Impact of Halogen-Free PCB Material on PCIe® Signaling

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Agenda

- What does “Halogen-Free” mean and what is the impact?
  - ✓ Background, environment concerns, and government regulations
  - ✓ Material properties and electrical impact
- Standard FR-4 versus Halogen Free PCB signal integrity results
  - ✓ Pre-Silicon simulation data
  - ✓ Post-Silicon electrical validation data
- Summary

Acronyms

- PCB: Printed Circuit Board
- HF: Halogen-Free
- FR-4: designation for fiberglass reinforced epoxy laminates that are Flame Retardant
- RoHS (Restriction of Hazardous Substances Directive): regulations that restrict the use of certain hazardous substances in new electronic equipment
- Dk: permittivity or dielectric constant
- Df: dissipation factor

Halogen-free Background

- Halogenated flame retardants are used in various materials
  - Substrate, PCB laminate, Mold compounds, Cables
  - Flux materials
- Going “Halogen-free” changes the flame retardant used for epoxy laminate materials and, thus the fundamental composition of resin materials is different
- There is movement in the industry to transition from halogenated materials to “halogen-free” due to environmental concerns
  - ✓ Not currently government mandated but could be in the future; RoHS may legislate in future
  - ✓ Eco-labels award products that meet environmental requirements, such as Halogen reduction; Thus it is a competitive advantage for some companies to claim they are ‘halogen-free’

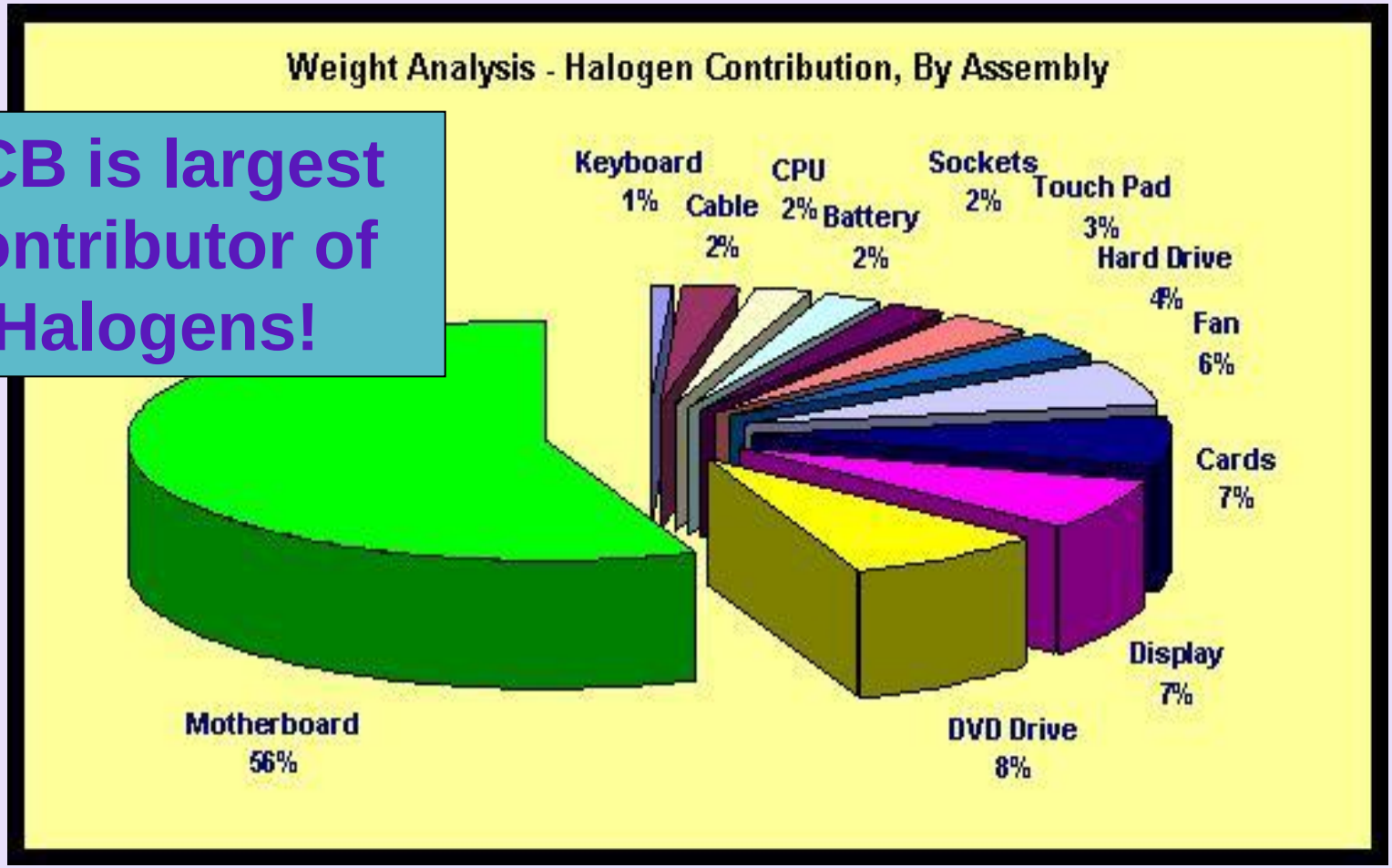
Halogen-free Legislation Likely Being Written Into RoHS Revision

- Potential Legislation:
  - ✓ The European Parliament draft report on the RoHS recast has just been made public and contains bans on flame retardants, PVC, and chlorinated plasticizers.
  - ✓ Some other chemicals listed include: Arsenic compounds, Beryllium and its compounds, Antimony trioxide and Dinickel trioxide.

Halogen-free Legislation Potentially Targeted at 2014 – Update Expected Q3' 2010

Halogen Profile of a Typical Generic Notebook PC

PCB is largest contributor of Halogens!



