FR-4 Circuit Board Technology: An Introduction to Fabrication Issues in High Speed Channels

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This presentation covers an overview of the issues and concerns in fabrication technology from a holistic, system level, point of view. The intent is to provide an understanding to technical and economic feasibility.

Note: Added “FR-4” into the title.

A Grateful Thanks To:

- Steve Billiet – TTM
- Chudy Nwachukwu - Isola
- David Senk – Cisco
- Dale Beitelspacher - Cisco

25Gbps … Economic and Technical Feasibility … Where Do I Start?

- Standards
- *System Components*
- *Channel Components*
- Modules and Interfaces
- Interface Feasibility
- Simulation Methods
- SERDES
- Connectors
- Coding and Signaling

Any Place to Start … Standards: A Quick Look From MY VIEW

- There is not an industry accepted standard today covering 25Gbps signaling
    - Chip to Chip
    - Chip to Back Plane / Mid Plane
    - Chip to Module ?? There seems to be agreement here
- OIF, IEEE802, and Fiber Channel are all pursuing next generation signaling speeds, with OIF seeding the efforts since 2005.

Standards:
What Will Be Difficult in 25Gbps

- Power Noise

  Won’t really be discussed, but always a problem.

- Cross Talk

  Always discussed and always blamed on the connector. Reduction efforts often result in little over-all gain compared to the whole.

- PCB Material and Fabrication Technology

  Everyone wants the material to cost 1X FR-4

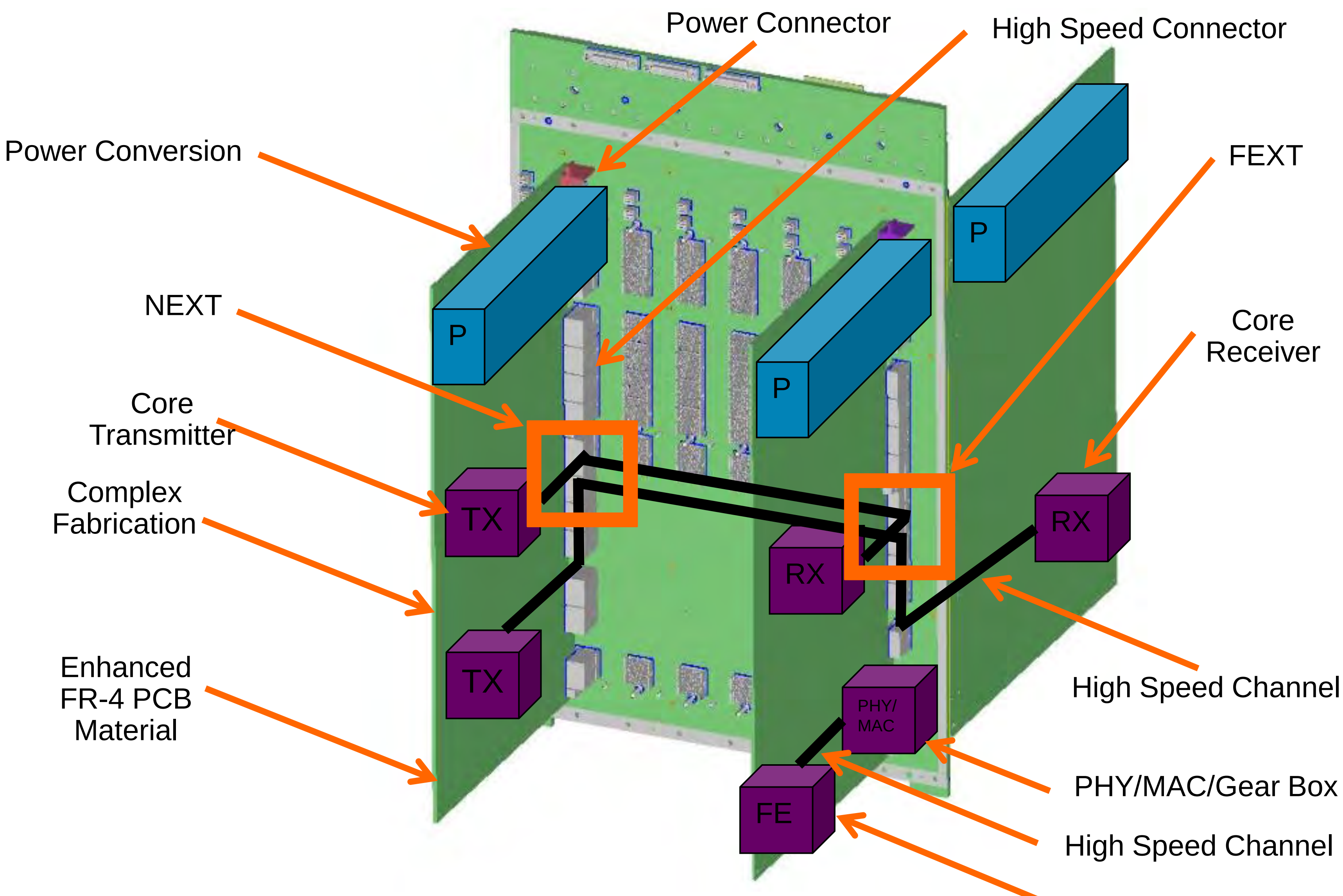
  The complexity impacts cost

  Assembly is a problem, but rarely discussed.

- SERDES Core

  Whatever the coding and signaling, the power has to be low and the latency has to be low.

