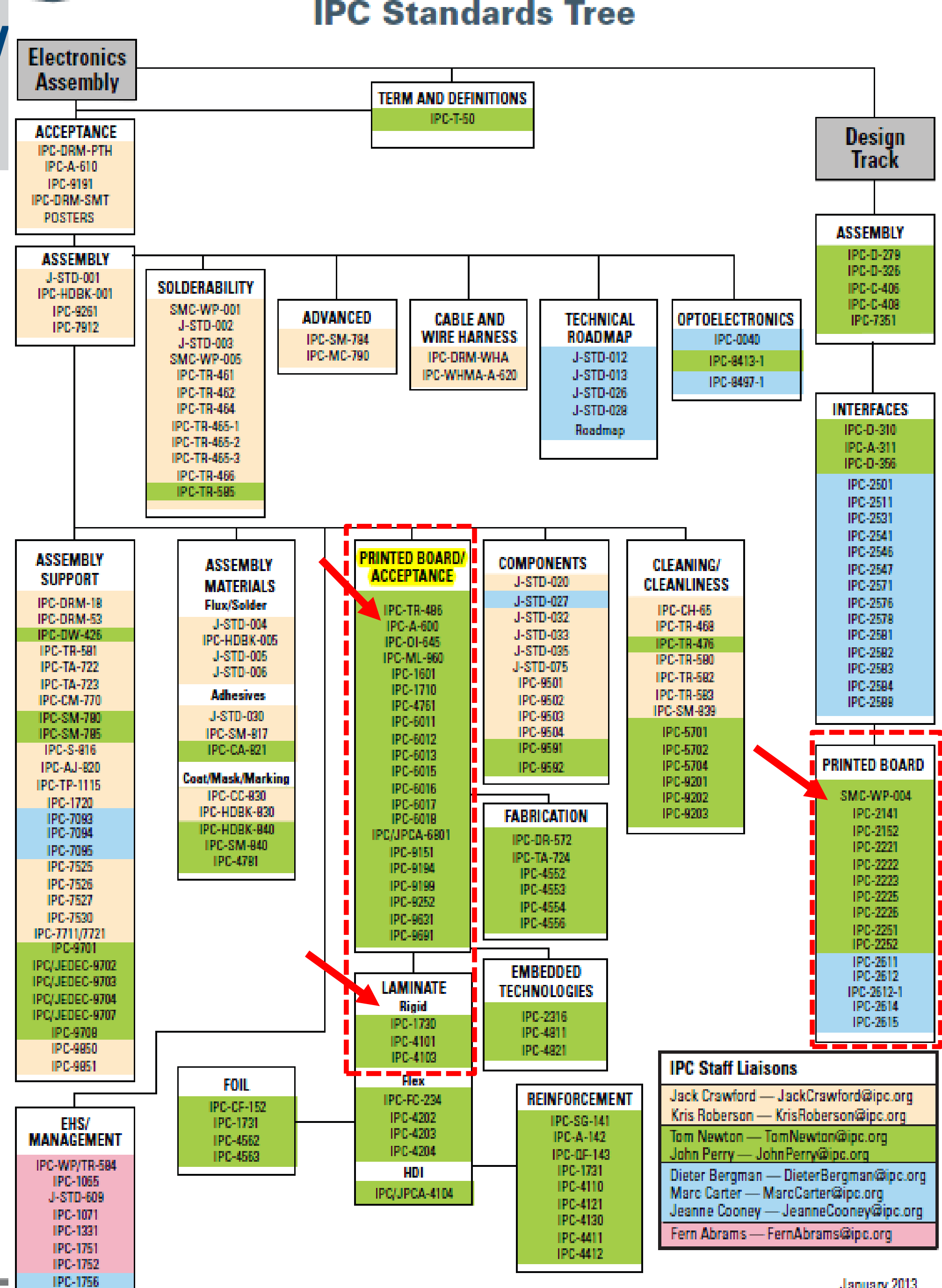
        (Note: Simple PCBs can often be processed with cooler soldering profiles and fewer soldering passes)
  - Often are essential to vehicle operation and safety.
    - Loss of a costly essential vehicle operating function is a larger customer dissatisfier than lose of a map lamp.
  - Have a high replacement costs
- These issues justify needing a more capable laminate for complex PCBs.
  - Applying the same PCB requirements to a small, simple PCB could needlessly increase costs.

Proposal: An "AEC Spec" on PCBs that References, Leverages & Focuses IPC PCB Specs on Automotive Needs

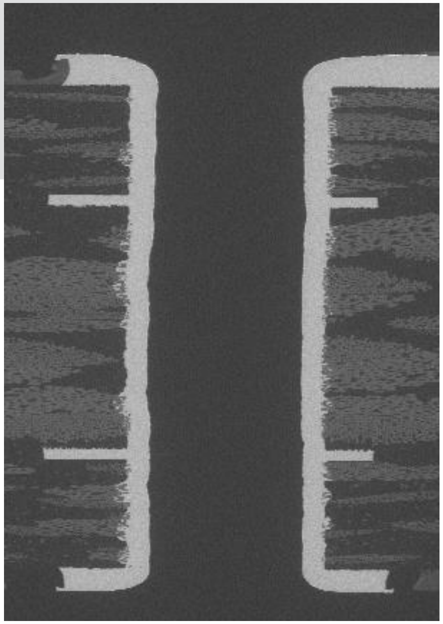
- The IPC already has PCB specs & an infrastructure of test methods.
  - However the IPC specs are written to apply to the vast range of electronic products and applications.
  - It is up to the end user/developer to stipulate requirements beyond the 3 IPC category minimuns for harsh environments (per IPC A 610 - 7.5.5.1).
- Would be a huge effort to develop AEC versions of existing specs.
  - Propose instead an AEC exception and guideline document that explain the IPC PCB Spec structure and how to use it to define which IPC requirements are suitable or require exceptions/enhancement to be acceptable for use in different types of vehicle electronics application
    - i.e. Under hood, on or in engine or trans, chassis, passenger compartment . . . etc.
- Developing and maintaining this type of standard is a less work than totally creating a new standard.

Contents: Leverage Existing IPC PCB Specs by Defining Parameters & Conditions Suitable for Automotive Electronics

- The IPC has an extensive set of PCB Standards, that apply to the vast range of E/E products that are widely cited in PCB specs.
  - **Class 1 General Electronics** (i.e. Consumer Products)
  - **Class 2 Dedicated Service** Industrial & Communications)
  - **Class 3 High Reliability Electronics** (i.e. applications where Continued Performance & Harsh Environment Endurance is critical.
    - Exceeding IPC Class 3 minimums often needed for High Reliability, Long Life & Harsh Environment Application such as automotive.
    - Is a class 4 – Automotive Grade Needed?



Example: IPC Class 3 Requirements
- Copper Plating of Plated Through Holes



- IPC 6012 Class 3 PTC copper plating min. of 20μm (.787 mils)
  - Can be too thin to prevent fatigue failure during thermal cycling life test
    - IPC Spec are written primarily by PCB Suppliers
    - Some OEM's are known to have more demanding requirement
    - Thicker PTH Plating Improves Fatigue Life Durability But Cost More.
  - Thicker plating is also more robust against drill hole variation and defects.

Table 3-3 Surface and Hole Copper Plating Minimum Requirements for Through-Holes, Blind, and Buried Vias > 2 Layers[1]

	Class 1	Class 2	Class 3
Copper – average[2,5]	20 μm [787 μin]	20 μm [787 μin]	25 μm [984 μin]
Thin areas[3,5]	18 μm [709 μin]	18 μm [709 μin]	20 μm [787 μin]
Wrap[4]	AABUS	5 μm [197 μin]	12 μm [472 μin]

Note 1. Does not apply to microvias. Microvias are vias that are ≤ 0.15 mm [0.006 in] in diameter and formed either through laser or mechanical drilling, wet/dry etching, photo imaging or conductive ink formation followed by a plating operation. Blind vias have greater than 1:1 aspect ratio.
Note 2. Copper plating (1.3.4.2) thickness **shall** be continuous and extend or wrap from hole walls onto outer surfaces. Refer to IPC-A-600 for discussion on copper plating thickness for hole walls.
Note 3. For Class 3 PBs having a drilled hole diameter ≤ 0.35 mm [0.0138 in] and having an aspect ratio > 3.5:1, the minimum thin area copper plating in the hole **shall** be 25 μm [984 μin].
Note 4. Wrap copper plating for filled PTHs and vias **shall** be in accordance with 3.6.2.11.1.
Note 5. See 3.6.2.11.1.