Note : 209 components analyzed, power adapter not included

Ack: Scott O'Connell (Dell)

PCB Material Properties Impacted by Halogen-free

Electrical differences	Reliability
Dk (Dielectric Constant) Df (Dissipation Factor) Moisture diffusivity	Via reliability (IST) CAF Assembly Compatibility Pad crater
Mechanical Differences	**Processing**
Flexure modulus Peel strengths	Lamination impacts Drilling impacts Plating impacts
Thermal differences	**Stability of Formulation**
CTE Tg Td Thermal diffusivity	Multiple lots

Electrical differences are main concern for signal integrity
Capitalize on halogen-free pluses and mitigate the negatives

Summary of Initial Data on PCB Properties

HF impacts many PCB properties; Dk and Df are main concerns for signal integrity

Property	Unit	HF	FR4	Affects
Tg (Glass transition temp)	C	X		Less Z axis expansion
Td (Thermal delamination temp)	C	X		Thermal processing/Assembly
CTE Z >Tg	PPM/C	X		MB Via reliability
Copper Peel strength	Kn/m		X	Pad adhesion
Flexure strength X/Y	PSI			HF is slightly stiffer: application dependant
Dk (Dielectric Constant)	1Mhz/1Ghz		X	Impedance: could affect line width; Crosstalk
Df (Dissipation Factor, Loss)	1Mhz/1Ghz	X		Less loss benefits longer channels
Moisture Absorption	%	X		Moisture will have less effect on Dk/Df

X - better for platform performance

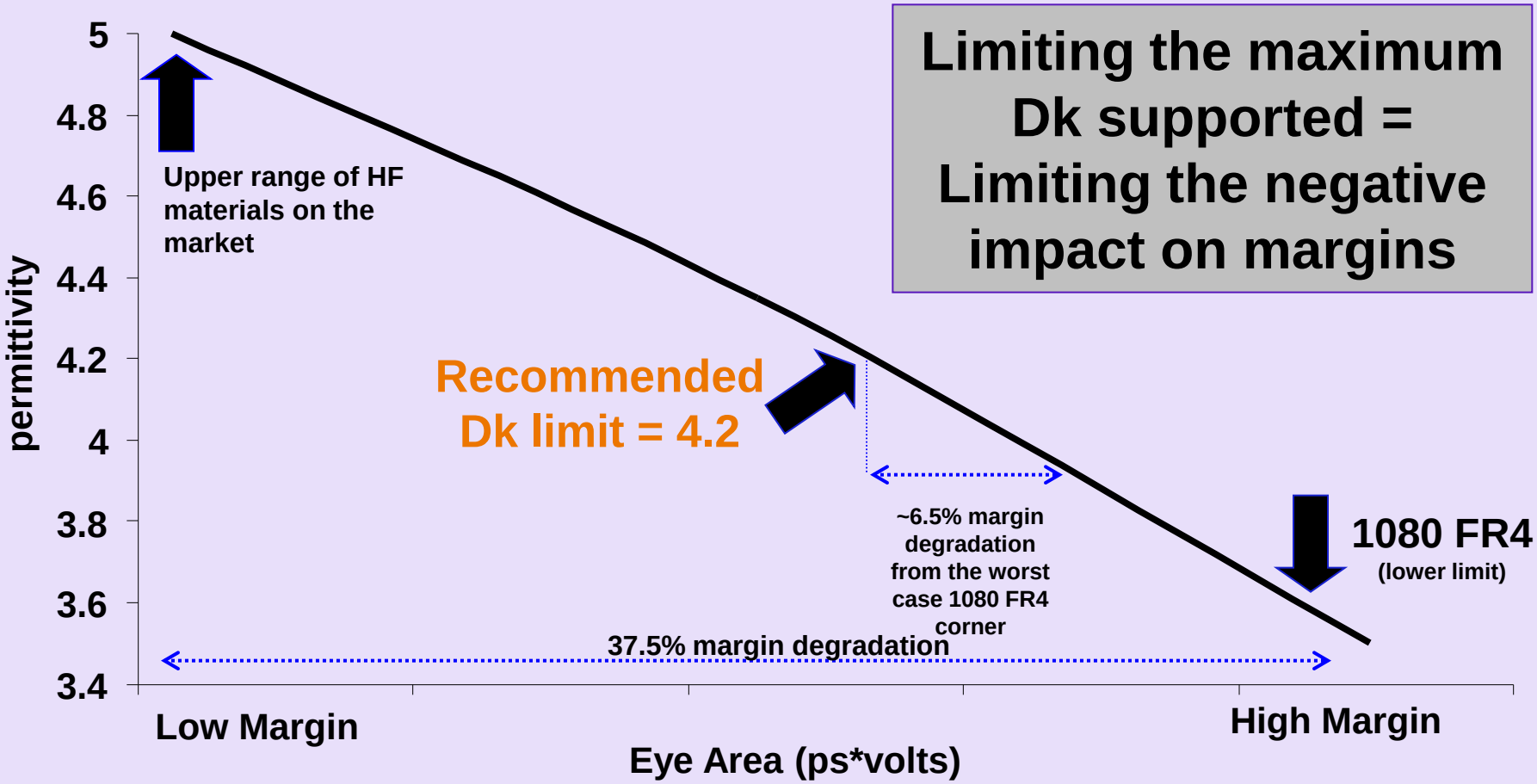
□ - property impacts signal integrity

Electrical Impact of Halogen-free

- Dk is higher and has a wider range than standard FR4
  - ✓ Impacts Impedance (lower), Crosstalk (higher), Propagation velocity (slower)
  - ✓ Standard 1080 FR4: 3.6<er<3.9
  - ✓ HF FR4: 3.6<er<5.2
- Df is lower than standard FR4
  - ✓ Dictates signal attenuation
  - ✓ Standard 1080 FR4: 0.025
  - ✓ HF FR4: 0.023
- Impacts of HF impedance adjustments:

