International Electronics Manufacturing Initiative

iNEMI
Halogen-Free Project

Phase 2 Proposal

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Overall Project Objectives:

- Build on industry knowledge and capability,
- Consider unique market segment requirements,
- Identify technology readiness and gaps,
- Stimulate supply capability, and
- Recommend standards development opportunities

Is / Is Not

This Project IS	This Project Is NOT
Technical evaluation of key electrical and mechanical properties	EHS assessment
Focused on those attributes which are of most value to supply chain.	Biased towards specific laminate suppliers, geographies, or market segments.
Build on learning from prior investigations	Repeat of prior work
Recommendations for standards development or further investigation	Standard Development
Focused on circuit board	Electronic components, Cables

Phase 2: Develop, Manage, and Execute Performance Testing

- **Phase 2 Tasks**

1. **Develop evaluation plan and schedule**
2. **Procure parts and test vehicles**
3. **Assign teams to carry out completion of the testing in a standardized fashion**
4. **Perform electrical and reliability testing on test vehicles.**

Anticipated Outcomes

1. **Validate electrical and mechanical properties**
   - Loss tangent and Dk modeling over required range of signal speed
   - Mechanical performance validation for lead free assembly (Delamination)
   - Critical Test Parameter Evaluation (CAF, IST, Flex etc)
2. **Validate material supplier and PCB manufacturer infrastructure capability**
3. **Estimate costs**
   - Volume market leader for new material may not achieve cost parity with best-in-class FR4

Candidate Materials

- Team Identified Materials Based on Information Available in The Industry and Through Laminate Supplier Consultation.

- Target Is to Have a Varied Cross Section of Laminate Material Suppliers, Geographies, and Chemistries Represented.
  - Identified 30 Candidate Halogen Free Laminate Materials From 15 Manufacturers
  - Eight (8) Laminates From 6 Suppliers Were Identified As Primary Candidates For Assessment.

- Materials Were Chosen Which Are Purported to Have a Reasonable Chance of Surviving Full Pb-free Assembly Process Conditions Within Their Target Market Segment / Design Point.

Materials To Be Assessed

Material	Tg. °C (by DSC unless otherwise noted)	Dk (reported, not assessed)	Df (reported, not assessed)	PCB Fab Shop
NanYa NPG-170TL	170	4.5 / 4.1 @ 1MHz / 1GHz	0.012 – 0.014 @ 1GHz	Multek, China
NanYa NPG-TL	150	3.8 – 4.0 @ 1GHz	0.012 – 0.014 @ 1GHz	GCE, Taiwan
Hitachi BE-67G(J)	145 (by TMA) 200 (by DMA)	5.0 – 5.2 @ 1MHz 4.5 – 4.7 @ 1 GHz	0.009 – 0.11 @ 1GHz	Multek, China
TUC TU-742	150	4.6 / 4.3 @ 1MHz / 1GHz	0.013 – 0.014 @ 1GHz	Sanmina
Panasonic/MEW R1566W	148	5.2 / 4.8 @ 1MHz / 1GHz	0.010 @ 1GHz	GCE, Taiwan
ITEQ IT140G	155 (method ?)	4.5 @ 1MHz	0.015 @ 1MHz	?
ITEQ IT155G	160 (method ?)	4.6 @ 1MHz	0.009 @ 1MHz	?
Shengyi S1155	135	4.7 @ 1MHz	0.010 @ 1MHz	?

Phase 2: Develop, Manage, and Execute Performance Testing

- **Test Vehicles Under Consideration**
  - **Electrical:** ▶
    - **IBM Short Pulse Propagation Method - SMASPP2z**
  - **High Temp Reflow Compatibility, Test Vehicle Options:**
    - **IBM HOP31 High Temp Reflow Laminate Assessment Test Vehicle** ▶
    - **Intel Materials Evaluation Board (MEB)** ▶

Identify key performance characteristics and test criteria

- **Proposed Stack Ups**
  - **SPP**
    - **1mm (40 mil)**
  - **HOP31 & MEB**
    - **1mm (40 mil)**
    - **2mm (80 mil)**
  - **Control Materials (or similar – Choose one)**
    - **Isola IS410**
    - **Polyclad Turbo 370**
    - **Nelco-4000-6**
    - **Nanya NP170**

- # Proposed Test Strategy
  - ## Screening of Materials
    - Evaluation of electrical, physical and **thermal properties** of commercially available Halogen-free laminate materials.

