Datacenter Optical Transceivers in the Next Decade

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Tu3C: High Performance Computer Networks and High Throughput Transceivers

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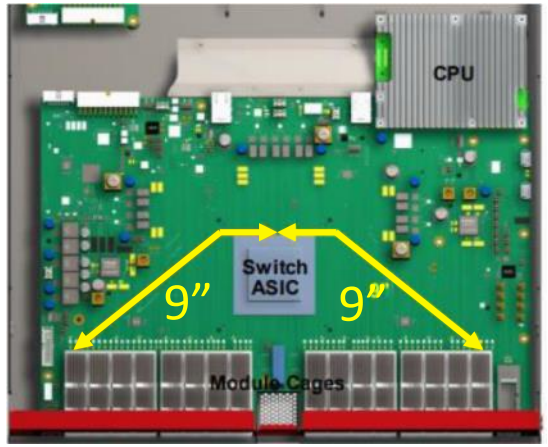
Outline

➢ Introduction

- Rack Power Limitations
- Dual ASIC VLC Baseline
- Vertical OSFP Connector
- Vertical OSFP-XD Connector
- Stripline vs. Twinax Loss
- Single ASIC VLC Alternative
- Summary

Horizontal Line Card (HLC)

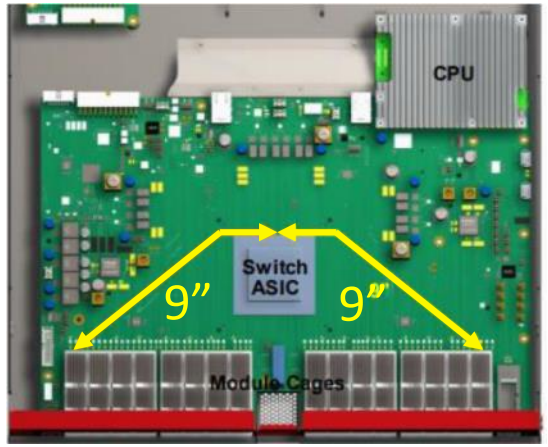
Front Pluggable
(OSFP, QSFP)
Stripline in PCB

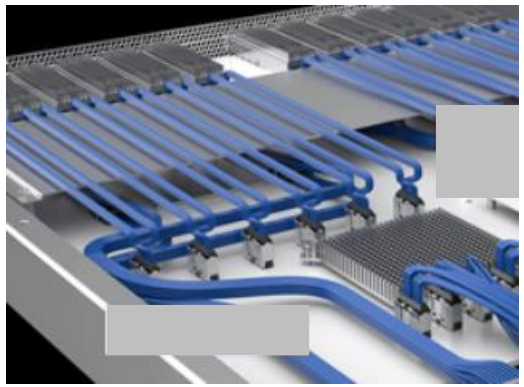


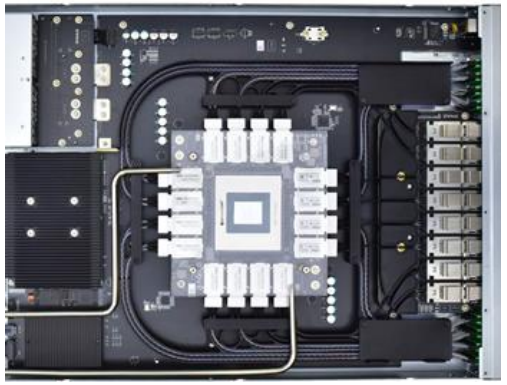
Horizontal Line Card (HLC) Optics Roadmap

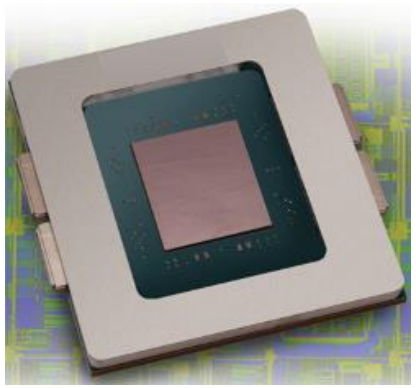
HLC →

Front Pluggable (OSFP, QSFP) Stripline in PCB	Front Pluggable (OSFP, QSFP) Twinax over PCB	Assembled on PCB Near ASIC Package (NPO)	Co-Packaged w/ ASIC (CPO)









Horizontal Line Card (HLC) Optics

Optics		RF Type	$L_{RF\text{-}MAX}$	RF I/O Density
HLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	9” - 12”	1x
	Front Pluggable (OSFP, QSFP)	Twinax over PCB	9” - 12”	1x
	Assembled on PCB Near Package (NPO)	Stripline in PCB	3” - 4”	2x
	Co-Packaged w/ ASIC (CPO)	Stripline in Ceramic	2”	>2x

Horizontal Line Card (HLC) Optics

Optics		RF Type	$L_{RF\text{-}MAX}$	RF I/O Density	Front Access	Air Flow Obstacles
HLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	9” - 12”	1x	Yes	Cage & Connector
	Front Pluggable (OSFP, QSFP)	Twinax over PCB	9” - 12”	1x	Yes	Cables & Connector
	Assembled on PCB Near Package (NPO)	Stripline in PCB	3” - 4”	2x	No	ASIC & other NPOs
	Co-Packaged w/ ASIC (CPO)	Stripline in Ceramic	2”	>2x	No	ASIC & other CPOs

Horizontal Line Card (HLC) Optics

Optics		RF Type	$L_{RF\text{-}MAX}$	RF I/O Density	Front Access	Air Flow Obstacles	Mature Tech.	Cost
HLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	9” - 12”	1x	Yes	Cage & Connector	Yes	1x
	Front Pluggable (OSFP, QSFP)	Twinax over PCB	9” - 12”	1x	Yes	Cables & Connector	No	>2x
	Assembled on PCB Near Package (NPO)	Stripline in PCB	3” - 4”	2x	No	ASIC & other NPOs	No	>1x
	Co-Packaged w/ ASIC (CPO)	Stripline in Ceramic	2”	>2x	No	ASIC & other CPOs	No	>2x

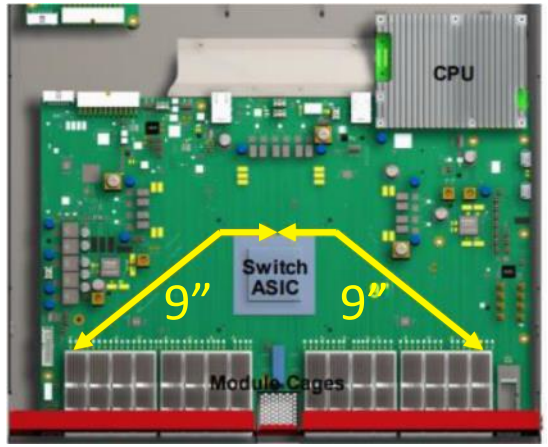
Background

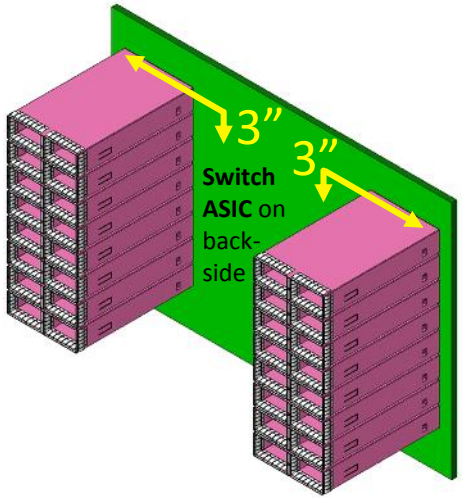
- HLC I/O bottlenecks require breakthroughs to advance compute, AI and ML, including:
  - Significantly denser, more scalable, and lower-power optics
  - Innovations across photonics, electronics, packaging, and manufacturing
- However, conventional approaches limit breakthroughs:
  - This presentation is an example of an unconventional approach, using mature technology from Yamaichi Electronics, dramatically improving performance
  - Other exciting innovations will come from Nubis Communications, once it is out of stealth mode

Vertical Line Card (VLC) Optics Roadmap

HLC → **VLC** →

Front Pluggable (OSFP, QSFP) Stripline in PCB	→	Front Pluggable (OSFP, QSFP) Stripline in PCB	→	Assembled on PCB Near ASIC Package (NPO)	→	Co-Packaged w/ ASIC (CPO)





HLC Optics vs. Vertical Line Card (VLC) Front Pluggable Optics

Optics		RF Type	$L_{RF\text{-}MAX}$	RF I/O Density
HLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	9” - 12”	1x
	Front Pluggable (OSFP, QSFP)	Twinax over PCB	9” - 12”	1x
	Assembled on PCB Near Package (NPO)	Stripline in PCB	3” - 4”	2x
VLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	3” - 4”	1x

HLC Optics vs. Vertical Line Card (VLC) Front Pluggable Optics

Optics		RF Type	$L_{RF\text{-}MAX}$	RF I/O Density	Front Access	Air Flow Obstacles	Mature Tech.	Cost
HLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	9” - 12”	1x	Yes	Cage & Connector	Yes	1x
	Front Pluggable (OSFP, QSFP)	Twinax over PCB	9” - 12”	1x	Yes	Cables & Connector	No	>2x
	Assembled on PCB Near Package (NPO)	Stripline in PCB	3” - 4”	2x	No	ASIC & other NPOs	No	>1x
VLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	3” - 4”	1x	Yes	None	Yes	1x

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➢ Rack Power Limitations

- Dual ASIC VLC Baseline
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- Vertical OSFP-XD Connector
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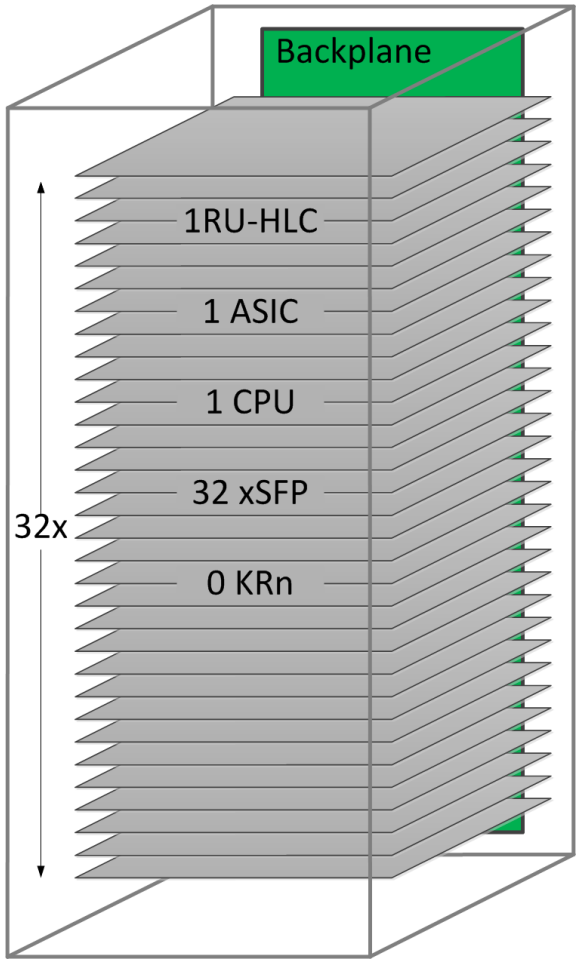
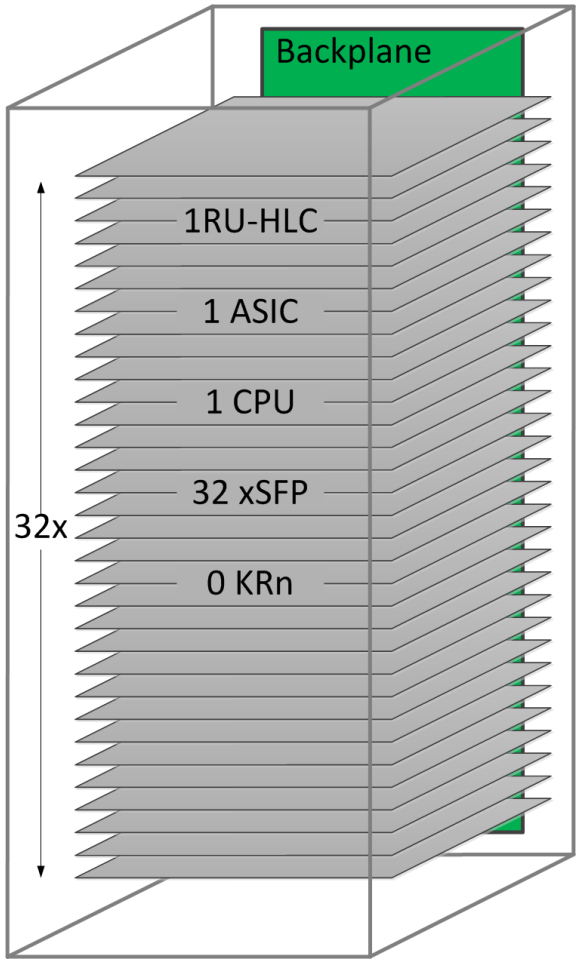
Ex.1: 12.8T ASIC HLC Racks



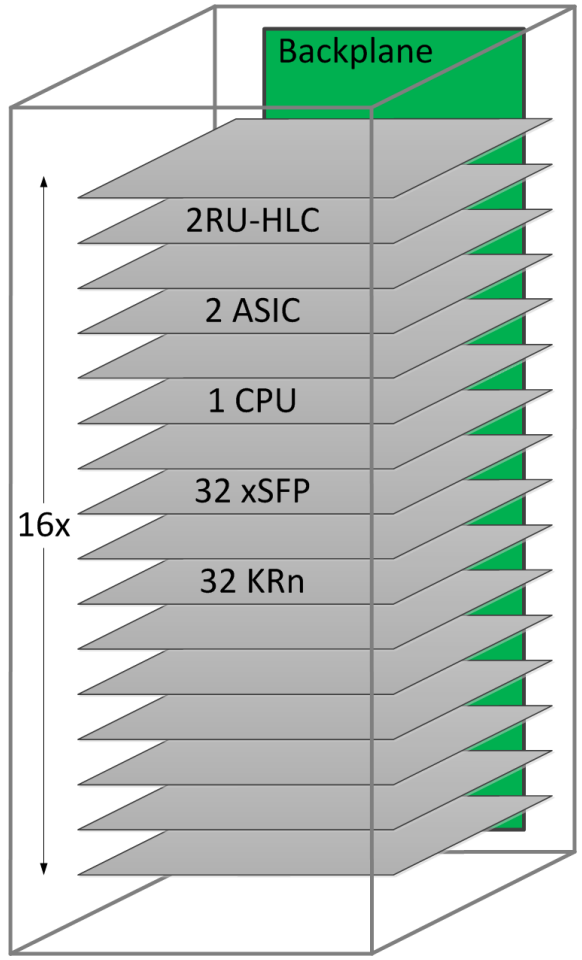
- 12.8T 1RU-HLC w/ 1x TH3 ASIC
- 32x 2x200G OSFPs (50G I/O)
- No Backplane links
- 1000W HLC (1200W OCP HLC)
- 32 Card Rack: 32KW

Ex.1: 12.8T ASIC HLC Racks



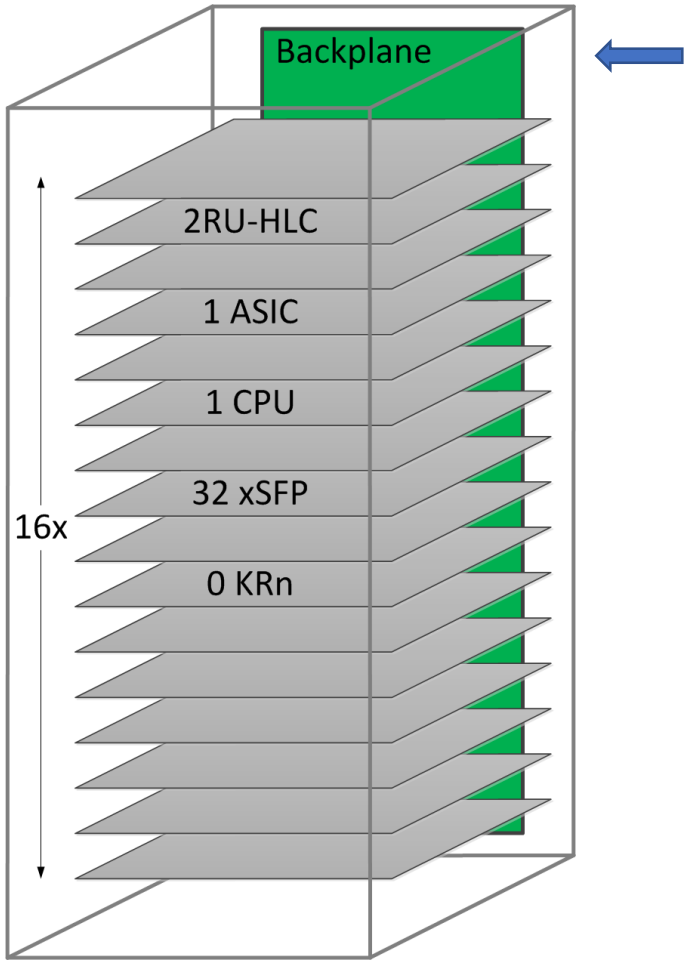
- 12.8T 1RU-HLC w/ 1x TH3 ASIC
- 32x 2x200G OSFPs (50G I/O)
- No Backplane links
- 1000W HLC (1200W OCP HLC)
- 32 Card Rack: 32KW

- 25.6T 2RU-HLC w/ 2x TH3 ASICs
- 32x 2x200G OSFPs (50G I/O)
- 32x 4x100G Backplane links
- 1950W HLC
- 16 Card Rack: 31KW



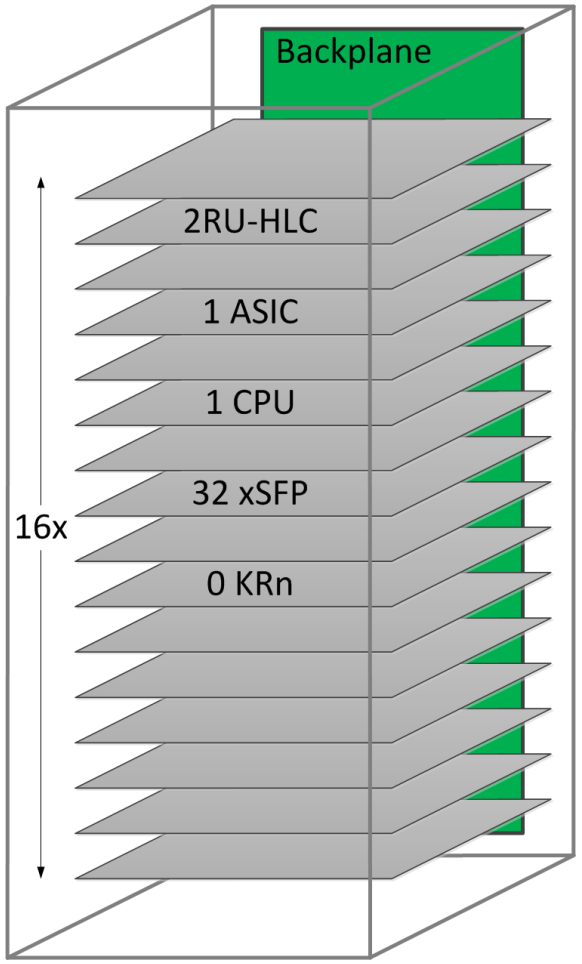
Fabric application

Ex.2: 25.6T ASIC HLC Racks



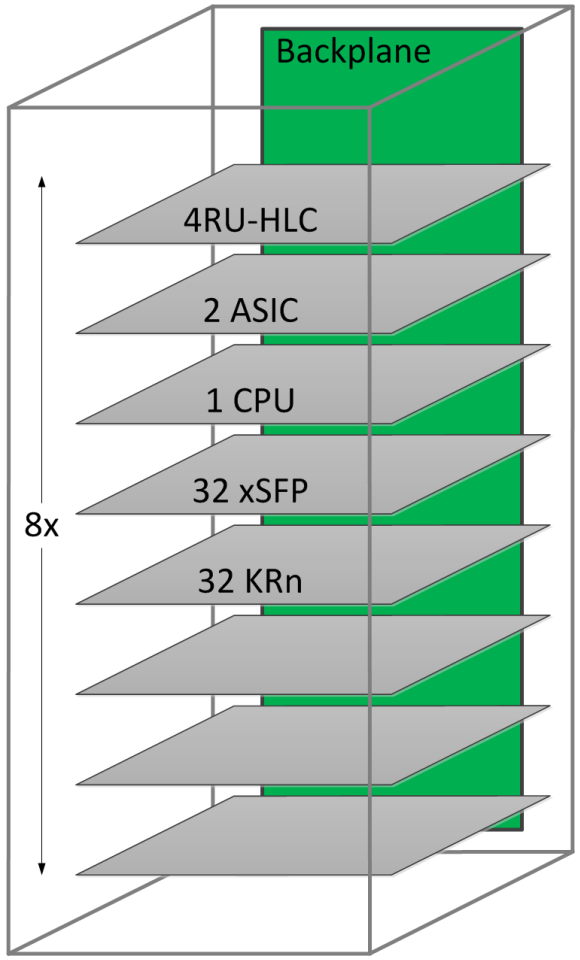
- 25.6T 2RU-HLC w/ 1x TH4 ASIC
- 32x 2x400G OSFPs (100G I/O)
- No Backplane links
- 1750W HLC
- 16 Card Rack: 28KW

Ex.2: 25.6T ASIC HLC Racks



- 25.6T 2RU-HLC w/ 1x TH4 ASIC
- 32x 2x400G OSFPs (100G I/O)
- No Backplane links
- 1750W HLC
- 16 Card Rack: 28KW

- 51.2T 4RU-HLC w/ 2x TH4 ASICs
- 32x 2x400G OSFPs (100G I/O)
- 32x 8x100G Backplane links
- 3400W HLC
- 8 Card Rack: 27KW



Fabric application

Line Card Component Power

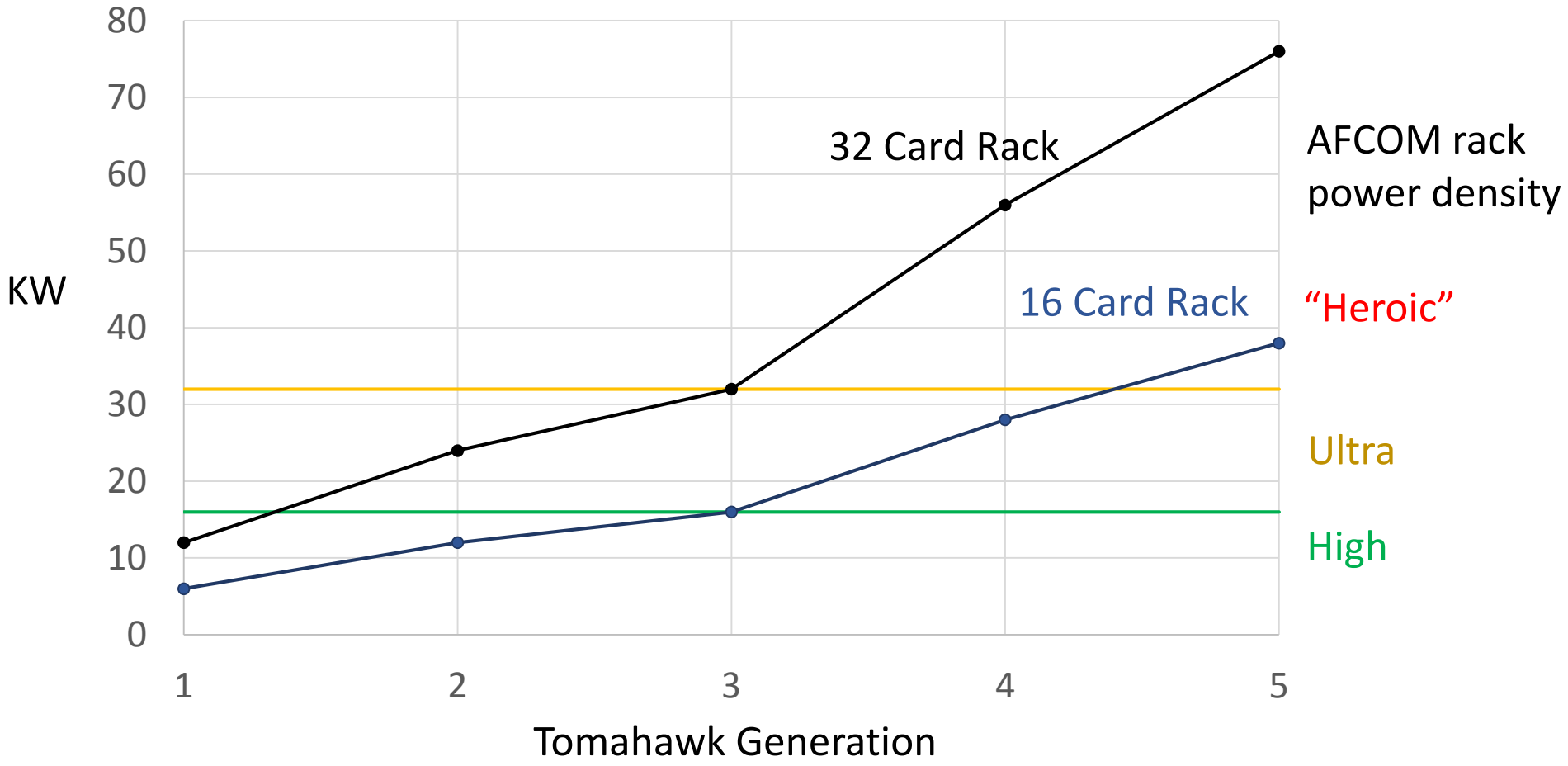
Tomahawk Switch ASIC				xSFP Optics	
Gen.	BW	CMOS node	Design Ref Pwr.	BW	Design Ref Pwr.
	Tb/s	nm	W	Gb/s	W
1	3.2	28	165	100	3
2	6.4	16	300	200	6
3	12.8	16	390	400	10
4	25.6	7	540	800	18
5	51.2	5	700	1600	28