System Level Overview - Breaking Down the Components



Material and Fabrication

FR-4 Type PCB Materials Overview and Relative Costs

Supplier	Material	Glass Transition °C	Dielectric Constant	Dissipation Factor	* Cost versus FR4	PRO's	CON's	Approximate Lead Time STD	Approximate Lead Time QTA
Tier 1 – Standard Performance									
Isola	370HR	170 – 180	3.7 – 4.7	.0135 – .026	Baseline	LF capable	None	5 days	3 days
Isola	FR406				Baseline	Cost effective	Not LF	5 days	3 days
Isola	IS410				1.0 – 1.25	–	Not LF	5 days	3 days
Isola	IS415				1.25 – 1.5	Superior electrical	Not LF	5 – 8 days	No QTA
Nelco	N4000-6				Baseline	Cost effective	Not LF	6 days	3 days
Nelco	N4000-29				Baseline	LF capable	Marginal CAF-R	6 days	3 days
Panasonic	R-1755V				1.25 – 1.5	LF capable, CAF-R	Cost	2 – 4 weeks	none
Tier 2 – Low Loss									
Isola	FR408	180 – 210	3.6 – 4.4	.008 – .0125	1.5 – 2.0	Low loss / good value	Not LF, high Z axis exp	5 days	3 days
Isola	FR408HR				2.5 – 2.75	Low loss / CAF-R	New, LF TBD	5 – 8 days	3 days
Isola	GETEK				1.75 – 2.25	Low loss / good value	Not LF, high Z axis exp	7 – 10 days	none
Nelco	N4000-12				1.5 – 2.0	Low loss / good value	Not LF, high Z axis exp	7 – 10 days	none
Nelco	N4000-13				2.0 – 2.5	Widely accepted	Not LF & CAF	7 – 10 days	3 days
Nelco	N4000-13EP				2.0 – 2.5	Improved LF capability	Concerns with CAF	5 days	4 days
Panasonic	R-2125				2.5 – 3.0	Excellent thermal / CAF	High Dk	2 – 4 weeks	none
Tier 3 – Ultra Low Loss									
Isola	IS620 LF	210 – 220	3.2 – 3.8	.002 – .008	2.75 – 3.0	Low Dk / low loss	Not LF	7 – 10 days	none
Nelco	N4000-13EP SI				3.0 – 3.25	Low Dk / low loss	Concerns with CAF-R	7 – 10 days	none
Panasonic	Megtron 6				5.0 – 5.25	Superior thermal / CAF	Cost, Copper Filling	2 – 4 weeks	none
RF Microwave Materials – Non Teflon Base									
Rogers	4350 / 4450	> 280	3.38	0.004	5.0	Normal processing	Low peel strength	7 – 14 days	none
RF Microwave Materials – Teflon Base									
Arlon	Numerous	N/A	2.2 – 10	As low as .0009	5.0 – 60.0	Superior signal integrity at high speeds	Cost / Processing	10 days	none
Nelco	N9000							7 – 10 days	none
Rogers	3000, 6000							2 – 4 weeks	none
Taconic	Numerous							2 – 4 weeks	none

FR-4 Type PCB Materials Overview and Relative Costs

- Tier 1, standard electrical performance
  - **Materials advertised to be lead-free capable**

Caution: *Use as a rough guide only. The details shown are taken from laminate supplier data sheets. Results vary due to test method and sample construction differences*

Supplier Material ID	Isola IS410	Isola -370HR	ITEQ IT-180	Nan Ya NP-170TL	Nelco N4000-29	Panasonic R-1755	Panasonic R-1755V
Dk @ 1 Mhz			4.60	4.30	4.50	4.68	4.70
Dk @ 1 Ghz				3.90	4.30	4.31	4.40
Dk @ 2 Ghz	3.76	4.04				4.27	4.30
Dk @ 5 Ghz	3.69	3.92				4.22	4.30
Dk @ 10 Ghz	3.69	3.92			4.10	4.16	4.20
Df @ 1 Mhz			0.0180	0.0175	0.0160	0.0153	0.0135
Df @ 1 Ghz				0.0140		0.0153	0.0160
Df @ 2 Ghz	0.0210	0.0210			0.0150	0.0170	0.0170
Df @ 5 Ghz	0.0250	0.0250				0.0190	0.0185
Df @ 10 Ghz	0.0250	0.0250			0.0170	0.0220	0.0210

Supplier Material ID	TUC TU-722-7	Ventec VT-47
Dk @ 1 Mhz	4.70	4.40
Dk @ 1 Ghz	4.40	4.30
Dk @ 2 Ghz		4.15
Dk @ 5 Ghz		
Dk @ 10 Ghz		
Df @ 1 Mhz	0.0230	0.0175
Df @ 1 Ghz	0.0140	0.0165
Df @ 2 Ghz		0.0180
Df @ 5 Ghz		0.0195
Df @ 10 Ghz		

1X FR-4

	Dicy cured (eutectic)	
	Isola FR406	Nelco N4000-6FC
Dk @ 1 Mhz		4.30
Dk @ 1 Ghz		4.10
Dk @ 2 Ghz	3.79	4.00
Dk @ 5 Ghz	3.76	
Dk @ 10 Ghz	3.76	
Df @ 1 Mhz		0.0230
Df @ 1 Ghz		
Df @ 2 Ghz	0.0180	0.0220
Df @ 5 Ghz	0.0186	
Df @ 10 Ghz	0.0188	

FR406 & -6FC serve as a ref baseline representing traditional FR-4 materials that are not lead-free capable

- Tier 2, low loss electrical performance (0.006 – 0.015 Df)
  - **Materials advertised to be lead-free capable**

Supplier Material ID	Isola IS415	Isola FR408	Isola FR408HR	Isola IS620 i	Nelco N4000-12	Nelco N4000-13	Nelco N4000-13EP	Nelco ~-13EPSI	Panasonic Megtron+	Panasonic R-2125
Dk @ 1 Mhz					3.90	3.88			3.90	4.60
Dk @ 1 Ghz					3.70	3.70	3.70	3.40	3.80	4.40
Dk @ 2 Ghz	3.70	3.65	3.75	3.60	3.70	3.70	3.70	3.20		4.30
Dk @ 5 Ghz	3.68	3.63	3.73	3.57	3.60	3.60				4.30
Dk @ 10 Ghz	3.68	3.63	3.72	3.57	3.65	3.65	3.65	3.25		4.20
Df @ 1 Mhz					0.0100	0.0090			0.0088	0.0060
Df @ 1 Ghz						0.0100			0.0090	0.0100
Df @ 2 Ghz	0.0130	0.0120	0.0084	0.0060	0.0080	0.0090	0.0090	0.0080		0.0120
Df @ 5 Ghz	0.0133	0.0130	0.0097	0.0066						0.0135
Df @ 10 Ghz	0.0133	0.0130	0.0100	0.0071	0.0080	0.0085	0.0085	0.0075		0.0150