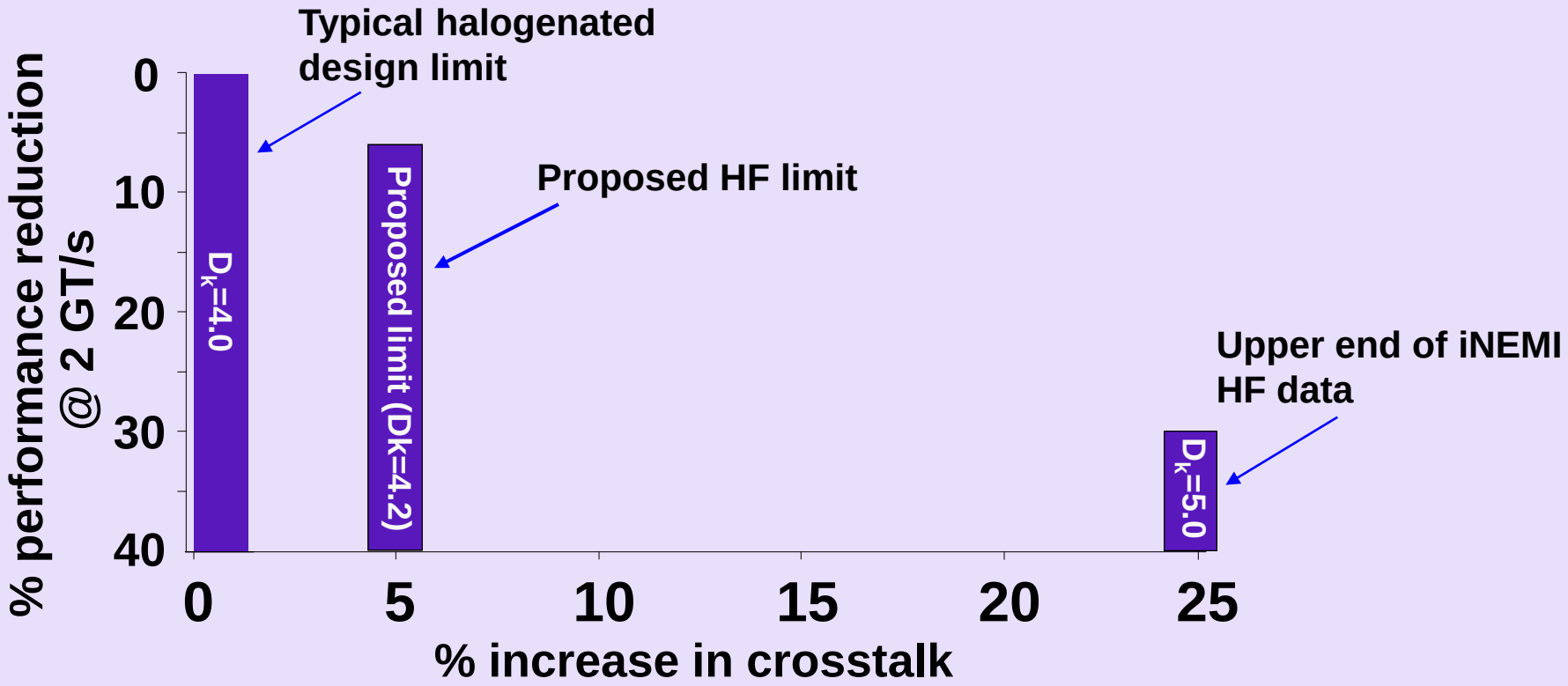
Increase dielectric thickness	Decrease trace width	Maintain original trace width and dielectric thickness
•Increased cross talk •May result in different prepreg/glass styles being used	•Increased signal loss •Cost/capability issues for fabrication - Trace width capability; Impedance tolerance capability	•Lower impedance target value

Eye Area vs. Dielectric Constant



Note: The dielectric thickness was adjusted for a constant impedance of 50 ohms; 2 GT/sec; 3 coupled microstrip lines; 10 inches long; 4 mil wide; 12 mils between traces

Bus Performance vs. Crosstalk



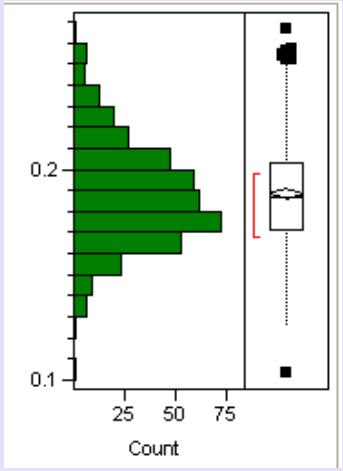
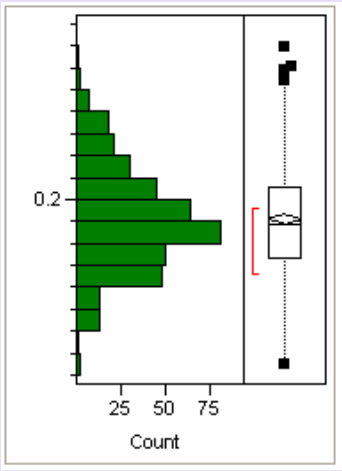
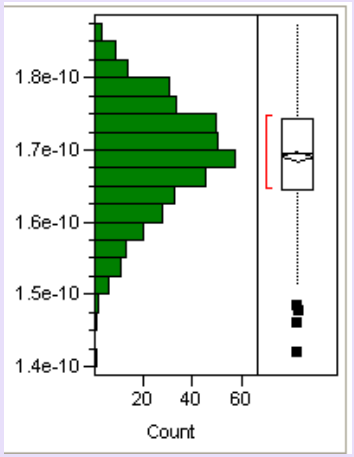
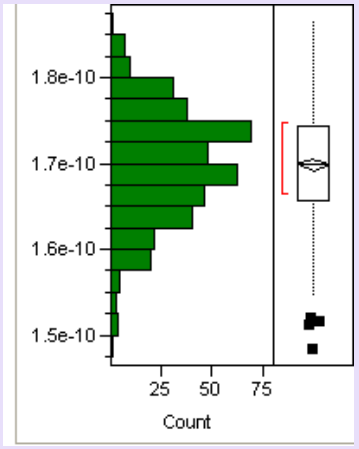
Higher Dk leads to reduced performance for the same board area