Component, Line Card & Rack Power

Tomahawk Switch ASIC				xSFP Optics		HLC		Rack	
Gen.	BW	CMOS node	Design Ref Pwr.	BW	Design Ref Pwr.	32 Units	Total	32 Cards	16 Cards
	Tb/s	nm	W	Gb/s	W	W	W	KW	KW
1	3.2	28	165	100	3	100	360	12	6
2	6.4	16	300	200	6	200	750	24	12
3	12.8	16	390	400	10	320	1000	32	16
4	25.6	7	540	800	18	580	1750	56	28
5	51.2	5	700	1600	28	900	2400	76	38

AFCOM rack power density: Low $\leq$ 4KW < Medium $\leq$ 8KW < High $\leq$ 16KW < Ultra $\leq$ 32KW < "Heroic"

Rack Card Density is Limited by Power Dissipation



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➢ Dual ASIC VLC Baseline

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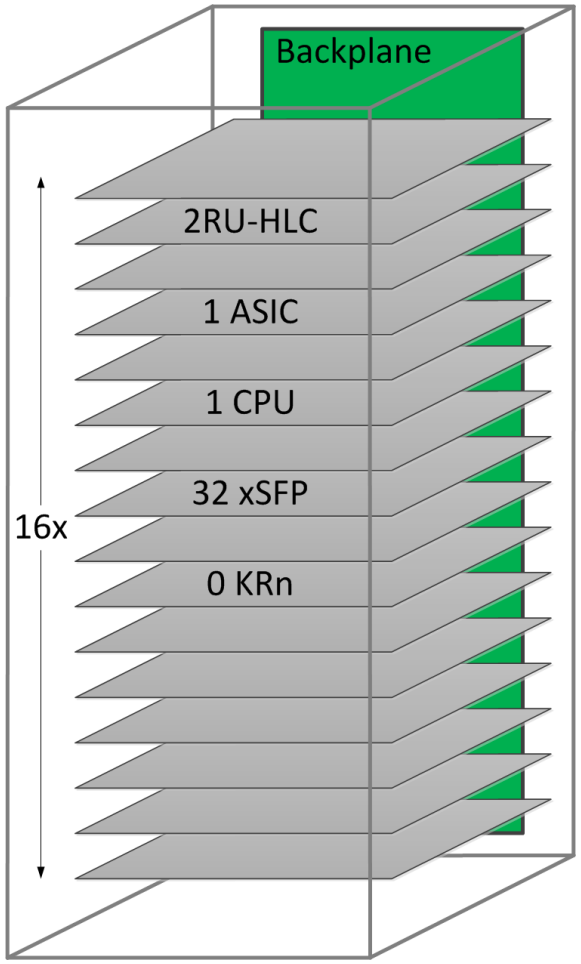
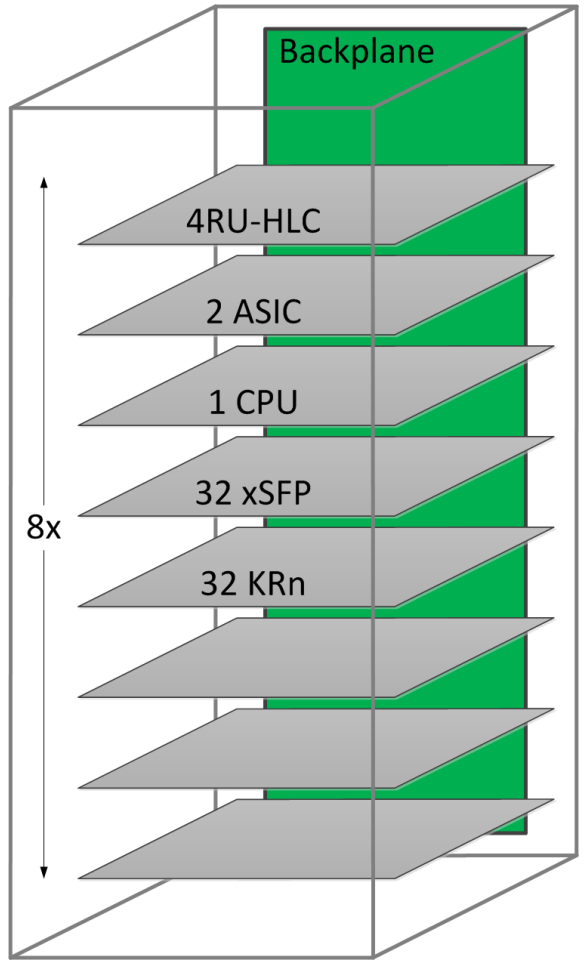
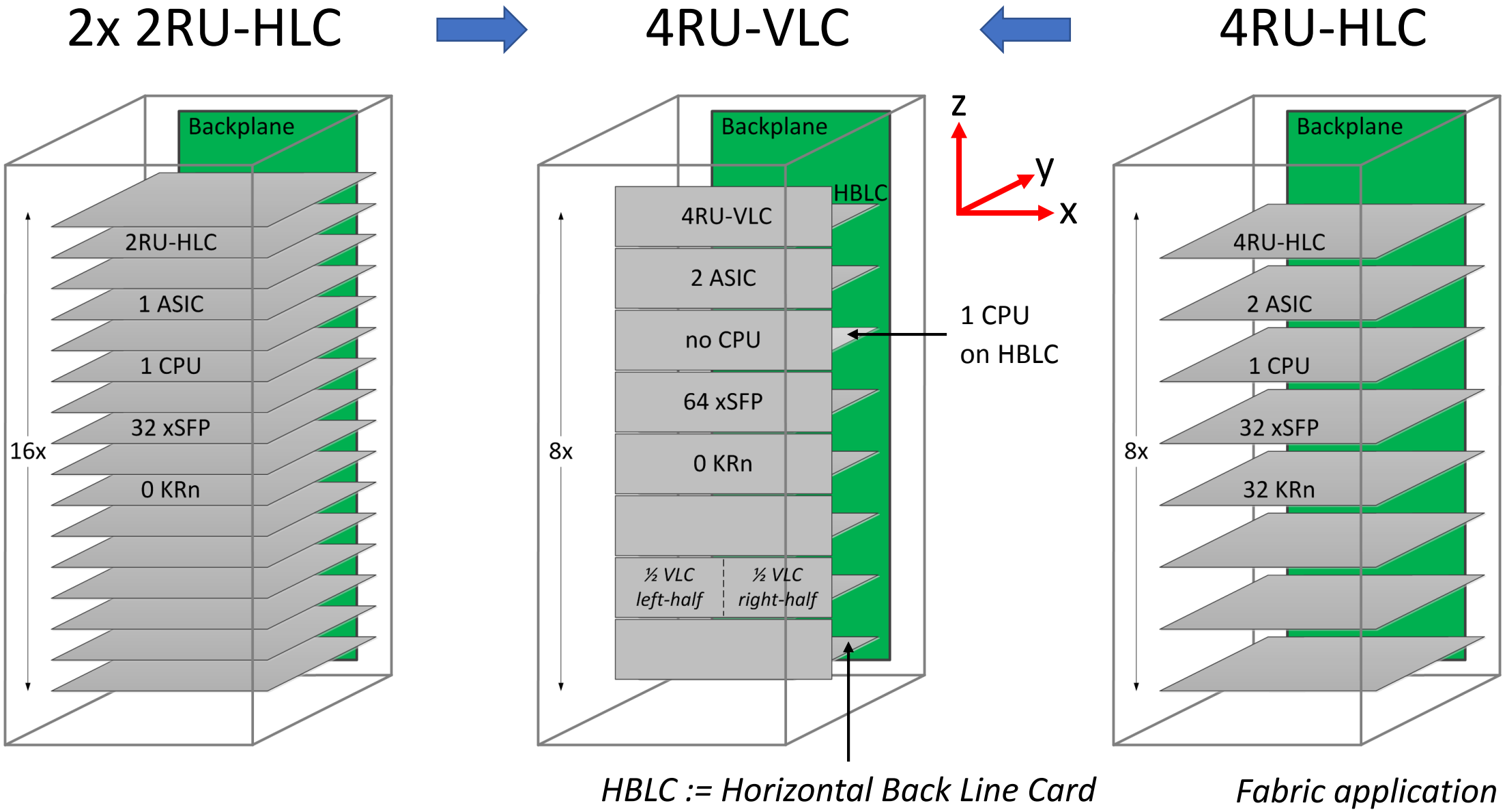
16x 2RU-HLC



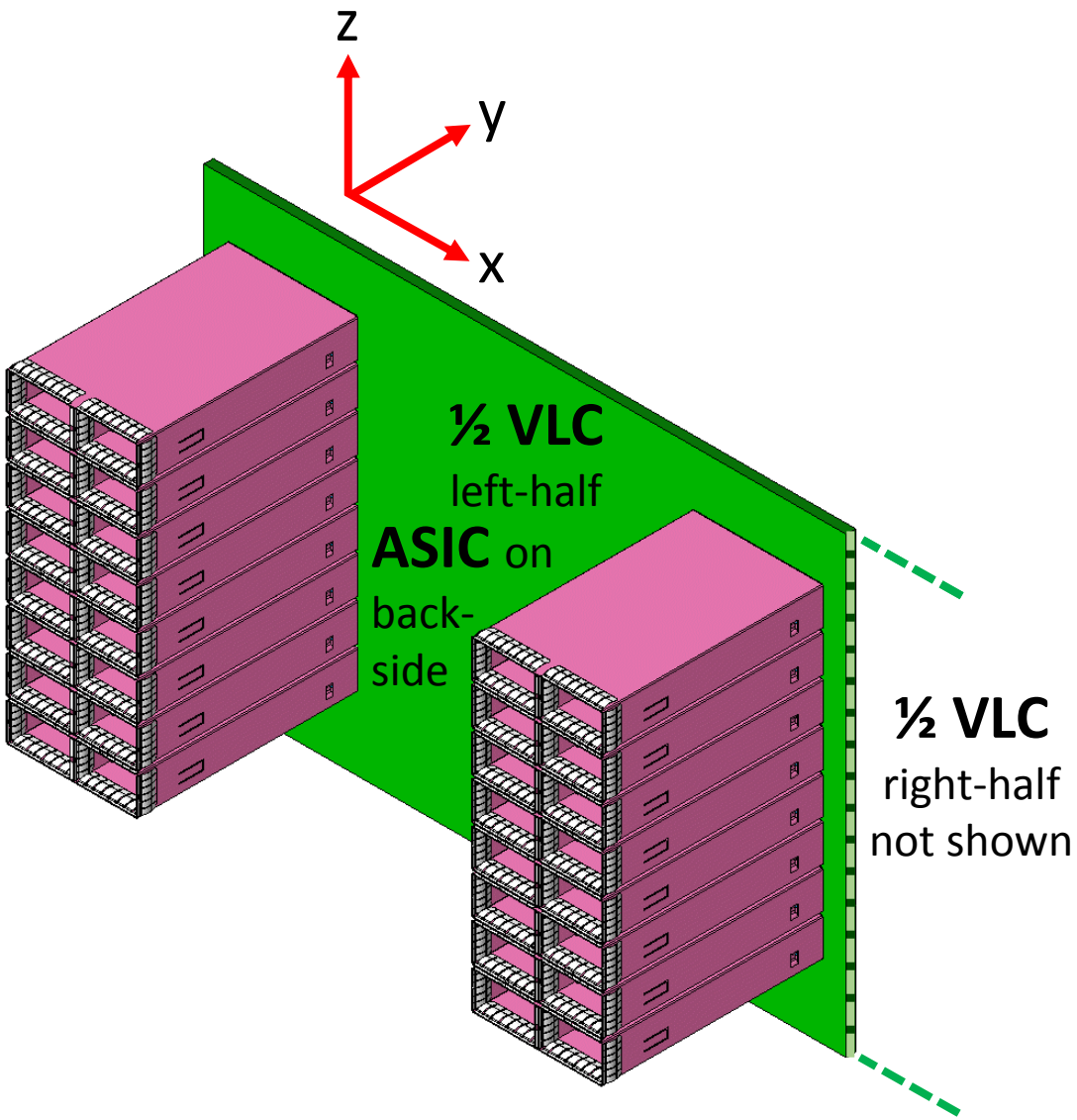
8x 4RU-HLC



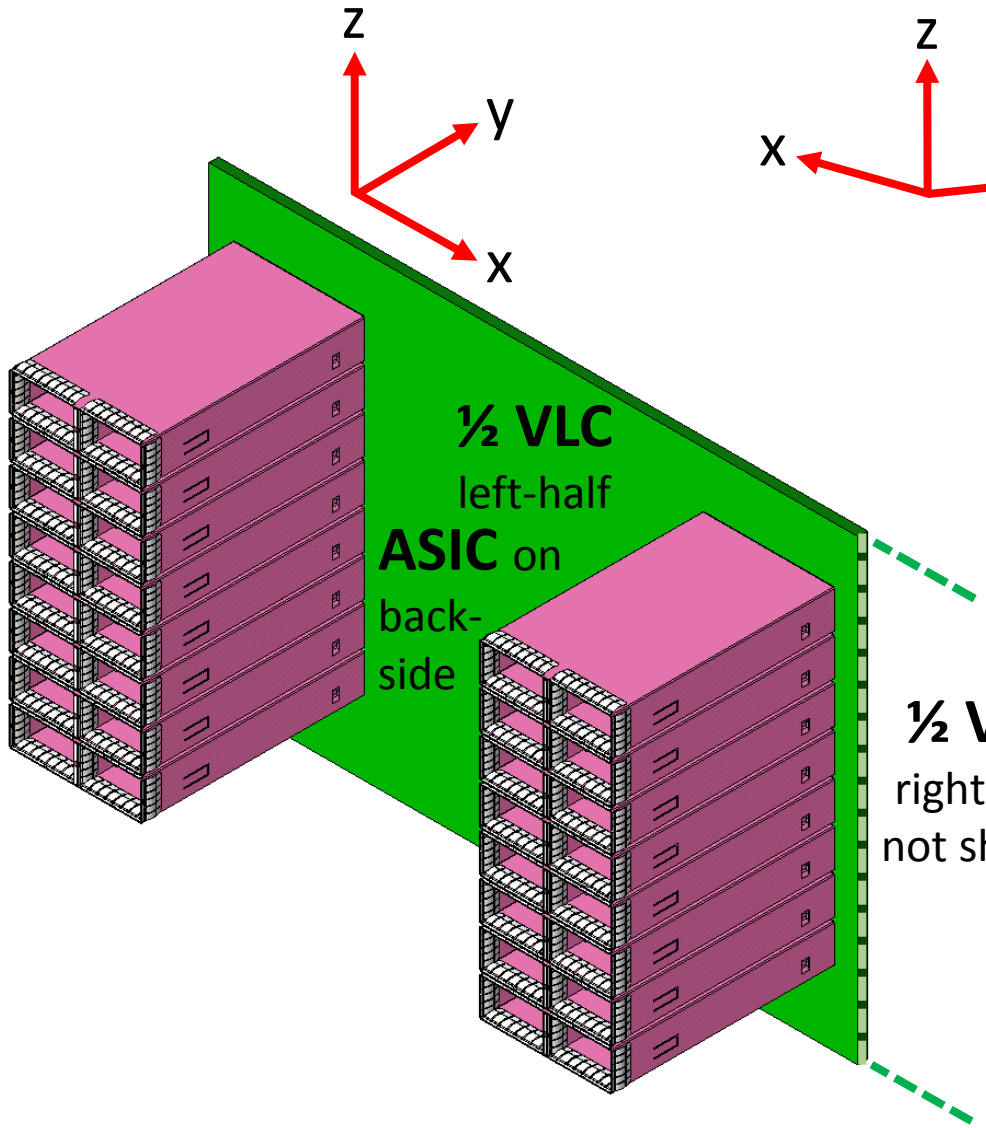
Fabric application

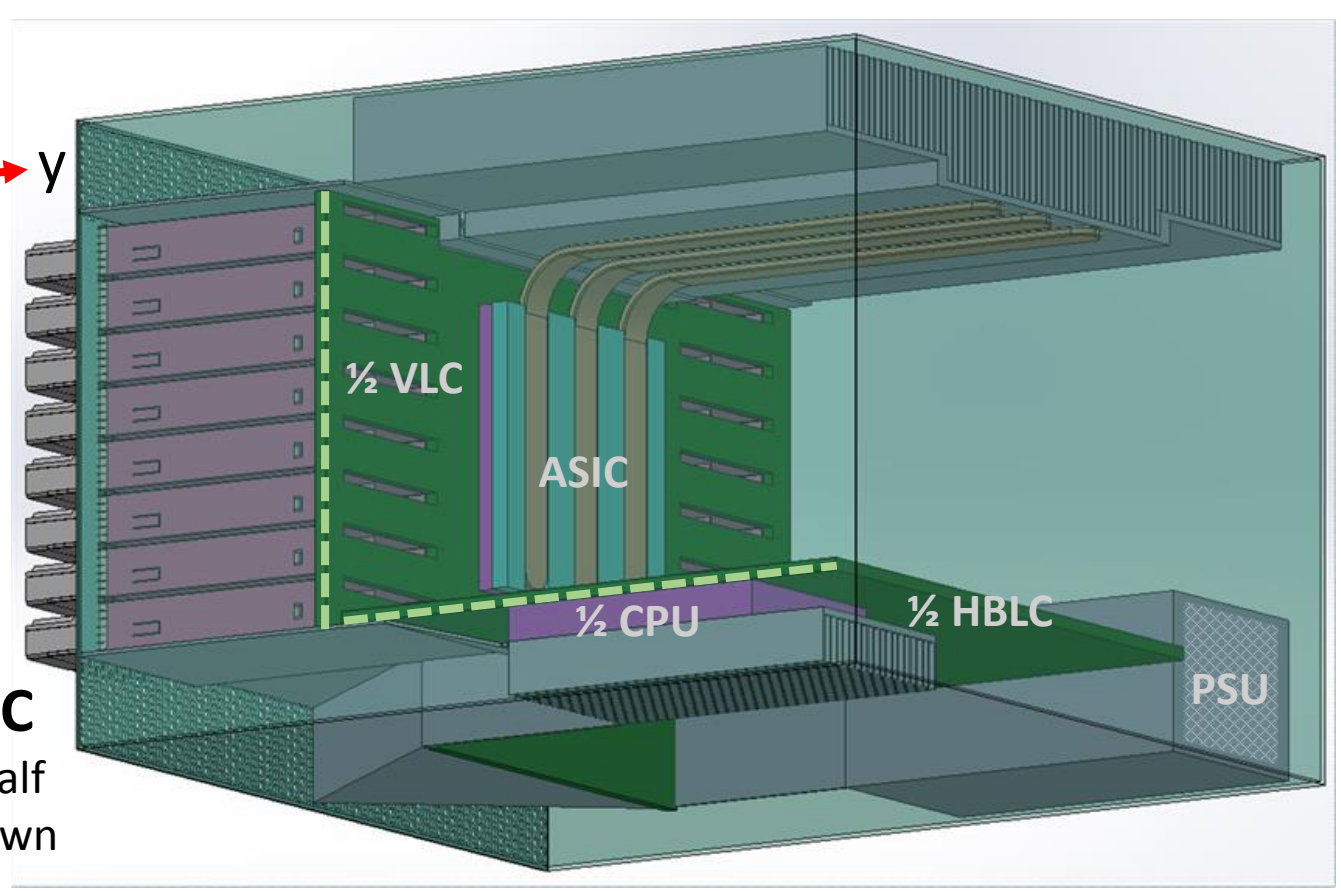

2x 2RU-HLC
4RU-VLC
4RU-HLC
Backplane
2RU-HLC
1 ASIC
1 CPU
32 xSFP
0 KRn
16x
Backplane
HBLC
4RU-VLC
2 ASIC
no CPU
64 xSFP
0 KRn
½ VLC left-half
½ VLC right-half
8x
z
y
x
1 CPU on HBLC
Backplane
4RU-HLC
2 ASIC
1 CPU
32 xSFP
32 KRn
8x
HBLC := Horizontal Back Line Card
Fabric application

4RU-VLC, 64 OSFP, 2 ASIC (Assembly Left-half 3-D Views)

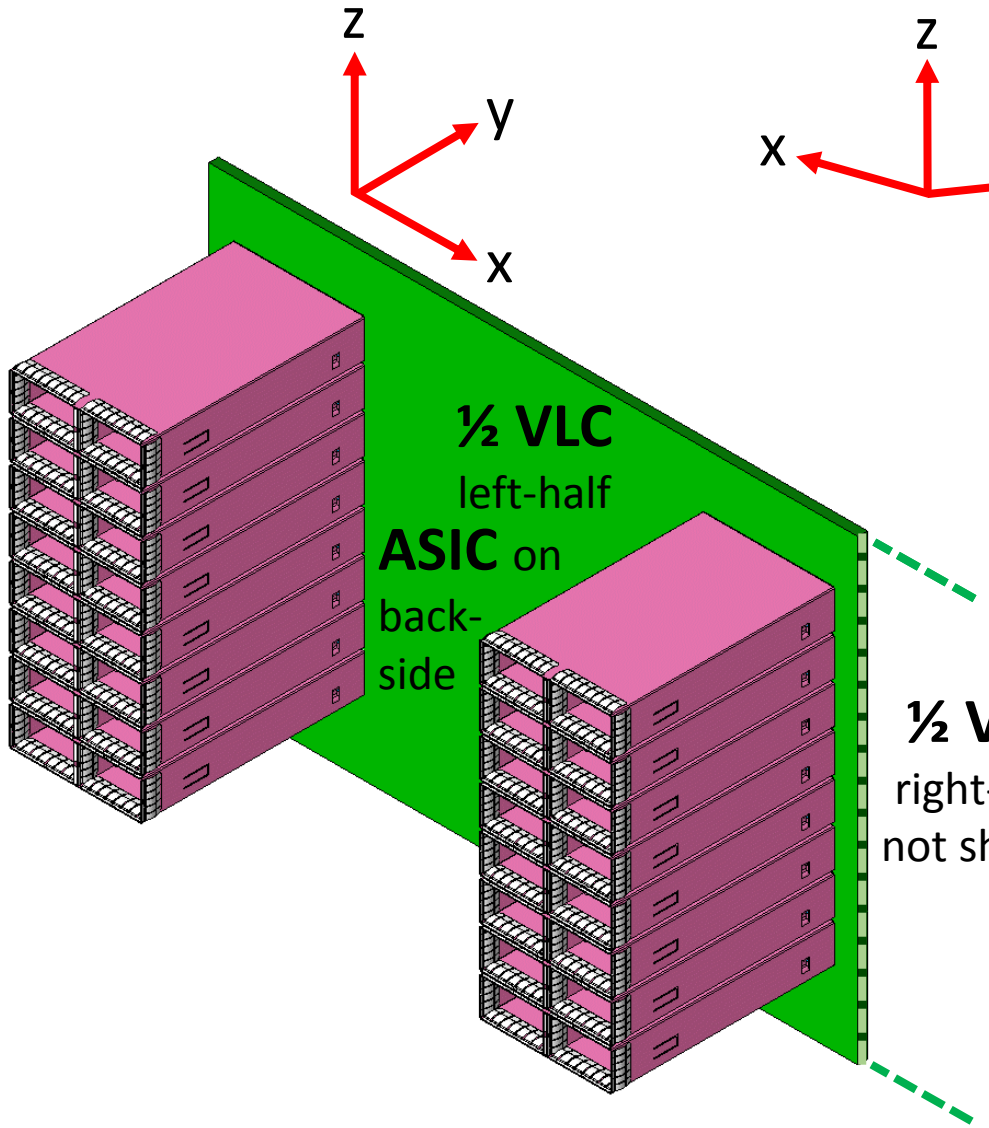


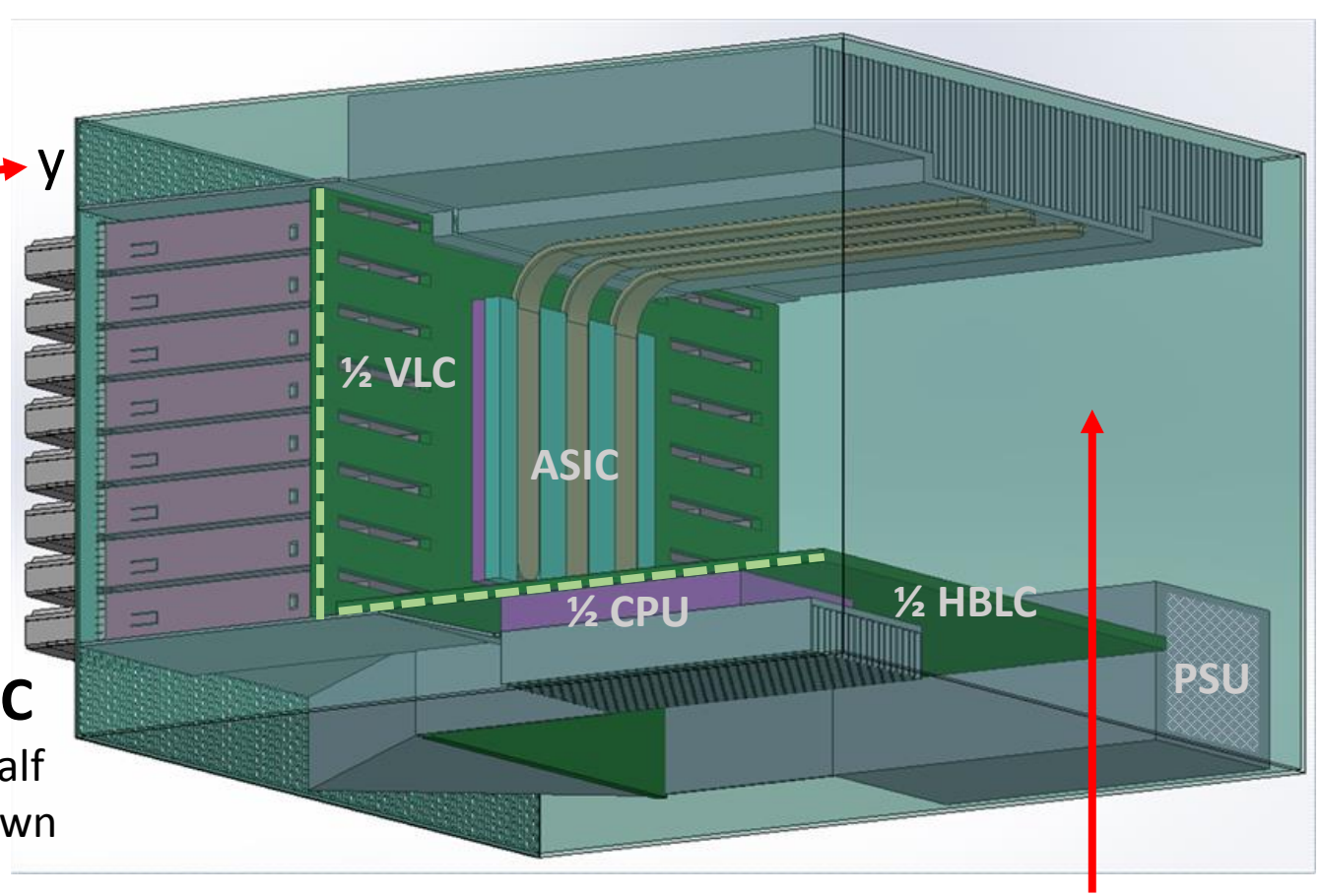
4RU-VLC, 64 OSFP, 2 ASIC (Assembly Left-half 3-D Views)