Supplier Material ID	Panasonic Megtron 4	TUC TU-768(752)	TUC TU-872	TUC TU-872LK
Dk @ 1 Mhz		4.60	4.10	New / prelim
Dk @ 1 Ghz	3.80	4.30	4.00	4.00
Dk @ 2 Ghz	3.80			3.90
Dk @ 5 Ghz	3.75			
Dk @ 10 Ghz	3.72			3.80
Df @ 1 Mhz		0.0140	0.0070	0.0080
Df @ 1 Ghz	0.0050	0.0130	0.0080	0.0080
Df @ 2 Ghz	0.0060			
Df @ 5 Ghz	0.0065			
Df @ 10 Ghz	0.0080			0.0090

2-3X FR-4

Caution: *Use as a rough guide only. The details shown are taken from laminate supplier data sheets. Results vary due to test method and sample construction differences*

- Tier 2, low loss electrical performance (0.006 – 0.015 Df)
  - **Materials advertised to be lead-free capable**

Supplier Material ID	Polyimide: Arlon 35N	Polyimide: Arlon EP-2	Polyimide: Nelco -2HT / -3	Halogen free: EMC EM-285	Halogen free: Nan Ya NPG-170TL	Halogen free: Nan Ya NPGN-170	Halogen free: Nelco N4000-7EF	Halogen free: Panasonic R-1577	Halogen free: Rogers * Theta	Halogen free: TUC TU-862 HF
Dk @ 1 Mhz	4.20	4.20			4.40	4.40	4.10			4.50
Dk @ 1 Ghz		New / prelim	3.80	4.50	4.00	4.00	4.00	4.10	3.90	4.30
Dk @ 2 Ghz		4.16	3.50							
Dk @ 5 Ghz		4.15								
Dk @ 10 Ghz		4.13	3.50				3.80		4.01	
Df @ 1 Mhz	0.01	0.006			0.015	0.015	0.0130			0.0110
Df @ 1 Ghz				0.0100	0.013	0.013		0.0100	0.0080	0.0100
Df @ 2 Ghz		0.0079	0.015							
Df @ 5 Ghz		0.0081								
Df @ 10 Ghz		0.0083	0.0090				0.0160		0.0118	

Note: Materials shown for comparison purposes. Some materials may not be available at Chippewa Falls.

* Rogers Theta material is equivalent to Hitachi's HE-679G

2-3X FR-4

Caution: *Use as a rough guide only. The details shown are taken from laminate supplier data sheets. Results vary due to test method and sample construction differences*

- Tier 3, very low loss electrical performance **(<0.006 Df)**
  - **Materials advertised to be lead-free capable**

Supplier Material ID	Hitachi MCL-FX-II	Isola IS680	Mitsubishi FL700	Nelco Mercurywave	Nelco D6300	Panasonic Megtron 6
Dk @ 1 Mhz		Rf designs	New/prelim.	Rf designs		
Dk @ 1 Ghz	3.48	only	3.80	only	3.90	3.7
Dk @ 2 Ghz	3.47	2.80 - 3.45		3.70	3.80	3.4
Dk @ 5 Ghz	3.46	2.80 - 3.45	3.70			3.4
Dk @ 10 Ghz	3.45	2.80 - 3.45	3.60	3.60	3.65	3.4
Df @ 1 Mhz						
Df @ 1 Ghz	0.0028		0.0030		0.0020	0.0020
Df @ 2 Ghz	0.0035	.0028-.0036		0.0040	0.0040	0.0020
Df @ 5 Ghz	0.0046	.0028-.0036	0.0040			0.0030
Df @ 10 Ghz	0.0052	.0028-.0036	0.0050	0.0040	0.0045	0.0040

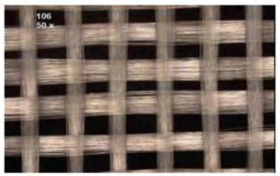
Note: Materials shown for comparison purposes. Some materials may not be available at Chippewa Falls.

3-6X FR-4

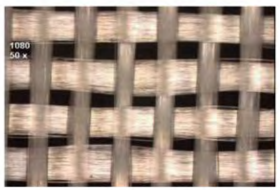
Caution: *Use as a rough guide only. The details shown are taken from laminate supplier data sheets. Results vary due to test method and sample construction differences*

Glass Construction

Woven Glass Fabric isola



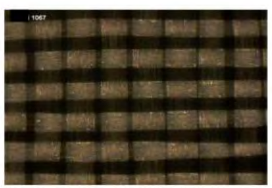
106
Warp & Fill Count: 56 x 56 (ends/in)
Thickness: 0.0015" / 0.038 mm



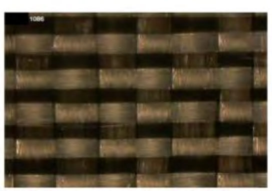
1080
Warp & Fill Count: 60 x 47 (ends/in)
Thickness: 0.0025" / 0.064 mm

