IEEE 802.3ap FR-4 Material Review: Past Review and Future Recommendations

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This presentation will cover the material definitions discussed in the channel group within IEEE802.3ap, and conclude with a template and starting point for reference in the objectives and criteria for improved FR-4.

Note: Modified title to include “FR-4”.

A List of FR-4 Presentations from the IEEE 802.3ap Public Archives

- “Channel Model Criteria”, goergen_01_0304, March04.
- “FR-4 Definition”, goergen_02_0304, March04.
- “A Definition of FR-4”, goergen_01_0504, May04.
- “FR-4 Definition III”, goergen_01_0704, July04.
- “Channel Model and Material Characteristics”, goergen_01_0206, Feb2006.
- The above presentations provide a basic understanding to the words “Improved FR-4” used in the stated objectives.

http://www.ieee802.org/3/ap/802_3_ap_objectives.pdf

IEEE P802.3ap Objectives

- Preserve the 802.3/Ethernet frame format at the MAC Client service interface.
- Preserve min. and max. frame size of current 802.3 Std.
- Support existing media independent interfaces.
- Support operation over a single lane across 2 connectors over copper traces on improved FR-4 for links consistent with lengths up to at least 1m.
  - Define a 1 Gb/s PHY
  - Define a 10 Gb/s PHY
- Define a 4-lane 10Gb/s PHY for operation over the 802.3ap channel model.
- Consider auto-negotiation.
- Support BER of 10^-12 or better.
- Meet CISPR/FCC Class A.

Highlights - “Channel Model Criteria”, goergen_01_0304, March04

- Basic Design Issues
- Material Selection Impacted by:
  - Temperature and Humidity effects on Df/Dk.
  - Required mounting holes for mother-card mounting, as well as shock and vibration requirements.
  - Required number of times a chip can be replaced on a mother-card.
  - Required number of times a pin can be replaced on a back plane.
  - Aspect ratio.
  - Power plane copper weight.

Trace Length Combinations - Max

24in to 34in height (2 or 3 per rack)

	N+1 Fabric			
	Position: Top or Bottom of Line Cards			
Case		LC -1	LC -2	LC -3
	Trace Length	16	6	4
SF -1	18	56	46	44
SF -2	12	50	40	38
Back Plane	22			

	A/B Fabric			
	Position: Top or Bottom of Line Cards			
Case		LC -1	LC -2	LC -3
	Trace Length	16	6	4
SF -3	14	52	42	40
Back Plane	22			

	N+1 Fabric			
	Position: Middle of Line Cards			
Case		LC -1	LC -2	LC -3
	Trace Length	16	6	4
SF -1	18	52	42	40
SF -2	12	46	36	34
Back Plane	18			

	A/B Fabric			
	Position: Middle of line cards			
Case		LC -1	LC -2	LC -3
	Trace Length	16	6	4
SF -3	14	48	38	36
Back Plane	18			

Note: All dimensions in inches

Trace Length Combinations - Min

24in to 34in height (2 or 3 per rack)

	N+1 Fabric			
	Position: Top or Bottom of Line Cards			
Case		LC -1	LC -2	LC -3
	Trace Length	16	6	4
SF -1	18	39	29	27
SF -2	12	33	23	21
Back Plane	5			

	A/B Fabric			
	Position: Top or Bottom of Line Cards			
Case		LC -1	LC -2	LC -3
	Trace Length	16	6	4
SF -3	14	35	25	23
Back Plane	5			

	N+1 Fabric			
	Position: Middle of Line Cards			
Case		LC -1	LC -2	LC -3
	Trace Length	16	6	4
SF -1	18	36	26	24
SF -2	12	30	20	18
Back Plane	2			

	A/B Fabric			
	Position: Middle of line cards			
Case		LC -1	LC -2	LC -3
	Trace Length	16	6	4
SF -3	14	32	22	20
Back Plane	2			

Note: All dimensions in inches

Highlights - “FR-4 Definition”, goergen_02_0304, March04

- FR-4 Definition
- **Flame retardant type 4 woven glass reinforced epoxy resin system[1].**

- [1]Electronics Manufacture and Test Online. WWW.emtonthenet.net/glossary/fr4laminate.html.