    - Determination of **propensity for failure (ie, delamination, via fatigue degradation)** in the Pb-free process environment on a per-application basis.
      - Pb-free on thinner / less thermally massive applications at up to 245 C (4-10 layer)
      - Pb-free on more thermally massive applications at up to 260 C. (12 – 24 layer)
      - The third party lab evaluates these boards per IPC 6012B Class 2 (if deemed necessary)

Identify key performance characteristics and test criteria

- **Proposed Test Strategy**
  - **Electrical Evaluation (< 20GHz)**
    - **Dielectric Constant (10KHz - 20GHz)**
    - **Dissipation Factor (10KHz - 20 GHz)**
    - **Surface Insulation Resistance (before solder mask)**
    - **Dielectric Voltage Breakdown (Dielectric Withstanding)**
    - **Moisture Diffusivity**
    - Capacitance
  - **Mechanical Evaluation**
    - **Tg and z-axis CTE**
    - **T-260 / T-288**
    - Cross Sections
    - Line width & spacing
    - Hole to Pad Registration
    - **Peel Strength**
    - **Solder Mask Adhesion**
    - **Flex Modulus**
    - Resin Microhardness
    - **Reliability**
      - **CAF**
      - **IST**
      - **HATS**

Path Forward

Next steps: Q2 2007

Commence Phase 2 Immediately

- **Identify participants and team leads**
- **Set up meeting schedules / logistics**
  - **Review Original Schedules and update as needed**
- **Identify Fabricators**
- **Complete Test Vehicles Builds – SPP & HOP31 by July 1st**
  - MEB II by Aug 1st
- **Identify Test Methods**
- **Identify who will perform the required testing**

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BACKUP

Task 2: Identify Candidate Materials

Laminate Supplier	Material	Country of Manufacture
NanYa	NPG-R	Taiwan / China
	NPG-TL / NPG-170TL *	
Hitachi	BE-67G(H)	Japan / Hong Kong / China
	E-679FG *	Japan
	EX-77G	? Japan ?
Elite Materials Co	EM280	China
Isola	IS500 *	Italy
	DE156	Germany, Taiwan
	HF571 (formally Polyclad) *	Germany, Taiwan
Nelco	4000-7EF *	Singapore
LG Chemical	LG-E(B) 481	Korea

Laminate Supplier	Material	Country of Manufacture
TUC	TU-642	Taiwan
ITEQ	IT155G	Taiwan
	IT140G	Taiwan
	IT170G * (??)	
Mitsubishi	CCL-EL150	Japan
Panasonic / MEW	R1566	Japan/Taiwan/China
	R1515T *	Japan
	R1515B	
Ventec	VT44	China
Grace	GAHF14 / GAHFR / GAHFTL *	China
Doosan	DS7402 (H) *	South Korea
	DS7402	South Korea
Guangdong Shengyi	S1165 *	China
Sumitomo Bakelite	ELC-4785GS / ELC-6785GS / ELC-4765GF	Japan