Signal Integrity Analysis Setup

- Mobile analysis:
  - ✓PCIe 2.0 Graphics Device down topology
  - ✓Half-swing with 3.5db de-emphasis driver
  - ✓8” motherboard length; 85ohm differential impedance; all stripline routing
  - ✓Type 3 PCB (Plated-through-hole vias, used in mainstream mobile systems)
  - ✓Type 4 PCB or High-Density Interconnect (buried vias and micro vias, used in small form-factor mobile systems)
- Desktop analysis:
  - ✓PCIe 2.0 Graphics Device down topology
  - ✓Full swing with 3.5dB de-emphasis or 6dB de-emphasis driver
  - ✓80ohm differential impedance; all microstrip routing
  - ✓Analyzed both short channel and long channel configurations

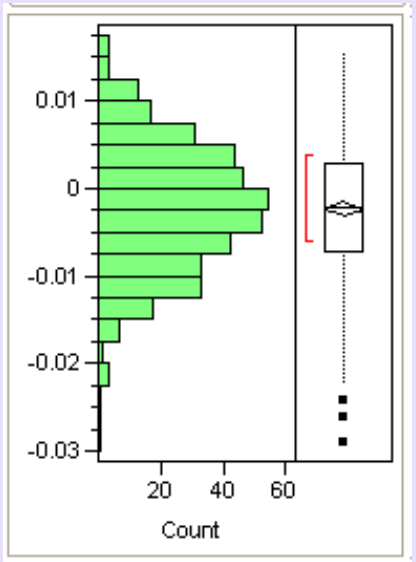
Mobile Analysis
Type 3 PCB; 85ohms; stripline routing

Distribution of margins over 400 cases; Lower loss tangent associated with HF PCB improves eye height margins; HF has less impact on eye width

		Standard FR4	Halogen-free
Eye Height	Max	 +2mV	
	Median	+3mV	
	Min	+22mV	
Eye Width	Max	 +1ps	
	Median	+0ps	
	Min	+6ps	

Mobile Analysis
Type 3 PCB; 85ohms; stripline routing

Eye Height Delta (V)

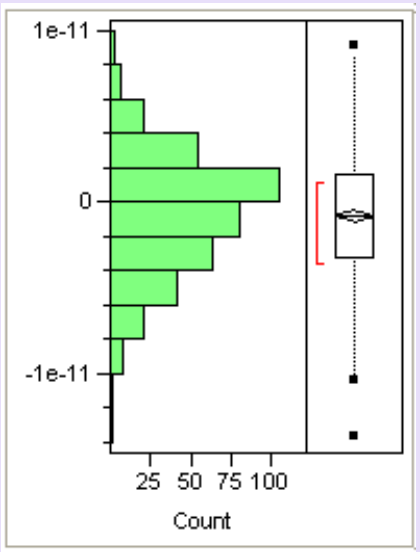


Quantiles

100.0%	maximum	0.0156
99.5%		0.0153
97.5%		0.0118
90.0%		0.0069
75.0%	quartile	0.0029
50.0%	median	-0.0022
25.0%	quartile	-0.0073
10.0%		-0.0122
2.5%		-0.0169
0.5%		-0.0260
0.0%	minimum	-0.0291

Up to 16mV improvement in margins or down to 29mV degradation in margins

Eye Width Delta (seconds)



Quantiles

100.0%	maximum	9.2e-12
99.5%		8.4e-12
97.5%		6.56e-12
90.0%		3.6e-12
75.0%	quartile	1.6e-12
50.0%	median	-8e-13
25.0%	quartile	-3.2e-12
10.0%		-5.6e-12
2.5%		-8.68e-12
0.5%		-1.04e-11
0.0%	minimum	-1.36e-11

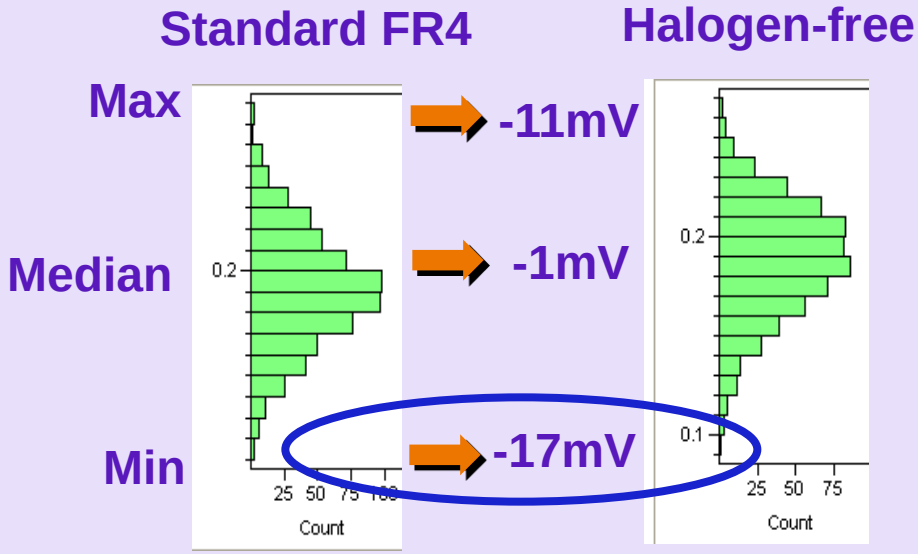
Up to 9ps improvement in margins or down to 14ps degradation in margins

HF vs Standard FR-4 delta in margins for 400 cases; Case-to-case comparison where only difference was standard FR4 vs HF PCB