Key IPC PCB Specifications & Guidelines that can be Reference for An Automotive PCB Specs

- IPC-4101 - Specification for Base Materials for Rigid PCBs
  - Covers the requirements for base materials that are referred to as laminate or prepreg. used in rigid and multilayer printed boards for electrical and electronic circuits.
- IPC-2221- Generic Standard on Printed Board Design
  - IPC-2221A is the foundation design standard for the IPC-2220 series.
    - Establishes the generic requirements for the design of printed boards
- IPC-2222- Design Standard for Rigid Organic Printed Boards
  - A supplement to IPC-2221 that establishes specific requirements for the design of rigid PCBs
- IPC-TM-650: Test Methods Manual
  - Section 1.0: Reporting and Measurement Analysis Methods
  - Section 2.1: Visual Test Methods
  - Section 2.2: Dimensional Test Methods
  - Section 2.3: Chemical Test Methods
  - Section 2.4: Mechanical Test Methods
  - Section 2.5: Electrical Test Methods
  - Section 2.6: Environmental Test Methods

Proposed Scope of an Automotive PCB Spec
1) Initial Focus on Complex/Critical/Safety Related Rigid PCBs

- Proposed Title:
  - Recommend Practices for Specification & Qualification of Rigid Printed Circuit Boards for Automotive Electronic Applications
- Proposed Scope:
  - This document defines recommendations and specifications governing the classification, composition, test procedures and properties of RoHS compliant, Rigid Printed Circuit Boards (PCBs) used in vehicular applications.
  - This document applies to PCBs used in complex vehicular electronic modules that are:
    - Essential to vehicle operation or safety,
      have more than 2 conductive layers,
      hold more that 25 E/E components total,
      or have hold more than 10 E/E component types.
      (Need to Refine)

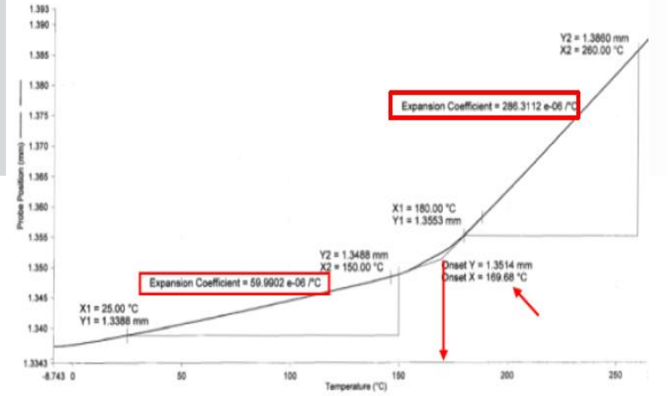
DfR Solutions

Proposed Purpose of an Automotive PCB Spec
2) Initial Focus on Complex/Critical/Safety Related Rigid PCBs

- Purpose:
  - The purpose of this specification is to ensure that:
    - An Automotive PCB is capable of enduring appropriate lead free soldering assembly processes, without damage or degradation.
    - An automotive PCB is engineered to accommodate the E/E components it is required to carry, so that the resulting Printed Circuit Board Assembly (PCBA) is a Harmonized, Robust Design capable of:
      - Passing (without failures) the accelerated durability/reliability demonstrated validation testing requirements of the application.
      - Meeting the in service operating-storage, reliability-durability and warranty objectives of the vehicle application of the PCBA.

DfR Solutions

Examples of Proposed Content of an AEC PCB Spec
3a) Parameters for Enduring Pb-Free Soldering: Tg



○ Tg - Glass Transition Temperature:

- Temperature where the PCB laminate changes from a hard, glass-like state with a low (CTE) (α1) to a soft, pliable, rubber-like state with a much larger CTE (α2)
- The larger CTE above the Tg creates higher stresses in the PCB and on the Cu Plated Through Hold (PTH) vias that connect PCB's conductive layers
- Measured by 1 of 3 methods
  - TMA - Thermo-Mechanical Analysis per IPC-TM-650-2.4.24 "Glass Transition Temperature and Z-Axis Thermal Expansion by TMA", (denoted as Tg (TMA).
  - DSC - Differential Scanning Calorimetry per IPC-TM-650-2.4.25 "Glass Transition Temperature & Cure Factor by DSC", (denoted as Tg (DSC)) (method typical cited on Laminate datasheets)
  - DMA Dynamic Mechanical Analysis - IPC-TM-650-2.4.24.4 ""Glass Transition & Modulus of Materials - DMA Method", (denoted as Tg (DMA)
- Pre RoHS Tin-Lead Soldering PCB Tg's were as low as 115°C
- Tg's up to 260°C for Pb-Free Laminates
- For Complex PB-Free PCBs Tg of at least 170°C (DSC) is recommended
  - *Trade Offs: High Tg Laminates are harder & more brittle which:*
    - Can increase the potential for pad cratering defects
    - May reduce copper peel strength &
    - Shorten times to delamination &
    - Higher Tg resins cost more

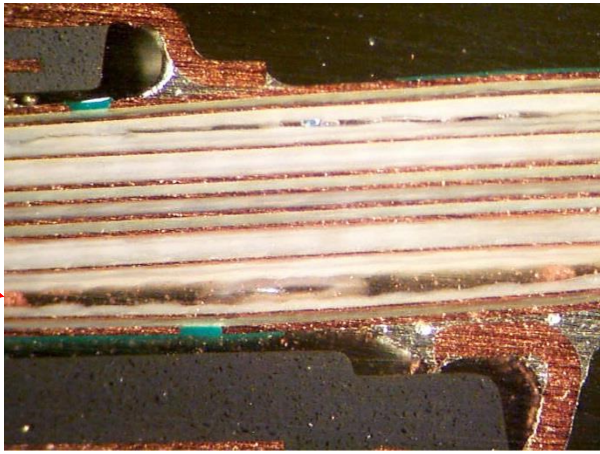
DfR Solutions

Examples of Proposed Content of an AEC PCB Spec
3b) Parameters for Enduring Pb-Free Soldering: Td

- Td - Decomposition Temperature:
  - Temperature where substance starts to chemically decomposes as heat break chemical bonds and releases of volatile compounds which reduces the mass of the laminate
    - The laminate is basically burning up
  - Td5% is the temperature where 5% of the PCB laminate sample is loss
  - Measured by IPC-TM-640 2.4.24.6 “Decomposition Temperature (Td) of Laminate Material Using Thermogravimetric Analyzer (TGA)
  - Td is considered to be more critical to soldering degradation mitigation than Tg
    - Typical values for Td5% range from 310°C to 400°C for Pb-Free assembly
    - For Complex PCBs in Pb-Free Soldering, a Td5% of at least 340° is recommended

Examples of Proposed Content of an AEC PCB Spec

3c) Parameters for Enduring Pb-Free Soldering: T260/T288/T300



- Time-To-Delamination:
  - Time to PCB delaminate after exposure to a constant temperature of either 260°C, 288°C or 300°C, Indicator of a PCB material's ability to withstand multiple soldering cycles without degradation
    - Delamination is the separation of the laminate layers determined by monitoring the PCB thickness to detect layer separation expansion.
    - Time-to-delamination & Decomposition Td are both measures of PCB thermal stability, material data sheets may list both or one or the other.
  - Measured by IPC-TM-650 Method 2.4.24.1 "Time to Delamination (TMA Method)", that can be combined with measuring the Tg & the Z axis CTE
    - For Tin-Lead soldering PCB T260 ≥ 5 minutes are required
    - For low end Pb-free PCBs products, T280 ≥ 5 minutes is the starting point
    - For Complex PCBs in Pb-Free Soldering recommend T260 ≥ 60 minutes, or a T288 ≥ 30 minutes

Examples Proposed Content of an AEC PCB Spec
4) PCB Durability/Reliability Robustness – Test & Field Conditions

- Reliability/Durability of the PCB involves the capability of the PCB to endure the application's loads & environmental stresses over the required service life, involves:
  - Structural Integrity - Delamination, Swelling, Corrosion, Measling, Cratering …
  - Electrical Connections - Trace/Pad Integrity, Load Capability & Adhesion, PTH Via Fatigue ...
  - Electrical Isolation Current Leakage/shorts: Dendritic Growths, CAF, Dielectric Breakdown…
  - Signal Integrity for High Frequency PCBs - Dielectric Thickness & Relative Permittivity

- Reliability/Durability of the Assembled PCB involves selecting a PCB material with a (CTExy) that manages the CTE mismatch between the board and its E/E Components, so that attachment fatigue does not occur over the thermal cycling life profile of the test or field conditions.