Materials Classified as FR-4

- FR-4 ‘generic’ material, FR402/4000-2, and FR406/4000-6. Typical Dk of 4.3 and higher.

  Reference Nationwide Circuits, Inc., Materials Specification. www.nciproto.com/info/Base%20/mat.htm

  Reference Electronics Manufacture and Test Online. WWW.emtonthenet.net/glossary/fr4laminate.html.

- GETEK. Typical Dk of 3.6 to 4.2.

  Reference Nationwide Circuits, Inc., Materials Specification. www.nciproto.com/info/Base%20/mat.htm

Materials Classified as FR-4

- 4000-13 and 4000-13SI. Typical Dk of 3.5 to 3.7.

  Reference Park Nelco. www.parknelco.com

- FR408. Typical Dk of 3.7

  Reference Isola Laminate Systems. www.isola-usa.com/products/productdetail.shtml?16

- Isola620. Typical Dk of 3.7 but low Df. Similar to Nelco SI glass.

  Reference Isola Laminate Systems. www.isola-usa.com

Materials NOT Classified as FR-4

- BT/Epoxy (Isola G200 or N5000-30/32). Typical Dk of 4.1 to 4.4.
  Reference Park Nelco. www.parknelco.com or www.isola-usa.com
- Polyimide (Isola P95 or N7000). Typical Dk of 3.8 to 3.9.
  Reference Park Nelco. www.parknelco.com or www.isola-usa.com
- PTFE (Taconic TLT or N9000-13/N9000-13RF). Typical Dk of 3.0 to 3.5 but very low Df.
  Reference Park Nelco. www.parknelco.com or www.isola-usa.com
- CE (N8000). Typical Dk 3.5 to 3.7.
  Reference Park Nelco. www.parknelco.com
- GIL (MC3D)

Materials NOT Classified as FR-4

- BEND/flex (Rogers BEND/flex 2400)

  Reference www.rogerscorporation.com

- Kapton (Dupont Pyralux LF)
- Rogers non-PTFE 4003/4350. Typical Dk of 3.38 to 3.48 but very low Df