Photos courtesy of Isola R & D Laboratories

Woven Glass Fabric isola



1067
Warp & Fill Count: 70 x 70 (ends/in)
Thickness: 0.0013" / 0.032 mm

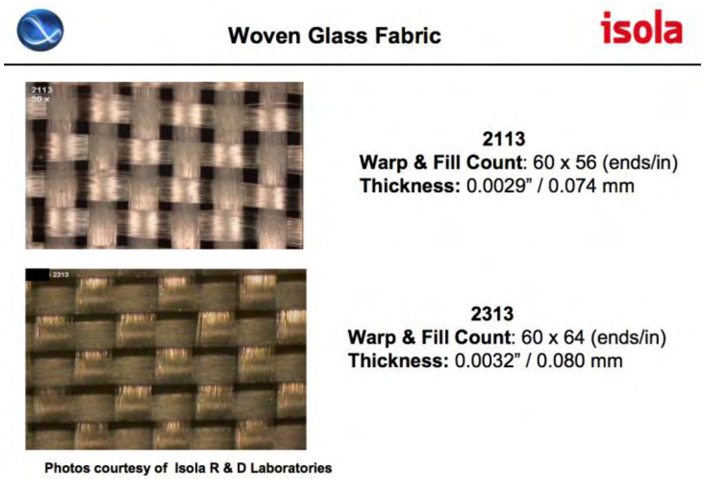


1086
Warp & Fill Count: 60 x 60 (ends/in)
Thickness: 0.002" / 0.050 mm

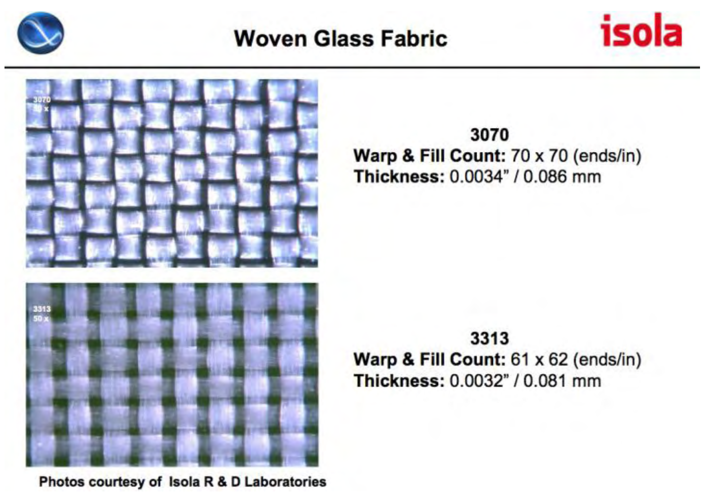
Photos courtesy of Isola R & D Laboratories

- 106 / 1080 glass do not perform well at speeds above 6.25Gbps.
- This glass performs well for 10Gbps.

Glass Construction

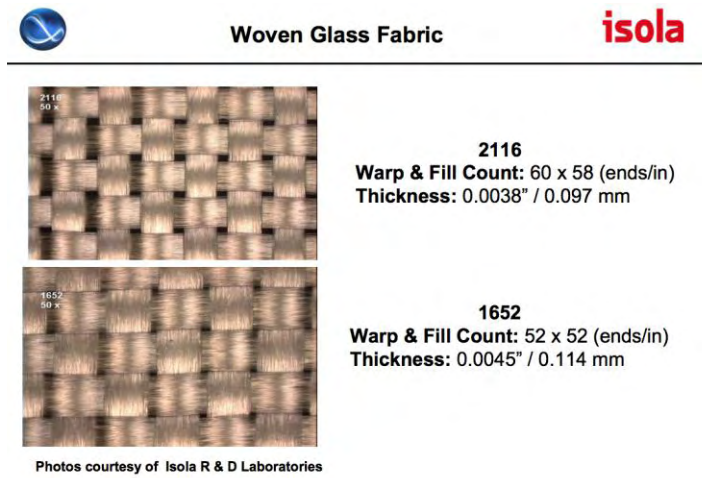


- This glass performs well for 10Gbps.



- This glass performs well for 10Gbps.

Glass Construction



- Both Glass types behave well at 10Gbps and appear to work at speeds to 25Gbps.
- 7628 Does not perform well at high speeds in part to the Dielectric instability of the glass.

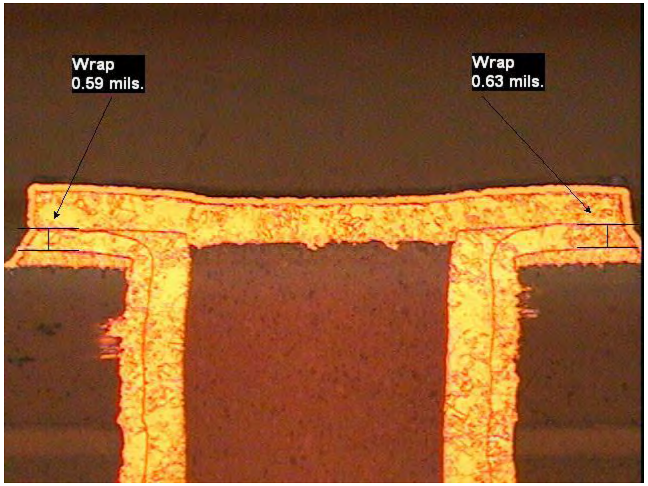
Glass Construction

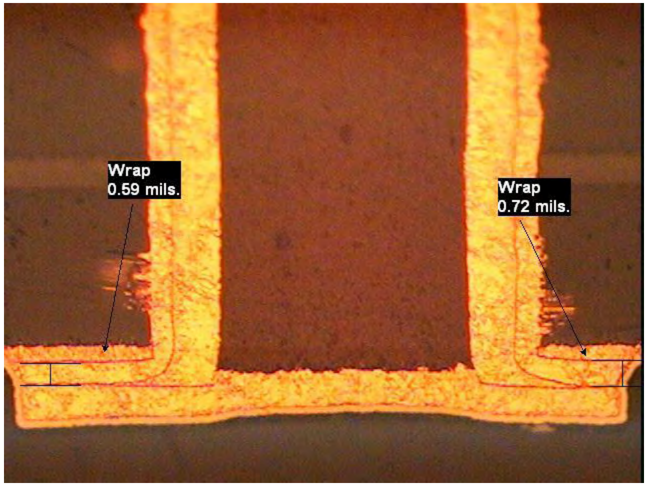
- Figure 1. Cross sectional view of differential signal pair with very equal proximity and alignment to the fiberglass yarn bundle. Within a few inches this can and does change to skewed alignment relative to signals