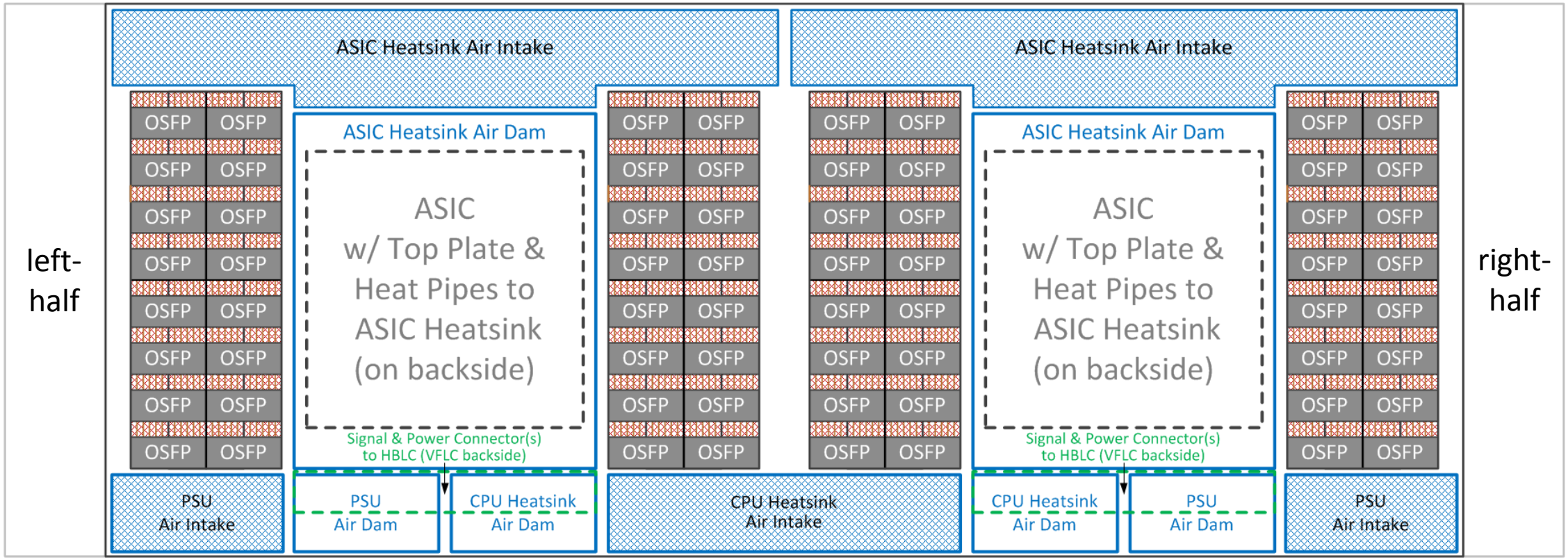
4RU-VLC, 64 OSFP, 2 ASIC (Assembly Left-half 3-D Views)



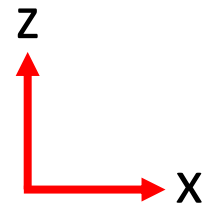


unimpeded inlet-air VLC 4RU fans use less energy than HLC 1RU or 2RU fans

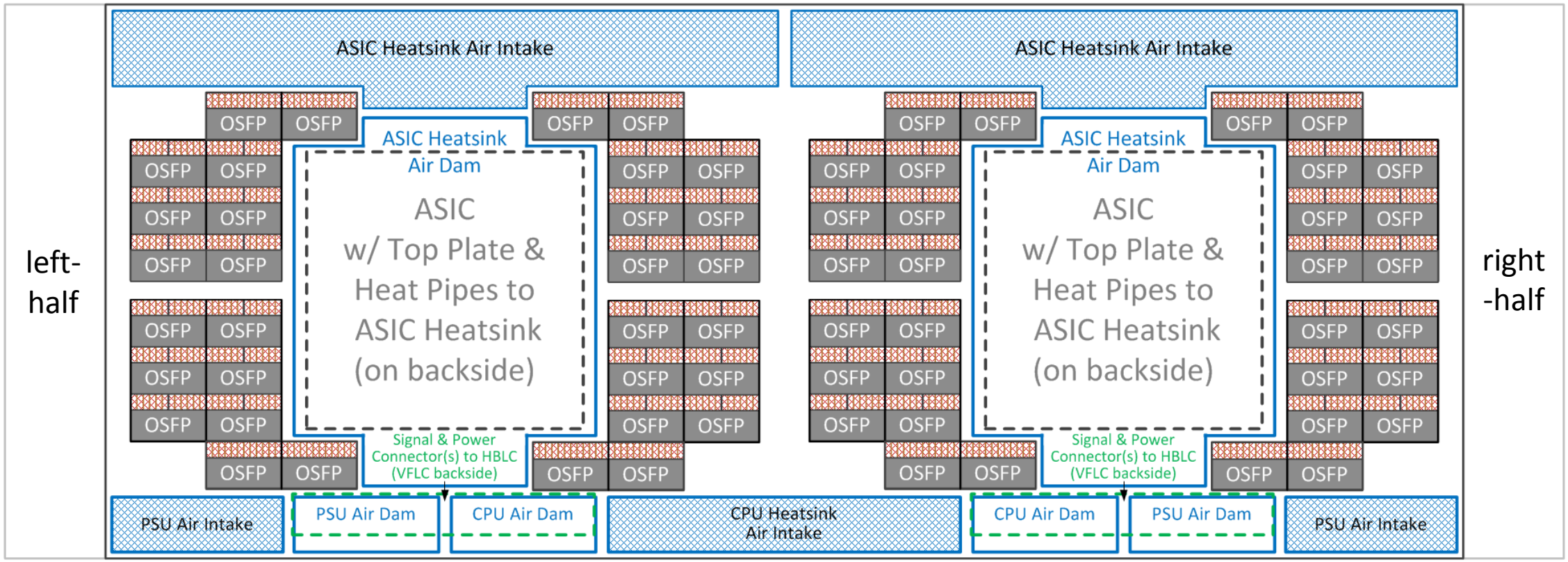
4RU-VLC (2RU-HLC Density), 64 OSFP, 3.0” $L_{RF\text{-}MAX}$ (Full Front View)



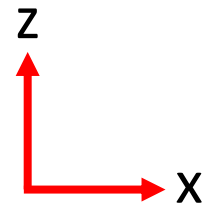
- OSFP vertical pitch = 15mm (MSA spec)
  horizontal pitch = 24mm
- PCB Stripline $L_{RF\text{-}MAX}$ =
  64mm + 12mm = 76mm **(3.0")**



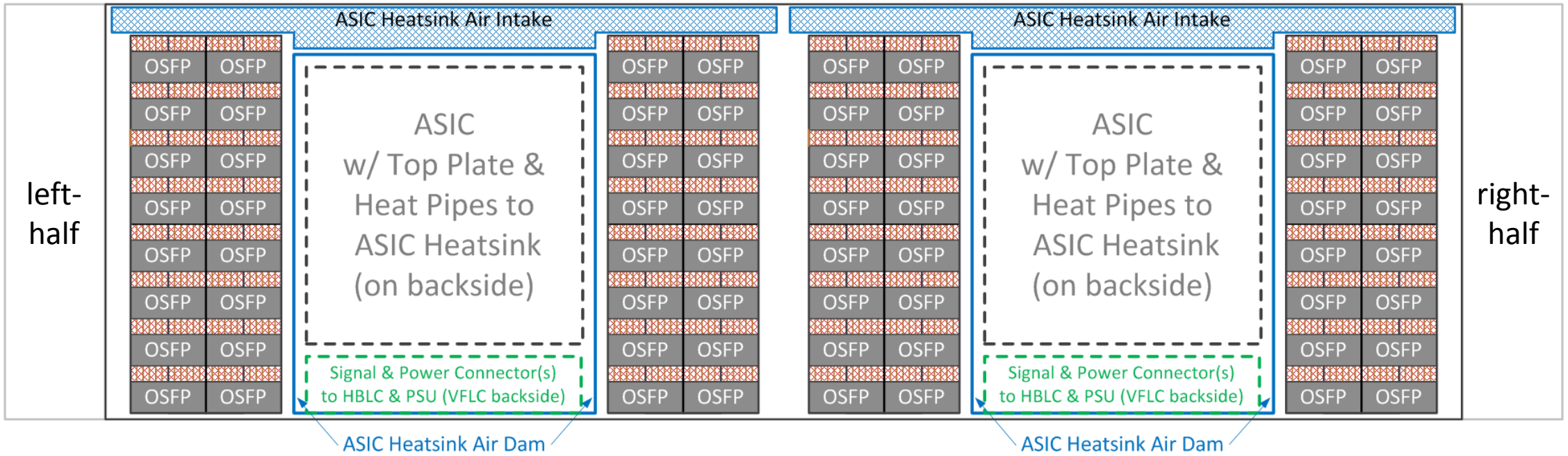
4RU-VLC (2RU-HLC Density), 64 OSFP, 2.5” $L_{RF\text{-}MAX}$ (Full Front View)



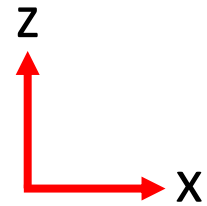
- OSFP vertical pitch = 15mm (MSA spec)
  horizontal pitch = 24mm
- PCB Stripline $L_{RF\text{-}MAX}$ =
  52mm + 12mm = 64mm **(2.5")**



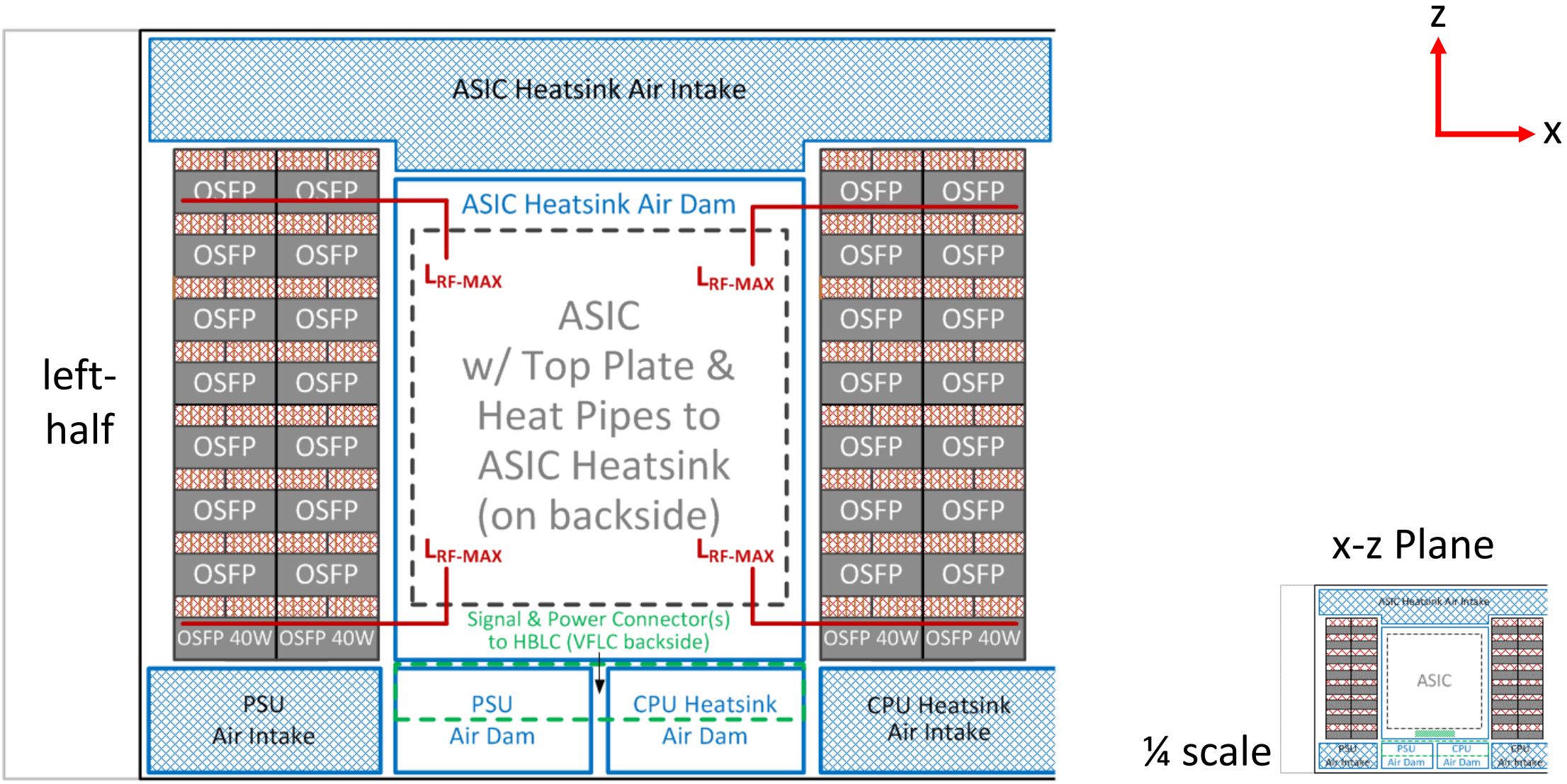
3RU-VLC (1.5RU-HLC Density), 64 OSFP, 3.5” $L_{RF\text{-}MAX}$ (Front View)



- OSFP vertical pitch = 15mm (MSA spec)
  horizontal pitch = 24mm
- PCB Stripline $L_{RF\text{-}MAX}$ =
  64mm + 25mm = 89mm **(3.5")**



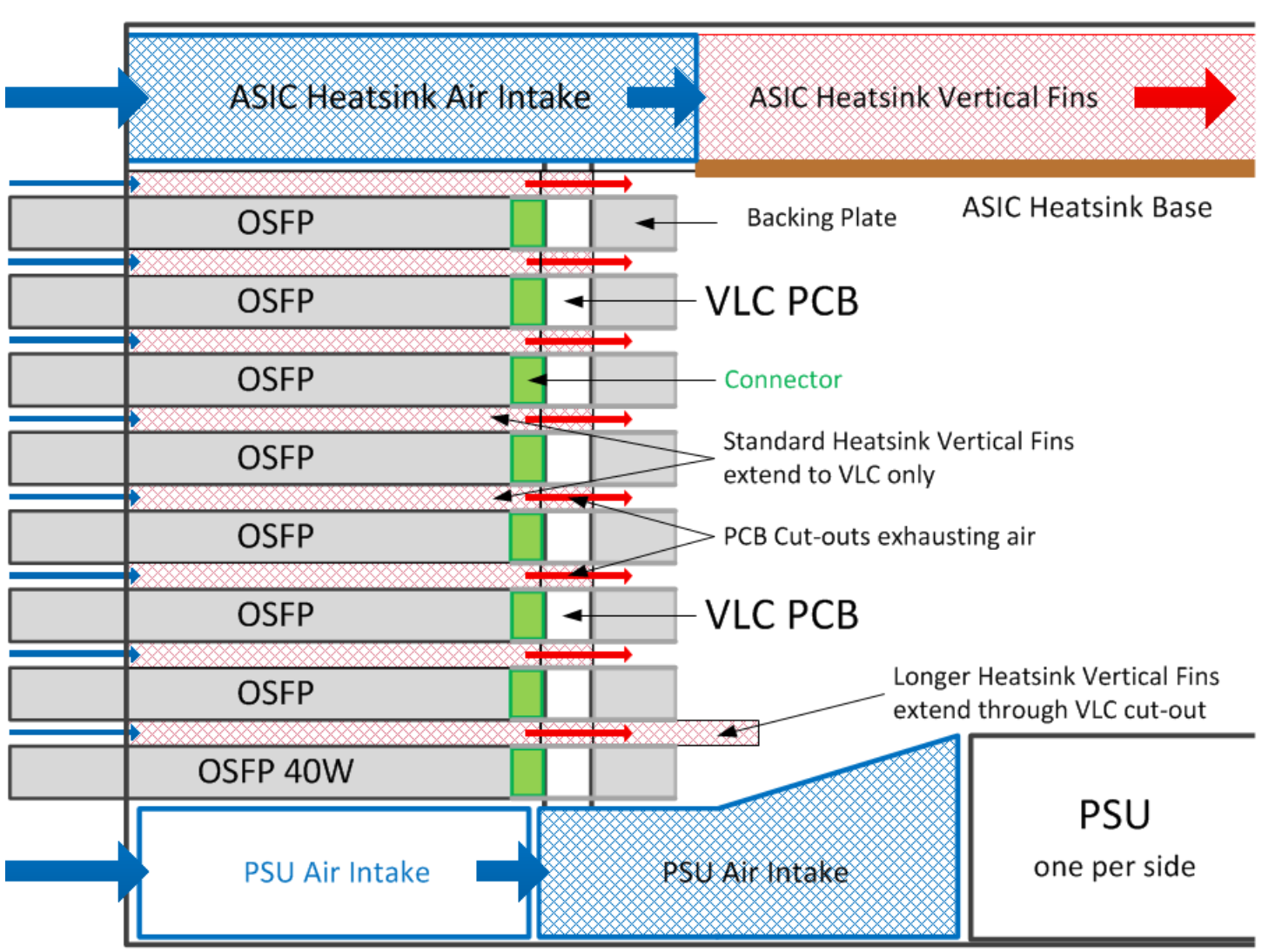
4RU-VLC, 64 OSFP, 2 ASIC, 3.0” $L_{RF\text{-}MAX}$ (Left-half Front View)

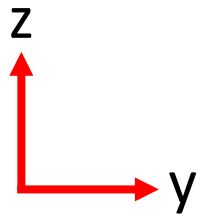


x-z Plane

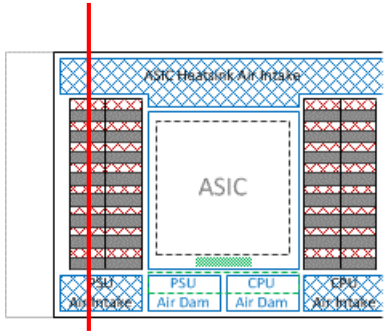
¼ scale

4RU-VLC, 64 OSFP (y-z Plane 1 Front-half Side View)

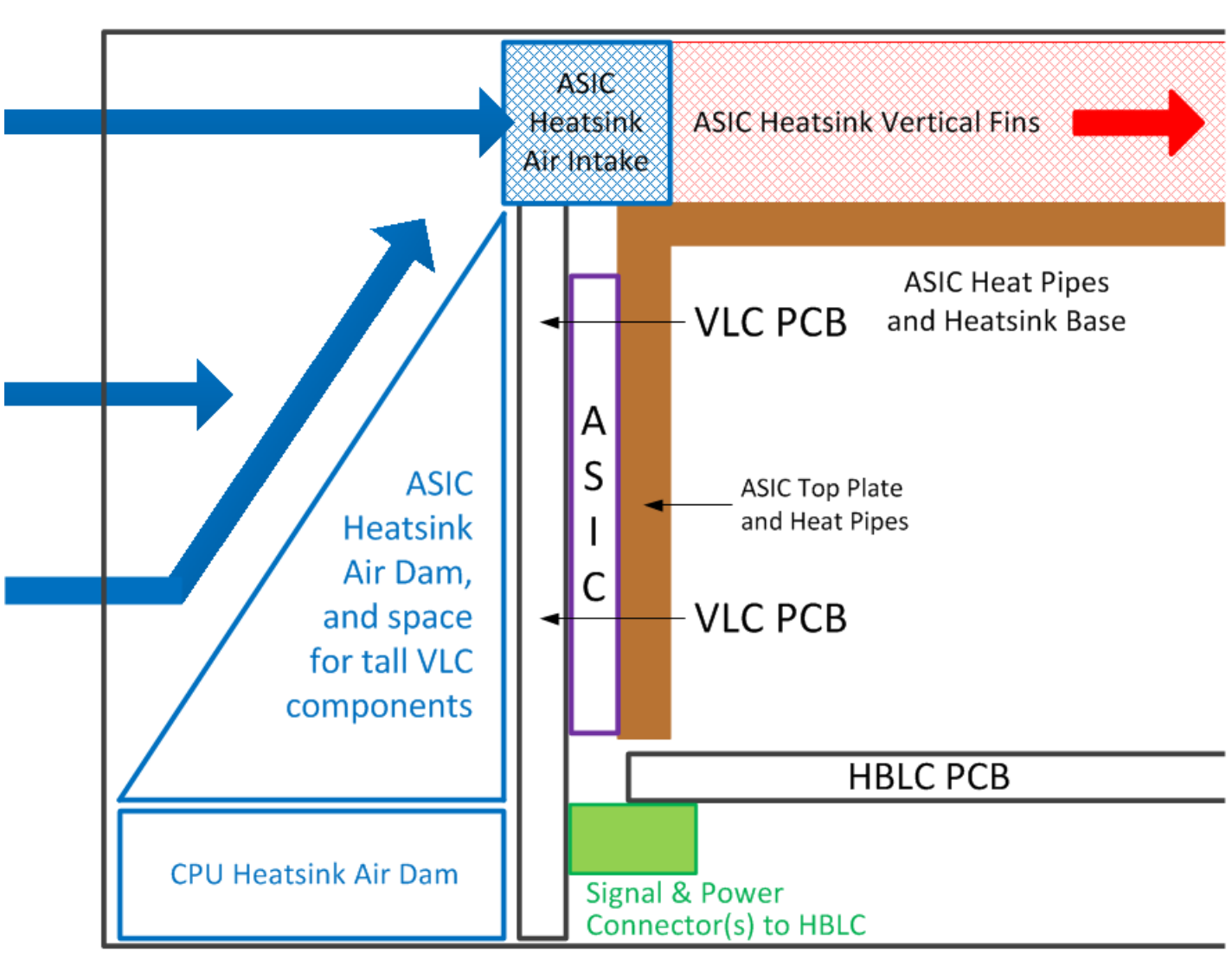


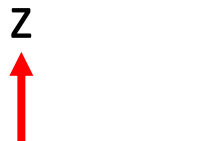


y-z
Plane 1

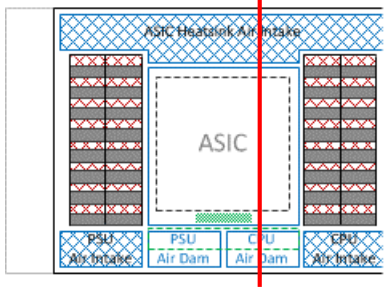


4RU-VLC, 64 OSFP (y-z Plane 2 Front-half Side View)

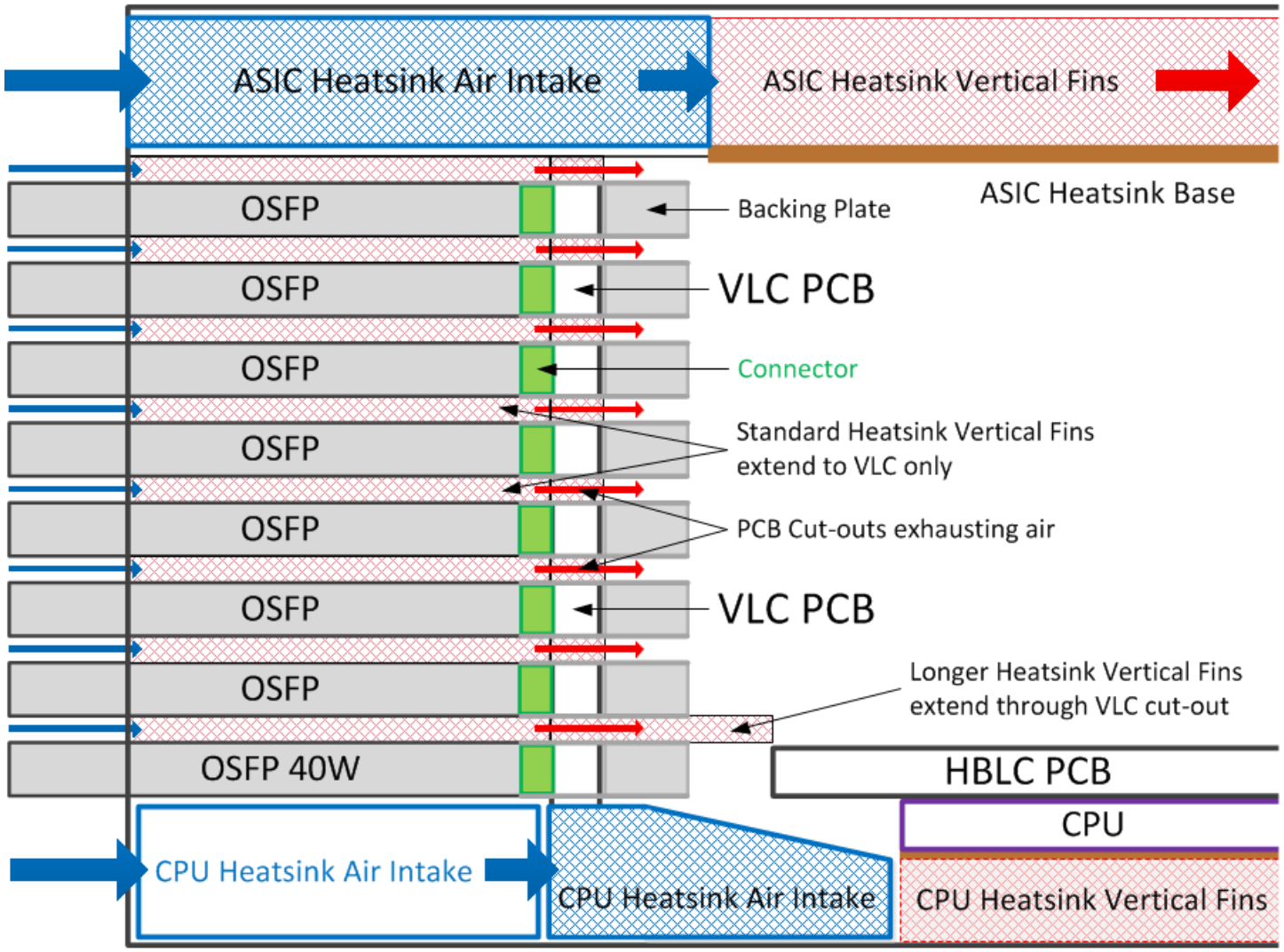


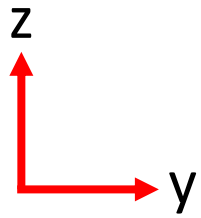


y-z
Plane 2

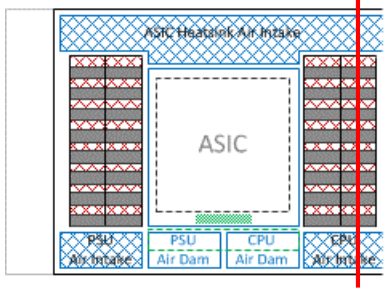


4RU-VLC, 64 OSFP (y-z Plane 3 Front-half Side View)