  Reference www.rogerscorporation.com/mwu/pdf/ro4000ds_4.pdf

Highlights - “A Definition of FR-4”, goergen_01_0504, May04

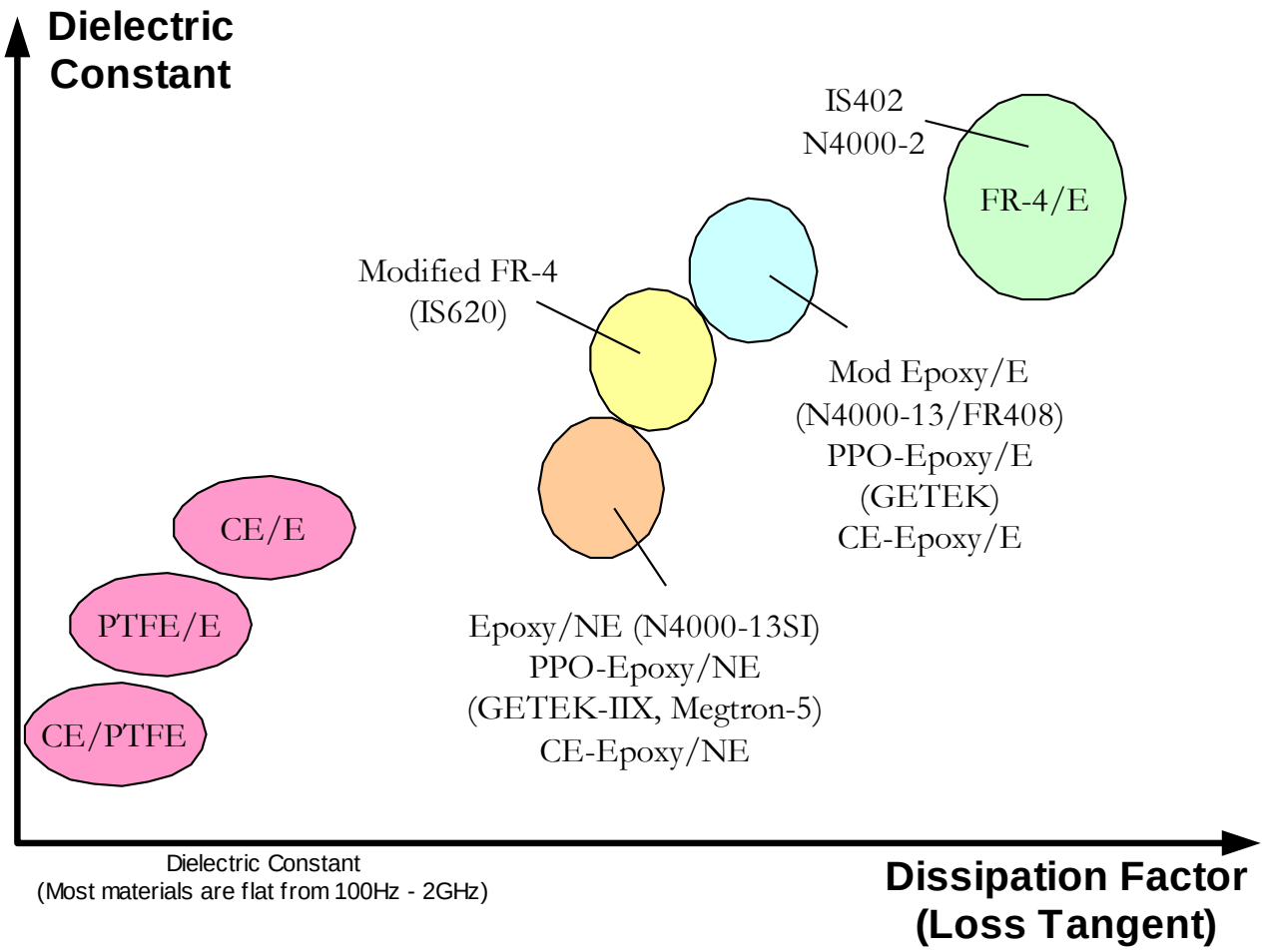
- FR-4 Definition
- **Flame retardant type 4 Brominated woven glass reinforced epoxy resin system[1].**

- [1]Electronics Manufacture and Test Online. WWW.emtonthenet.net/glossary/fr4laminate.html.
- [1]UL Confirms definition in phone conversation 29April04. New definition and testing process to be released for review in June/July.

UL Involvement in FR-4

- FR-4 was established in 1968.
- Infrared scans where done for conformance then.
- Later a thermal degradation scan was implemented.
- Position of UL: With various Tg, Dk, Df, Halogen Free materials … FR-4 is too vague. Re-classification to be suggested in June of 2004. At this time, re-classification will only cover flame rating based on resistance of material suppliers to position Dk and Df values within class groups tested by UL.
- Though UL is not an International Body, the results of the degradation coupons are accepted World-Wide. PCB Manufacturers test to no other recognized Body/Standard, with exception to additional GR-78/NEBS conformance tests as required by Telecom Carriers.
- UL suggests reviewing concerns and comments with both itself and IPC.