Similar to SAE J1879 Robustness Validation Process Presented in AEC W.4 by W. Kenert

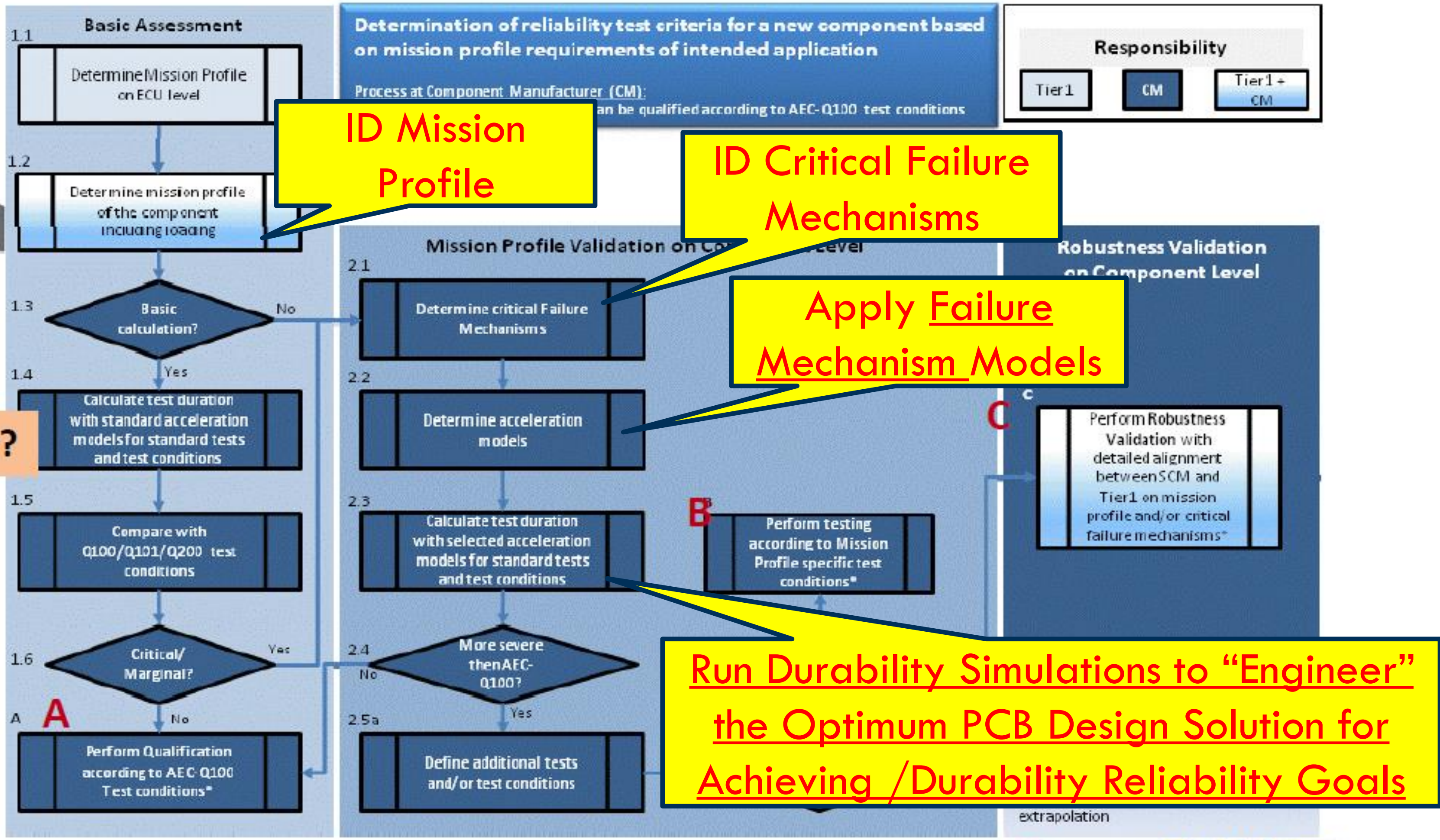
Determination of reliability test criteria for a new component based on mission profile requirements of intended application

Process at Component Manufacturer (CM):
Assess whether a new component can be qualified according to AEC-Q100 test conditions

Automotive Electronics Council
Component Technical Committee

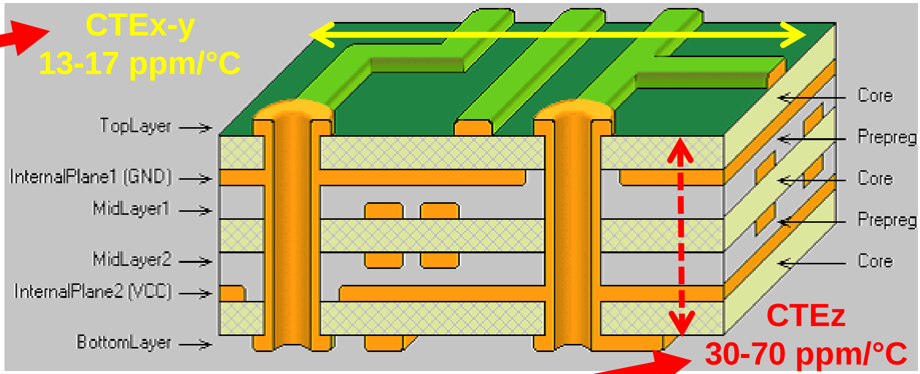
Flow chart 1

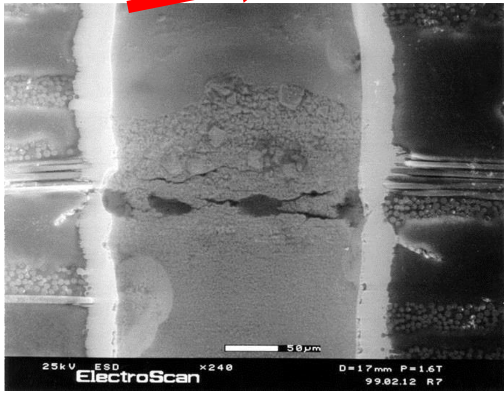
Remember?

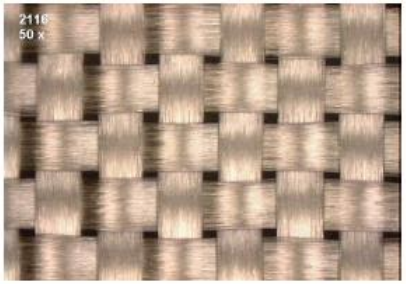


Example of an Engineered Robustness Solution Calculations for 4a) Cu Plated Through Holes (PTH) Via Fatigue Endurance

- **PTH Via Fatigue Failure is a PCB Durability Issue**
  - Barrel cracks form intermittent or open circuits
  - PCB Z axis CTE is higher than in plane CTExy
  - Woven Glass Fiber constrain the PCB in the X-Y plane but not through the Z axis.
  - Thermal cycling stresses will eventually fatigue the Cu barrels resulting in cracking around the center of the barrel.
  - Key Factors:
    - Board Thickness & Overall CTEz
    - Number of Thermal Cycles & Delta T
    - Drill Diameter, Plating Thickness & Quality
      - Larger Dia. holes w/thicker plating have more copper to resist fatigue
      - Smaller diameter holes are hard to plate.