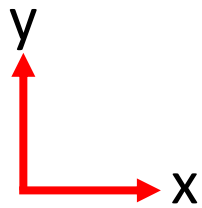


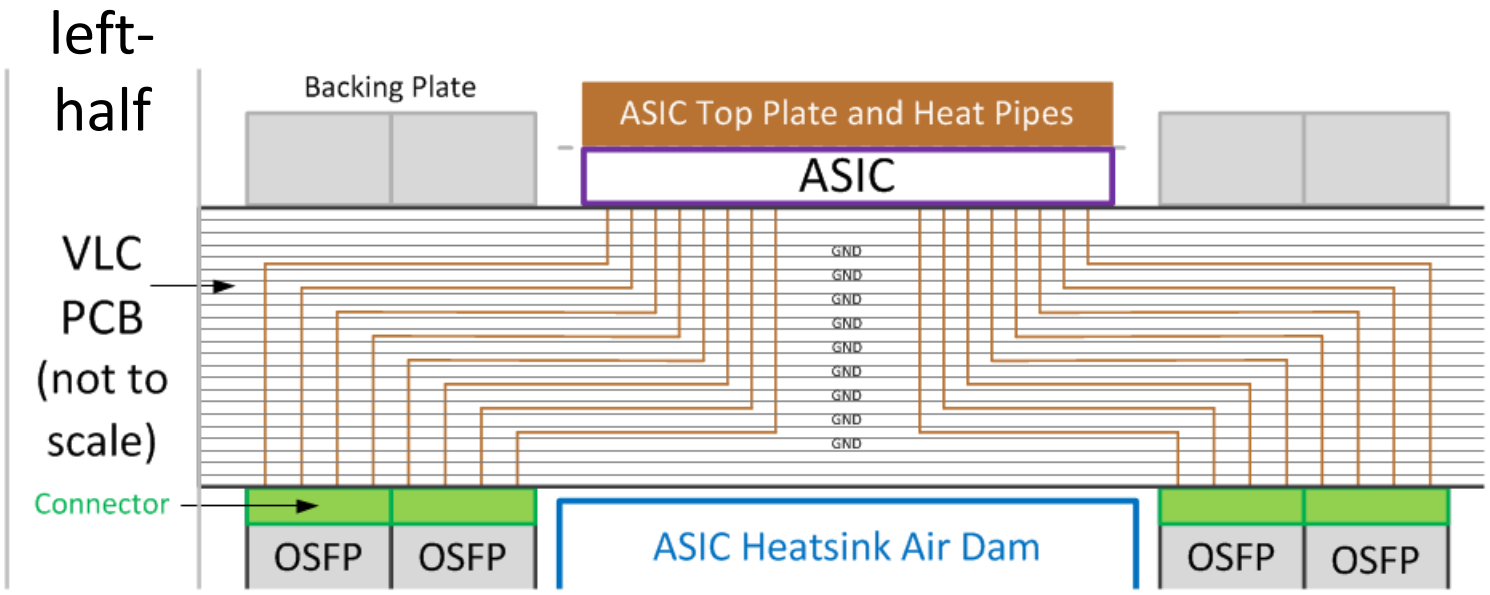


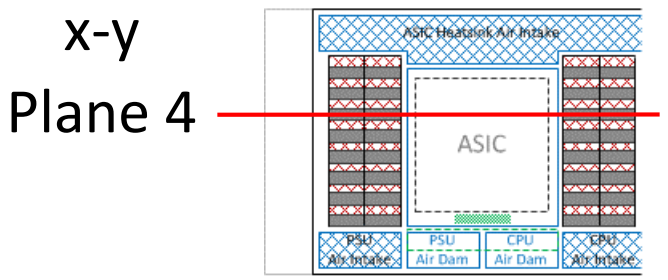
y-z
Plane 3



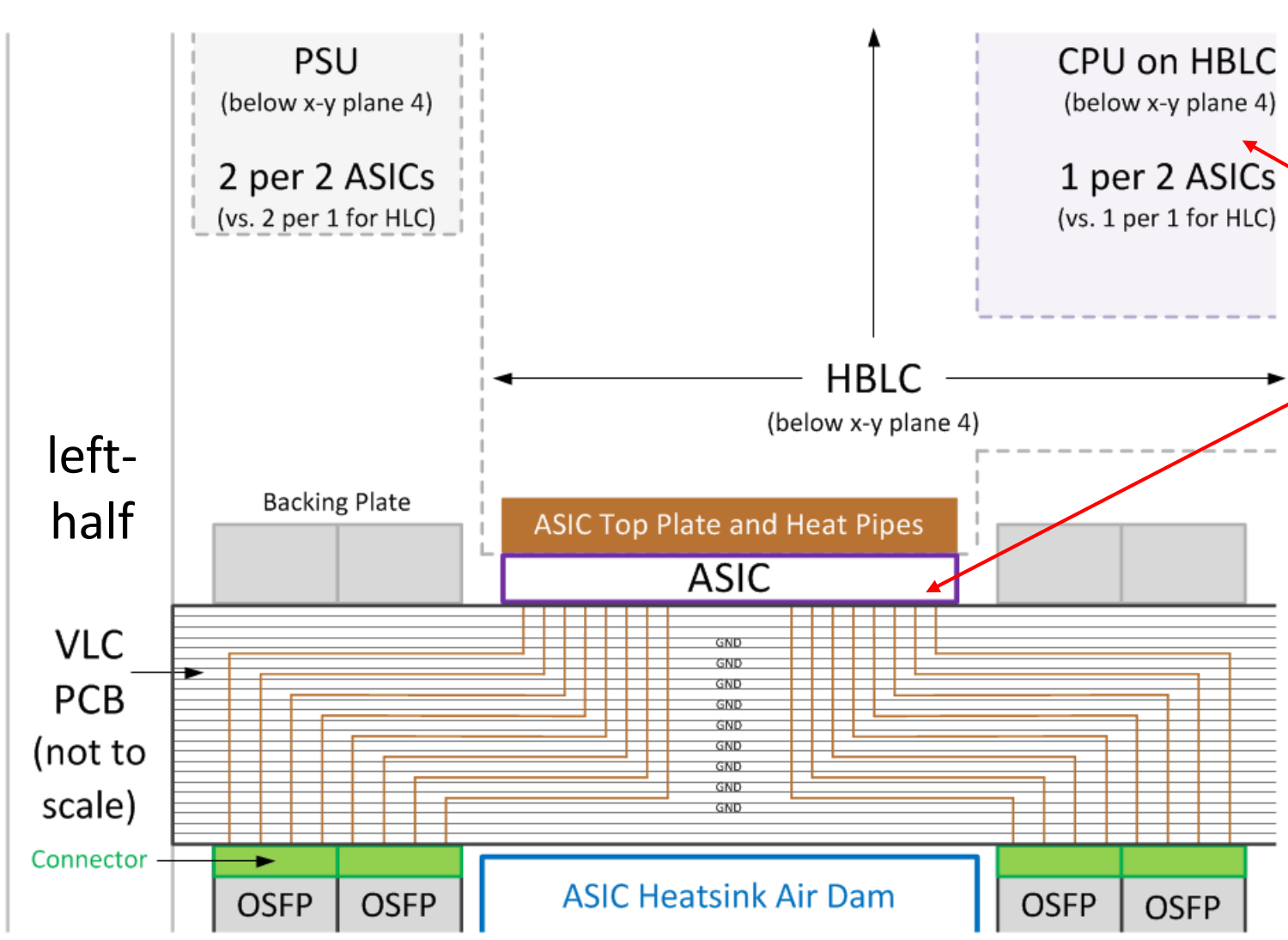
4RU-VLC, 64 OSFP (x-y Plane 4 Left-half Top View)

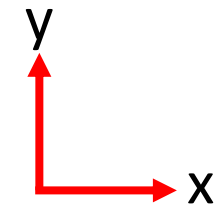




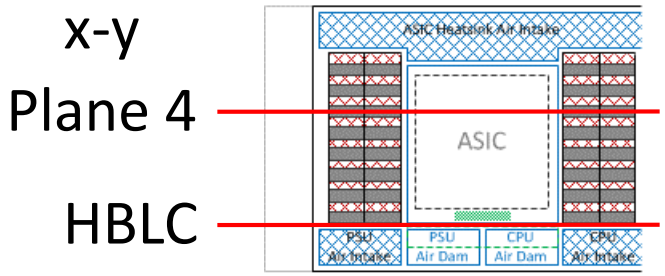


4RU-VLC, 64 OSFP (x-y Plane 4 Left-half Top View)

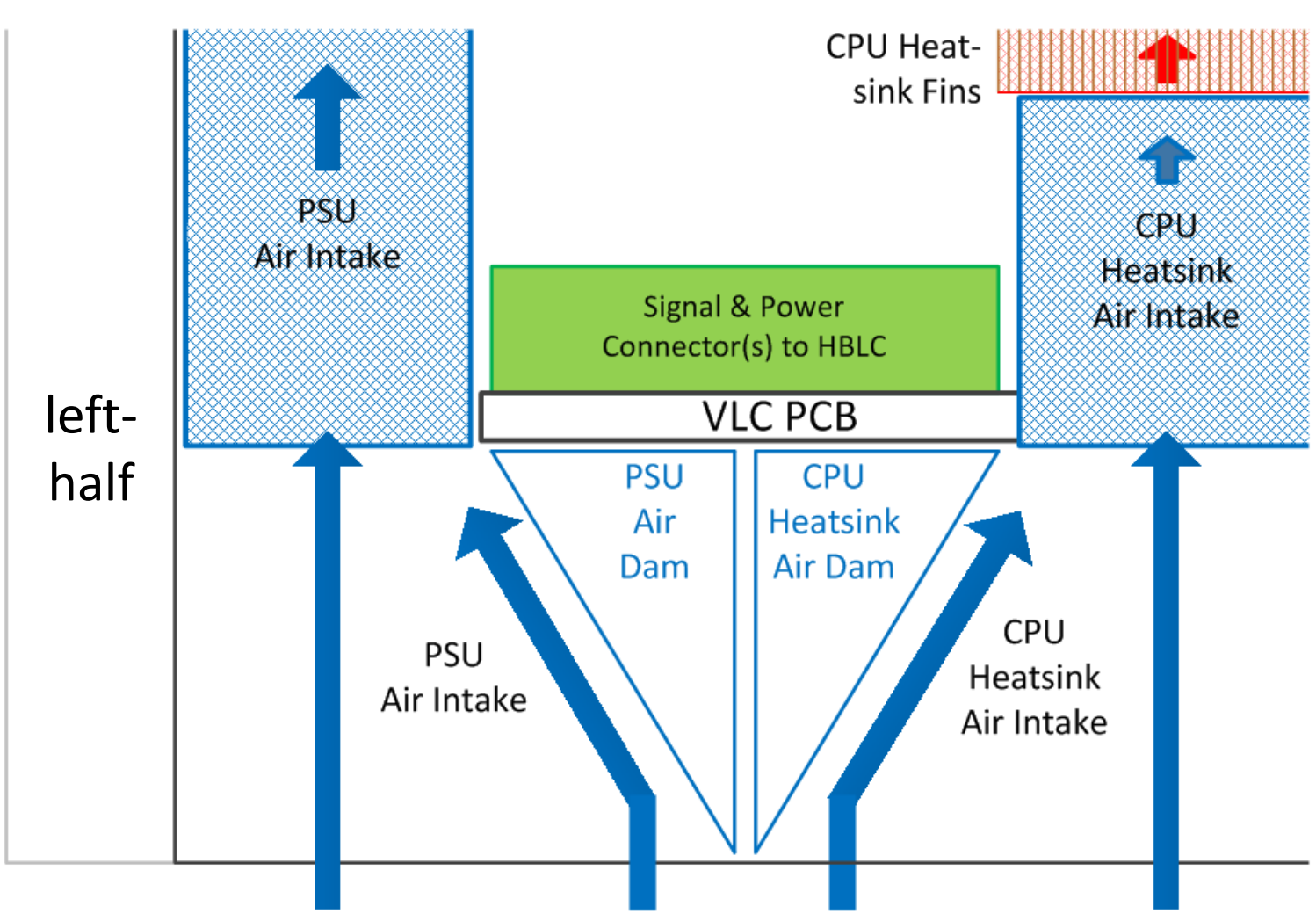




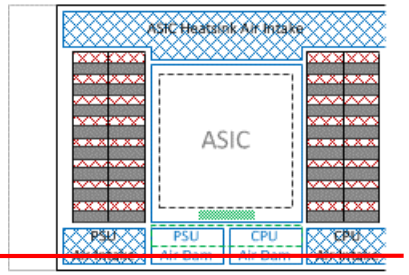
ASIC and CPU on separate PCBAs decouples design and chip generations



4RU-VLC, 64 OSFP (x-y Plane 5 Left-half Top View)



x-y
Plane 5



Outline

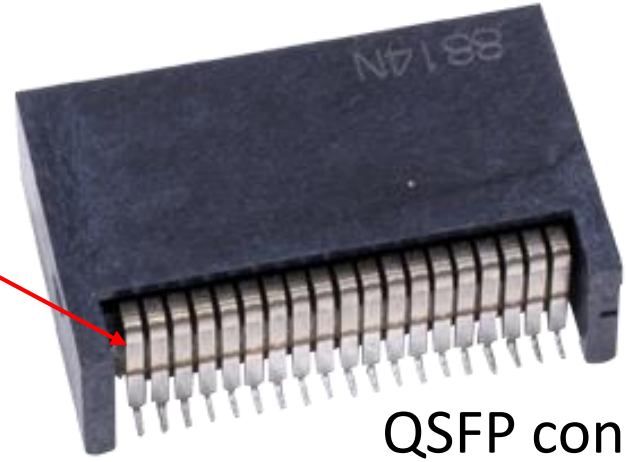
- Introduction
- Rack Power Limitations
- Dual ASIC VLC Baseline

➢ **Vertical OSFP Connector**

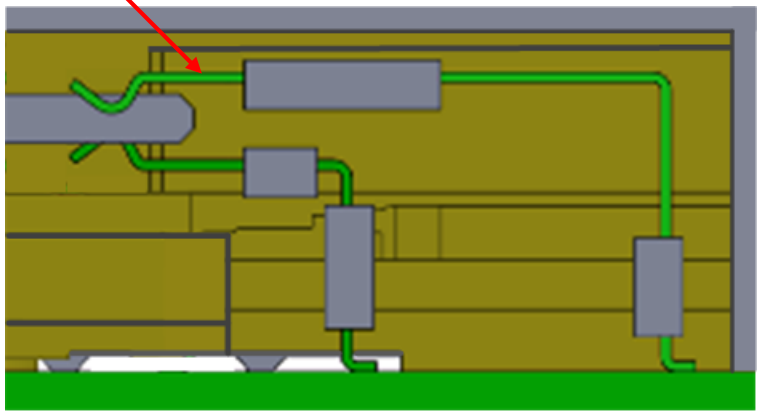
- Vertical OSFP-XD Connector
- Stripline vs. Twinax Loss
- Single ASIC VLC Alternative
- Summary