Materials in Perspective



- Graph provided by Zhi Wong zwong@altera.com

My Thoughts on Classification

- FR-4 (Low Resolution Signal Integrity):
  - Dk@2Ghz 3.9 to 4.7
  - Df@2Ghz .015 to .022
- Improved FR-4 (Mid Resolution Signal Integrity):
  - Dk@2Ghz 3.1 to 3.9
  - Df@2Ghz .008 to .015
- Supper FR-4 or Ceramics (High Resolution Signal Integrity):
  - Dk@2Ghz 2.4 to 3.1
  - Df@2Ghz .002 to .008
- Note: classes above to be defined at 1, 100, 1000, 2000, 5000, 10000, 15000 and 20000 Mhz. 2Ghz is shown for reference.

My Thoughts on 'Improved FR-4' in reference to IEEE802.3ap – Straw Poll Agreement

- Improved FR-4 (Mid Resolution Signal Integrity):
  - 100Mhz: Dk ≤ 3.60; Df ≤ .0092
  - 1Ghz: Dk ≤ 3.60; Df ≤ .0092
  - 2Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 5Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 10Ghz: Dk ≤ 3.40; Df ≤ .0125
  - 20Ghz: Dk ≤ 3.20; Df ≤ .0140
- Temperature and Humidity Tolerance (0-55degC, 10-90% non-condensing):
  - Dk:+/- .04
  - Df: +/- .001
- Resin Tolerance (standard +/-2%):
  - Dk:+/- .02
  - Df: +/- .0005

http://www.ieee802.org/3/ap/public/may04/minutes_1_0504.pdf

- **Straw Poll #2 Adopt *Dk / Df values presented in goergen_01_0504 (Reference Slide #15) as a working definition for "improved FR-4" for future channel modeling in Ad Hoc Group***
- ***All Yes – 29No – 1Abstain - 8***
- ***Test data is needed •Forward channel less of concern •But crosstalk is a concerno "Calibration board" (different lengths) would have uses o Need to search for a body defining backplane environment•Concern regarding values cited and whether data being received by board material venders is per same test methodologyo Manufacturers are required to test per parallel plate method per IPC test specification. Variability will be in design of boards. Dk / Df values need to be set to evaluate channel model development efforts.•Some concern that it might be too early and further data may be necessary. •Material selection getting more restrictive (taking into account temperature,humidity, and resin content). Estimate approximately 65% of "improved FR-4"material still useable. •Analog bandwidth is not known yet. •We need a model for simulations. •Presentation that shows Joel's selection process would be useful and educational •Objective is 1m with "improved FR-4". Shorter distances with different materialsare permissible. •How do we build test fixturing without knowing what materials are permissible touse? •This is not a binding motion. It is intended for guidance.***

Highlights - “FR-4 Definition III”, goergen_01_0704, July04

- Meeting Minutes http://www.ieee802.org/3/ap/public/jul04/minutes_1_0704.pdf
- Straw Poll#2 – Preference for definition of “Improved-FR-4”
  - Option A - Slide #5 from Goergen_01_0704 (original numbers)
  - Option B - Slide #6 from Goergen_01_0704 (proposed modified numbers
  - Results: Option A - 21 Option B – 15
- **Motion # 2 Description: General Session Motion Move to adopt the Dk/Df values defined in goergen_01_0704, (pdf) page 5, as the minimum definition of “Improved FR-4” with modification to temperature tolerance from “0 to 55°C” to “0 to 70°C.”Reference goergen_01_0704, goergen_01_0504, and Goergen_02_0304.**
- **Motion Type:** Technical 75 % required
- **Moved By: Joel Goergen / Seconded By: Jeff Cain**
- **Results:**
  - **ALL Yes – 41 No – 0 Abstain – 6**
  - **802.3 Yes – 14 No – 0 Abstain - 6 Motion Passes**

My Thoughts on 'Improved FR-4' in reference to IEEE802.3ap – Option A - ADOPTED

- Improved FR-4 (Mid Resolution Signal Integrity):
  - 100Mhz: Dk ≤ 3.60; Df ≤ .0092
  - 1Ghz: Dk ≤ 3.60; Df ≤ .0092
  - 2Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 5Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 10Ghz: Dk ≤ 3.40; Df ≤ .0125
  - 20Ghz: Dk ≤ 3.20; Df ≤ .0140
- Temperature and Humidity Tolerance (0-55degC, 10-90% non-condensing):
  - Dk:+/- .04
  - Df: +/- .001
- Resin Tolerance (standard +/-2%):
  - Dk:+/- .02
  - Df: +/- .0005