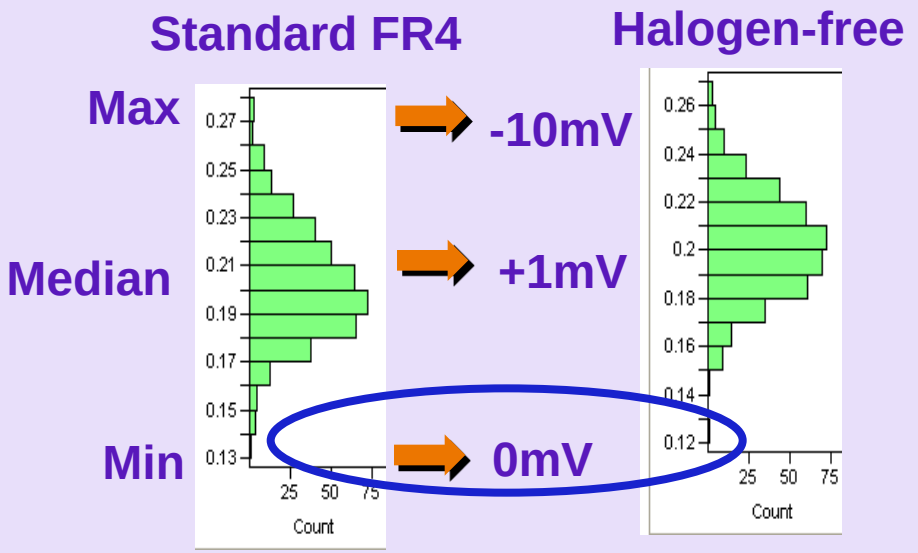
Mobile Analysis
Type 4 PCB; 85ohms; stripline routing

- Distribution of eye height margins over 400 cases
- Trace widths for Type 4 PCB are ~3 - 3.5mils
- Moving to HF requires a decrease in trace width in order to maintain the same impedance; negative impact on margins
- Reducing motherboard length reduces negative impact of HF

Motherboard Length = 10”



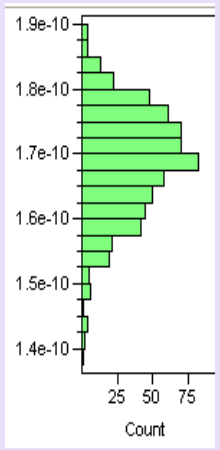
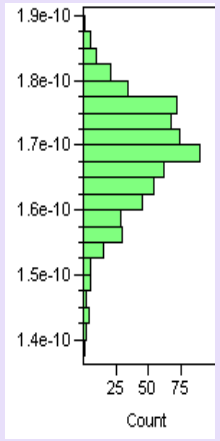
Motherboard Length = 8”



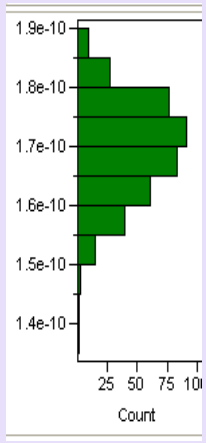
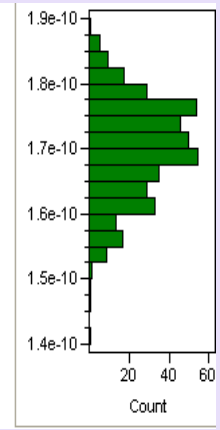
Mobile Analysis
Type 4 PCB; 85ohms; stripline routing

- Distribution of eye width margins over 400 cases
- Trace widths for Type 4 PCB are ~3-3.5mils
- Moving to HF requires a decrease in trace width in order to maintain the same impedance
- Reducing motherboard length has little impact on eye width

Motherboard Length = 10”

	Standard FR4		Halogen-free
Max		→ 0ps	
Median		→ +1ps	
Min		→ 0ps	

Motherboard Length = 8”

	Standard FR4		Halogen-free
Max		→ 0ps	
Median		→ +1ps	
Min		→ +1ps	

Impact of Loss Tangent

- Sweep trace length and loss tangent values and compare eye height and width
  - ✓ Loss tangent simulated: 0.010, 0.013, 0.015, 0.018, 0.021
  - ✓ Motherboard simulated: 6, 7, 8, 9, 10”
- The reduction in loss tangent associated with halogen-free benefits margins at longer routing lengths

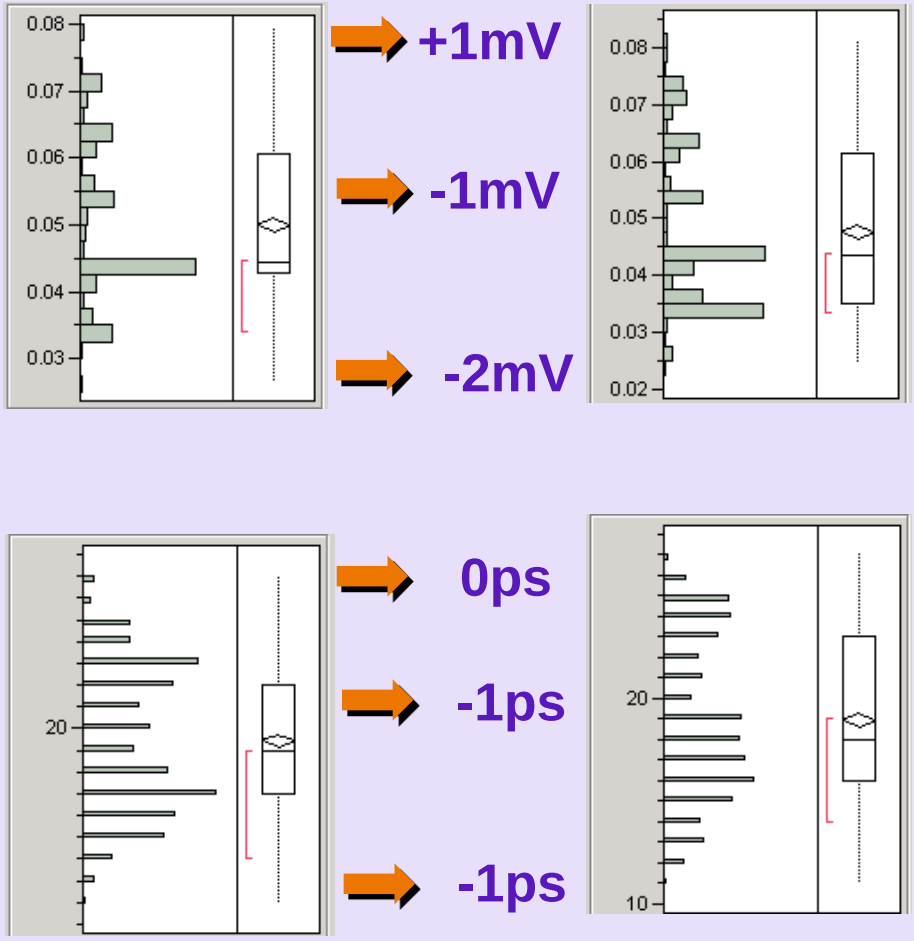
MB (inch)	tand value and Eye height					
tand-->	0.010	0.013	0.015	0.018	0.021	0.023
6	3	1	-1	-2	-4	baseline
7	5	4	2	-1	-3	baseline
8	6	3	1	-2	-5	baseline
9	8	5	3	0	-4	baseline
10	9	7	4	1	-2	baseline