The New High Speed Channel: 25Gbps

VIA in PAD Plated Over (VIPPO) Technology

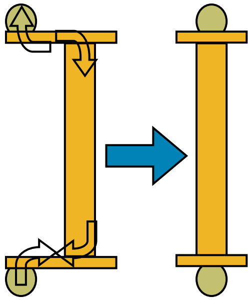
VIA in PAD

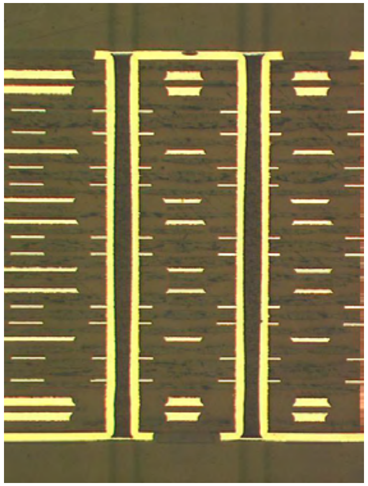




VIA in PAD Plated Over

Item	Comment
Signal Integrity	Eliminate dogbones
Routability	Very little – freed up outer layer area, but requires outer layer features and spaces
Reliability (SnPb)	Proven
Reliability (Pb-free)	No issues found yet
Supply Base	Large
Process Complexity	Moderate – additional plating, epoxy fill and planarization
Cost	~10-25% adder, dependant on tech level, layer count, etc
Hidden Cons	Restricted OL feature size Restricted OL spacing



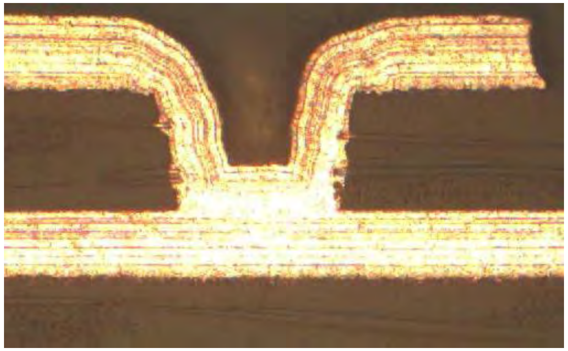


Micro VIA

- **What is it?**

A standard through hole board with controlled depth vias (laser formed) which connect layer 1 to 2 and n to (n-1)

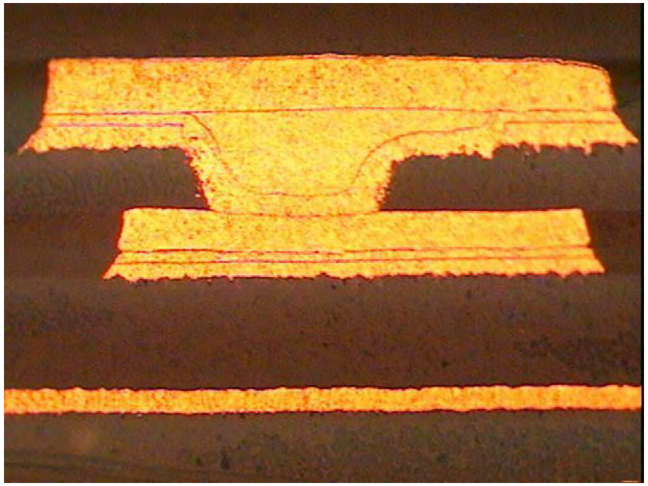
Vias can be conformal plated or Cu fill plated

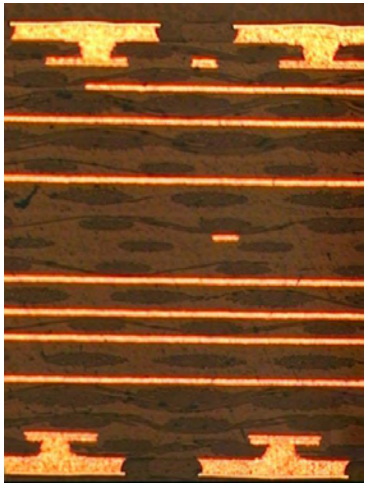


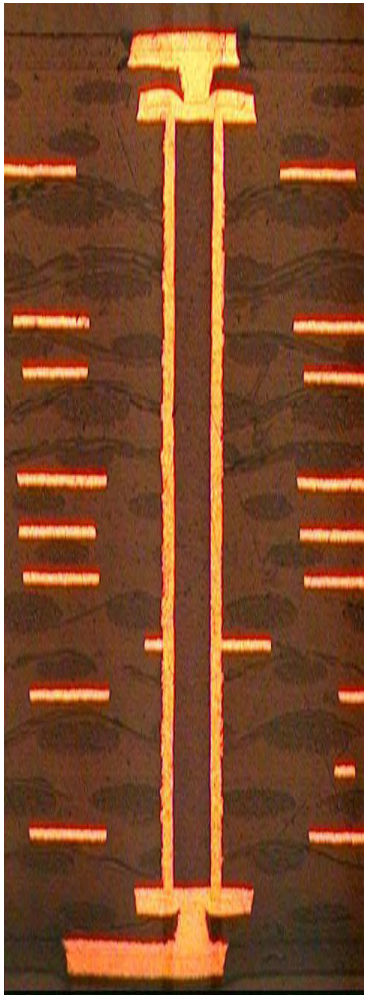
Conformal plated laser via

Fill plated laser via

Micro VIA







Micro VIA

Item	Comment
Signal Integrity	Small, stubless via
Routability	Freed up space on layer below via
Reliability (SnPb)	Proven – Passed L1 & L2 qualifications
Reliability (Pb-free)	Proven - Passed L1 & L2 qualifications
Supply Base	Large
Process Complexity	Minimal – laser drilling and microvia plating…pretty common technology for most suppliers
Cost	~5-15% (Conformal plated) ~15-40% (Cu fill plated)
Hidden Cons	Design tools not 100% optimized