Identify key performance characteristics and test criteria

Physical Properties Data

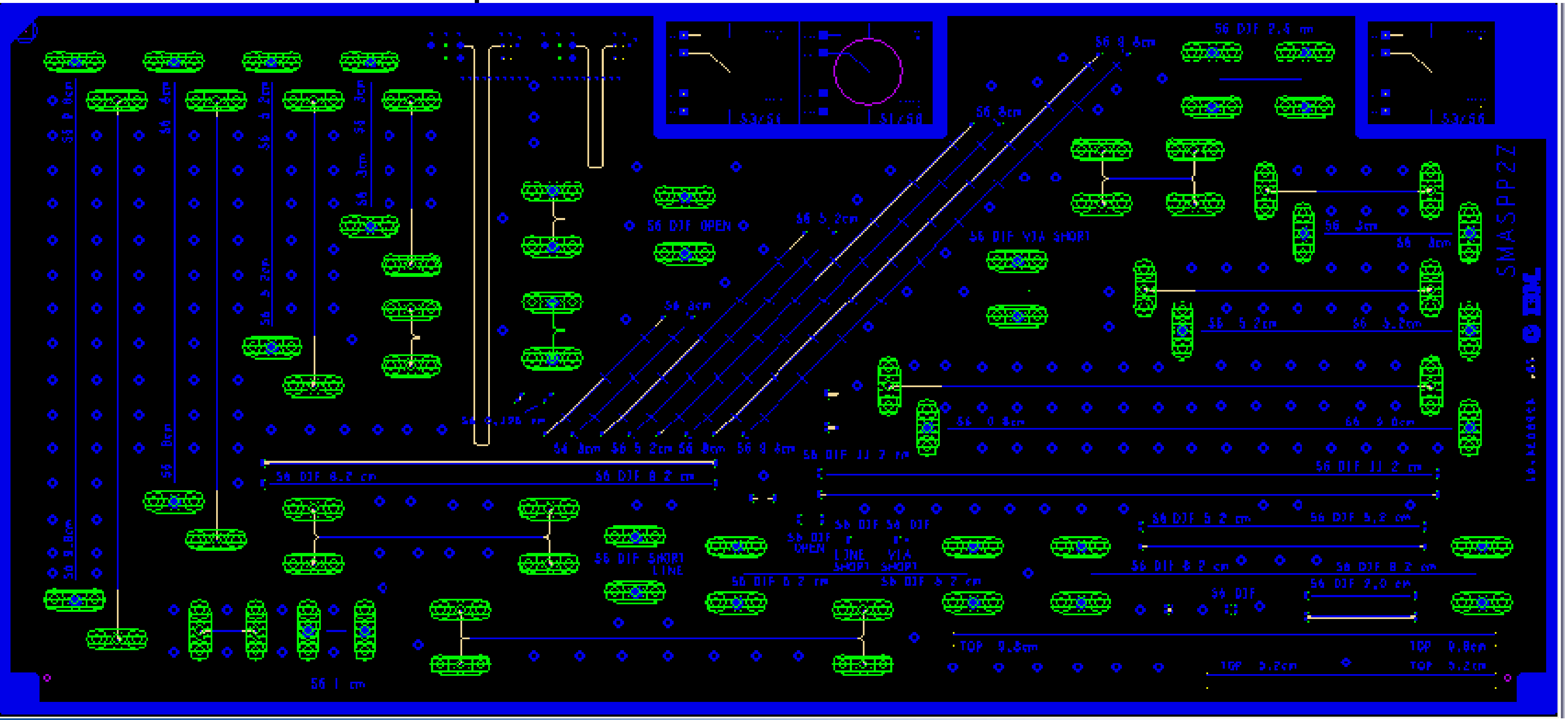
Property Tested	Test Method	Acceptable	Ideal
Dielectric constant 1-2.5 GHz	2.5.5.6 (IPC-TM-650)	< 4.5	< 3.3
Loss factor @ 1 MHz	2.5.5.6 (IPC-TM-650	< 0.017	< 0.007
Glass transition temperature, DSC (C	2.4.25 (IPC-TM-650)	> 180	>200
Glass transition temperature, TMA (C)	2.4.24.5 (IPC-TM-650)	> 180	>200
Decomposition temperature, TGA (C)		> 300	> 350
Time to delamination (min@260/288 C)	2.4.24.1A (IPC-TM-650)	> 60	> 120
Flammability	C-H 6-0430-102	V0 – Br-free	V0 – Br-free
Pressure cooker test (min)	2.6.16 (IPC-TM-650)	> 30	> 120
Moisture, 24hr/RT (Wt% Gain)	2.6.2.1 (IPC-TM-650)	< 0.3	< 0.1
Moisture, 1hr/PCT (Wt% Gain)	ASTM D570 (E 1/105 and D 24/23)	< 1.0	< 0.5
Cu Peel (lb/in)	2.4.8.2 (IPC-TM-650)	> 5	➢10
Sticker ILB (lb/in)		> 3	➢6
Oxide ILB (lb/in)		> 2	➢5
CTE (ppm/C) X, Y below Tg	2.4.41 (IPC-TM-650)	16 - 18	16 - 18
CTE (ppm/C) Z below Tg	2.4.41 (IPC-TM-650)	~ 60	30
CTE (ppm/C) X, Y above Tg	2.4.41 (IPC-TM-650)	5 - 8	5 – 8
CTE (ppm/C) Z above Tg	2.4.41 (IPC-TM-650)	300	150

Short Pulse Propagation

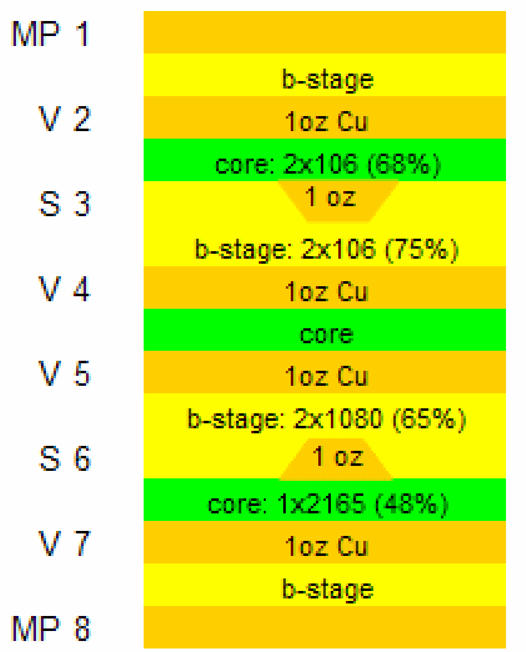
- Short Pulse Propagation Technique
  - Provides Time Domain Broadband Assessment of Laminate Material Dielectric Constant and Loss Tangent
  - Capable of Providing Results Up to 50GHz With Proper Equipment.
    - Setup Used for iNEMI HF Effort Will Provide Valid Results Up To 20GHz
  - Uses Test Structures Which Are Used in Real Applications.
  - Material is Excited in Same Fashion as System Operation vs. Traditional Resonant Techniques