MB (inch)	tand value and Eye width					
tand-->	0.010	0.013	0.015	0.018	0.021	0.023
6	4	5	5	7	7	baseline
7	4	5	5	6	7	baseline
8	4	5	6	7	7	baseline
9	5	4	4	3	2	baseline
10	8	9	8	7	6	baseline

Desktop Analysis
Short channel (5”); 80ohms; microstrip routing

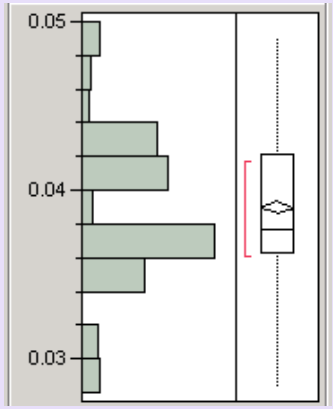
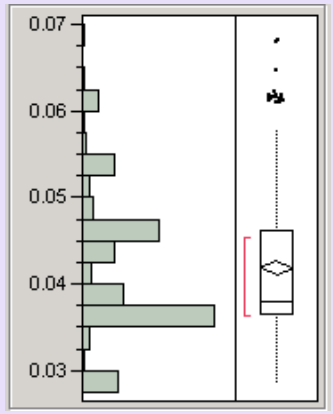
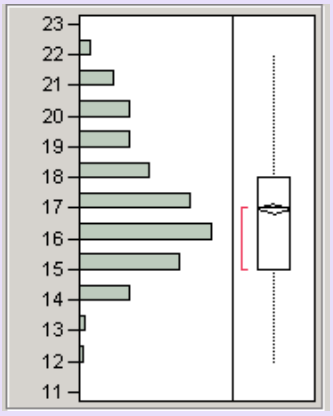
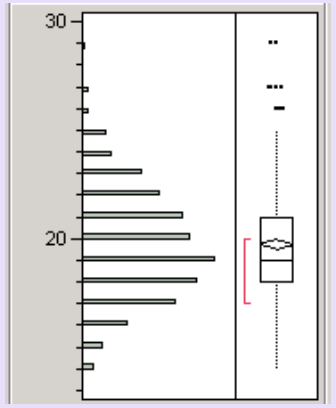
Distribution of margins over 480 cases; At short channel lengths, halogen-free has little impact on eye height or width

		Standard FR4	Halogen-free
Eye Height	Max	+1mV	
	Median	-1mV	
	Min	-2mV	
Eye Width	Max	0ps	
	Median	-1ps	
	Min	-1ps	



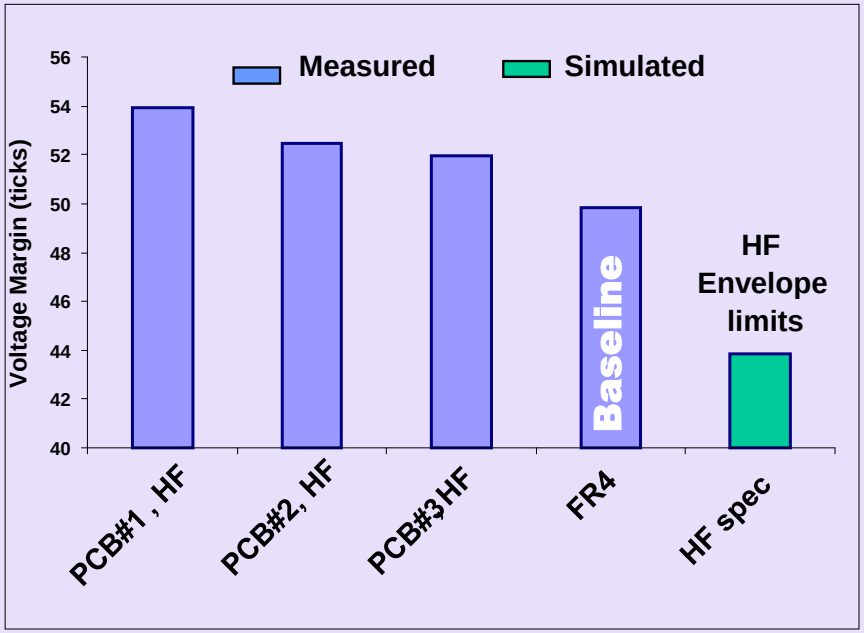
Desktop Analysis
Long channel (8”); 80ohms; microstrip routing

Distribution of margins over 480 cases; At long channel lengths, halogen-free has little impact on eye width but more impact on eye height

		Standard FR4		Halogen-free
Eye Height	Max		+20mV	
	Median		0mV	
	Min		0mV	
Eye Width	Max		+7ps	
	Median		+2ps	
	Min		+2ps	