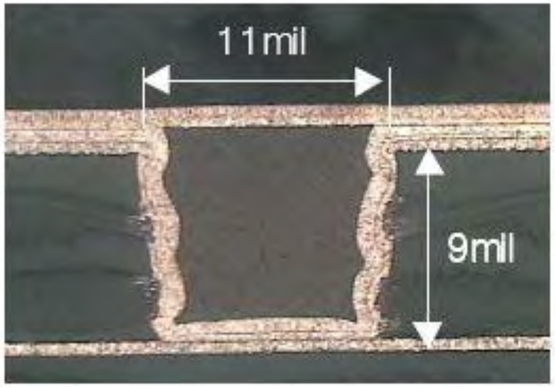
Skip VIA

- **What is it?**

  Laser vias which connect layer 1 to 3 and n to (n-2)

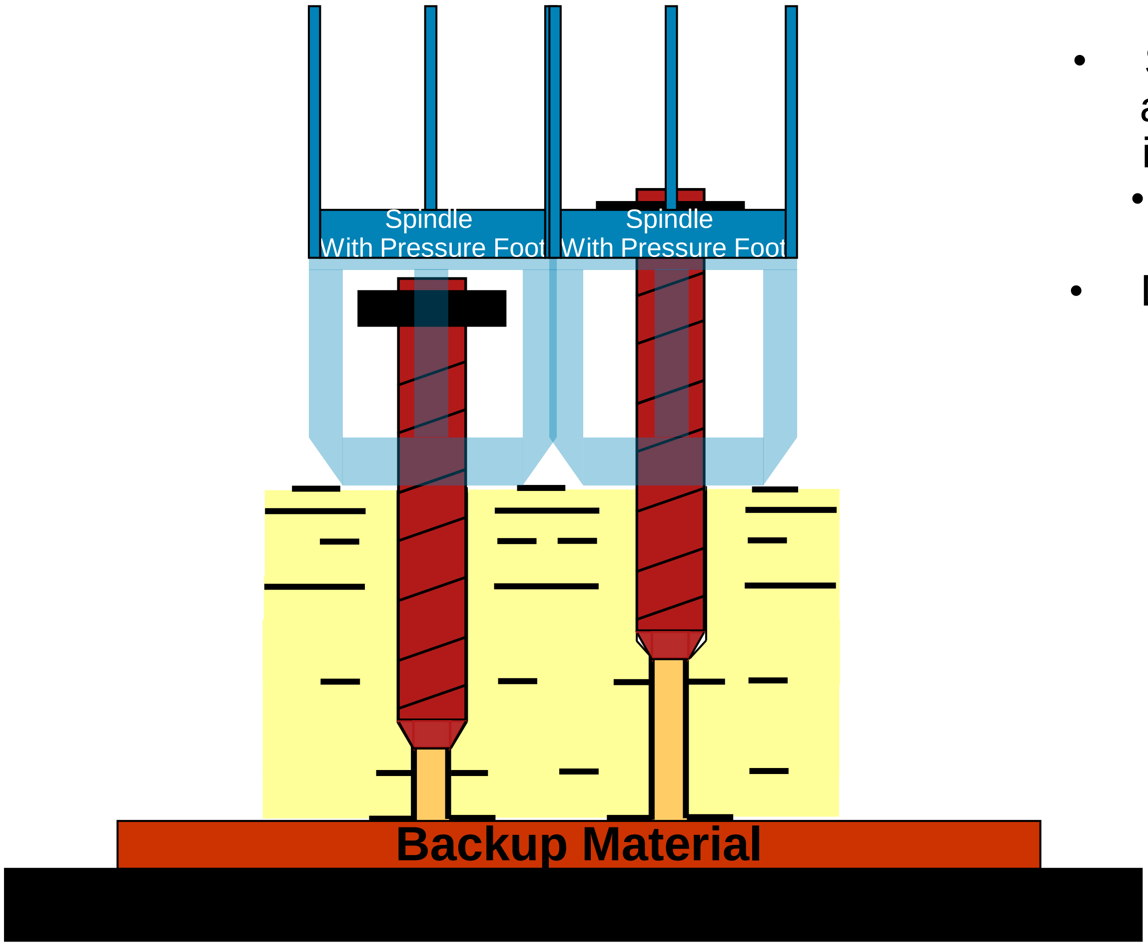
  Normally combined with the use of microvias

  Vias can be conformal plated or epoxy filled and plated over (SKIPPO)



Item	Comment
Signal Integrity	Stubless via connection for high speed signals
Routability	Freed up space on layer below via
Reliability (SnPb)	Passed
Reliability (Pb-free)	Passed
Supply Base	Limited
Process Complexity	Moderate – complex laser drilling process
Cost	~15-20% (Conformal plated) ~30-40% (SKIPPO)
Hidden Cons	Prone to laminate cracking below via