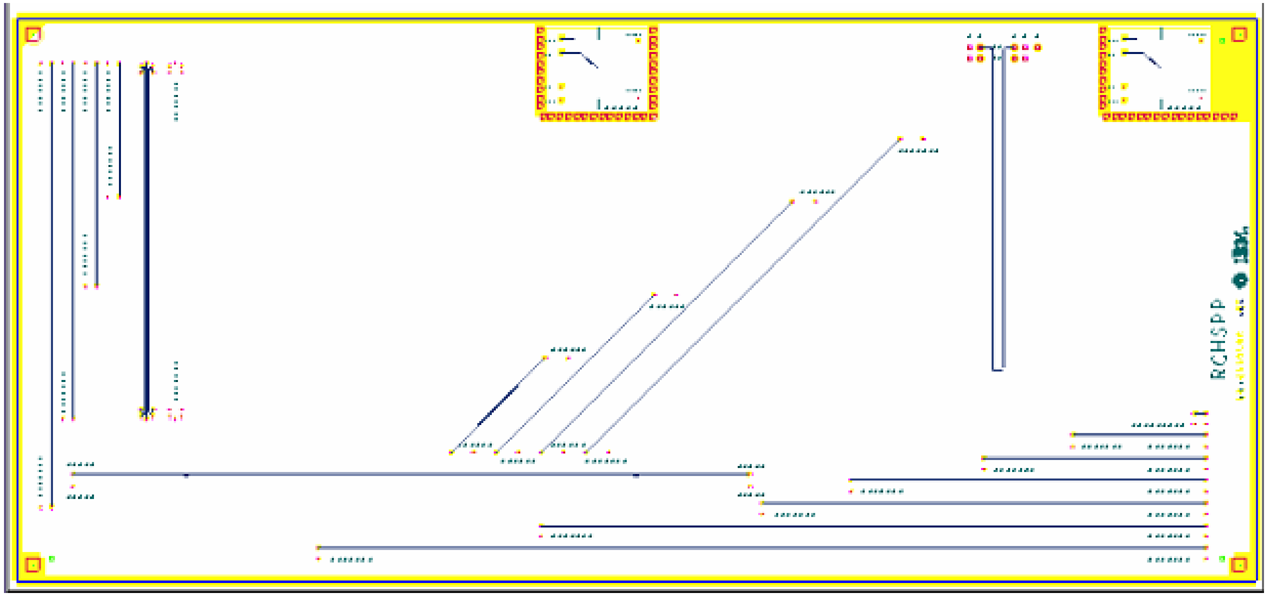
Phase 2: Develop, Manage, and Execute Performance Testing

- IBM SMASPP2z Electrical Test Vehicle
  - 8 Layer Design
    - Resin Rich Stripline Layer
    - Resin Poor Stripline Layer
  - 5” x 11” (6up per panel)
  - Extract Dk and Df from 10KHz to 20GHz Using Short Pulse Propagation Technique