Horizontal Line Card Connector

top row lead



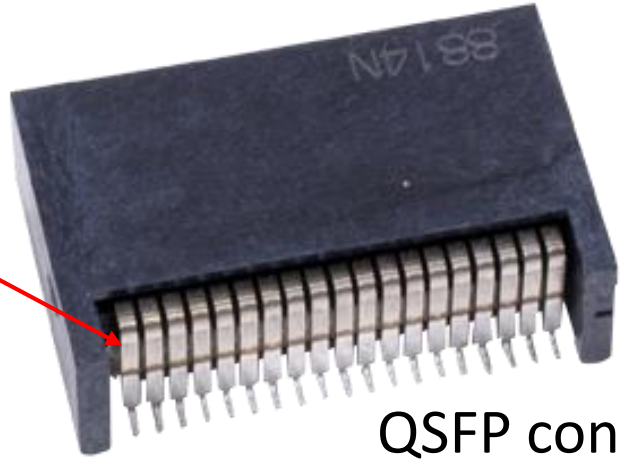
QSFP connector



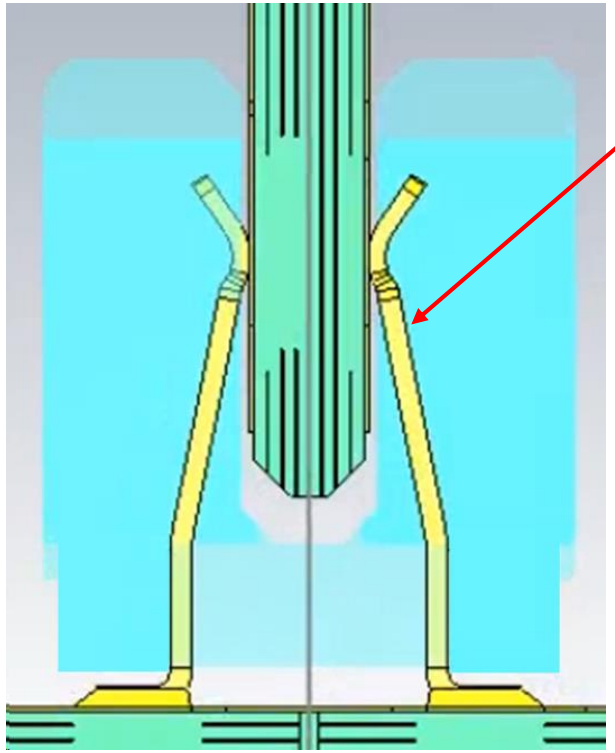
HLC

Vertical vs. Horizontal Line Card Connector

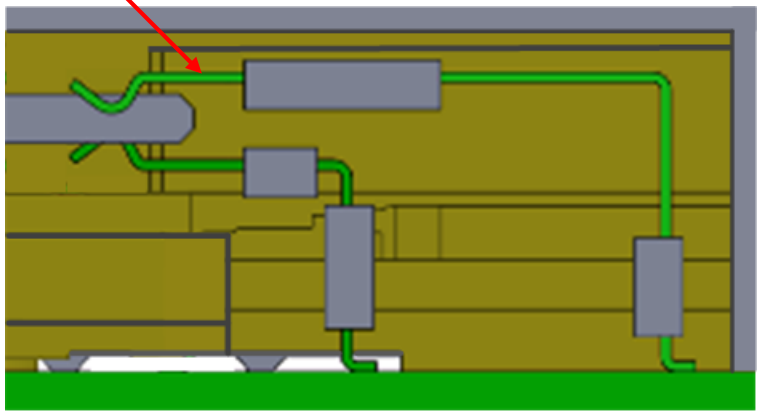
top row lead



QSFP connector

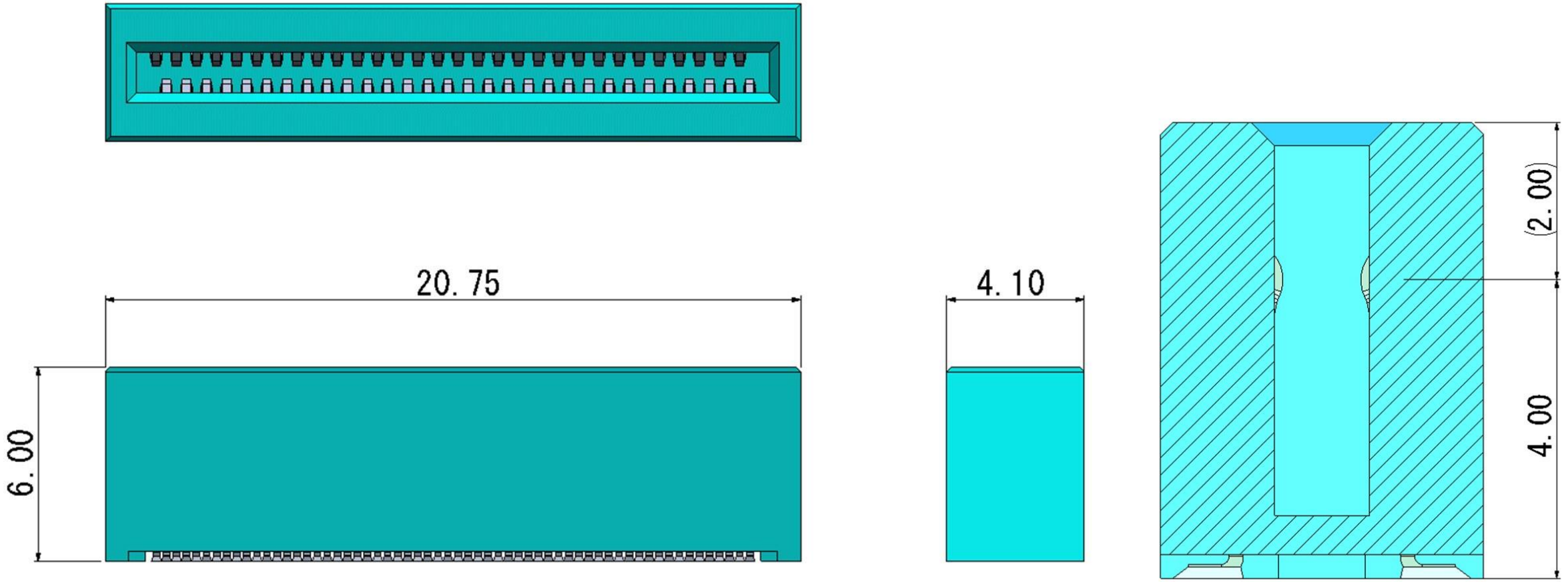


VLC

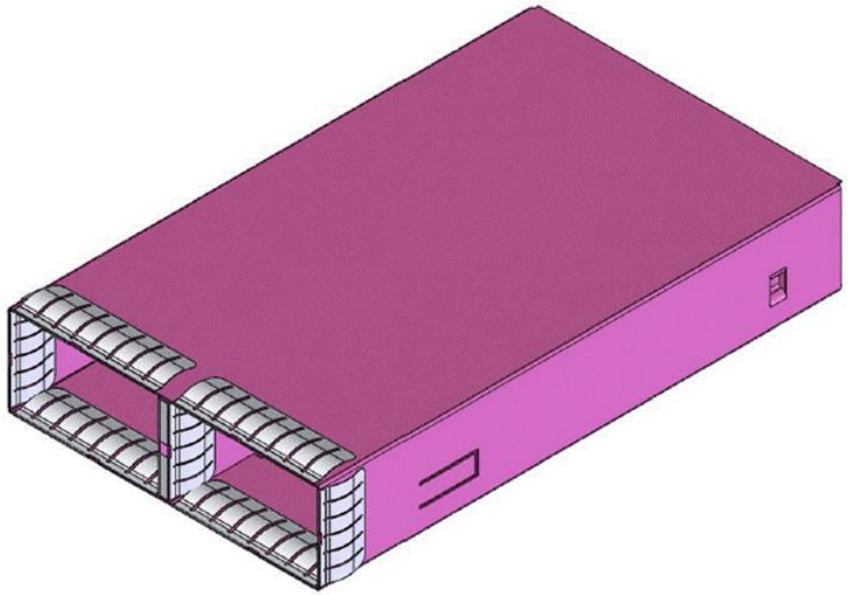


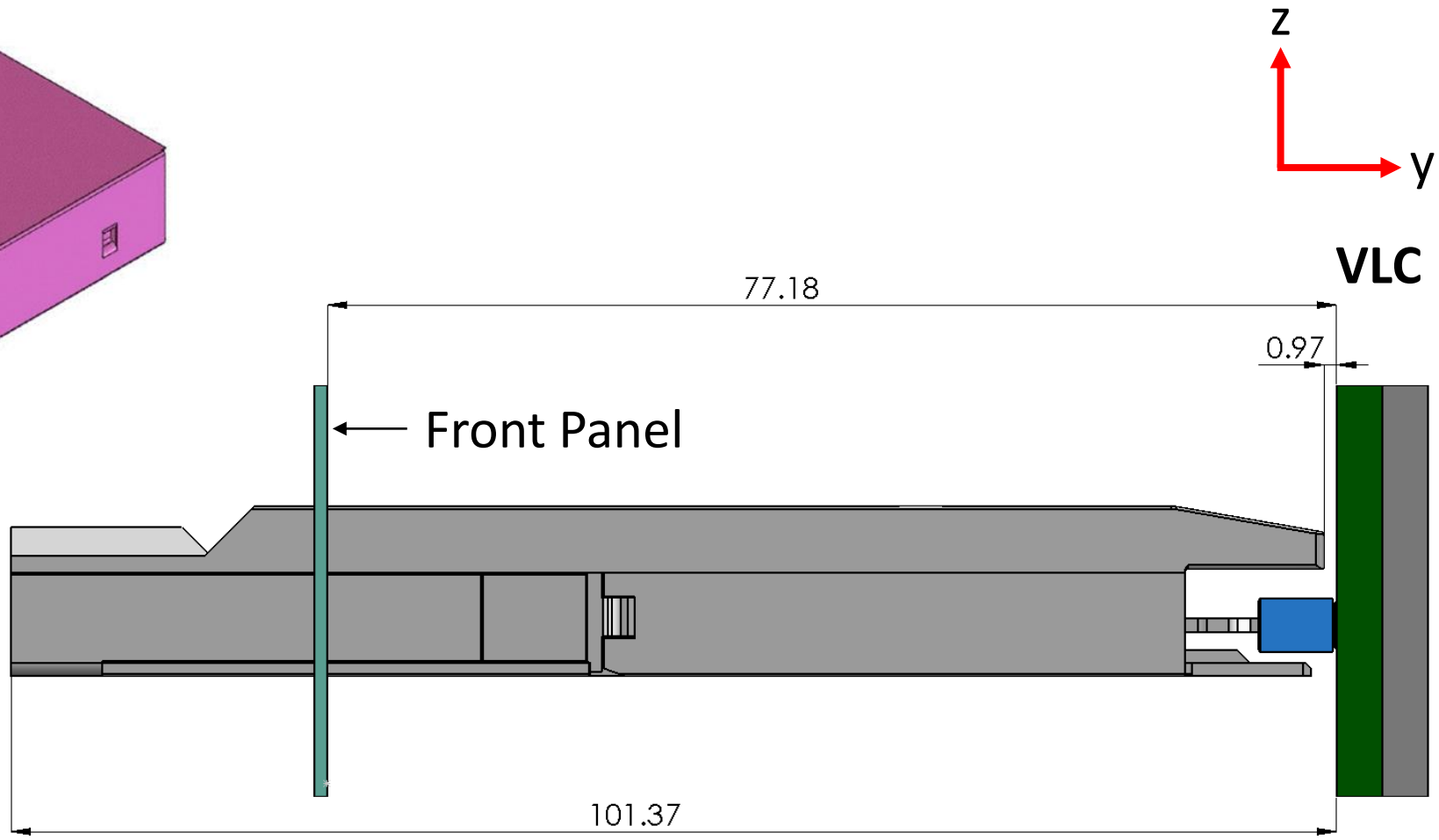
HLC

Vertical OSFP Connector

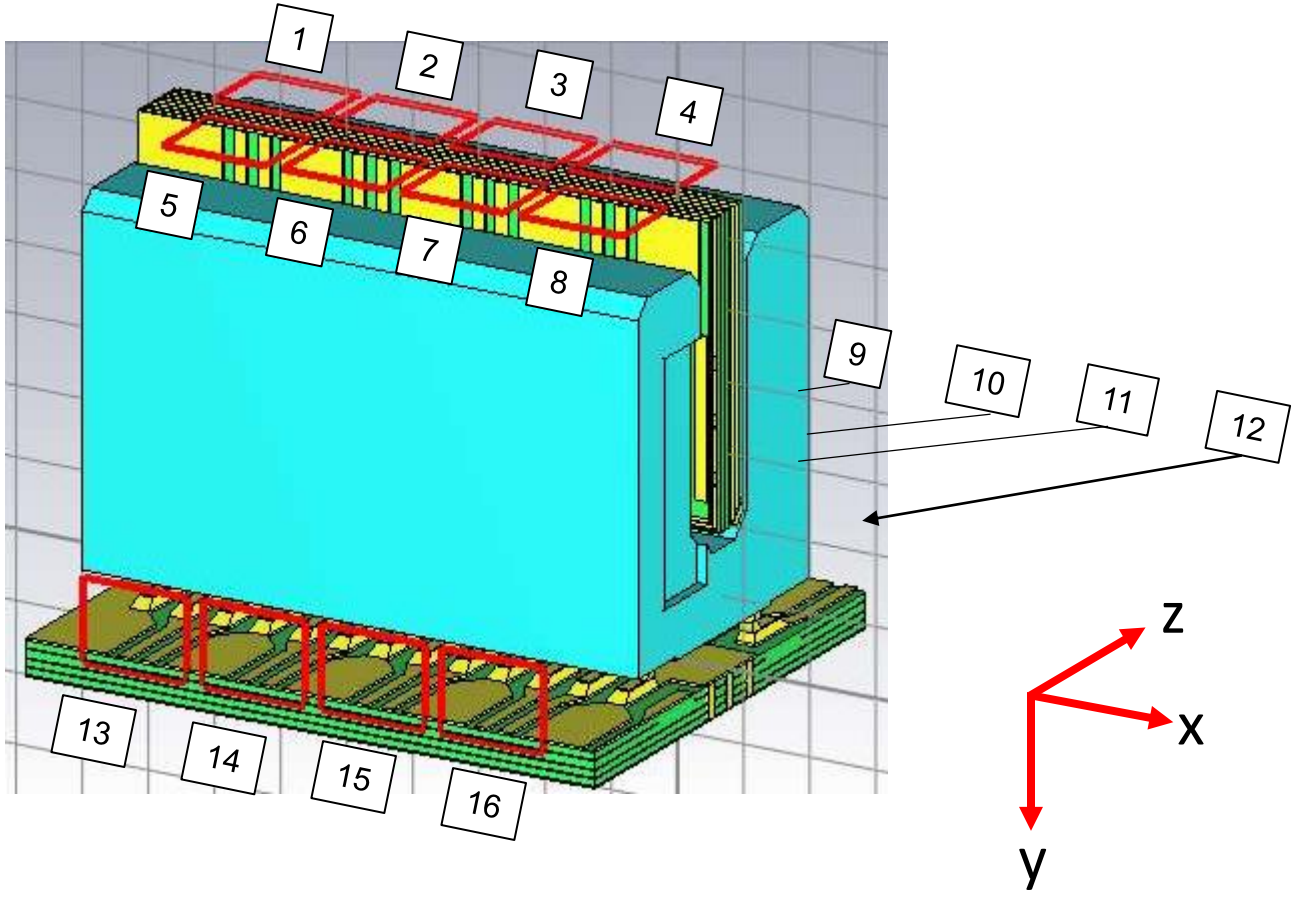


Vertical OSFP Connector Cage & Mating View

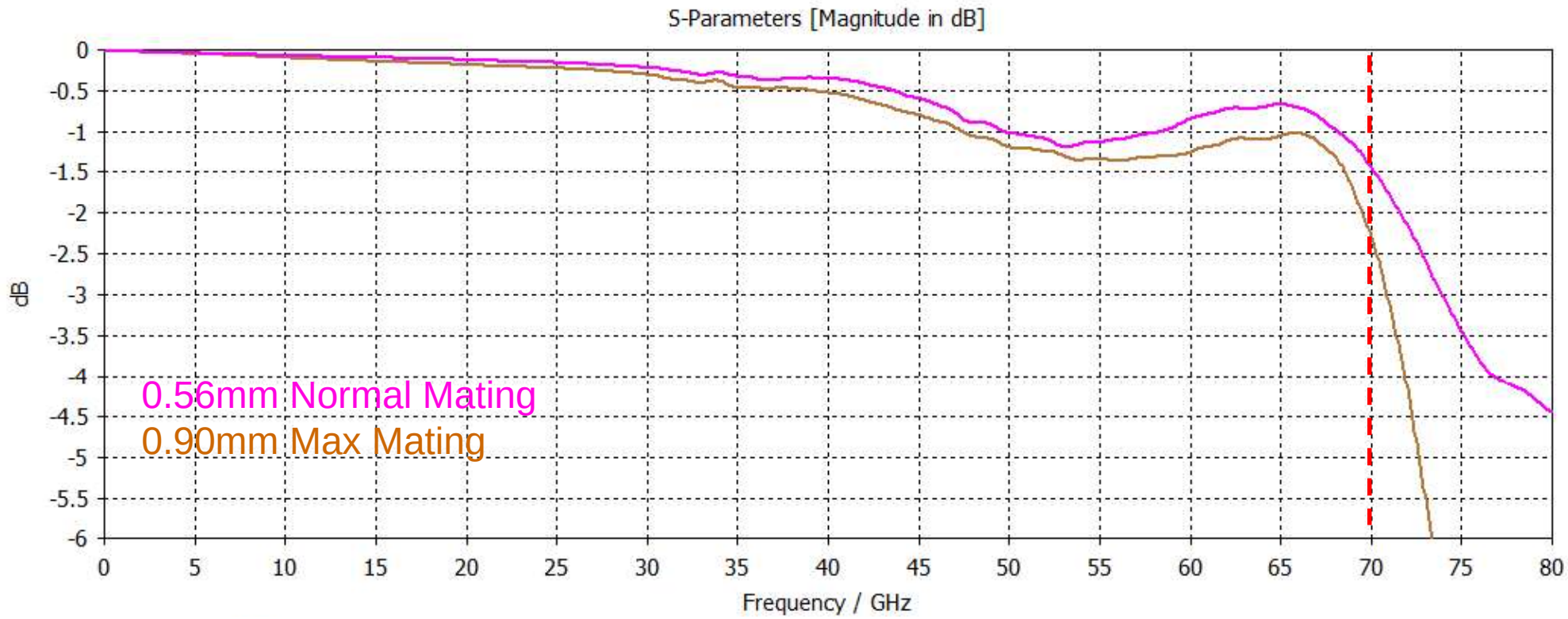




Vertical OSFP Connector Simulation Model



Vertical OSFP Connector Insertion Loss

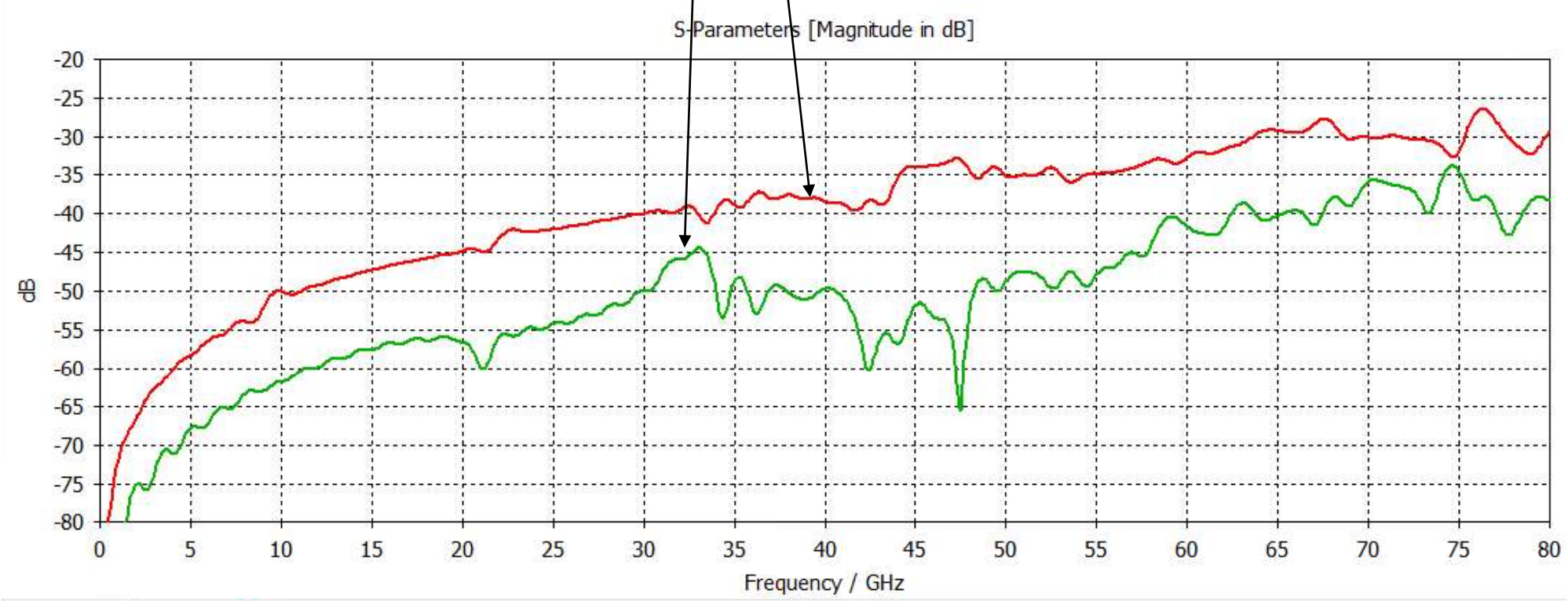


Vertical OSFP Connector FEXT 0.56mm Normal Mating

Module side			
Front			
1	2	3	4
Back			
5	6	7	8

Line Card side			
Front			
9	10	11	12
Back			
13	14	15	16

Victim

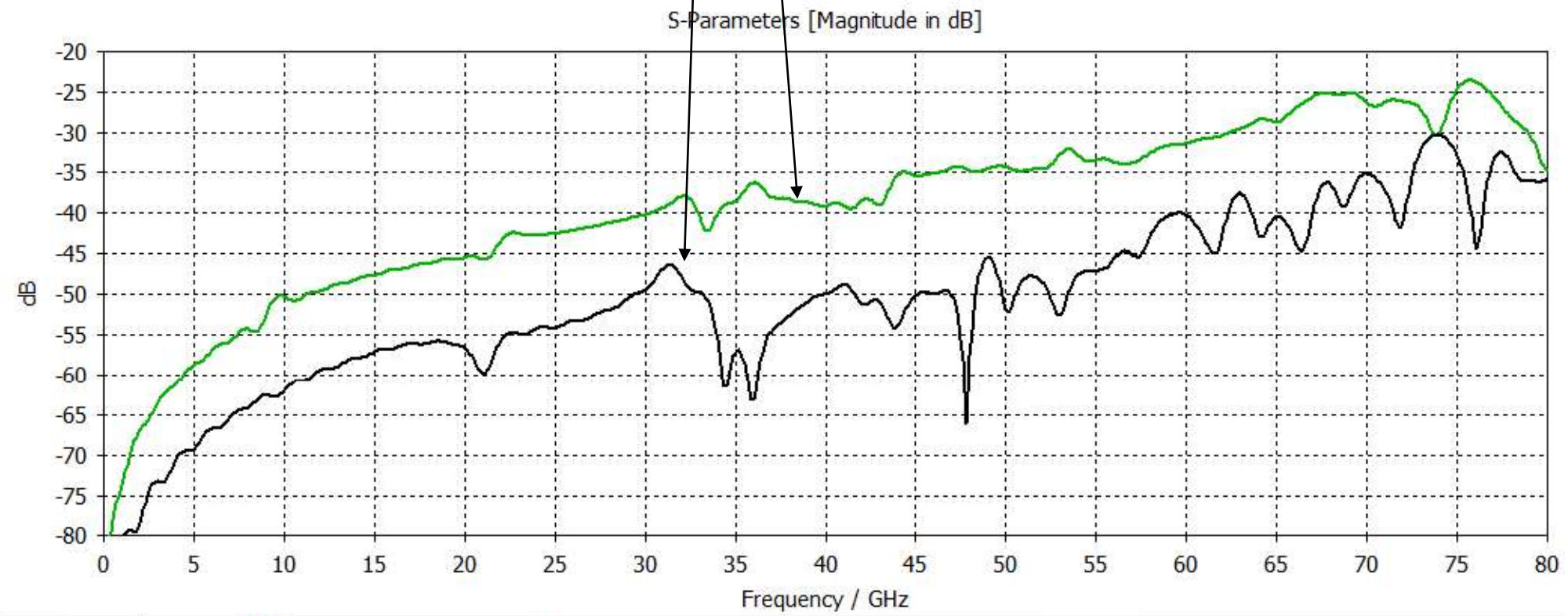


Vertical OSFP Connector FEXT 0.90mm Max Mating

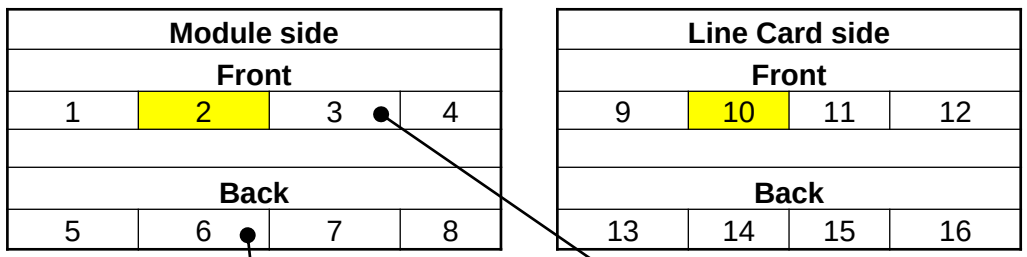
Module side			
Front			
1	2	3	4
Back			
5	6	7	8

Line Card side			
Front			
9	10	11	12
Back			
13	14	15	16

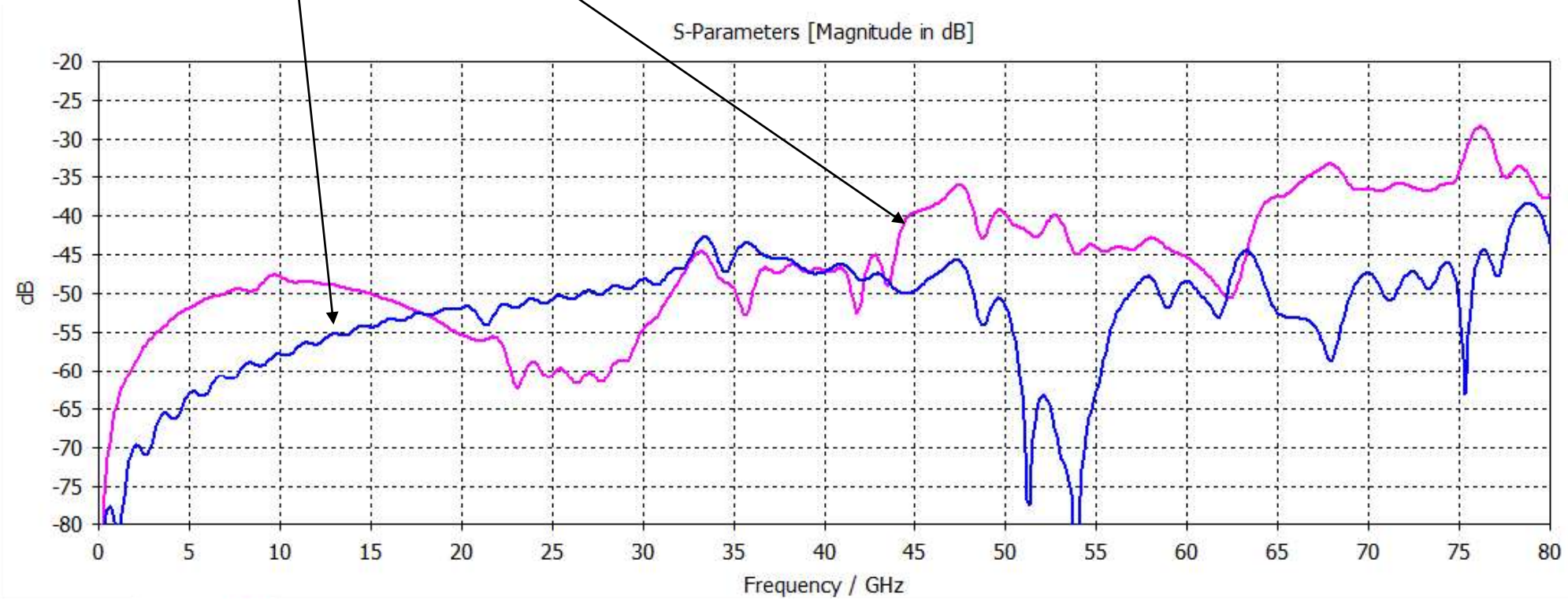
Victim



Vertical OSFP Connector NEXT 0.56mm Normal Mating



Victim

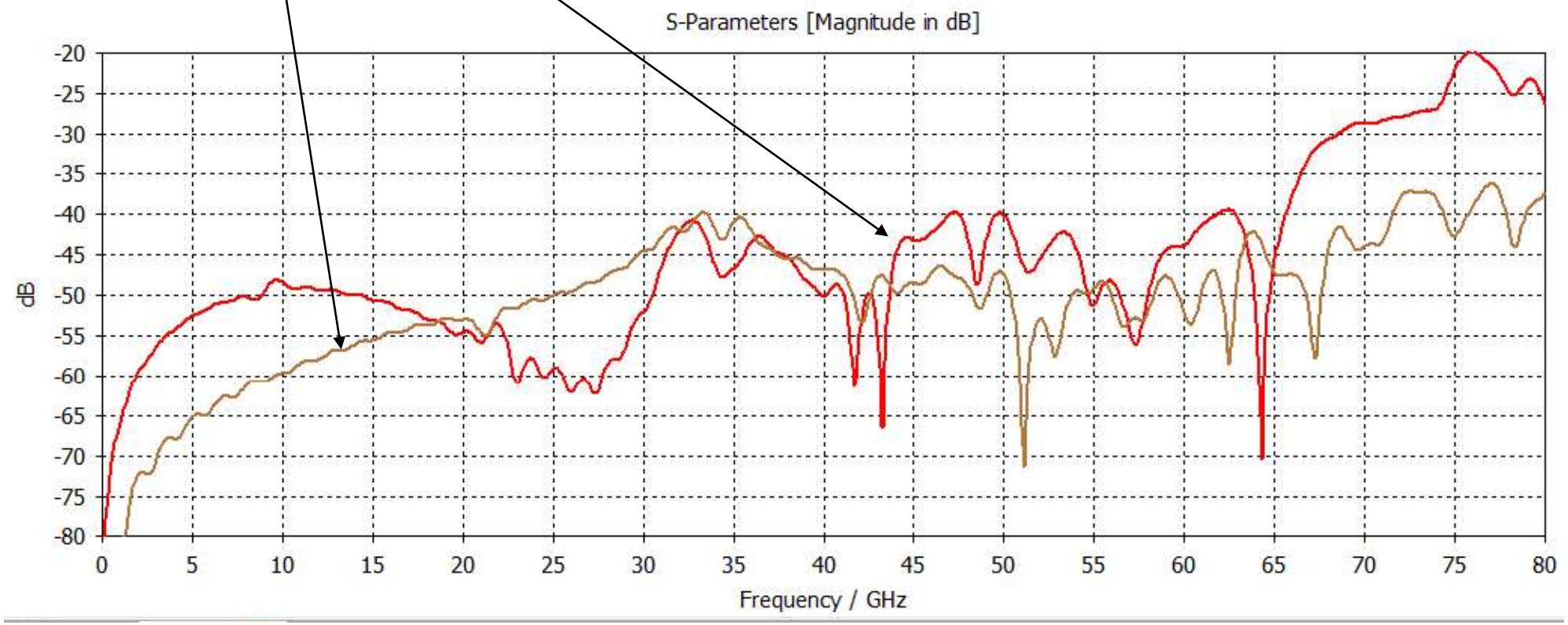


Vertical OSFP Connector NEXT 0.90mm Max Mating

Module side			
Front			
1	2	3	4
Back			
5	6	7	8

Line Card side			
Front			
9	10	11	12
Back			
13	14	15	16

Victim



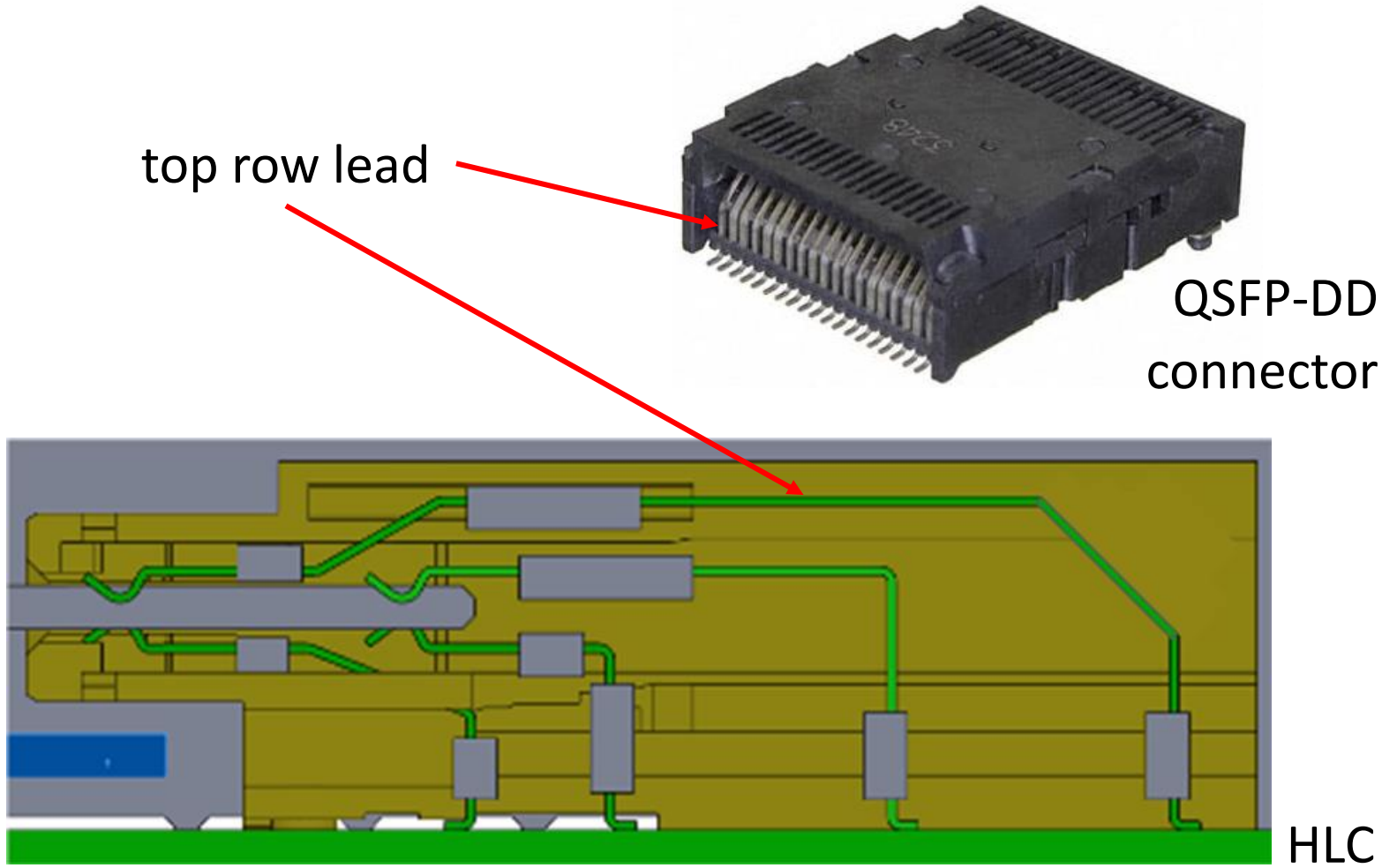
Outline

- Introduction
- Rack Power Limitations
- Dual ASIC VLC Baseline
- Vertical OSFP Connector