Desktop Analysis
Simulated and measured impact of HF materials

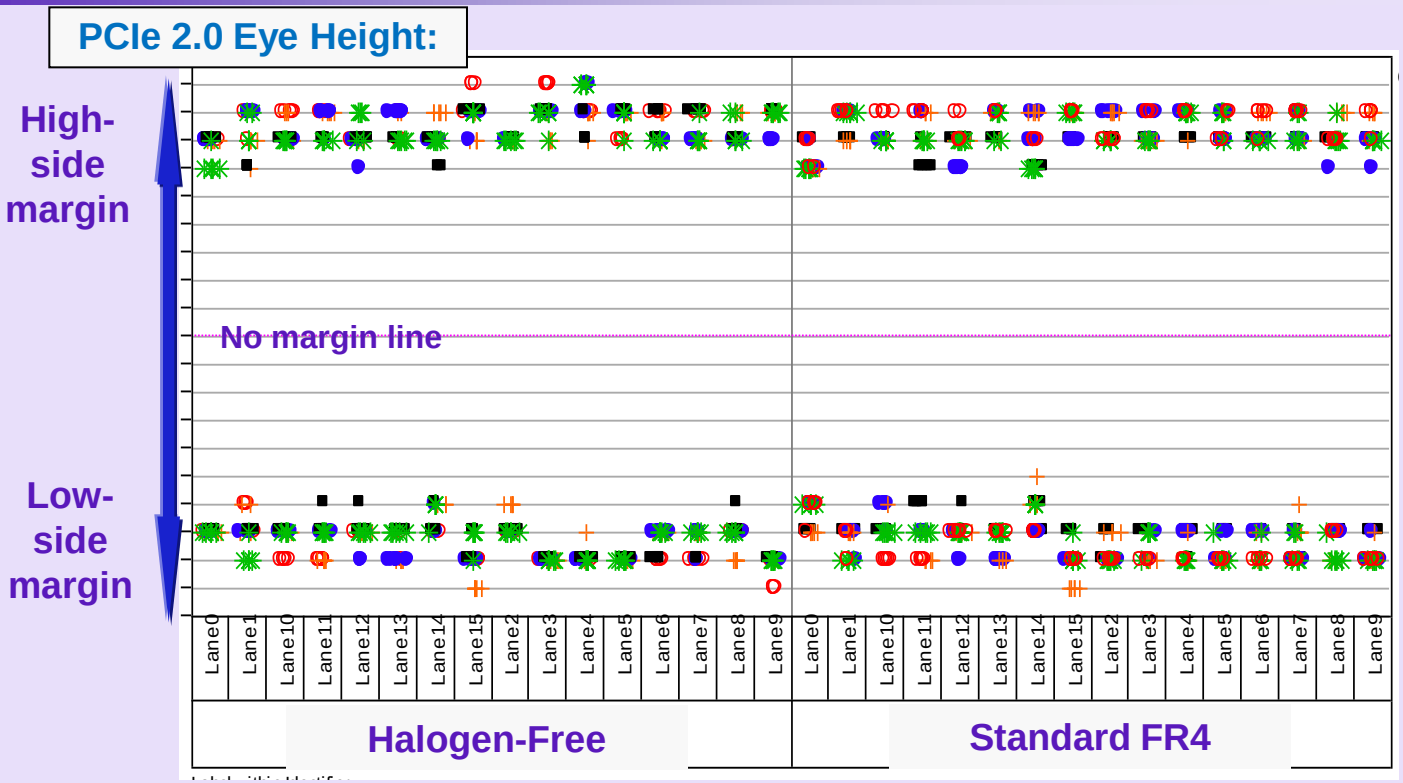
Measured & simulated PCIe 2.0 margin vs FR4 baseline
(~ 200 measurements per material on 4 boards, 2mV/tick)



Measurements show better margins than simulated data since HF boards tested have lower loss tangent then the spec max