SPP Test Vehicle Design

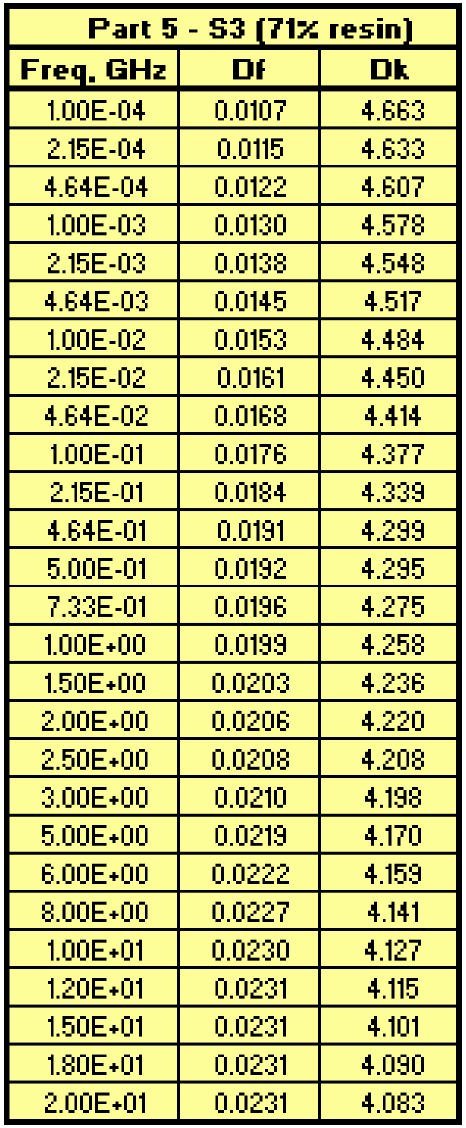




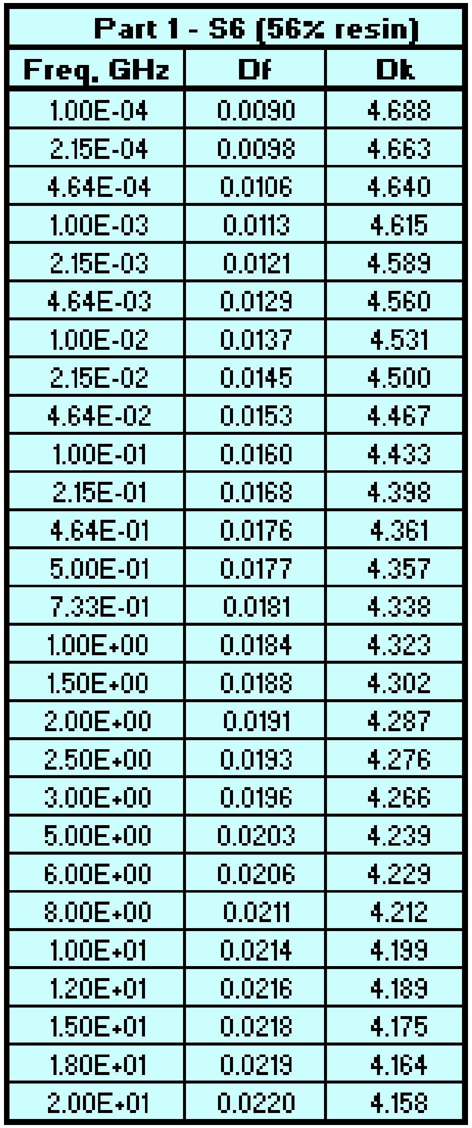
Cross Section Definition is Flexible. Desire One Resin Rich and One Resin Poor Building Block