Changes to 'Improved FR-4' in reference to IEEE802.3ap – Option B – NOT ADOPTED

- Improved FR-4 (Mid Resolution Signal Integrity):
  - 100Mhz: Dk ≤ 3.60; Df ≤ .0092
  - 1Ghz: Dk ≤ 3.60; Df ≤ .0092
  - 2Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 5Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 10Ghz: ***Dk ≤ 3.50***; Df ≤ .0125
  - 20Ghz: ***Dk ≤ 3.40***; Df ≤ .0140
- Temperature and Humidity Tolerance (0-55degC, 10-90% non-condensing):
  - Dk:+/- .04
  - Df: +/- .001
- Resin Tolerance (standard +/-2%):
  - Dk:+/- .02
  - Df: +/- .0005

Dk/Df Changes – NOT ADOPTED

- Adjust the 10Ghz Dk value to 3.5. This opens the door for more of the lower cost, improved fr-4 materials.
- Adjust the 20Ghz Dk value to 3.4. This opens the door for more of the lower cost, improved fr-4 materials.
- Df values are good.
- Without these Dk/Df constraints, it will be easy to design a fab using advanced -13SI or IS640 material that won't meet the channel model.

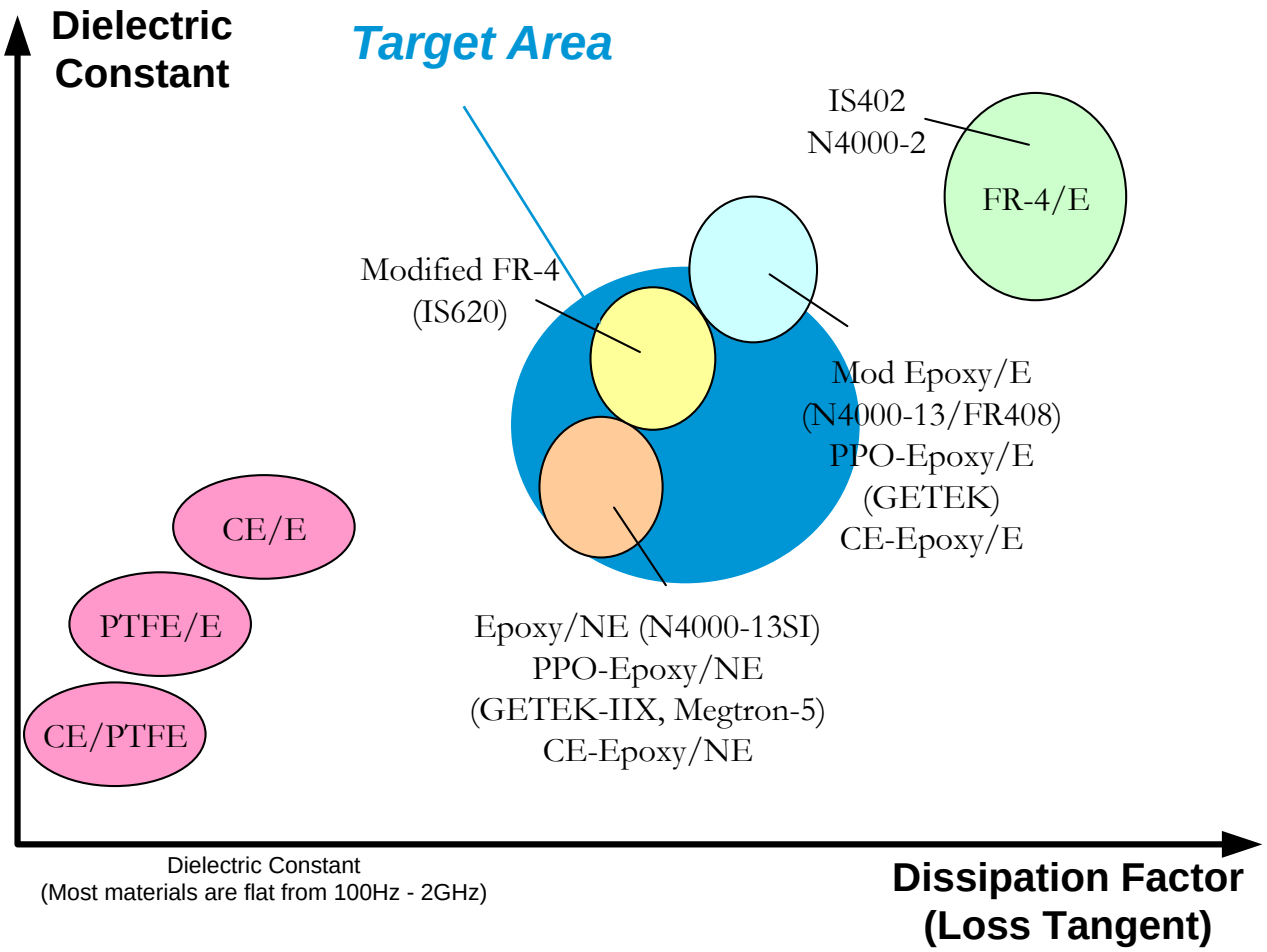
Highlights - “Channel Model and Material Characteristics”, goergen_01_0206