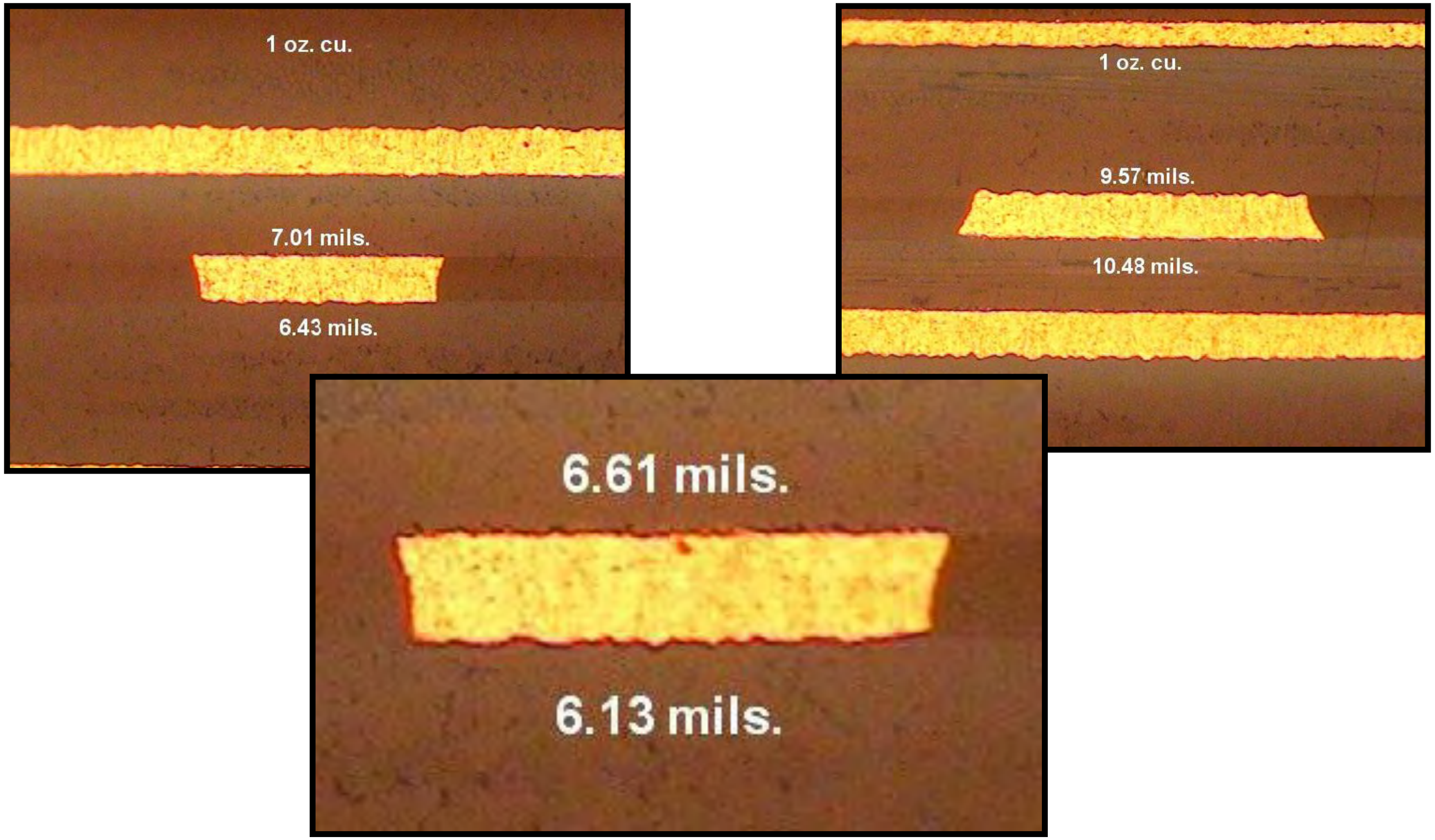
Back Drilling



- Back Drilling is a well defined process with very low cost impact.
- Stop depth tolerance can be as low as +/- 5 mils but often is in the range of +/- 10 mils.
- Removes a significant portion of the stub.
- Don't be afraid to deploy this fabrication technology. Seldom used in 2000, this technique is used today in almost all high speed designs.

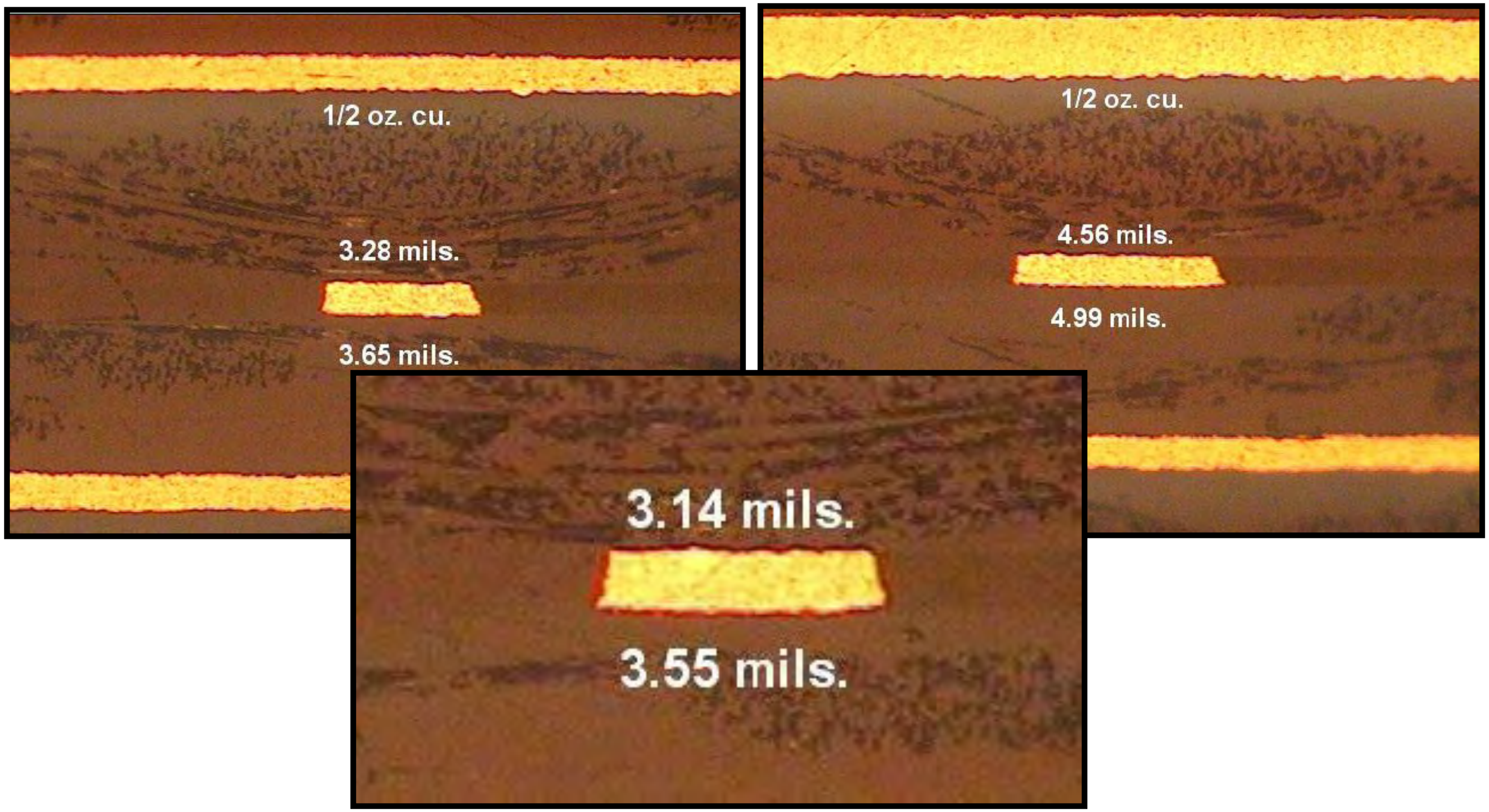
1 oz Copper Signal Internal Characteristics