PCB	Dk
PCB#1	4.15
PCB#2	4.17
PCB#3	4.4
FR4	3.8

Mobile Analysis
Type 3 PCB, Electrical validation



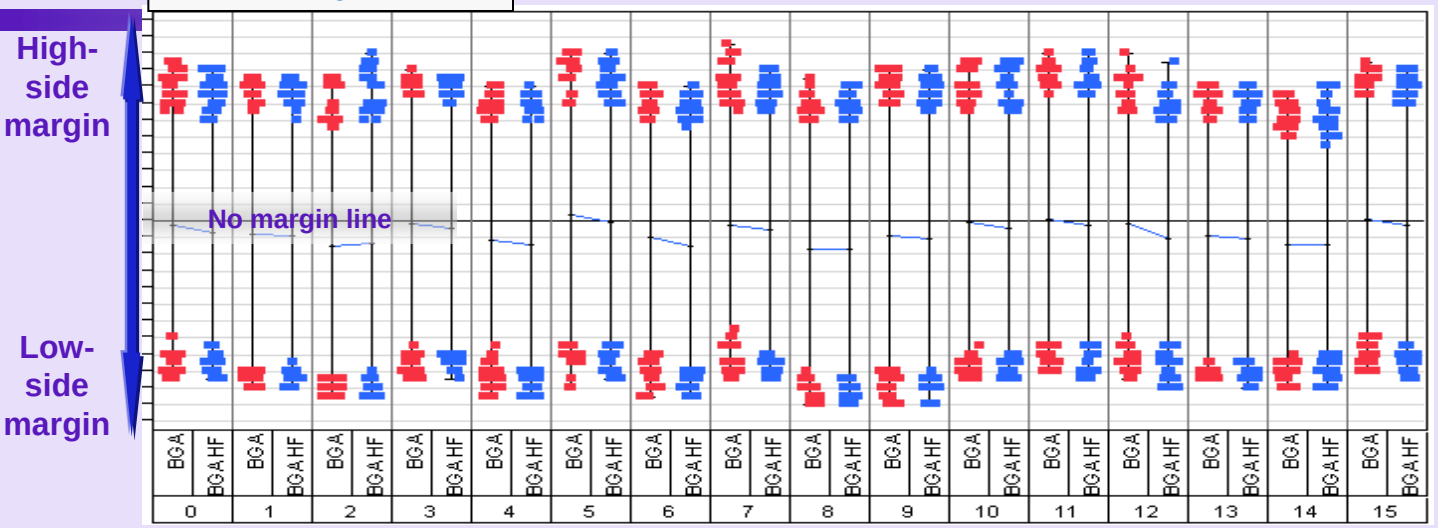
* Scale: each tick = 10mV

- Selected HF and Standard FR4 reference boards with similar impedance
  - ✓ Ran test 5 times with 5 CPUs on each board
  - ✓ Measured Eye height on PCIe Graphics 2.0

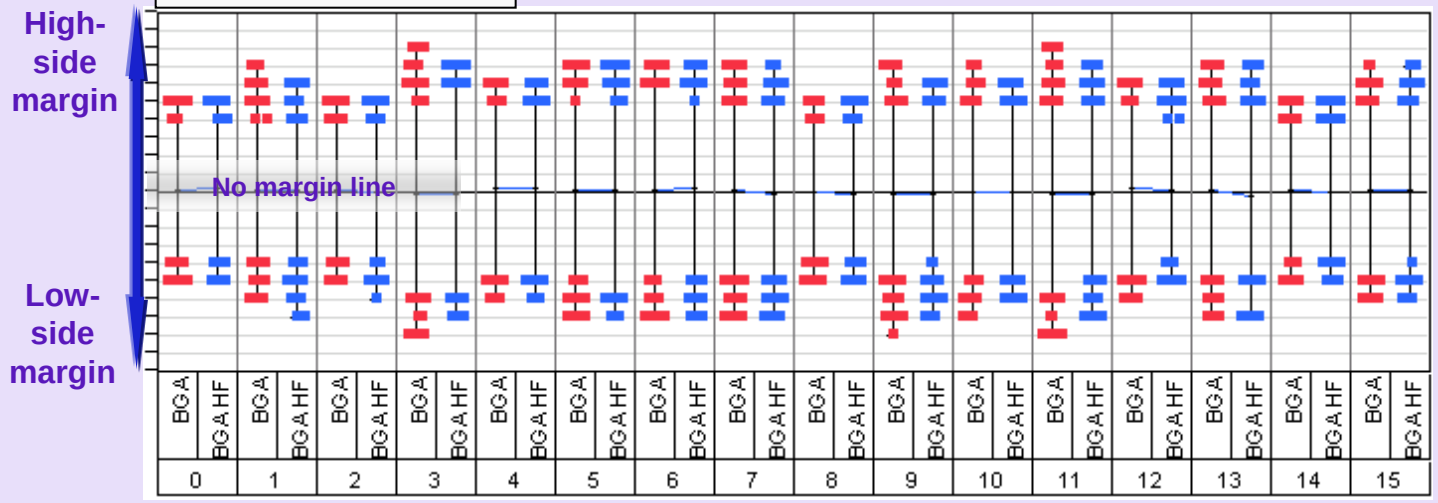
Similar margins observed on HF and Standard FR4 boards

Mobile Analysis
Type 4 PCB, Electrical validation

PCIe 2.0 Eye Width:



PCIe 2.0 Eye Height:



*** Scale: each tick = 3.3ps or 10mV**

- Selected HF and Standard FR4 reference boards with similar impedance
- Ran test with 5 CPUs on each board
- Measured Eye width and height on PCIe Graphics 2.0

Similar margins observed on HF and Standard FR4 boards

- Standard FR4
- Halogen-free

Summary

- Industry trend is to move to halogen-free materials for PCB manufacturing
- Using Halogen-free PCB changes the material properties we assume when running PCIe signal integrity analysis
  - ✓ Dk is higher and has a wider range than standard FR4
  - ✓ Df is lower than standard FR4
- The impact of Dk can be minimized by limiting the supported range to be <= 4.2
  - ✓ Before implementing halogen-free on your designs, verify that your PCB manufacturer is using a material that falls in this range
- Current analysis shows no negative impact due to the change in Df
- So far halogen-free has not impacted the motherboard solution space for PCIe

Thank you for attending the
PCI-SIG Developers Conference 2010.

For more information please go to
www.pcisig.com

Definition of Halogen-free

- JPCA (Japan Printed Circuit Association) JPCA-ES-01-1999 defines criteria and method for “halogen-free”
  - Br < 0.09wt% (900ppm)
  - Cl < 0.09wt% (900ppm)
- IEC (International Electrotechnical Commission)
  - ✓ Finalized requirements of IEC 61249-2-21:
    - 900 ppm maximum Cl
    - 900 ppm maximum Br
    - 1500 ppm maximum total halogens
- IPC - 4101B has adopted the IEC definition of halogen-free
    - 900 ppm maximum Cl
    - 900 ppm maximum Br
    - 1500 ppm maximum total halogens

Note: Fluorine, Iodine, and Astatine (other Group VIIA halogens) are not restricted in the industry definition of “halogen-free”.

RoHS Compliance vs. HF

	RoHS	Halogen Free
Driver	Legislation - July 1, 2006 EU Restriction on the Use of Hazardous Substances (RoHS) in Electrical and Electronic Equipment Directive, 2002/95/EC, (1/27/03)	Potential Legislation Customer Reqmt's "Green" Marketing NGO Target
Materials Involved	Cadmium Hexavalent Chromium Lead Mercury Polybrominated biphenyls (PBB) Polybrominated diphenyl ethers (PBDE)	All Brominated Flame Retardants (TBBPA is main FR in substrate & PCB Materials) All Chlorinated Flame Retardants and PVC
Standards	N/A	IEC 61249-2-21 JPCA-ES-01-1999 IPC - 4101B