Glass Style: 2116
Plain Weave
Count: 60x58 (ends/in)
Thickness: 0.0038"

DfR Solutions

4a) Use IPC-TR-579 (1988) PTH Via Barrel Cracking Fatigue Life Model to Identify Optimum PCB CTEz for Any Thermal Cycling Profile & Duration

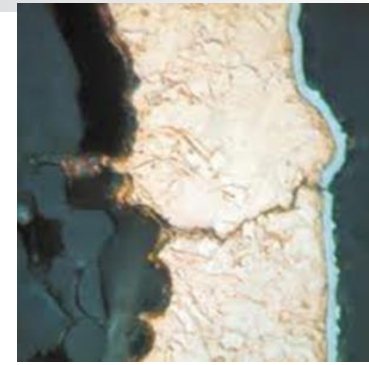
- Determine applied stress (σ)

$$\sigma = \frac{(\alpha_E - \alpha_{Cu})\Delta T A_E E_E E_{Cu}}{A_E E_E + A_{Cu} E_{Cu}}, \text{for } \sigma \le S_y$$

$$\sigma = \frac{\left[(\alpha_E - \alpha_{Cu})\Delta T + S_y \frac{E_{Cu} - E'_{Cu}}{E_{Cu} E'_{Cu}}\right] A_E E_E E'_{Cu}}{A_E E_E + A_{Cu} E'_{Cu}}, \text{for } \sigma > S_y$$

$$A_E = \frac{\pi}{4}\left[(h + d)^2 - d^2\right]$$

$$A_{Cu} = \frac{\pi}{4}\left[d^2 - (d - 2t)^2\right]$$



- Determine strain range (Δε)

$$\Delta\varepsilon = \frac{\sigma}{E_{Cu}}, \text{ for } \sigma < S_y$$

$$\Delta\varepsilon = \frac{S_y}{E_{Cu}} + \frac{\sigma - S_y}{E'_{Cu}}, \text{ for } \sigma > S_y$$

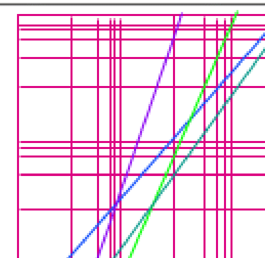
- Apply calibration constants
  - Strain distribution factor, K_d(2.5 –5.0)
  - PTH & Cu quality factor K_Q(0 –10)

$$\Delta\varepsilon_{eff} = \Delta\varepsilon\left(K_d \frac{10}{K_Q}\right)$$

- Calculate mean cycles-to-failure (N_{f50})

$$N_f^{-0.6} D_f^{0.75} + 0.9 \frac{S_u}{E}\left[\frac{\exp(D_f)}{0.36}\right]^{0.1785 \log \frac{10^5}{N_f}} - \Delta\varepsilon = 0$$

- Calculate Distribution About the Mean to Determine the Time to First Failure



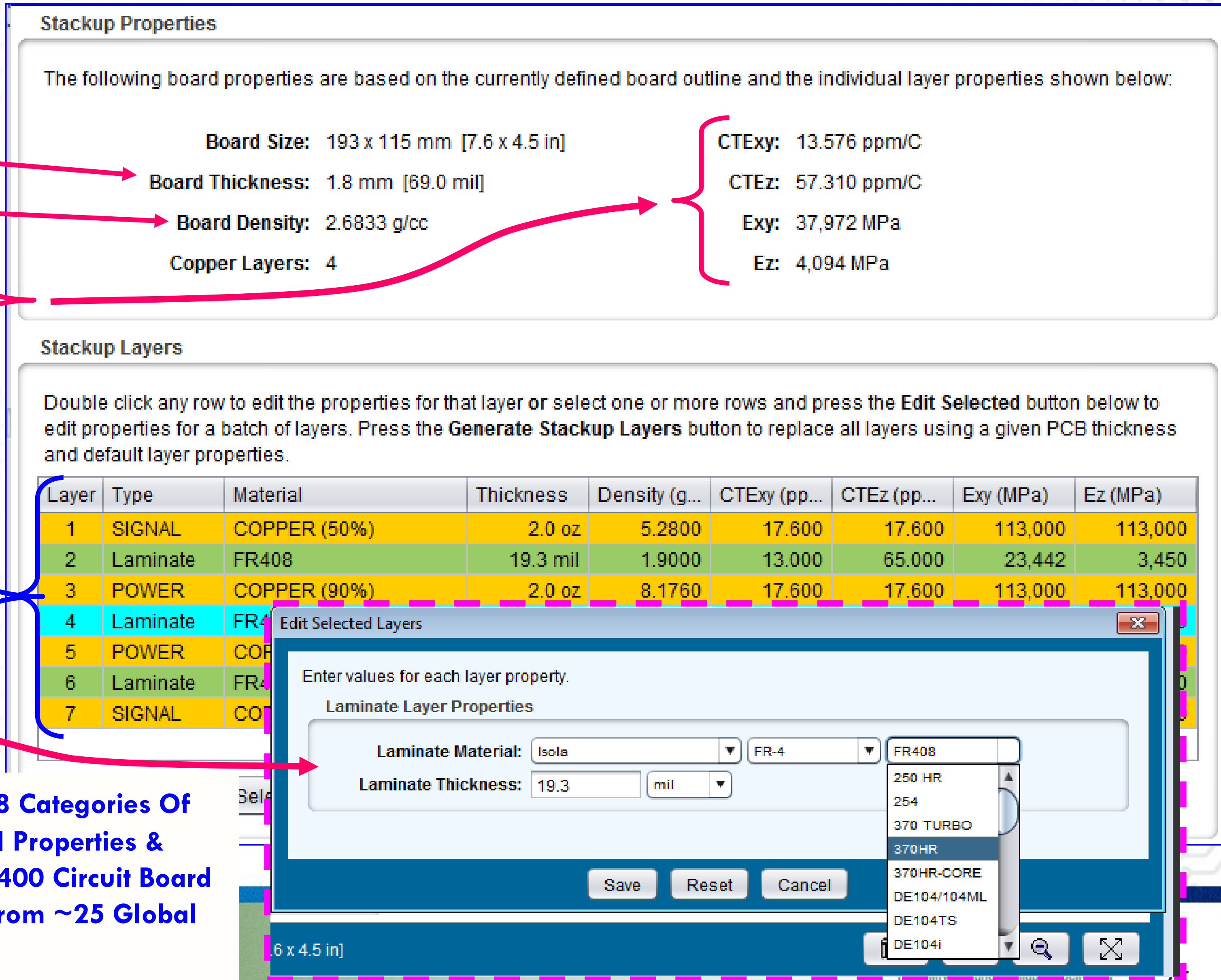
DfR Solutions

4a) Example of PCB Mechanical Stack Up Analysis Calculator

– Calculates fabricated PCB Properties from Dimensions & Materials for IPC-TR-579 Analysis

Calculates

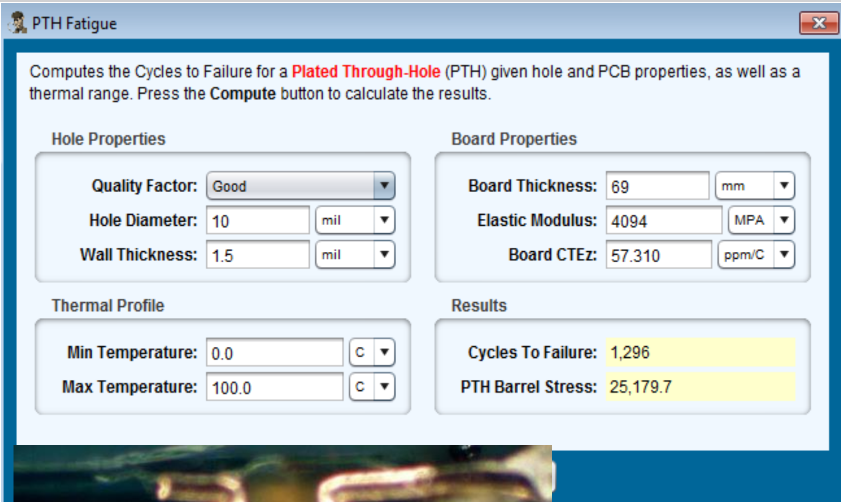
- Thickness
- Density
- CTE x-y
- CTE z
- Modulus x-y
- Modulus z
- From the material properties of each layer
- Using the Built in Laminate Data Library