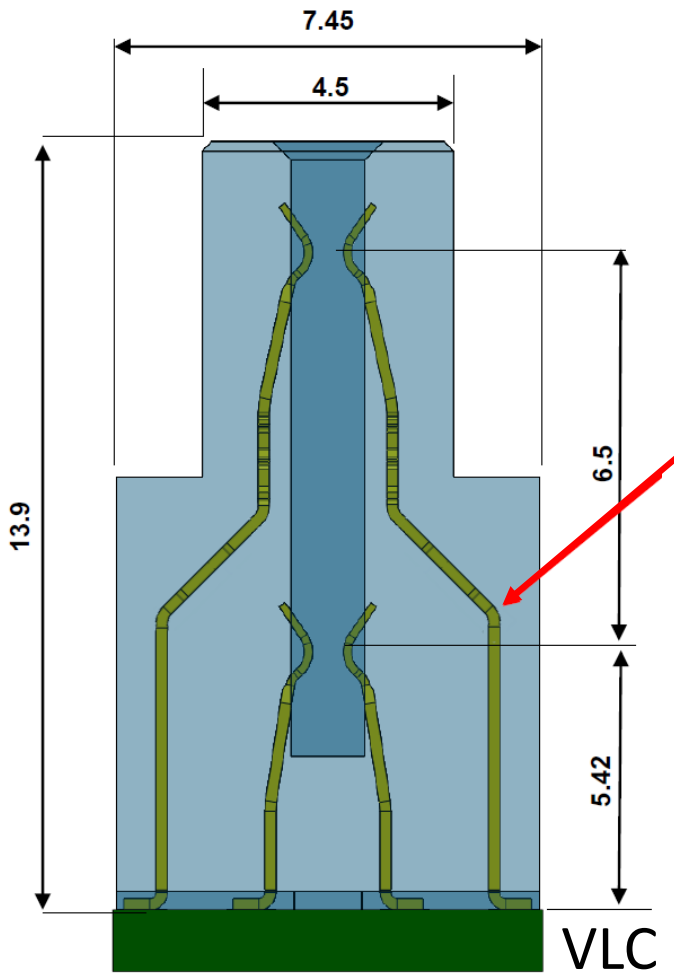
➢ **Vertical OSFP-XD Connector**

- Stripline vs. Twinax Loss
- Single ASIC VLC Alternative
- Summary

Horizontal Line Card Double Density Connector



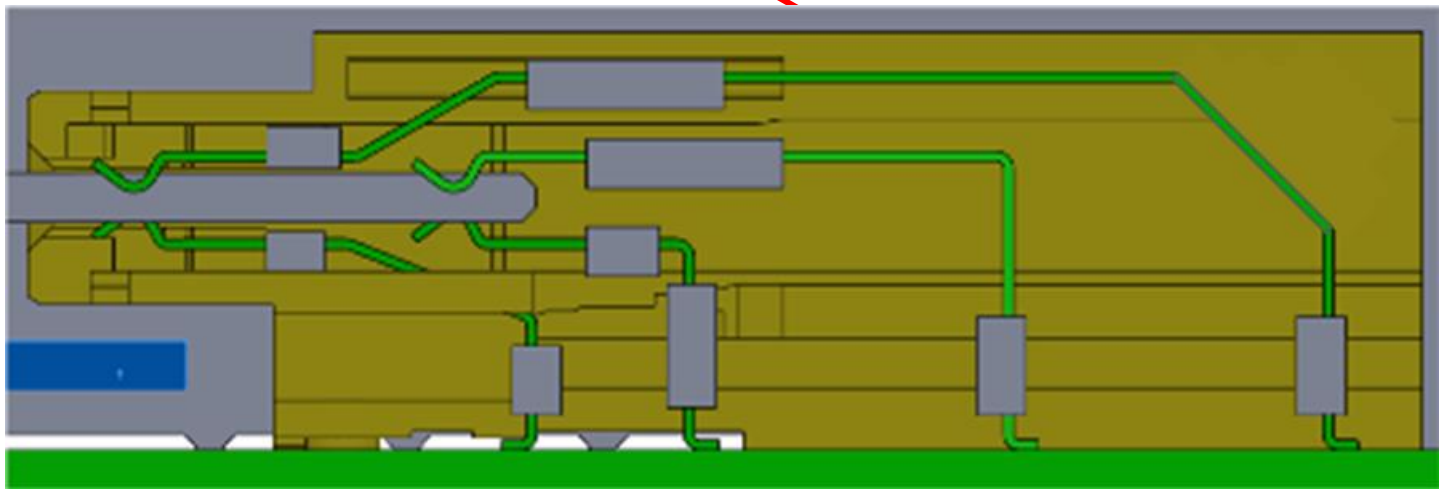
Vertical vs. Horizontal Line Card Double Density Connector



VLC

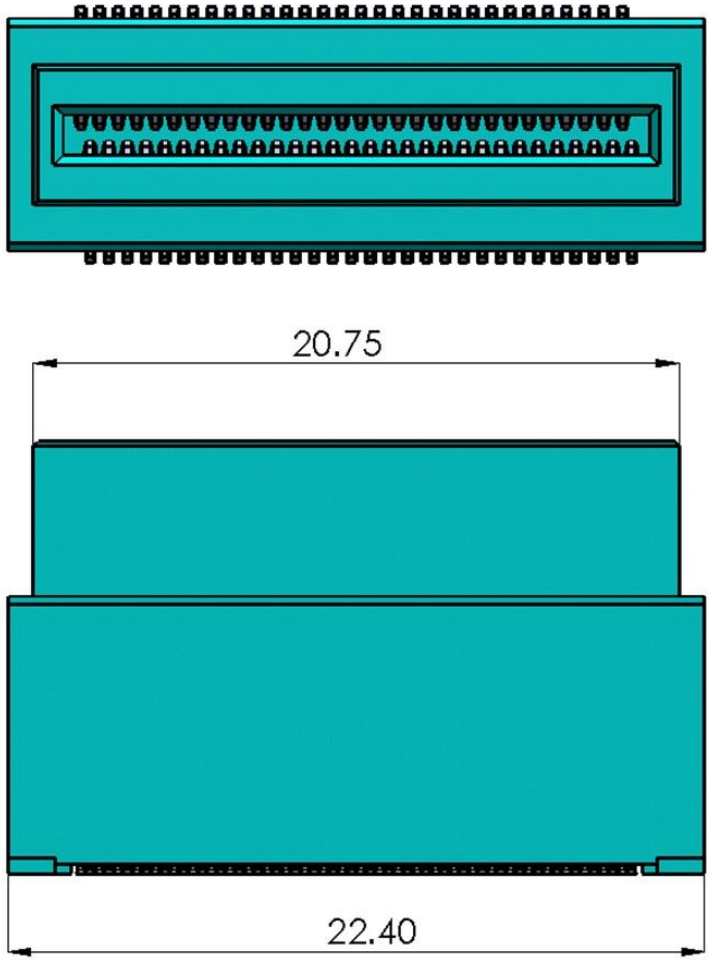
top row lead

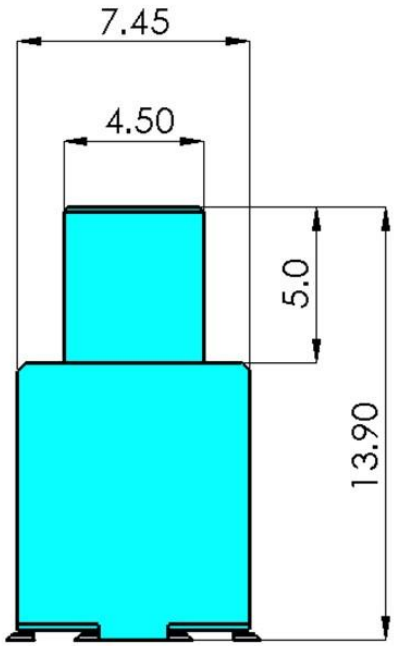
QSFP-DD connector

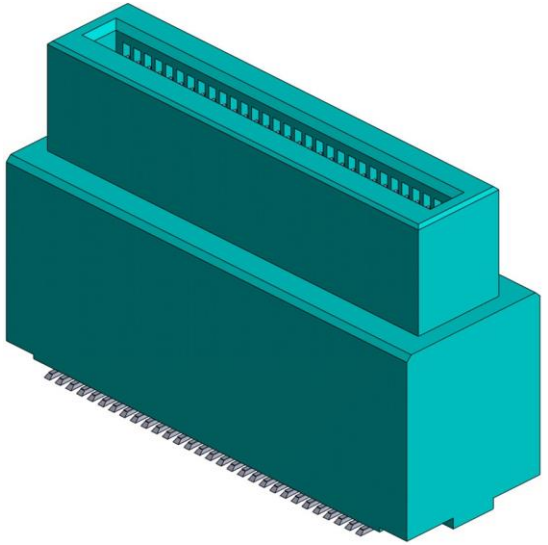


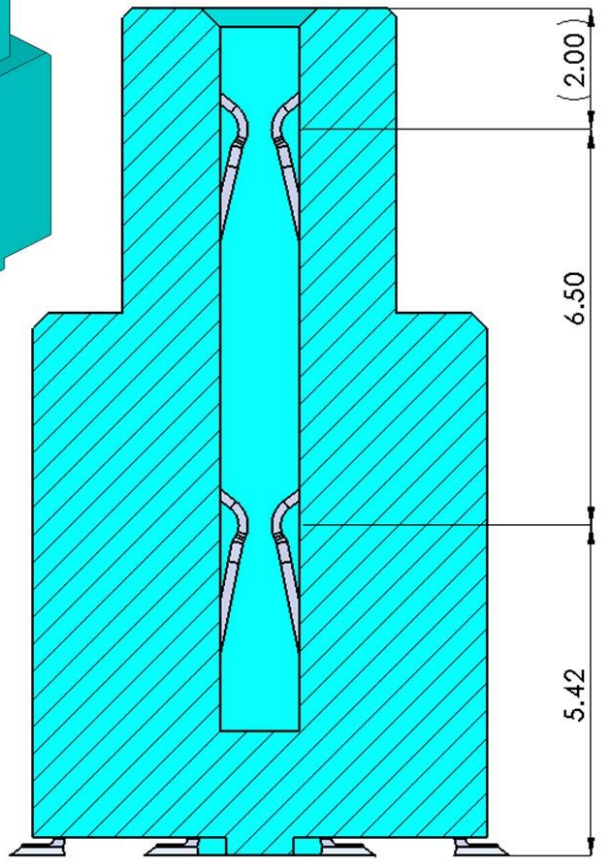
HLC

Vertical OSFP-XD Connector

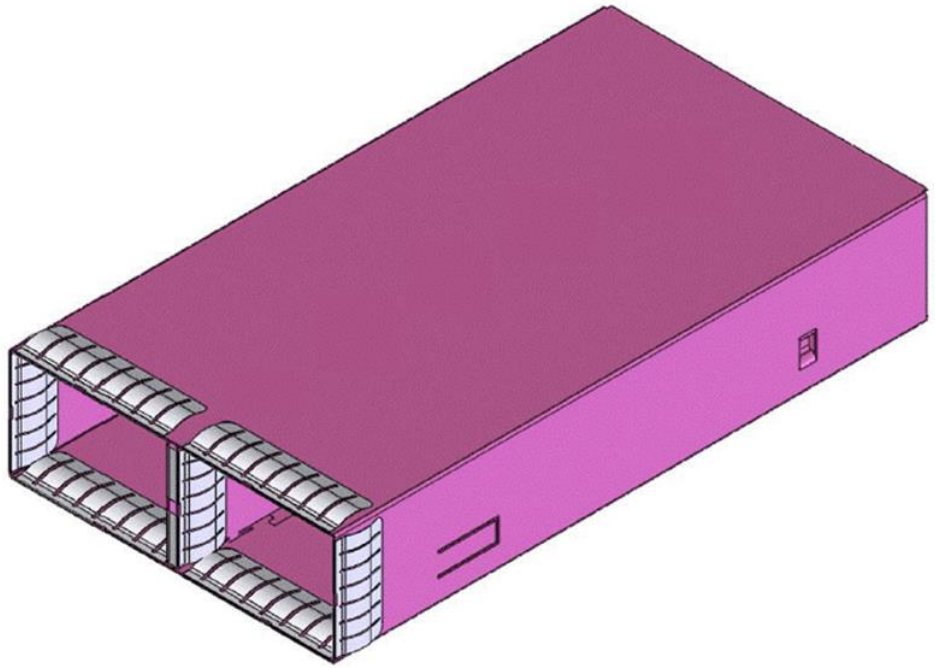


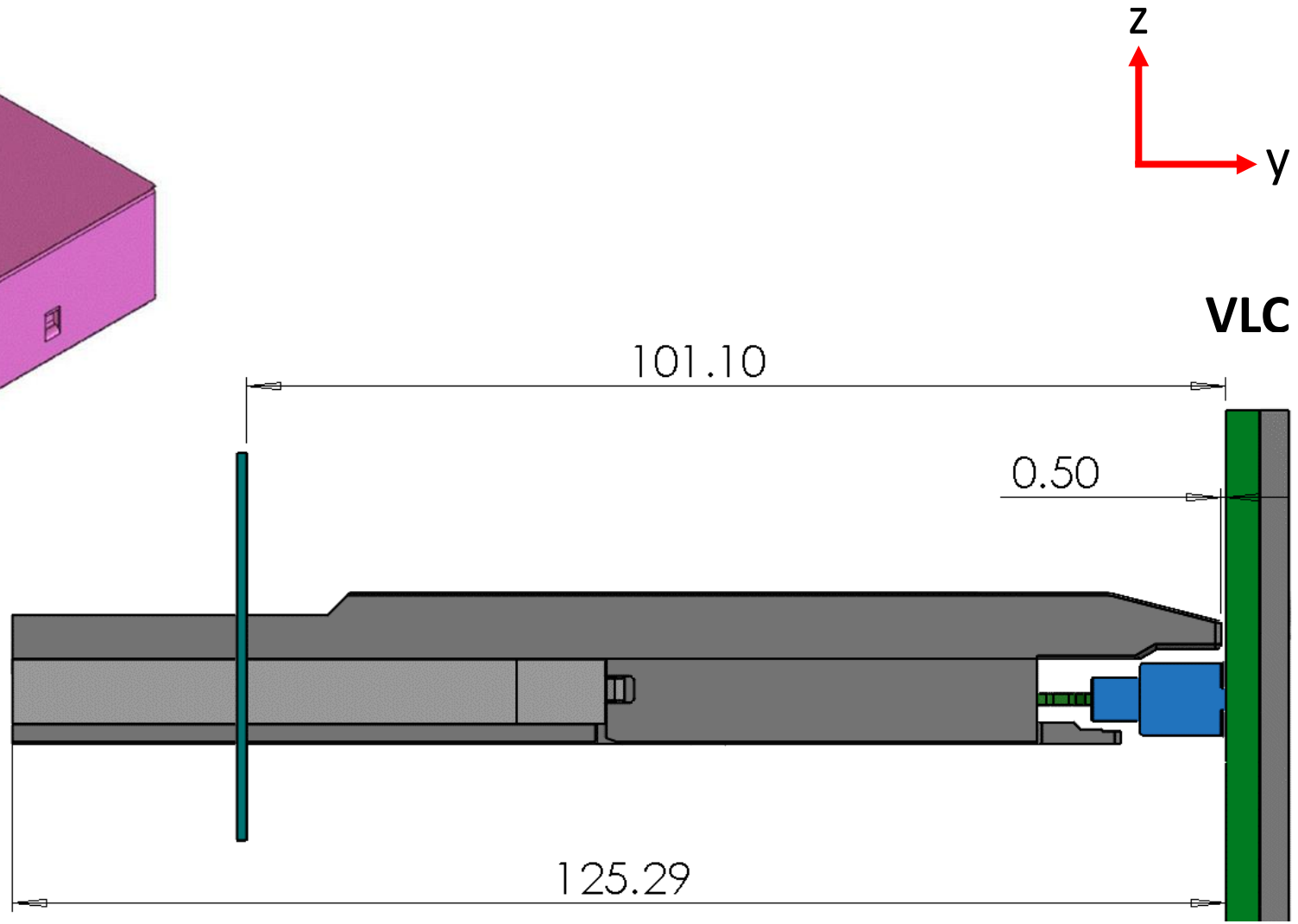




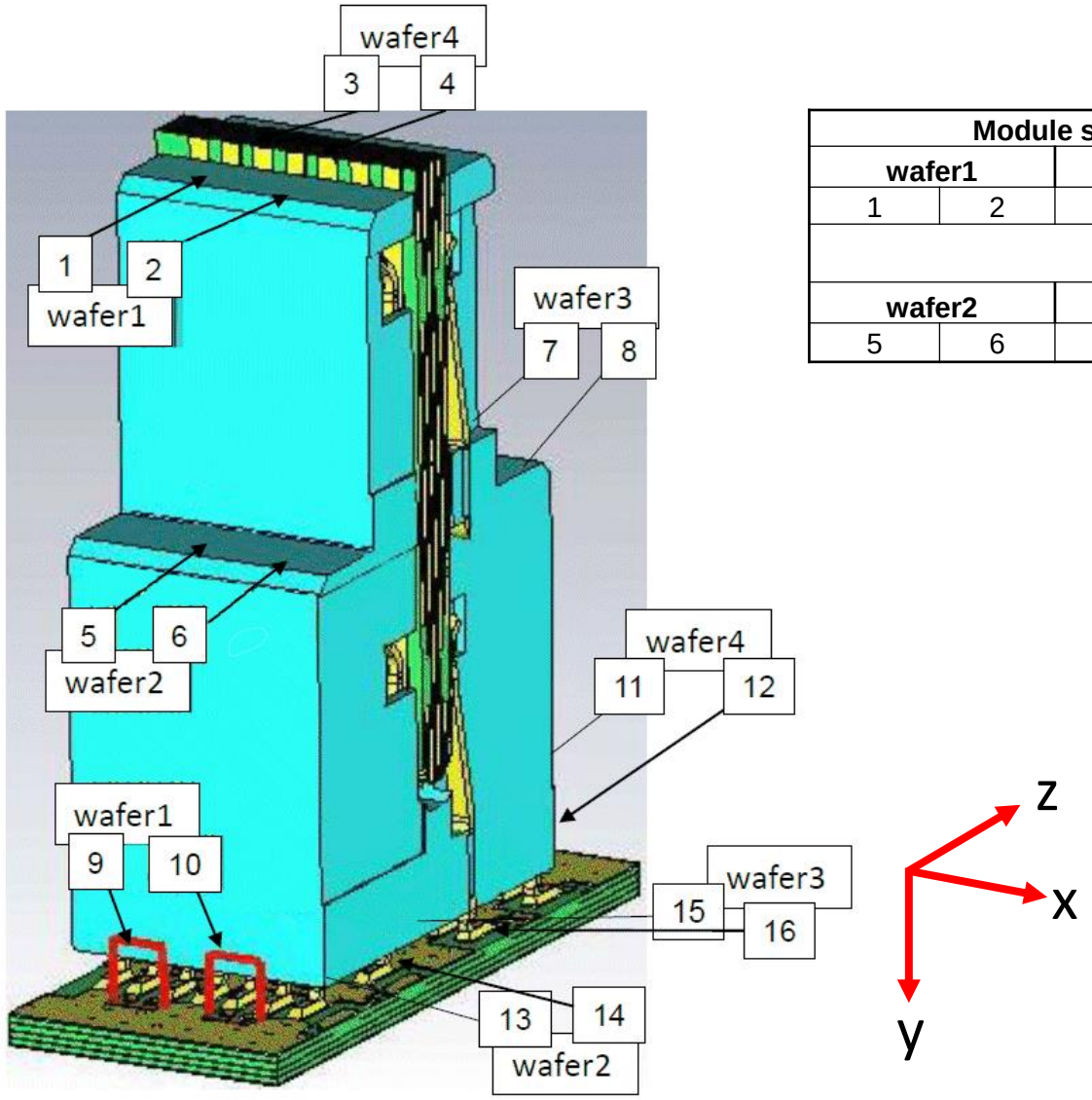


Vertical OSFP-XD Cage & Mating View





Vertical OSFP-XD Connector Simulation Model



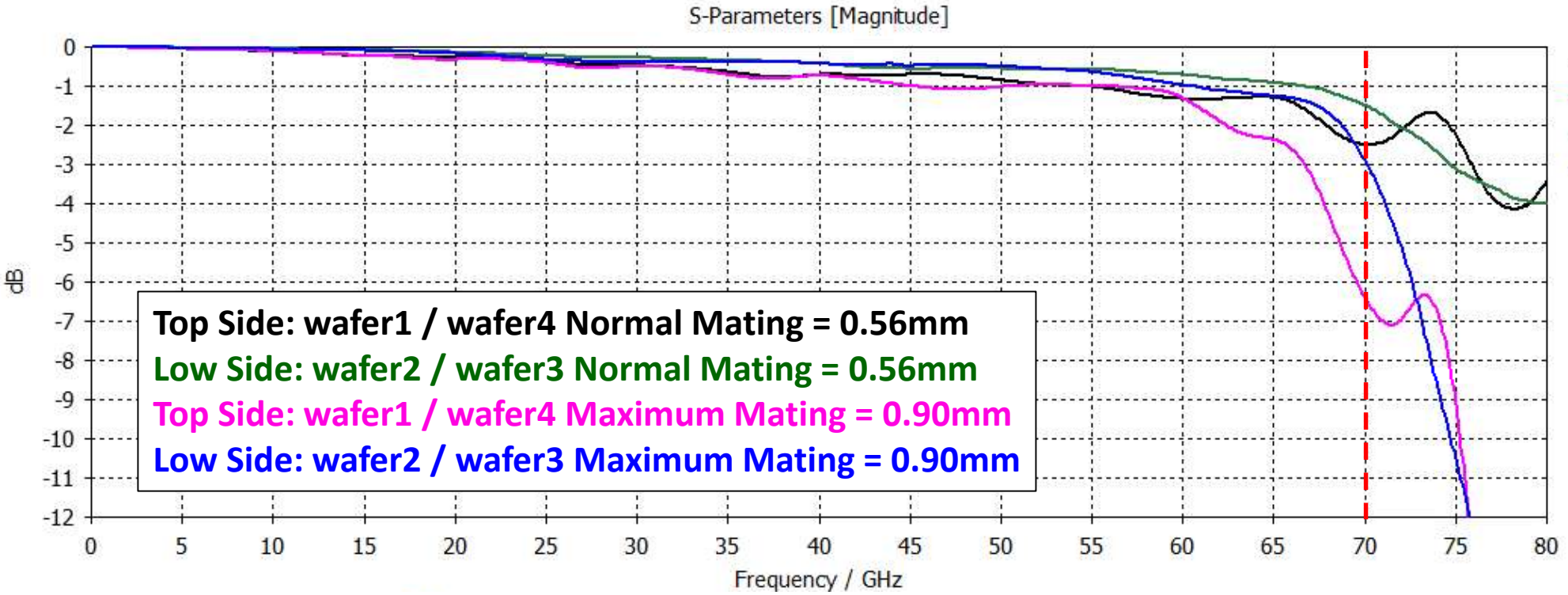
Module side			
wafer1		wafer4	
1	2	3	4
wafer2		wafer3	
5	6	7	8

Line Card side			
wafer1		wafer4	
9	10	11	12
wafer2		wafer3	
13	14	15	16

Vertical OSFP-XD Connector Insertion Loss

Module side			
wafer1		wafer4	
1	2	3	4
wafer2		wafer3	
5	6	7	8

Line Card side			
wafer1		wafer4	
9	10	11	12
wafer2		wafer3	
13	14	15	16

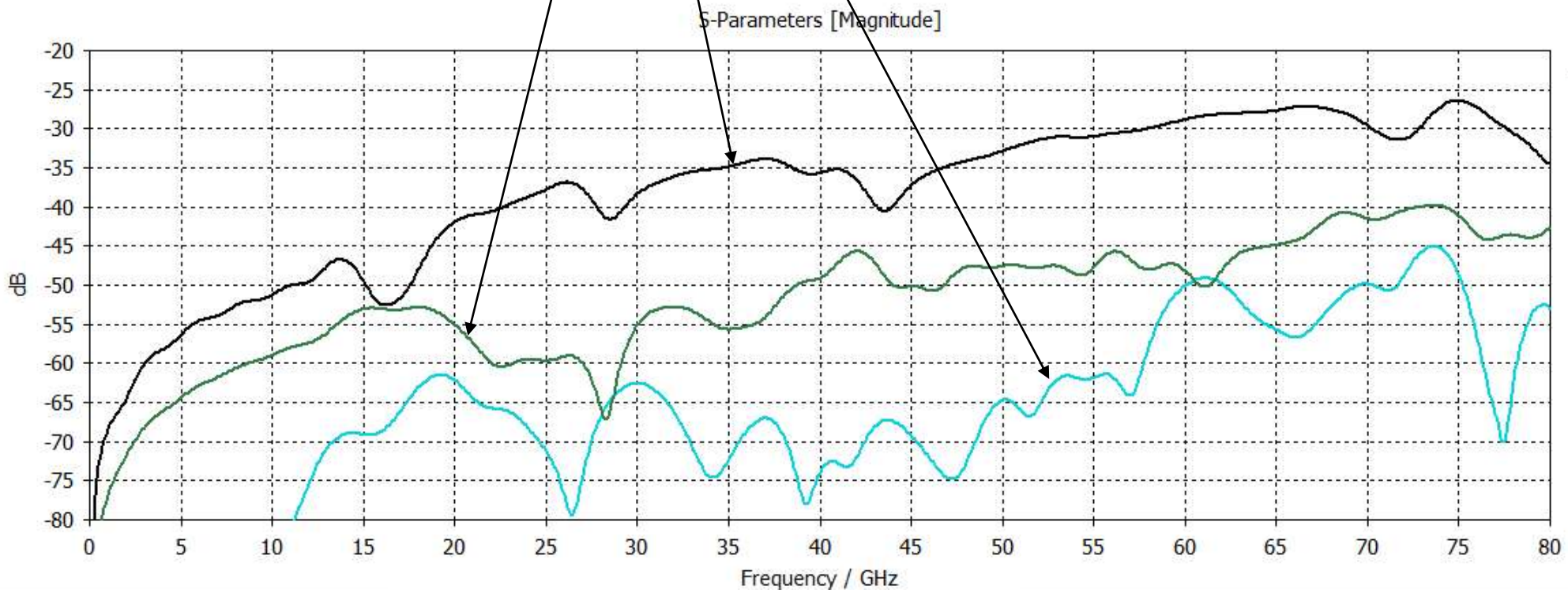


Vertical OSFP-XD Connector FEXT 0.56mm Normal Mating

Module side			
Top Side			
wafer1		wafer4	
1	2	3	4
Low Side			
wafer2		wafer3	
5	6	7	8