Example Results, Halogen Free Laminate

- Example Results, Polyclad HF571 (now Isola)
  - November, 2005

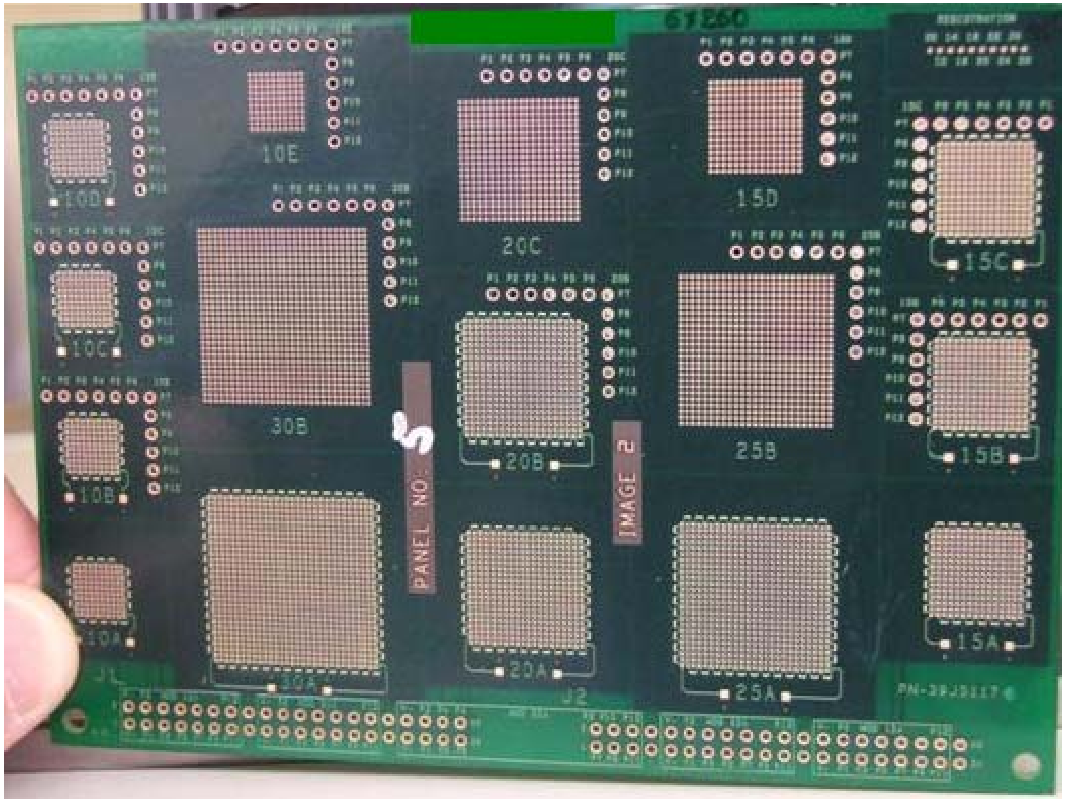


Part 5 - S3 (71% resin)		
Freq. GHz	**Df**	**Dk**
1.00E-04	0.0107	4.663
2.15E-04	0.0115	4.633
4.64E-04	0.0122	4.607
1.00E-03	0.0130	4.578
2.15E-03	0.0138	4.548
4.64E-03	0.0145	4.517
1.00E-02	0.0153	4.484
2.15E-02	0.0161	4.450
4.64E-02	0.0168	4.414
1.00E-01	0.0176	4.377
2.15E-01	0.0184	4.339
4.64E-01	0.0191	4.299
5.00E-01	0.0192	4.295
7.33E-01	0.0196	4.275
1.00E+00	0.0199	4.258
1.50E+00	0.0203	4.236
2.00E+00	0.0206	4.220
2.50E+00	0.0208	4.208
3.00E+00	0.0210	4.198
5.00E+00	0.0219	4.170
6.00E+00	0.0222	4.159
8.00E+00	0.0227	4.141
1.00E+01	0.0230	4.127
1.20E+01	0.0231	4.115
1.50E+01	0.0231	4.101
1.80E+01	0.0231	4.090
2.00E+01	0.0231	4.083



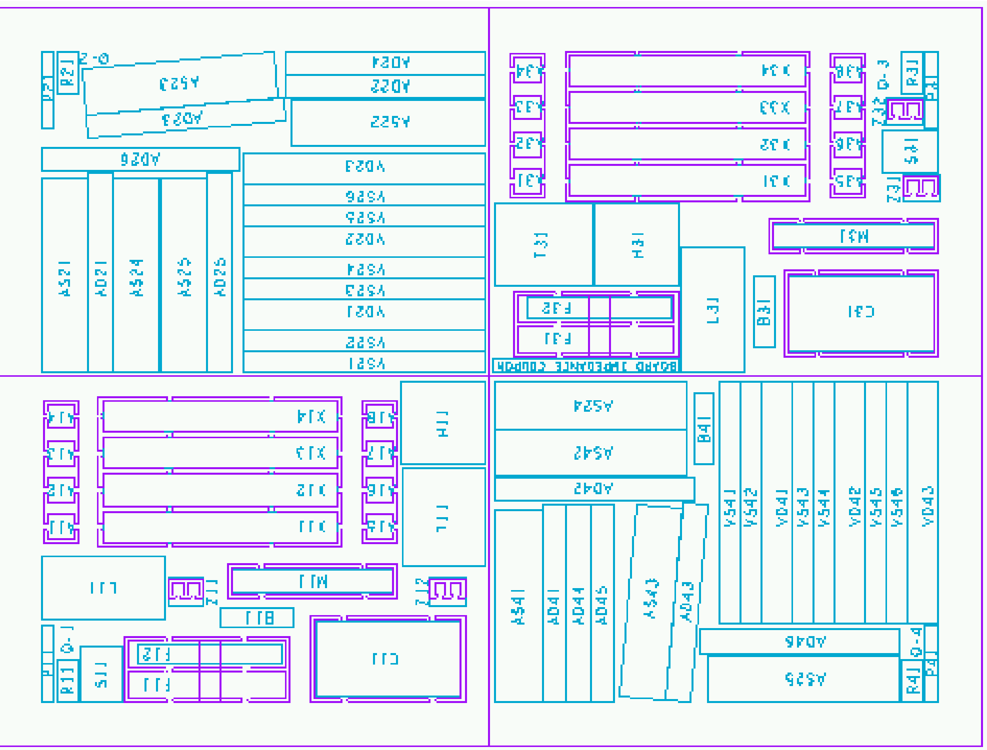
Part 1 - S6 (56% resin)		
Freq. GHz	**Df**	**Dk**
1.00E-04	0.0090	4.688
2.15E-04	0.0098	4.663
4.64E-04	0.0106	4.640
1.00E-03	0.0113	4.615
2.15E-03	0.0121	4.589
4.64E-03	0.0129	4.560
1.00E-02	0.0137	4.531
2.15E-02	0.0145	4.500
4.64E-02	0.0153	4.467
1.00E-01	0.0160	4.433
2.15E-01	0.0168	4.398
4.64E-01	0.0176	4.361
5.00E-01	0.0177	4.357
7.33E-01	0.0181	4.338
1.00E+00	0.0184	4.323
1.50E+00	0.0188	4.302
2.00E+00	0.0191	4.287
2.50E+00	0.0193	4.276
3.00E+00	0.0196	4.266
5.00E+00	0.0203	4.239
6.00E+00	0.0206	4.229
8.00E+00	0.0211	4.212
1.00E+01	0.0214	4.199
1.20E+01	0.0216	4.189
1.50E+01	0.0218	4.175
1.80E+01	0.0219	4.164
2.00E+01	0.0220	4.158