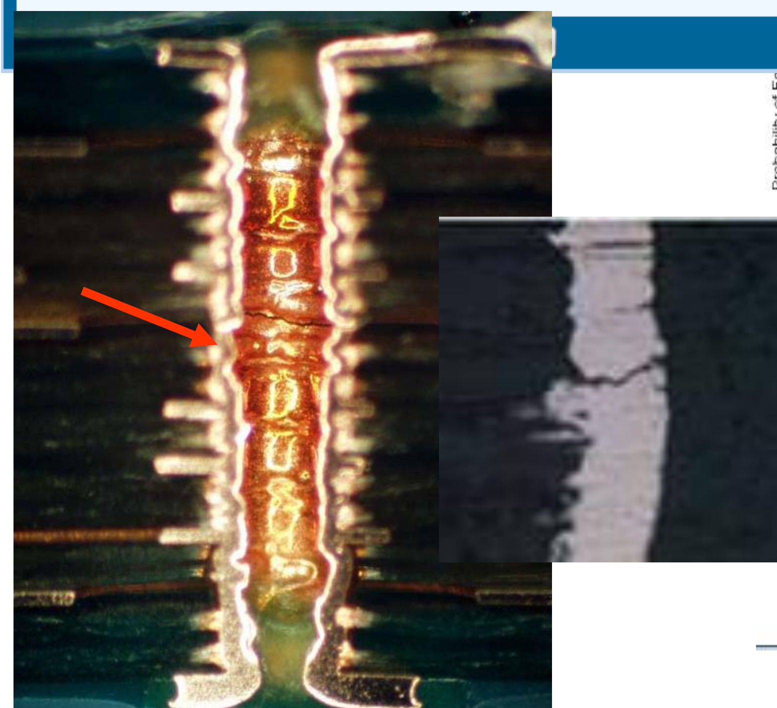


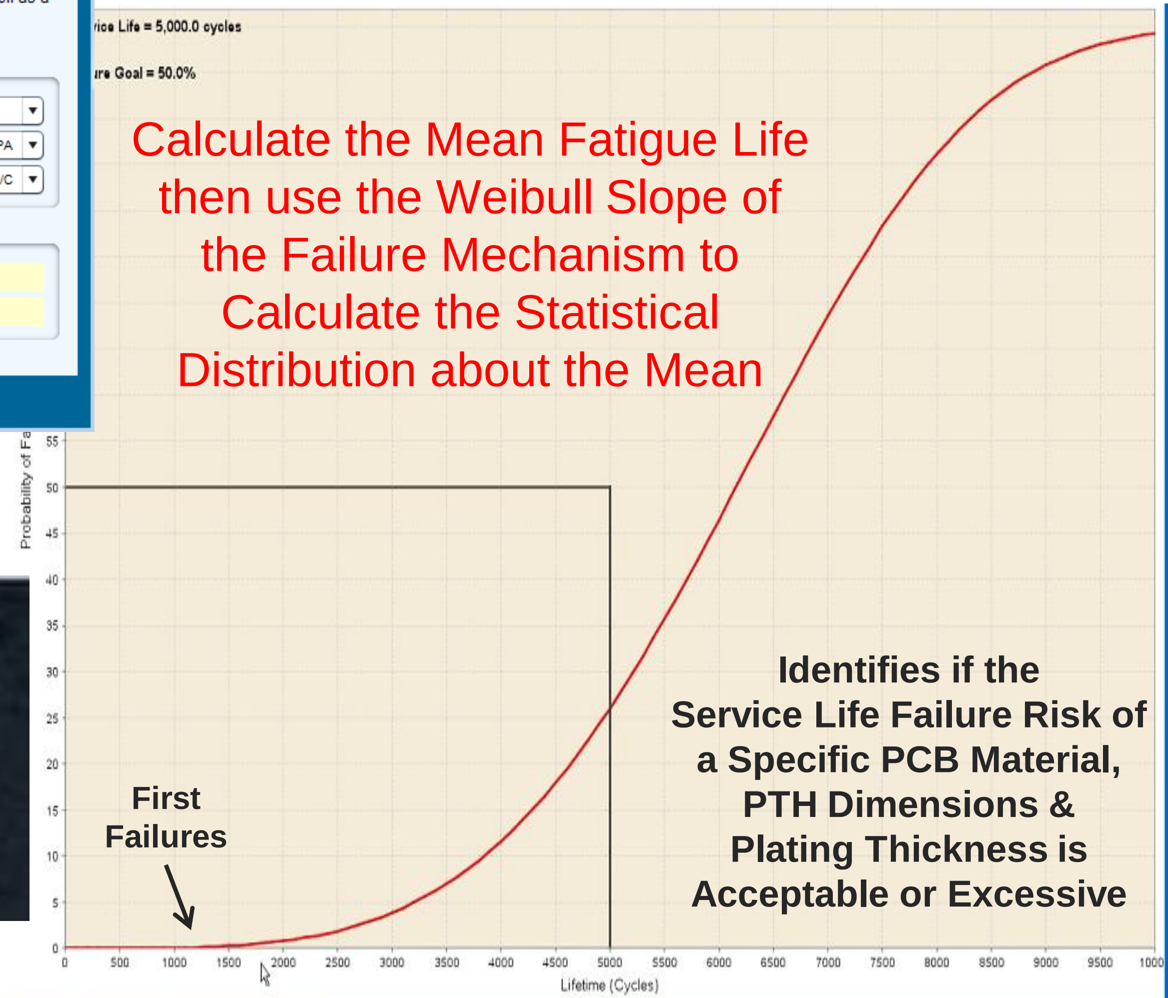
Layer	Type	Material	Thickness	Density (g...	CTExy (pp...	CTEz (pp...	Exy (MPa)	Ez (MPa)
1	SIGNAL	COPPER (50%)	2.0 oz	5.2800	17.600	17.600	113,000	113,000
2	Laminate	FR408	19.3 mil	1.9000	13.000	65.000	23,442	3,450
3	POWER	COPPER (90%)	2.0 oz	8.1760	17.600	17.600	113,000	113,000
4	Laminate	FR4						
5	POWER	COP						
6	Laminate	FR4						
7	SIGNAL	CO						

- **From a Library of 48 Categories Of PCB Laminate Material Properties & Characteristics from >400 Circuit Board Laminates Materials From ~25 Global Producers.**

4a) Example of Physics of Failure CAE App Calculator for PTH Fatigue Durability/Reliability Risk Assessments







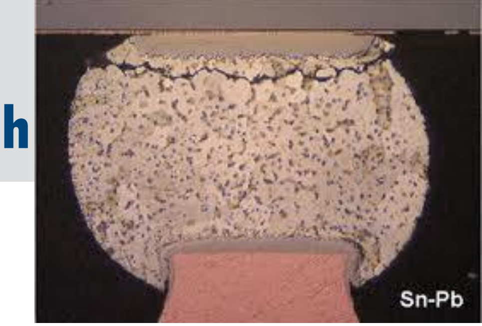
Calculate the Mean Fatigue Life then use the Weibull Slope of the Failure Mechanism to Calculate the Statistical Distribution about the Mean

First Failures

Identifies if the Service Life Failure Risk of a Specific PCB Material, PTH Dimensions & Plating Thickness is Acceptable or Excessive

DfR Solutions

4b) Example of a Thermal Cycling Solder Fatigue Model – Calculates Fatigue Life from Geometry & CTE Mismatch



- Modified Engelmaier
  - Semi-empirical analytical approach
  - Energy based fatigue

$$\Delta\gamma = C\frac{L_D}{h_s}\Delta\alpha\Delta T$$

- Determine the strain range ($\Delta\gamma$)
- Where: C is a function of activation energy, temperature and dwell time, L_D is diagonal distance, α is CTE, ΔT of temperature cycle & h is solder joint height
- Determine the shear force applied at the solder joint

$$(\alpha_2-\alpha_1)\cdot\Delta T\cdot L_D = F\cdot\left(\frac{L_D}{E_1A_1}+\frac{L_D}{E_2A_2}+\frac{h_s}{A_sG_s}+\frac{h_c}{A_cG_c}+\left(\frac{2-\nu}{9\cdot G_b a}\right)\right)$$