Line Card side			
Top Side			
wafer1		wafer4	
9	10	11	12
Low Side			
wafer2		wafer3	
13	14	15	16

Victim

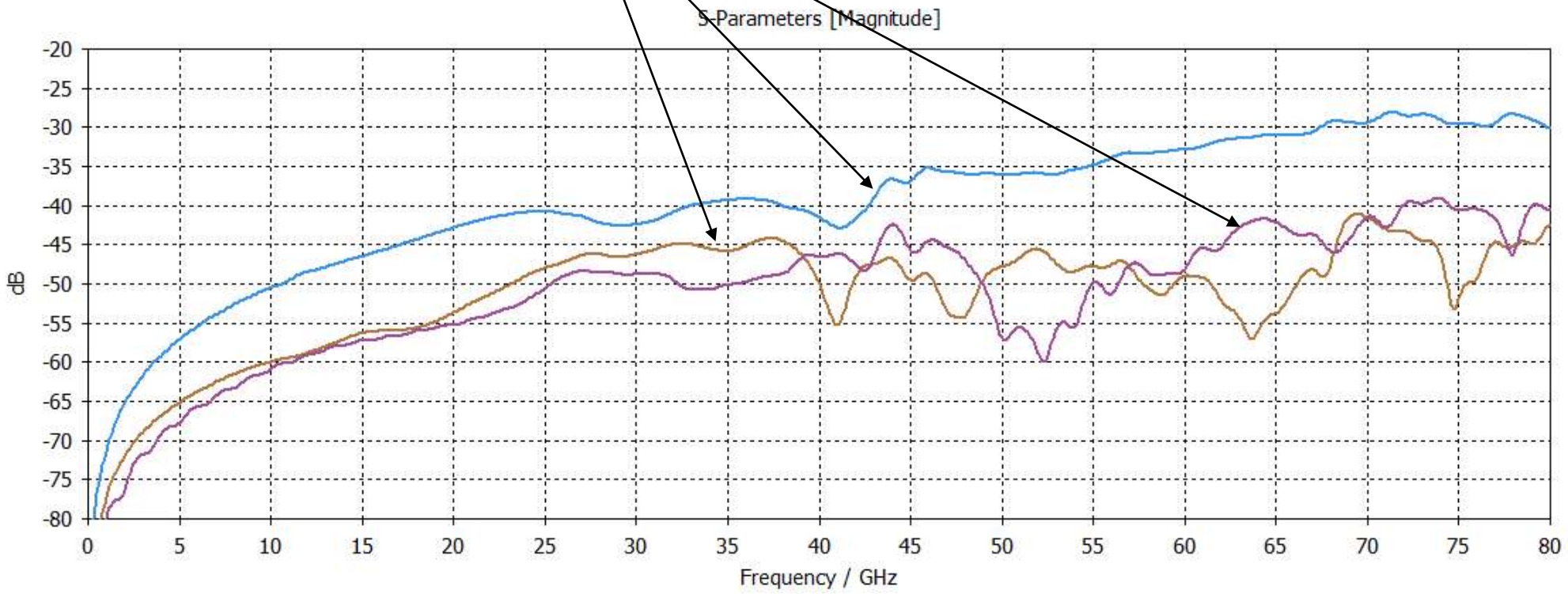


Vertical OSFP-XD Connector FEXT 0.56mm Normal Mating

Module side			
Top Side			
wafer1		wafer4	
1	2	3	4
Low Side			
wafer2		wafer3	
5	6	7	8

Line Card side			
Top Side			
wafer1		wafer4	
9	10	11	12
Low Side			
wafer2		wafer3	
13	14	15	16

Victim

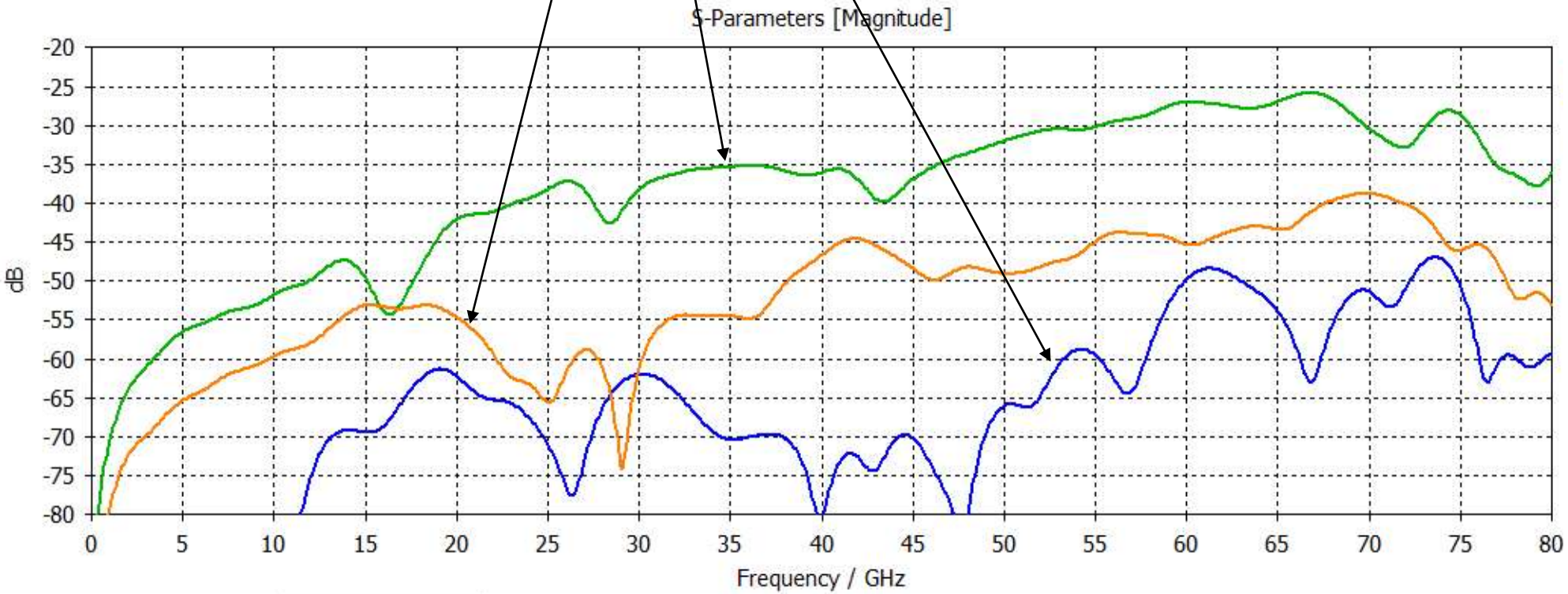


Vertical OSFP-XD Connector FEXT 0.90mm Max Mating

Module side			
Top Side			
wafer1		wafer4	
1	2	3	4
Low Side			
wafer2		wafer3	
5	6	7	8

Line Card side			
Top Side			
wafer1		wafer4	
9	10	11	12
Low Side			
wafer2		wafer3	
13	14	15	16

Victim

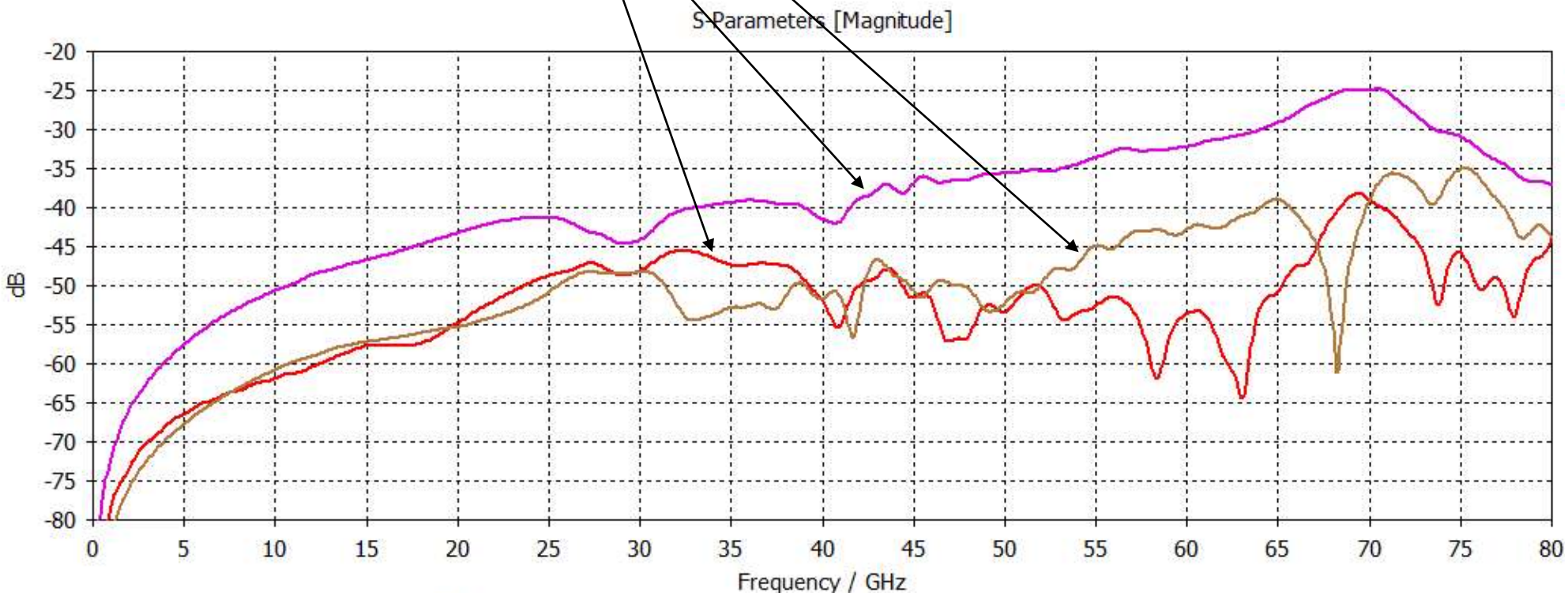


Vertical OSFP-XD Connector FEXT 0.90mm Max Mating

Module side			
Top Side			
wafer1		wafer4	
1	2	3	4
Low Side			
wafer2		wafer3	
5	6	7	8

Line Card side			
Top Side			
wafer1		wafer4	
9	10	11	12
Low Side			
wafer2		wafer3	
13	14	15	16

Victim

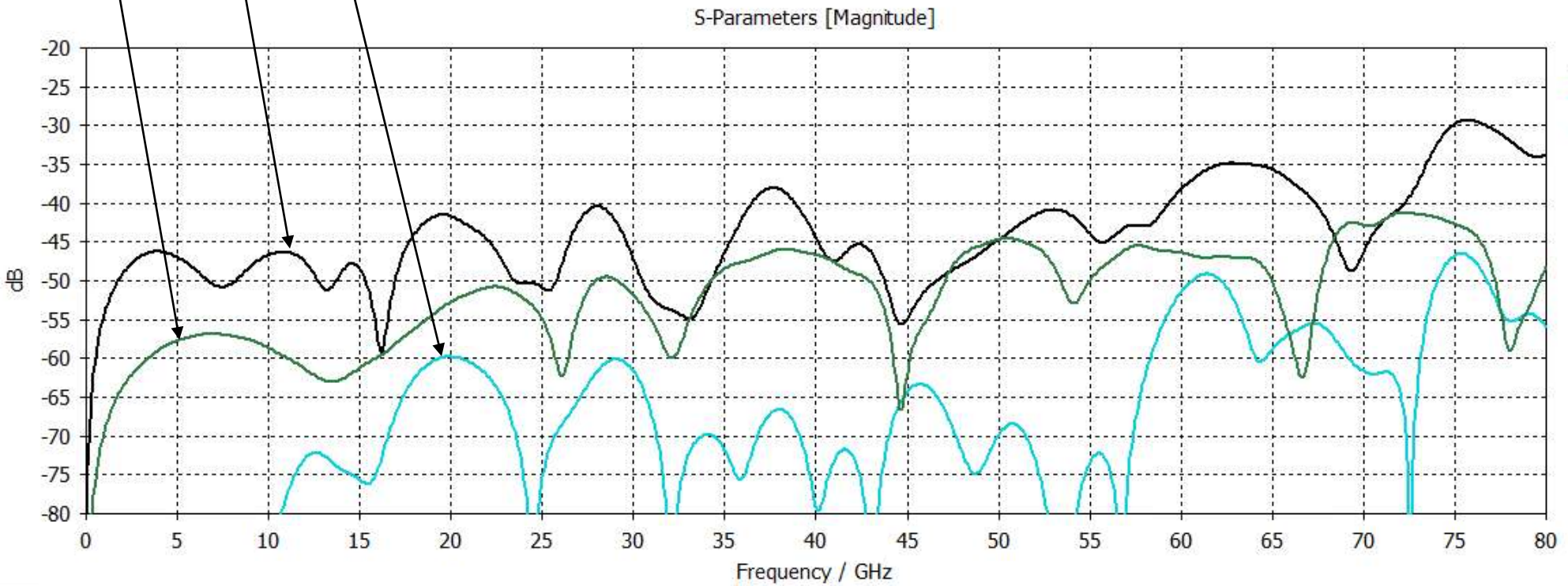


Vertical OSFP-XD Connector NEXT 0.56mm Normal Mating

Module side			
Top Side			
wafer1		wafer4	
1	2	3	4
Low Side			
wafer2		wafer3	
5	6	7	8

Line Card side			
Top Side			
wafer1		wafer4	
9	10	11	12
Low Side			
wafer2		wafer3	
13	14	15	16

Victim

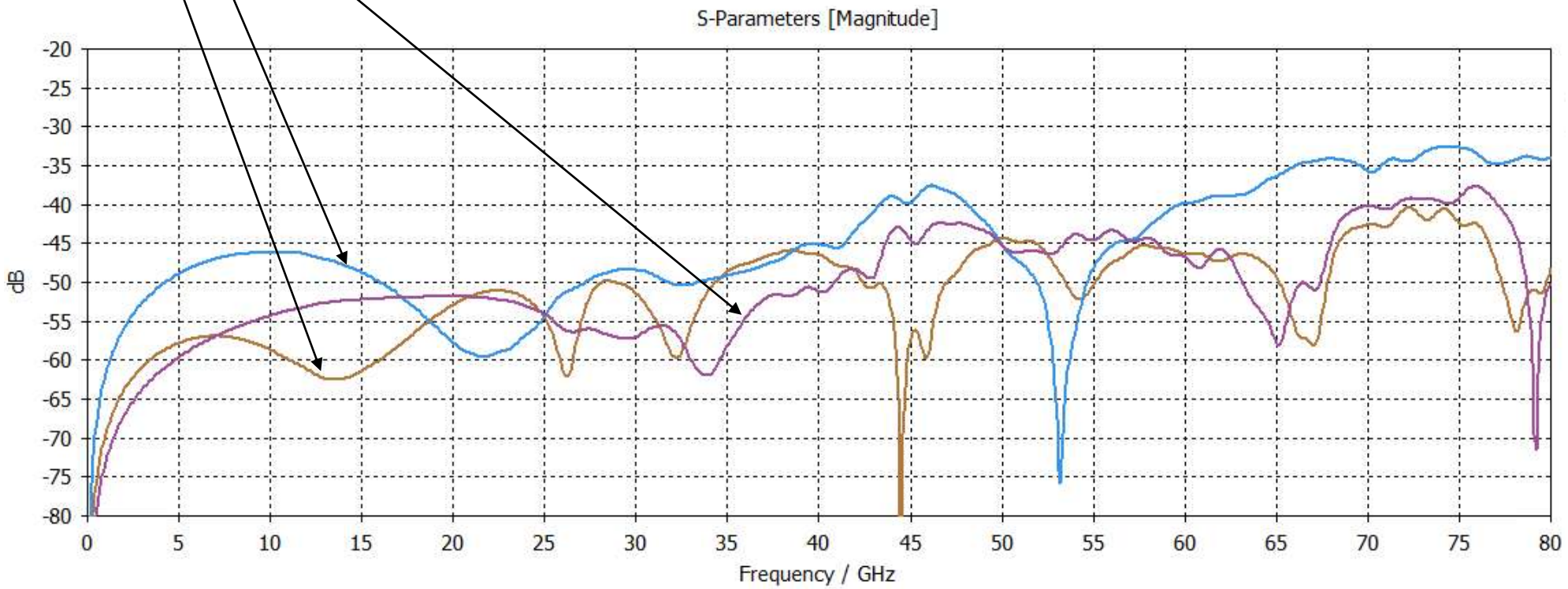


Vertical OSFP-XD Connector NEXT 0.56mm Normal Mating

Module side			
Top Side			
wafer1		wafer4	
1	2	3	4
Low Side			
wafer2		wafer3	
5	6	7	8

Line Card side			
Top Side			
wafer1		wafer4	
9	10	11	12
Low Side			
wafer2		wafer3	
13	14	15	16

Victim

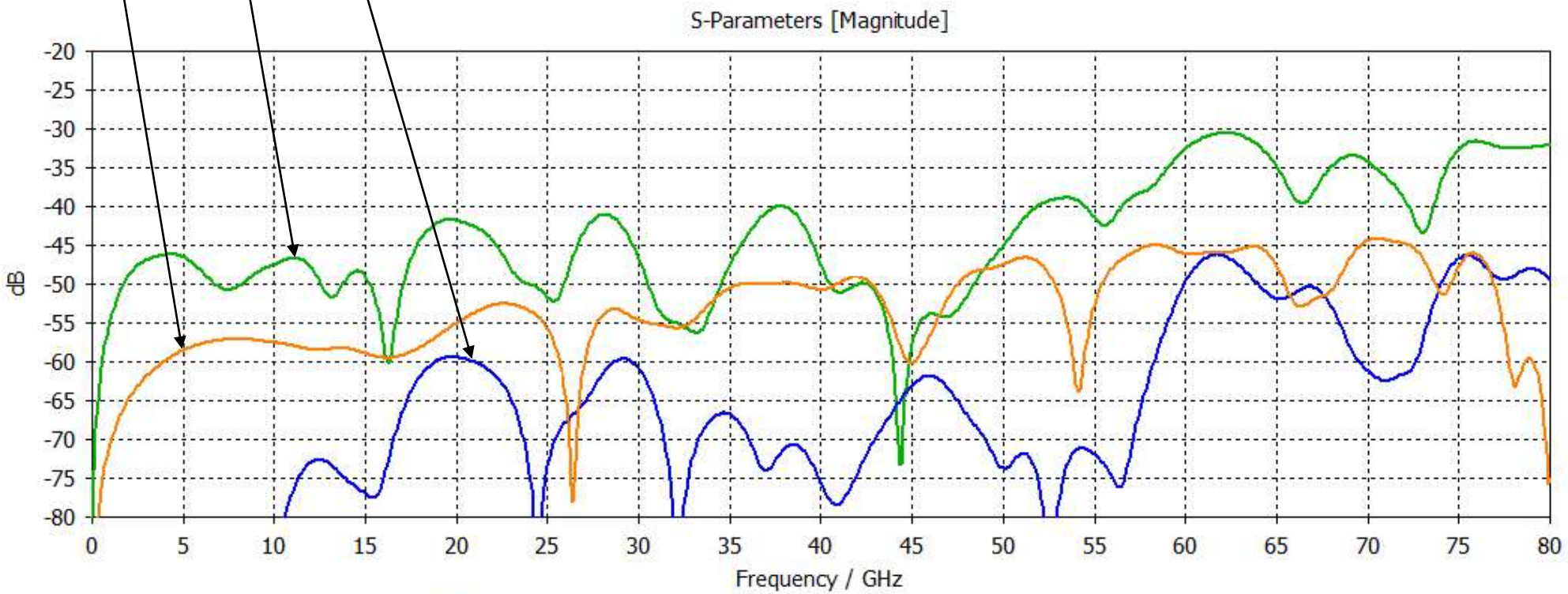


Vertical OSFP-XD Connector NEXT 0.90mm Max Mating

Module side			
Top Side			
wafer1		wafer4	
1	2	3	4
Low Side			
wafer2		wafer3	
5	6	7	8

Line Card side			
Top Side			
wafer1		wafer4	
9	10	11	12
Low Side			
wafer2		wafer3	
13	14	15	16

Victim

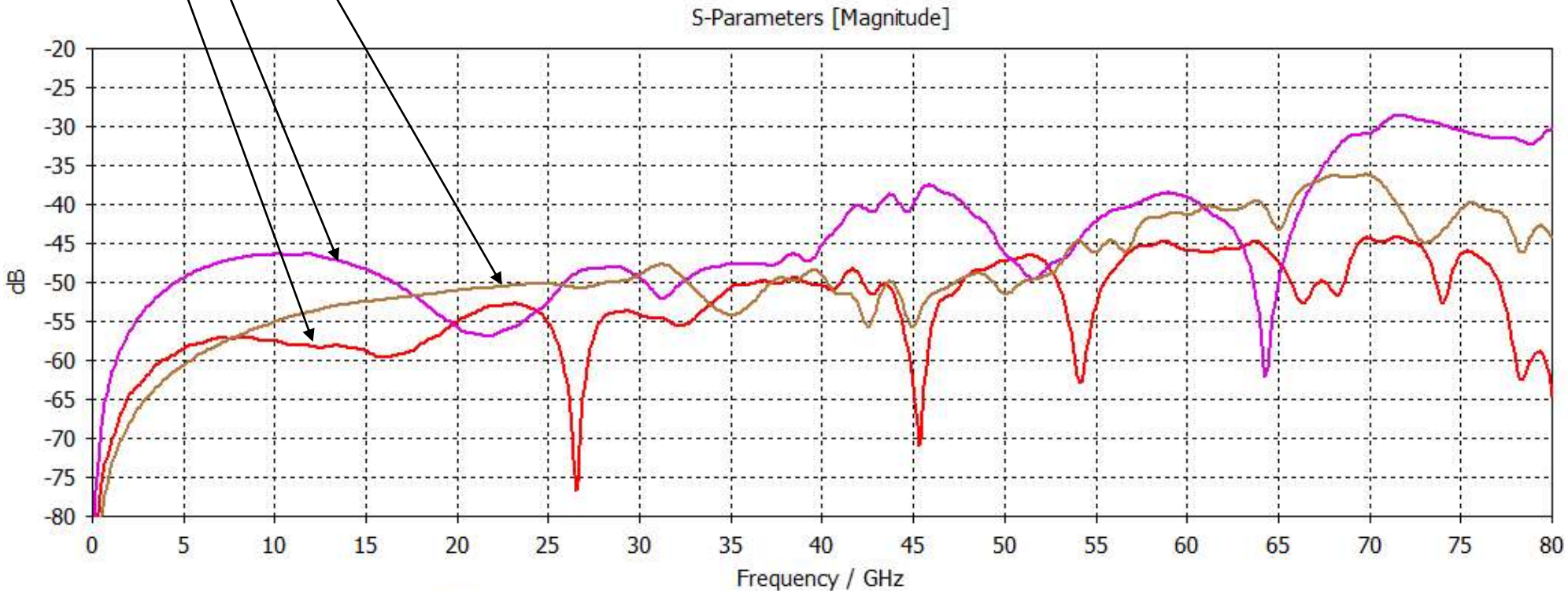


Vertical OSFP-XD Connector NEXT 0.90mm Max Mating

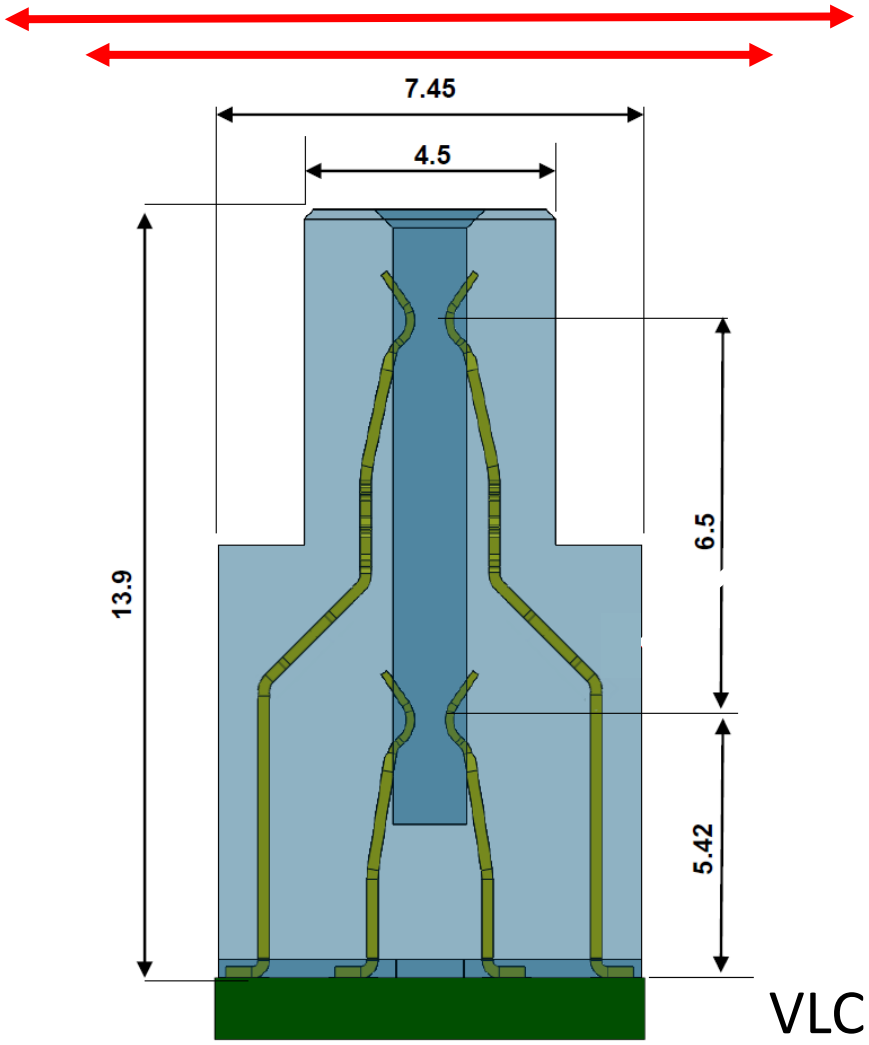
Module side			
Top Side			
wafer1		wafer4	
1	2	3	4
Low Side			
wafer2		wafer3	
5	6	7	8

Line Card side			
Top Side			
wafer1		wafer4	
9	10	11	12
Low Side			
wafer2		wafer3	
13	14	15	16

Victim



Future Vertical Line Card Triple or Quad Density Connector?