- 1 oz copper trapezoid shape ~ .50 -.90 mils total width reduction at top
- Copper thickness ~ 1.10-1.25 mils typically



½ oz Copper Internal Signal Characteristics

- ½ oz copper trapezoid shape ~ .40 -.50 mils total width reduction at top
- Copper thickness ~ .55 -.65 mils typically

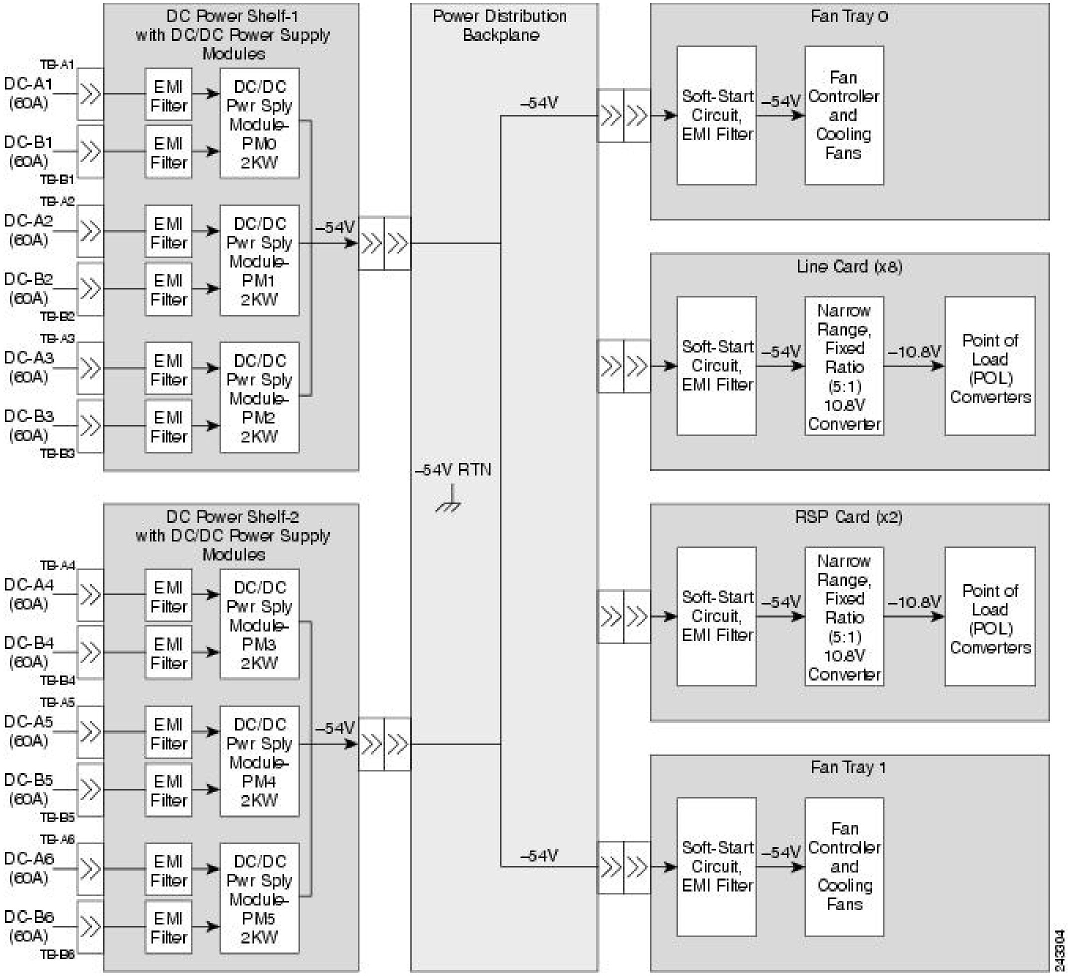


Copper Surface Roughness

- Much work has been done here.
- Impact at 10Gbps is not worth the added costs.
- Impact at 25Gbps shows improvement but still might not be worth the cost. Looking at a 15% to 20% cost adder.
- It really comes down to Channel Margin.

The Power System

Typical A/B Power System Design



SERDES Core Power Design Max Noise Targets

- SERDES Core Power

  Target < 30mV, 1MHz – 20Mhz

  Target < 60mV, 21Mhz – 500Mhz

- SERDES PLL Power

  Target < 10mV, 1MHz – 20MHz

- SERDES RX Power

  Target < 15mV, 1MHz – 20Mhz

  Target < 30mV, 21Mhz – 500Mhz

- SERDES TX Power

  Target < 15mV, 1MHz – 20Mhz

  Target < 30mV, 21Mhz – 500Mhz

The Take Away Slide

- Technical Feasibility
  - •Geometry
  - •Material
  - •Fabrication Process
- Economic Feasibility
  - •25Gbps PCB about 2X 10Gbps PCB