  - Where: F is shear force, LD is length, E is elastic modulus, A is the area, h is thickness, G is shear modulus, and a is edge length of bond pad.
  - Subscripts: 1 is component, 2 is board, s is solder joint, c is bond pad, and b is board
  - Takes into consideration foundation stiffness and both shear and axial loads *(Models of Leaded Components factor in lead stiffness / compliancy)*
- Determine the strain energy dissipated in the solder joint

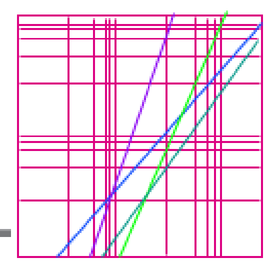
$$\Delta W = 0.5\cdot\Delta\gamma\cdot\frac{F}{A_s}$$

- Calculate Mean cycles-to-failure using:
  - An Energy Based model for SnPb
  - The Syed-Amkor model for SAC

$$N_f = (0.0019\cdot\Delta W)^{-1}$$

$$N_f = (0.0006061\cdot\Delta W)^{-1}$$

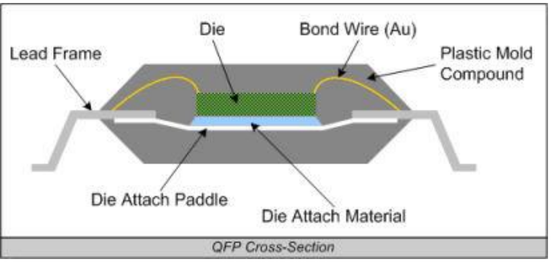
- Calculate Distribution About the Mean to Determine the Time to First Failure

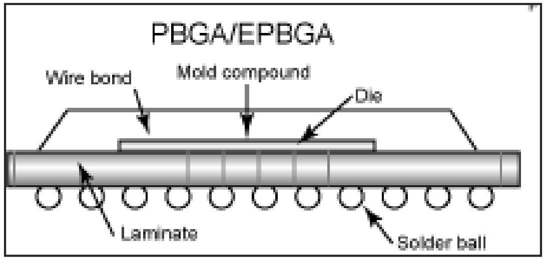


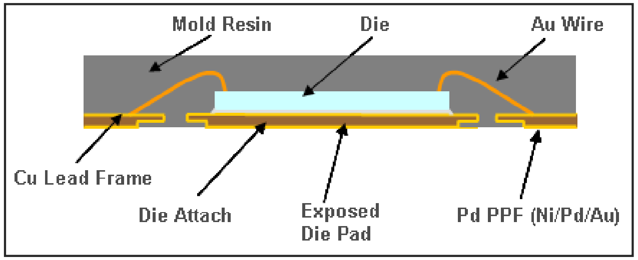
DfR Solutions

Comparison of PCB-IC Package Thermal Cycling Reliability Leaded IC, BGA & Flat No Lead Chip Scale Packages (CSP)

- Without a flexible terminal lead to absorb thermal Expansion/Contract motions, a high amount of thermal expansion stress is applied to the small, low profile under body solder joints, which accelerate solder fatigue failure.
- Solder Attachment Cycles to Failure
  - Order of magnitude (10X) reduction from QFPs
  - 3X reduction from BGAs







Gull Wing Leaded QFPs TTCL: >10,000 → Laminated BGAs: TTCL: 3,000 to 8,000 → FNL CSP: TTCL: 1,000 to 3,000

Package Type	Typical Thermal Cycles to Failure (-40C to 125C)
QFP	>10,000
BGA	3,000 – 8,000
QFN	1,000-3,000

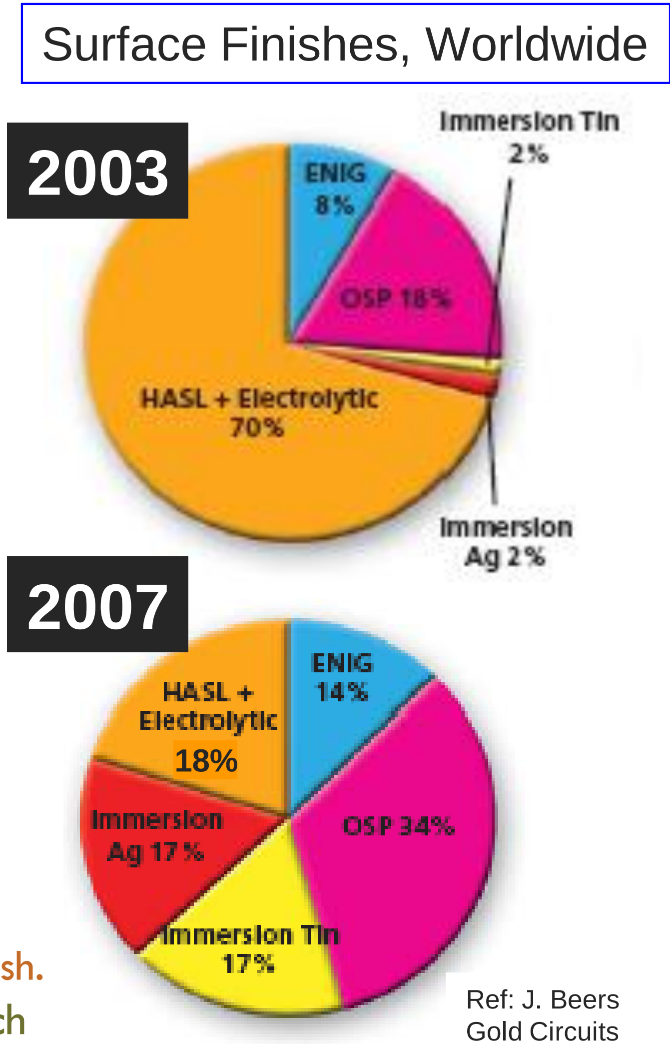
Typical Thermal Cycle Life -40° to +125°C

Variations Due to IC Package Size and PCB CTE Mis-Match Differences

DfR Solutions

5) PCB Surface Finishes - Post Pb-Free

- A circuit board surface finish is a coating over exposed PCB copper that prevents copper oxidation.
  - To ensure good solderability.
  - Must dissolves away during solder to enable bonding
- Prior to RoHS Tin-Lead Hot Air Solder Leveling (HASL) was the most popular surface finish due to:
  - Application Ease, Material Compatibility, Low Cost.
- Since RoHS Multiple Pb-Free Surface Finish Several Options Now widely used, but none dominate.
  - Each PCB surface has advantages & disadvantages for fabrication, solderability, testability, reliability, shelf life.
- The 5 most popular Pb-Free Surface Finishes are:
  1. Electroless nickel/immersion gold (ENIG)
  2. Immersion silver (ImAg)
  3. Immersion tin (ImSn)
  4. Organic Solderability Preservative (OSP)
  5. Pb-free HASL.
- No "Best Finish" - Not possible to universally require a single finish.
  - Instead propose an Appendix to define trade offs of each finish and the appropriate compensating measures.