Phase 2: Develop, Manage, and Execute Performance Testing



- IBM “Hop31” Laminate Evaluation Test Vehicle
  - Versatile cross section…whatever required.
  - Minimum PTH pitch of 31 mils (0.8mm)
  - Specifically designed for assessment of higher reflow compatibility of laminate materials.
  - Design tweaks underway to easy finding internal delamination. To be completed by next week (2/16/07).
  - 4” x 5.5”….many test vehicles / panel.

Phase 2: Develop, Manage, and Execute Performance Testing



- Intel Materials Evaluation Board (MEB) Laminate Evaluation Test Vehicle. Under redesign (MEB II) to move to finer pitch structures.
  - Flexible design
    - Multiple layer count and thicknesses capable
    - Designed for 18”x24” panel (16.5x22.5” useable area)
    - 4 Quadrants – 4 Subpanels
    - Some coupons have breakaway tabs
  - Focus on material properties
    - Reliability coupons
    - Electrical, Mechanical, Thermal property coupons
    - Minimal fabrication capability (trace/space coupons)
    - Minimum assembly testing

Targeted MEB II Stack-ups

MEB II Stackup

	Description		Thickness
Layer 1	Plated 1/2 oz Cu	🟧	2.1 mils
	Prepreg	🟩	2.8 mils
Layer 2	Plated 1/2 oz Cu	🟧	1.2 mils
	Prepreg	🟩	2.8 mils
Layer 3	Unplated 1/2 oz Cu	🟧	0.6 mils
	Core	🟩	4 mils
Layer 4	Unplated 1/2 oz Cu	🟧	0.6 mils
	Prepreg	🟩	3 mils
Layer 5	Unplated 1 oz Cu	🟧	1.2 mils
	Core	🟩	Adjust to achive overall thickness of 0.040"
Layer 6	Unplated 1 oz Cu	🟧	1.2 mils
	Prepreg	🟩	3 mils
Layer 7	Unplated 1/2 oz Cu	🟧	0.6 mils
	Core	🟩	4 mils
Layer 8	Unplated 1/2 oz Cu	🟧	0.6 mils
	Prepreg	🟩	2.8 mils
Layer 9	Plated 1/2 oz Cu	🟧	1.2 mils
	Prepreg	🟩	2.8 mils
Layer 10	Plated 1/2 oz Cu	🟧	2.1 mils
			40 mils

MEB II Stackup

	Description		Thickness
Layer 1	Plated 1/2 oz Cu	🟧	2.1 mils
	Prepreg	🟩	2.8 mils
Layer 2	Plated 1/2 oz Cu	🟧	1.2 mils
	Prepreg	🟩	2.8 mils
Layer 3	Unplated 1/2 oz Cu	🟧	0.6 mils
	Core	🟩	5 mils
Layer 4	Unplated 1/2 oz Cu	🟧	0.6 mils
	Prepreg	🟩	4.5 mils
Layer 5	Unplated 1 oz Cu	🟧	1.2 mils
	Core	🟩	Adjust to achive overall thickness of 0.080"
Layer 6	Unplated 1 oz Cu	🟧	1.2 mils
	Prepreg	🟩	4.5 mils
Layer 7	Unplated 1/2 oz Cu	🟧	0.6 mils
	Core	🟩	5 mils
Layer 8	Unplated 1/2 oz Cu	🟧	0.6 mils
	Prepreg	🟩	2.8 mils
Layer 9	Plated 1/2 oz Cu	🟧	1.2 mils
	Prepreg	🟩	2.8 mils
Layer 10	Plated 1/2 oz Cu	🟧	2.1 mils
			80 mils

MEB II Test Methods

Board Level Reliability and Mechanical Testing:

- **IST (Interconnect Stress Test) – Precondition samples 3X reflow prior to soldering connectors. Test per IPC TM-650 2.6.26 at a test temperature of 150C. Test to failure.**
- **CAF – Test per IPC TM-650 2.6.25. Test via to via, via to trace, trace to trace, and plane to plane with the following structures: modified IST coupon, trace and space coupon, Hi-pot coupon. Test conditions: 65 or 85C @ 87% RH with bias voltage of 10-20 volts depending on design. Test to failure.**
- **Flexural Modulus – Test per ASTM D790. 5” x ¾” sample. Test X and Y board directions.**
- **Copper Peel Strength - Test per IPC TM-650 2.4.8C “Peel Strength of Metallic Clad Laminates”. 5” x ¾” sample.**
- **Tg and z-axis CTE – Test per IPC TM650 2.4.24C test method. 6mm x 6mm sample.**
- Thermal Stress X-section – Test per IPC TM-650 2.6.8E. 1X and 3X floats at 288C.
- Resin Micro-hardness – Micro-hardness indenter on x-sectioned resin rich area of the laminate.
- Solder mask adhesion – Test per IPC TM-650 2.4.28B

MEB II Test Methods

Electrical Testing:

- **Permittivity (Dielectric Constant) and Loss Tangent (Dissipation Factor) – VNA S-parameter measurements up to 30 GHz.**
- **Moisture Diffusivity – In situ VNA S-parameter measurements at 105C bake, 85C/85% RH, and 35C/85% RH. Check moisture absorption rate and desorption rate.**
- **Insulation Resistance – Test per IPC TM-650 2.5.7**
- Capacitance – Test per IPC TM-650 2.5.2A

Assembly Testing:

- Temp Cycle – In situ air to air method (HATS machine). Conditions are product dependent, need to finalize test temps and dwells. Test to failure.
- Transient Bend – Package size dependent spans for bending. Measure strain curves and examine damage levels (Die and Peel, x-section)
- Rework – Test thermal limits of rework conditions.
- Board side ball pull – Dage ball pull equipment.

So Why do this?

1. **Emerging consideration of “Progressive” public, institutional, and corporate procurement groups in Sweden, Norway, Denmark, Netherlands, Germany, UK, France, Japan. Companies without HF product offerings have begun to lose bids in these regions, esp. in the mobile phone space**

2. **Very limited CE and IT product offerings are available.**

3. **Political and NGO hot-button. NGOs like Greenpeace are targeting actions against companies that use TBBPA**

4. **Lack of legislation results in “material-of-the month” behavior driven by multiple environmental groups – need a coordinated effort driven by a major industry influence**

5. **Supply chain capability and capacity is not established. Standards and generic technology.**

What is Halogen Free?

1. JPCA (Japan Printed Circuit Association) JPCA-ES-01-1999 defines criteria and method for "halogen-free"
    - Br < 0.09wt% (900ppm)
    - Cl < 0.09wt% (900ppm)
2. IEC (International Electrotechnical Commission)
    - Finalized requirements of IEC 61249-2-21:
        - 900 ppm maximum Cl
        - 900 ppm maximum Br
        - 1500 ppm maximum total halogens
3. 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".

TBBPA

- **In epoxy resin circuit boards, TBBA covalently reacts with the epoxy resin backbone and ceases to exist as a chemical entity.** ~96% of printed wiring boards utilize TBBA**.**

- **Swedish Environmental Protection Agency studies indicate that TBBA does not bind to human transthyretin in vivo,** suggesting no adverse endocrine effects**.**

- **In 1995, the World Health Organization (WHO IPCS) undertook a full scientific assessment of the environmental and human health impacts of TBBPA. Key findings from this study indicated that**
  - **1) TBBPA has little potential for bioaccumulation,**
  - **2) environmental detection is limited to very few sediment/soil samples and**
  - **3) the human health risks associated with TBBPA for the general population is considered to be insignificant.**

- **Six independent studies between 1990-1997 concluded that** TBBA is not found to be a significant source of potential human dioxin exposure upon <u>proper</u> incineration **(IPC, 2003)**

- **TBBPA has been analyzed for the presence of 15 2,3,7,8-substituted polybrominated-p-dibenzodioxins and dibenzofurans. None of the analytes were present at or above the quantitation limits established by the U.S. Environmental Protection Agency.**

- **TBBA has a 50 day half-life in aerobic and anaerobic solids (soil) and has an average half-life of 31 days in water.**

Identify key performance characteristics and test criteria

- **Proposed Test Strategy**
  - **Screening of Materials**
    - The third party lab evaluates these boards per IPC 6012B Class 2. This evaluation includes the following material related requirements:

      - 1X and 6X Thermal stress
      - -Glass Fiber protrusion
      - -Wicking
      - -plating integrity
      - -Etchback and Desmear

      - Thermal Shock
      - -Plating integrity
      - -Barrel separation
      - -Lifted lands
      - -Laminate Voids
      - -Laminate Cracks

      - Bow and Twist (PWB construction/material interaction)

      - Stack up analysis (validate prepreg yield per ply compares to Fab stackup)

      - Thermal Analysis (Tg and Delta Tg)

      - Soldermask thickness (Halogen Free board requires halogen free soldermask: validate thickness requirements to IPC SM 840