- Presentation #2
- Title – Channel Model and Material Characteristics
- By Joel Goergen - goergen_01_0206.pdf
- Straw Poll #4 – See Comment #71
- Straw Poll #5 – See Comment #131

Definition: “Improved FR-4” as defined by IEEE P802.3ap

- Improved FR-4 (Mid Resolution Signal Integrity):
  - 100Mhz: Dk ≤ 3.60; Df ≤ .0092
  - 1Ghz: Dk ≤ 3.60; Df ≤ .0092
  - 2Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 5Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 10Ghz: Dk ≤ 3.40; Df ≤ .0125
  - 20Ghz: Dk ≤ 3.20; Df ≤ .0140
- Temperature and Humidity Tolerance (0-70degC, 10-90% non-condensing):
  - Dk:+/- .04
  - Df: +/- .001
- Resin Tolerance (standard +/-2%):
  - Dk:+/- .02
  - Df: +/- .0005

Channel Model Perspective



Graph provided by Zhi Wong zwong@altera.com

Channel Model Equation
Fitted Attenuation - P8023ap-D33.pdf

- b1 = 2.00e-5
- b2 = 1.10e-10
- b3 = 3.20e-20
- b4 = -1.20e-30
- SDD21 = -20*log10(e)*(b1*sqrt(f) + b2*f + b3*f^2 + b4*f^3)
- f = 50Mhz to 15000Mhz

Suggested based on Specified Channel: New Definition "Improved FR-4"

- Improved FR-4 (Mid Resolution Signal Integrity):
  - 100Mhz: Dk ≤ 3.60; Df ≤ .010
  - 1Ghz: Dk ≤ 3.57; Df ≤ .010
  - 2Ghz: Dk ≤ 3.50; Df ≤ .011
  - 5Ghz: Dk ≤ 3.50; Df ≤ .011
  - 10Ghz: Dk ≤ 3.40; Df ≤ .012
  - 20Ghz: Dk ≤ 3.20; Df ≤ .0125
- Temperature and Humidity Tolerance (0-70degC, 10-90% non-condensing):
  - Dk:+/- .04
  - Df: +/- .001
- Resin Tolerance (standard +/-2%):
  - Dk:+/- .02
  - Df: +/- .0005