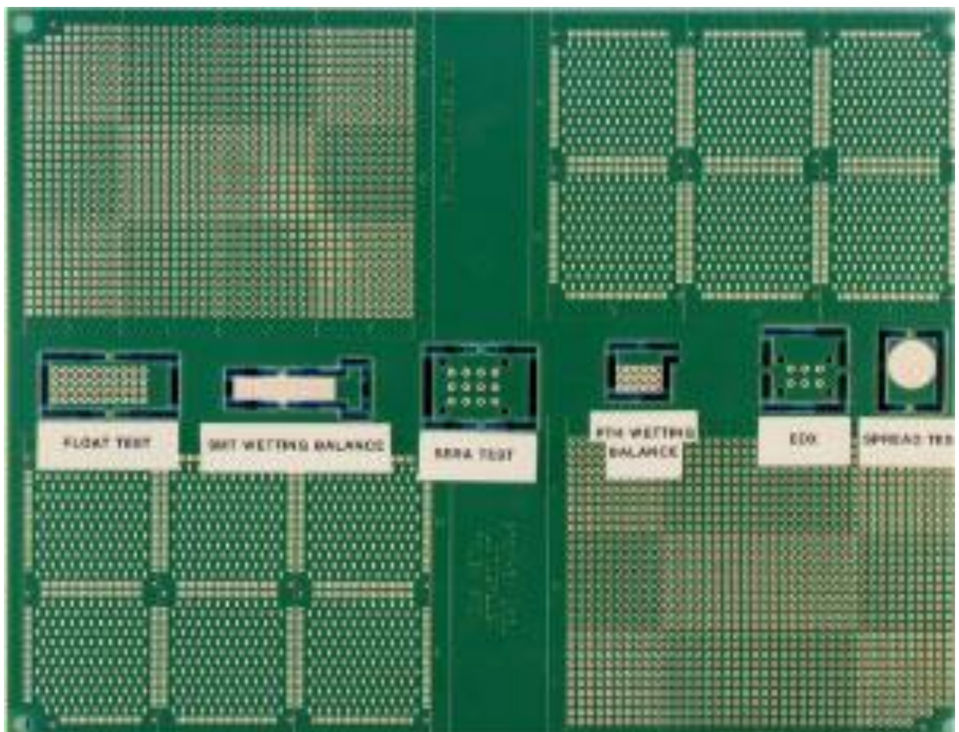


Ref: J. Beers Gold Circuits

DfR Solutions

6) Validation/Qualification of Bare PCBs

- Qualification, Stress Testing & Durability Characterization of PCB Materials & Design Feature is Performed on Daisy Chained Test Coupons.
  - Durability Stress Testing of Design Specific Bare PCBs is not practical
    - No easy way to detect failures on a Bare PCB
  - Durability Testing of an assembled PCBA that can be activated and monitored to detect failure is more practical.



DfR Solutions

6) Validation/Qualification of Bare PCBs

- However material properties and fabrication quality can be evaluated and certified by First Article Inspections (FAI) & Direct QRD Assessments.
  - A durability life test is a Indirect QRD Assessment where passing a life test is an indirect indicator that the item being tested has adequate QRD for the application.
  - Direct QRD assessments use IPC & PoF material science evaluations to:
    - Directly Measures or Evaluates If Critical to QRD Material Properties and Fabrication Parameter Have Been Achieved
    - Once the QRD of the formulation has been achieved, Evaluations to verify that the Formula is being followed are sufficient to verify the QRD will be achieved.
      - This is a foundation of the Materials & Chemical Industries
        - Verification that a proven fundamental formulation is being followed for each application of the technology.

DfR Solutions

6a) PCB Qualification & CoC's

Certificate of Conformance or Compliance to Requirements

- More Than One Way to Skin the Qualification Cat!
  - **Stress** Life Tests are not the only type of Qualification Methods
- CoC - A document certified by a competent authority that the supplied goods or service meets required industry of customer specifications
  - CoCs are a foundation of the Materials, Chemical and Fabrication Industries
  - Some CoCs are competent, others are not
    - What Specs are reference?,
      Check marks or Listing of measured values compared to the requirement
      - **Depends on competence of procurement specs, customer expectations, scrutiny & diligence**
- An AEC PCB Spec Could Include Defining a Recommended Auto Industry Common PCB CoC Format, Content & Procedures

Redacted PCB Certificate of Conformance Example:

[redacted] Co., Ltd

PCB Outgoing Inspection Report

HOLE AND SLOT MEASUREMENT

Customer	[redacted]	Part Number	[redacted]	Date :
LAYER	2	Quantity	0	

Hole Size (Unit：mm Tolerance:PTH ± 0.075 Non-PTH ± 0.050)

ITEM	Spec.	Actual	Result Acc	Result Rej	Remark PTH	Remark NP	ITEM	Spec.	Actual	Result Acc	Result Rej	Remrk PTH	Remrk NP
1	0.711	0.725	V		V								
2	0.914	0.925	V		V								
3	1.016	1.025	V		V								
4	2.997	3.000	V			V							
5	3.505	3.500	V			V							

OUTLINE DIMENSION–Unit: mm Tol. = ± 0.25mm

ITEM	Spec.	Actual	Result Acc	Result Rej	Remark	ITEM	Spec.	Actual	Result Acc	Result Rej	Remark
1	267.61	267.59	V								
	136.47	136.48	V								

[redacted] Co., Ltd

PCB Outgoing Inspection Report

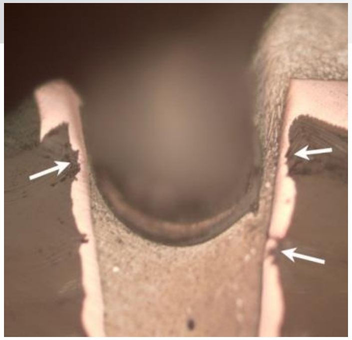
Customer	[redacted]	Part Number:	[redacted]	
Layer		Quantity:	Date:	[redacted]

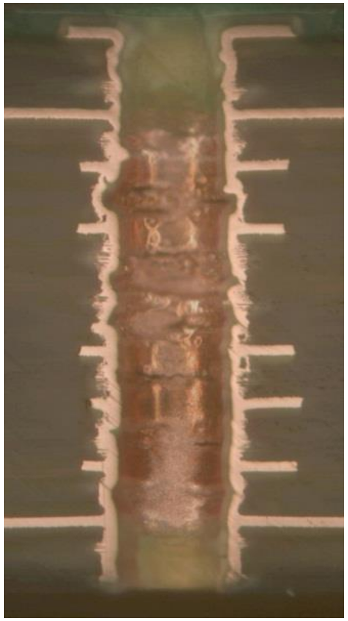
Item A.	Description	Specification	Actual	Results Acc	Results Rej
1	Date Code	N/A	N/A	V	
2	Flammability	N/A	N/A	V	
3	UL Logo	N/A	N/A	V	
4	Material	FR4	FR4	V	
5	Board Thickness	1.60mm ± 10%	1.61mm	V	
6	Color of Solder Mask	GREEN	GREEN	V	
7	Color of Legend	WHITE(1 side)	WHITE(1 side)	V	
8	Min. Conductor Width	14mil ± 20%	14.553mil	V	
9	Min. Conductor Space	9mil ± 20%	10.379mil	V	
10	Bow & Twist	≦0.7%	0.10%	V	
11	Surface Cu Thickness	N/A	N/A	V	
12	Min. PTH Cu Thickness	N/A	N/A	V	
13	Surface finish	HASL LF(RoHS compliant)	HASL LF	V	
14	Gold Thickness	N/A	N/A	V	
15	Inside Layer Cu Thickness	N/A	N/A	V	
16	G/F Bevelling	N/A	N/A	V	
Item B.	Electric Test Condition				
1	Voltage	150V Min.	150V	OK	
2	Insulation Resistance	2M OHM Min.	10M OHM	OK	
3	Continuity Resistance	50 OHM Max.	20 OHM	OK	
Item C.	Visual Inspection				
1	Copper Pattern	OK			
2	Solder Mask Integrity	OK			
3	Legend Pattern Integrity	OK			
4	Hole Quantity	OK			

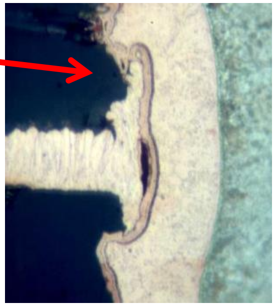
Approved [redacted] Ispected By : [redacted]

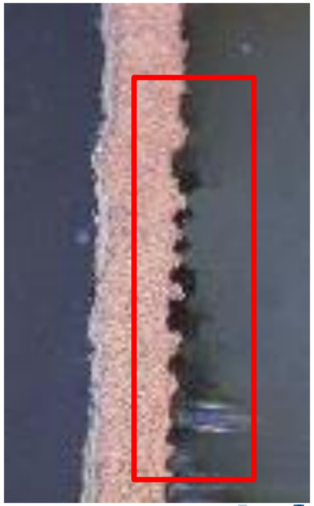
6a) Examples of Micro Sectioning Per IPC-IPC-TM-650-2.1.1.2a for PCB PTH Quality Assessments "First Article Inspection" - Since PCB Drill & Cu Plating Defects Will Weaken the Copper Barrel Which Will Hasten PTH Via Barrel Failure

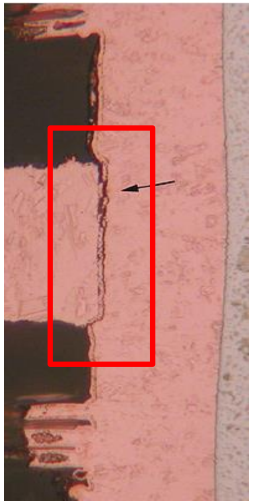
- Drilling Quality Issues & Defects
  - Glass Fiber Protrusion into Copper
    - From Rough Drilling/Dull Drill Bit
  - Irregular Drill Hole Walls
    - From Rough Drilling/Dull Drill Bit
  - Nail Head Separation
    - From Drilling Damage To Inner Copper Layers
  - Copper Pull Away From Drill Hole Walls or Inner Layer Connection Separation
    - From Drill Smear Residue/Improper De-Smearing Cleaning Process









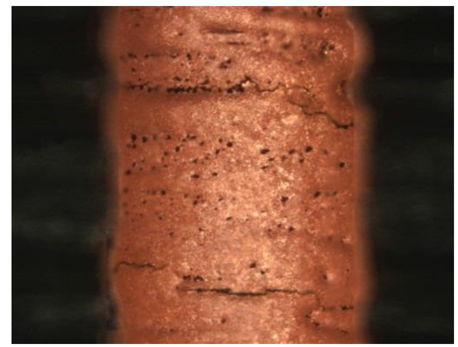


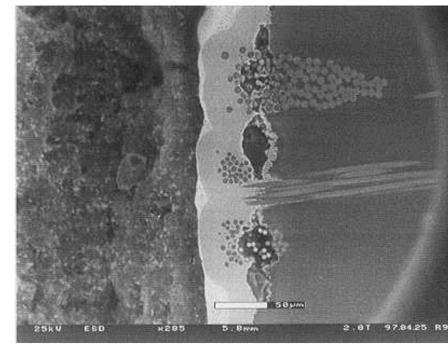
DfR Solutions

6a) Examples of Micro Sectioning Per IPC-IPC-TM-650-2.1.1.2a for PCB PTH Quality Assessments "First Article Inspection" - Since PCB Drill & Cu Plating Defects Will Weaken the Copper Barrel Which Will Hasten PTH Via Barrel Failure

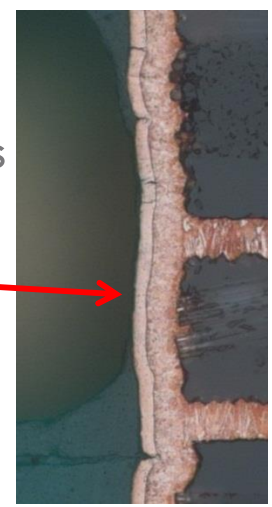
- Plating Quality Issues & Defects
  - Insufficient Plating Thickness
    - From Low Electroplating Current,
      Weak Plating Solution,
      Time in Solution too short

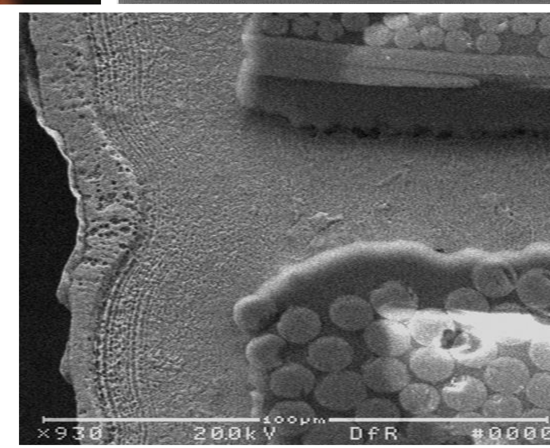
  - Plating Voids
    - From Air Bubbles &
      Plating Solution Quality Issues





  - Differences/Defects in Plating Layers
    - Use of Different Types of Plating Methods & Solutions can produces multiple copper stratification layers. Differences in strength, porosity, brittleness . . , etc. between the layer can lead to cracking failures .





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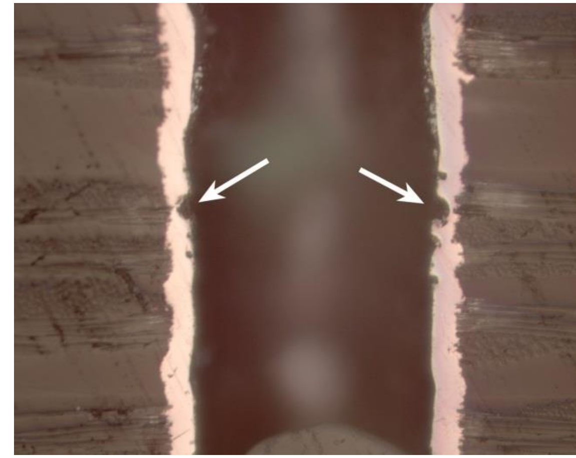
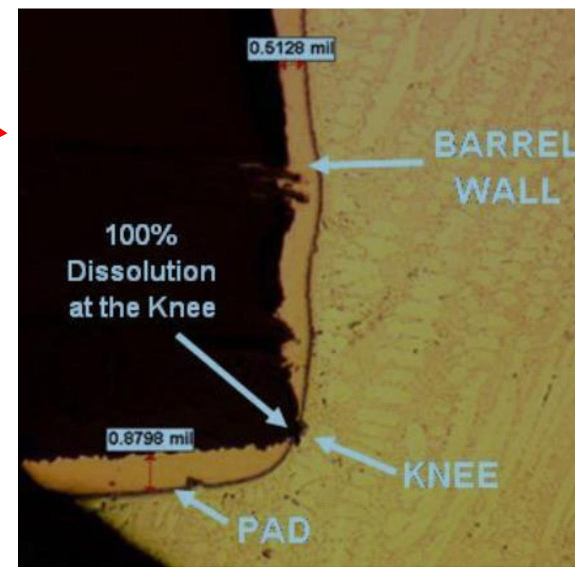
6a) Examples of Micro Sectioning Per IPC-IPC-TM-650-2.1.1.2a for PCB PTH Quality Assessments "First Article Inspection" - Since PCB Drill & Cu Plating Defects Will Weaken the Copper Barrel Which Will Hasten PTH Via Barrel Failure

- Damage to Via Copper Plating
  - Etch Pits Holes in Barrel Plating
    - Etchant Residues Trapped in Vias From Improper Outer Layer Etching or Rework Process and Follow Up Cleaning.



  - Copper Dissolution
    - Copper Dissolved into Lead Free Solder due to Excessive Exposure to Liquid Lead Free Solder



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Conclusions:

- There is no universal Circuit Board Spec
  - PCBs need to be a cost effective, solution **engineered for the application and the E/E components the PCB carries**, to achieve:
    - Degradation free endurance of Assembly Soldering Thermal Stresses
    - For Durability/Reliability of the PCB and the PCB Assembly
- There is an Rich Foundation of Existing PCB Specifications that can be Leveraged/Referenced in an AEC Spec for Selecting and Qualifying PCB for various types of automotive applications.
  - To provide guidance for specifying a PCB with optimum critical to QRD parameters for each of the wide range of automotive E/E applications.
    - Under hood, Passenger Compartment, Infotainment, Hybrid-Elect . . .
  - Focus of a PCB Qualification Spec
    - Materials Properties
    - Verification of PCB Fabrication Quality (Absence of Defects) by Direct Assessments, documented in an auto industry common CoC
      - Impractical to Life Stress Test a Design Specific, Bare PCB
      - Faster & Lower Cost than Stress Life Testing

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Discussion - Moving Forward

- Assemble a team of PCB Experts from AEC Member and Interested Companies
  - To meet monthly via conf. call and/or face to face meeting to refine the proposal and develop the AEC PCB Specification.
  - Objective to develop and draft the AEC PCB spec for review at 2015 AEC Reliability Workshop

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Questions & Discussion

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reliability designed, reliability delivered

Thank you!

For Further Questions / Discussion or to Request to be on the AEC PCB Spec Team?

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