- Conventional lead and PCB contact technology in a vertical configuration has room to grow
- Two-piece vertical connector technologies support much higher contact densities

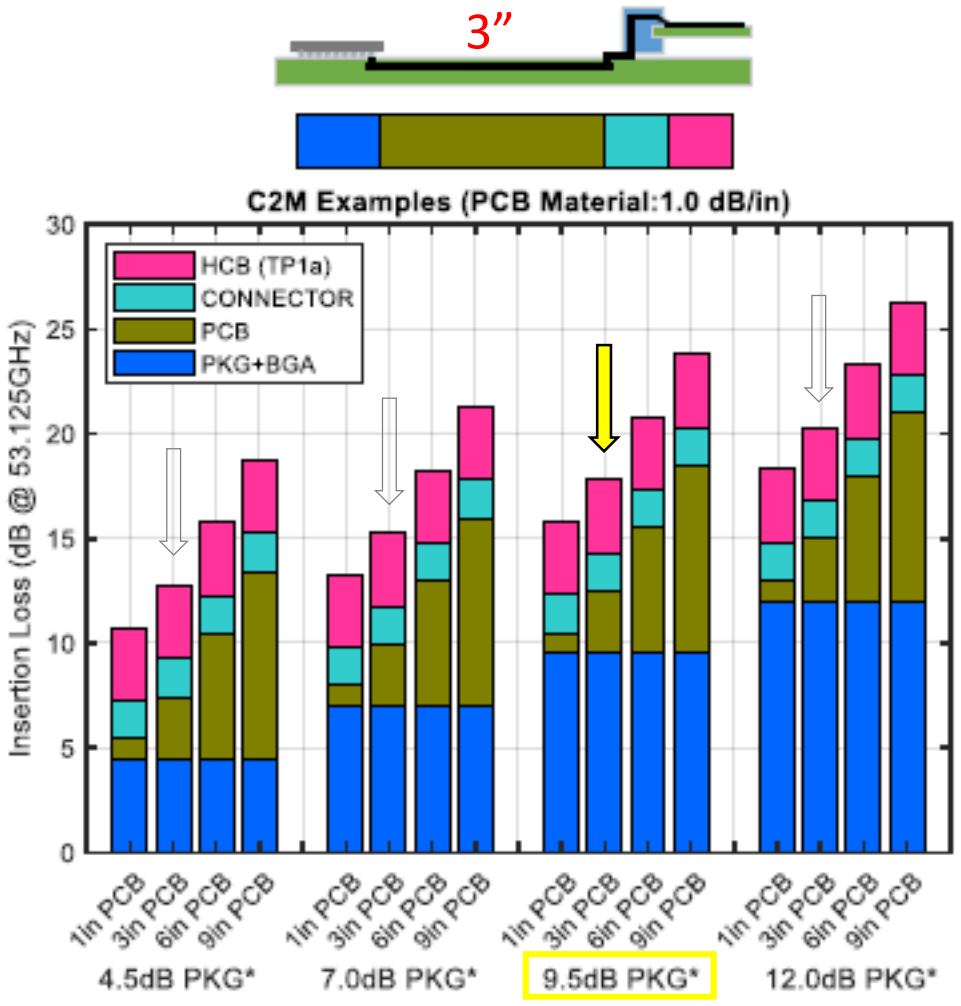
Outline

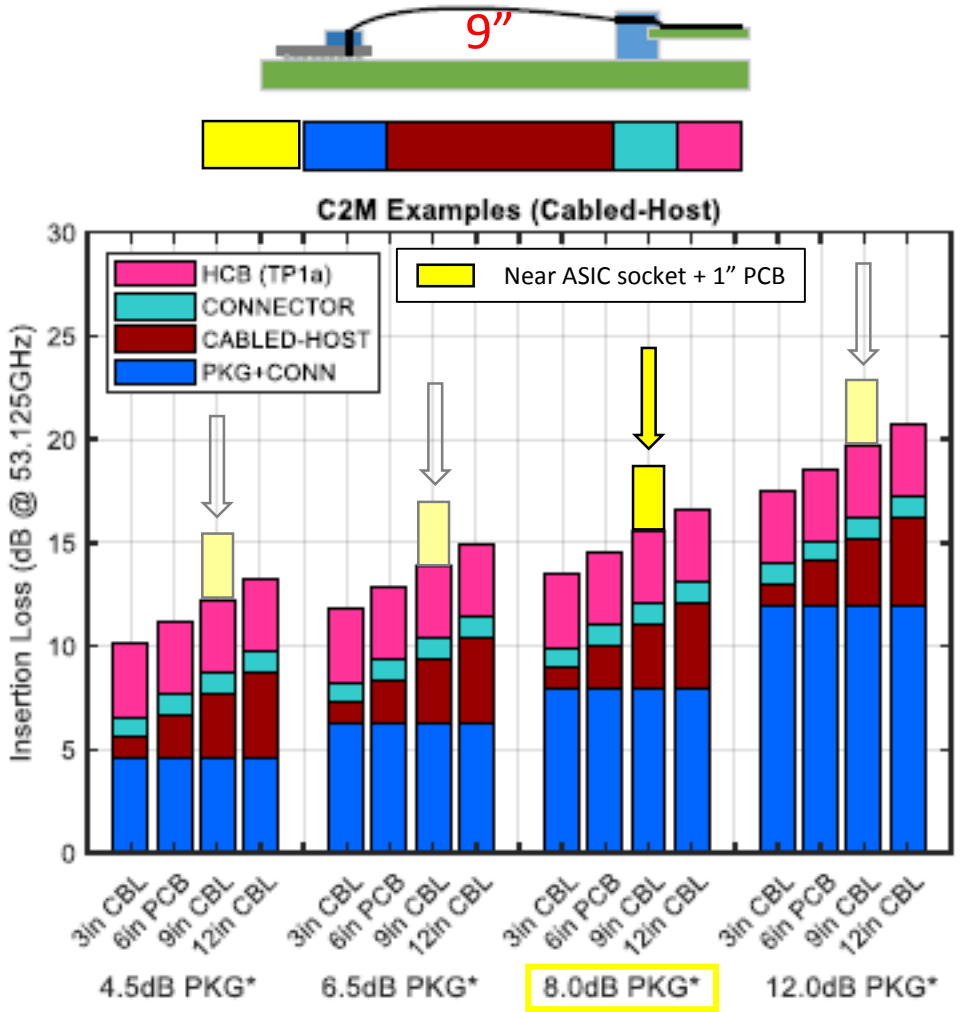
- Introduction
- Rack Power Limitations
- Dual ASIC VLC Baseline
- Vertical OSFP Connector
- Vertical OSFP-XD Connector

➢ **Stripline vs. Twinax Loss**

- Single ASIC VLC Alternative
- Summary

224G PAM4 ASIC to Module Stripline vs. Twinax/PCB Link Loss



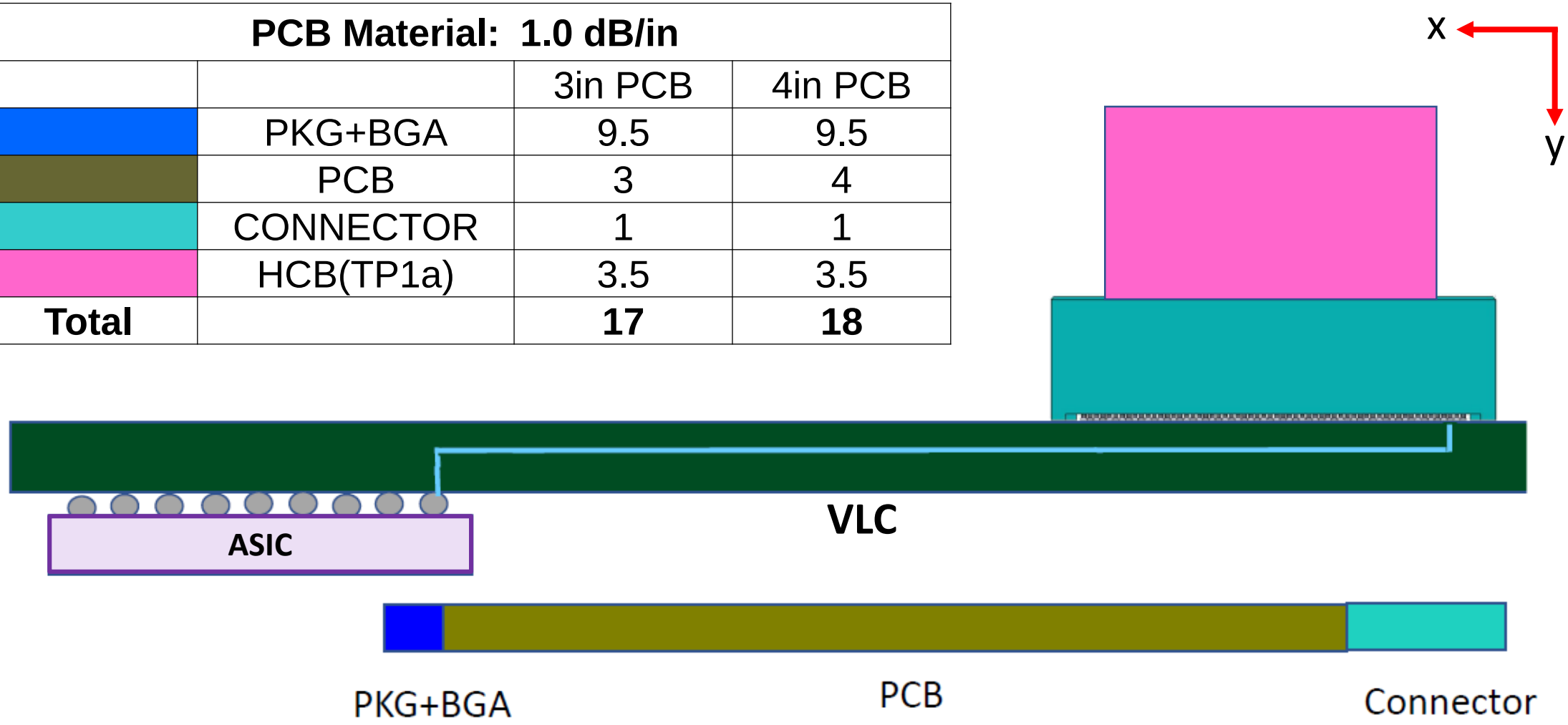


S. Kocis, Amphenol, N. Tracy, TE, 8/26/21, www.ieee802.org/3/B400G/public/21_08/kocsis_b400g_01a_210826.pdf

>9dB PKG: L. Ben-Artsi, Marvell, R. Mellitz, Samtec, www.ieee802.org/3/df/public/22_07/benartsi_3df_01a_2207.pdf

224G PAM4 ASIC to VLC Module Stripline Link Loss

PCB Material: 1.0 dB/in			
		3in PCB	4in PCB
	PKG+BGA	9.5	9.5
	PCB	3	4
	CONNECTOR	1	1
	HCB(TP1a)	3.5	3.5
Total		**17**	**18**



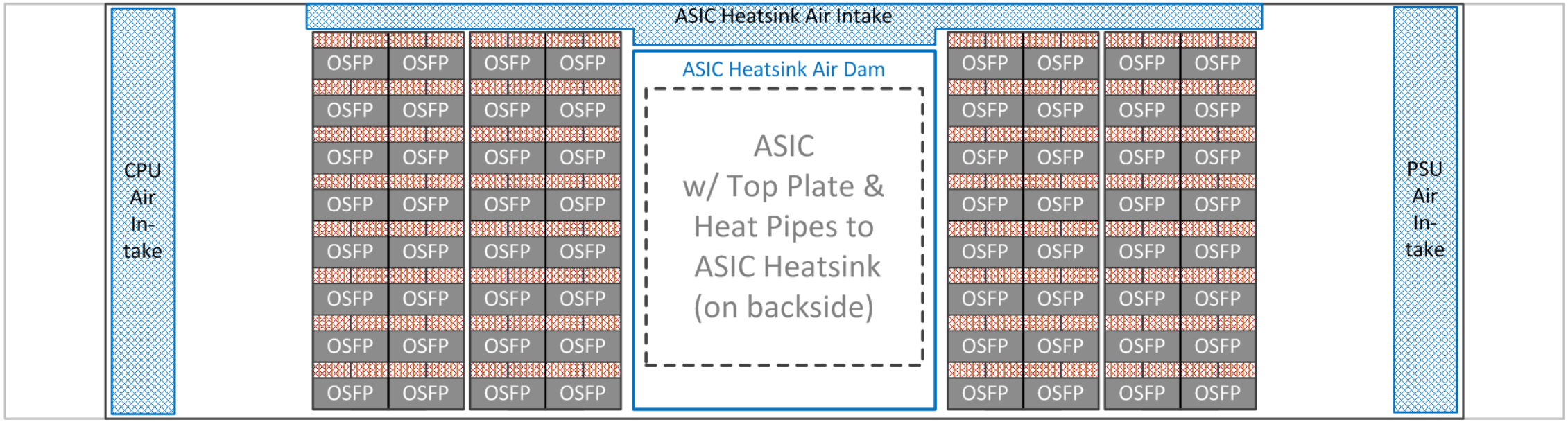
Outline

- Introduction
- Rack Power Limitations
- Dual ASIC VLC Baseline
- Vertical OSFP Connector
- Vertical OSFP-XD Connector
- Stripline vs. Twinax Loss

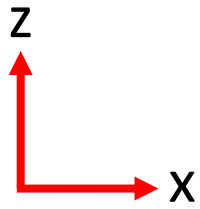
➢ **Single ASIC VLC Alternatives**

- Summary

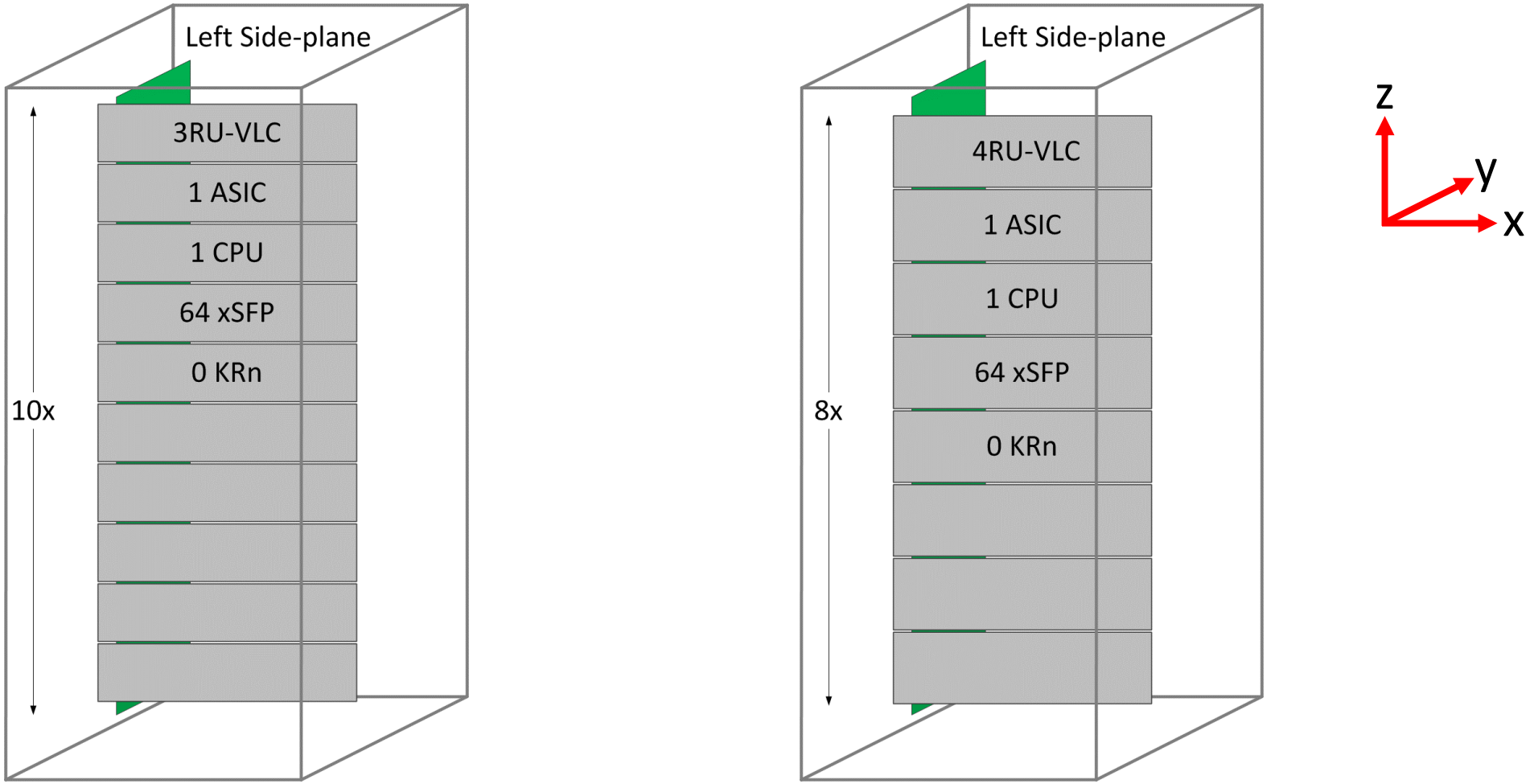
3RU-VLC, 64 OSFP, 1 ASIC, 4.5” $L_{RF\text{-}MAX}$ (Full Front View)



- OSFP vertical pitch = 15mm (per MSA)
  horizontal pitch = 24mm
- PCB Stripline $L_{RF\text{-}MAX}$ =
  102mm + 12mm = 102mm **(4.5")**

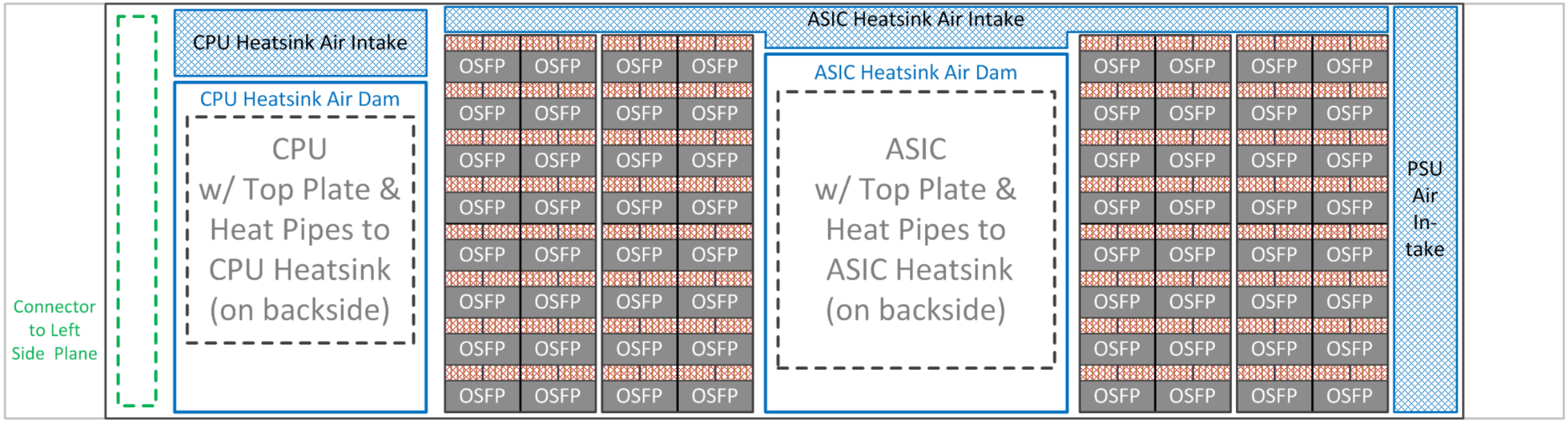


3RU & 4RU-VLC Racks w/ Left Side-plane

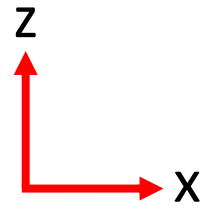


Right Side-plane is an equivalent alternative

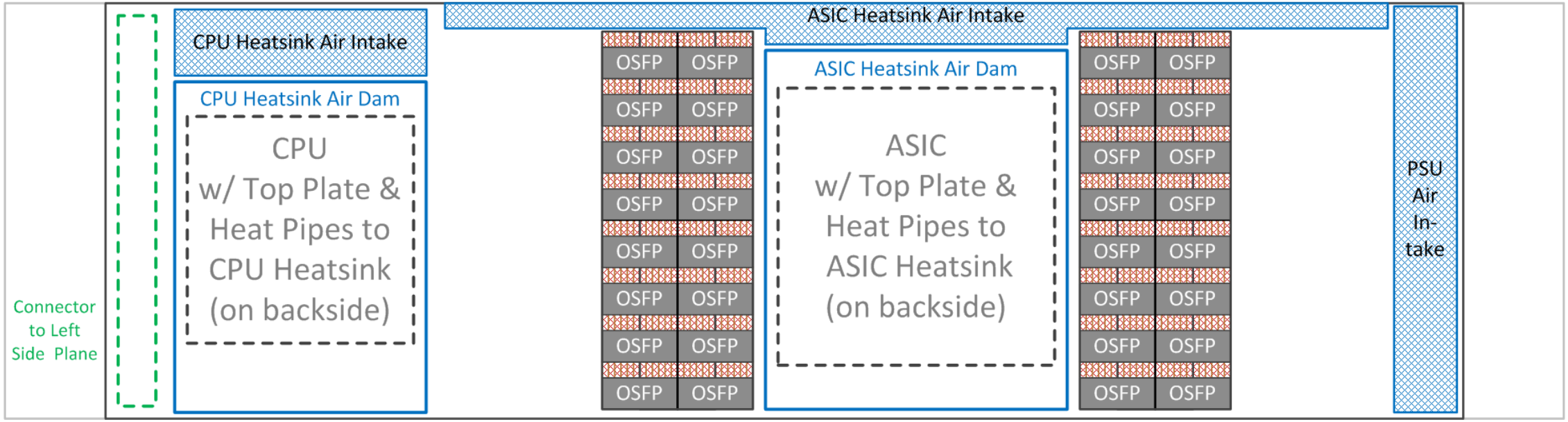
3RU-VLC, 64 OSFP, 1 ASIC, 1 CPU, 4.5” $L_{RF\text{-}MAX}$ (Full Front View)



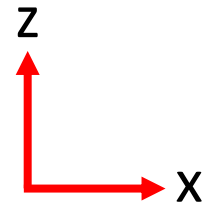
- OSFP vertical pitch = 15mm (per MSA)
  horizontal pitch = 24mm
- PCB Stripline $L_{RF\text{-}MAX}$ =
  102mm + 12mm = 102mm **(4.5")**



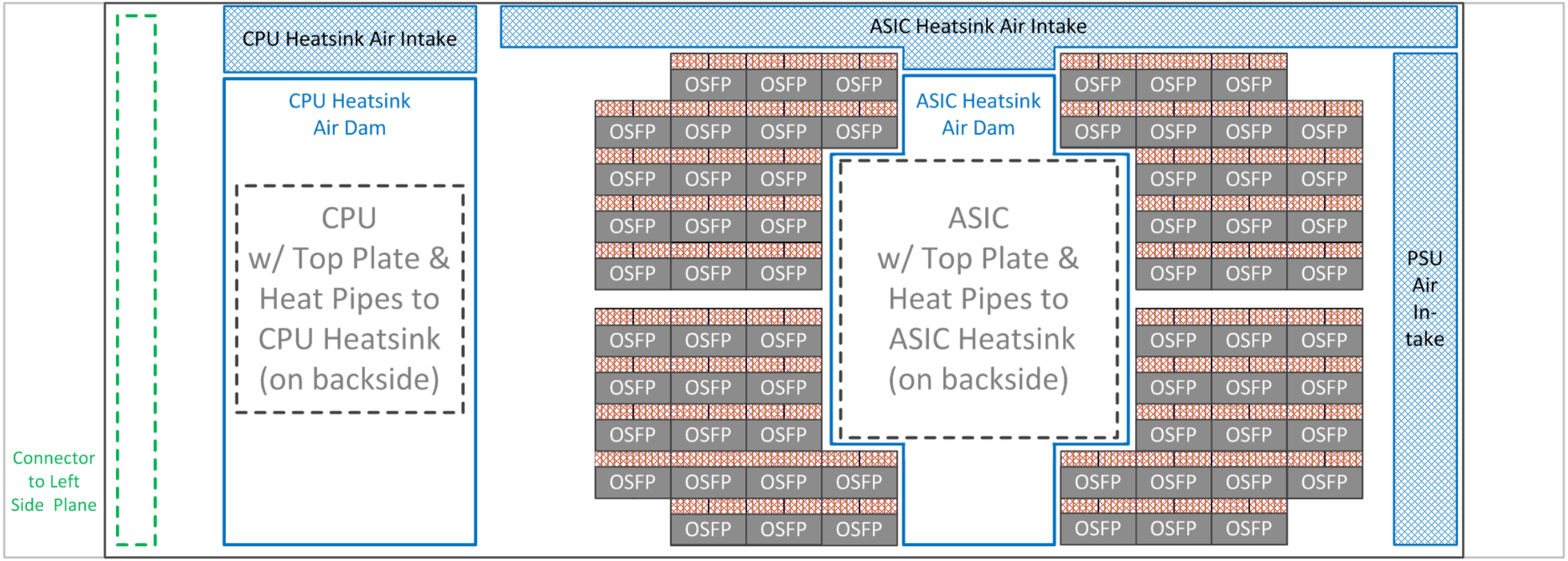
3RU-VLC, 32 OSFP, 1 ASIC, 1 CPU, 3.0” $L_{RF\text{-}MAX}$ (Full Front View)



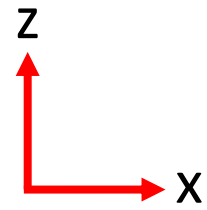
- OSFP vertical pitch = 15mm (per MSA)
  horizontal pitch = 24mm
- PCB Stripline $L_{RF\text{-}MAX}$ =
  64mm + 12mm = 102mm **(3.0")**



4RU-VLC, 64 OSFP, 1 ASIC, 1 CPU, 4.0” $L_{RF\text{-}MAX}$ (Full Front View)



- OSFP vertical pitch = 15mm (per MSA)
  horizontal pitch = 24mm
- PCB Stripline $L_{RF\text{-}MAX}$ =
  90mm + 12mm = 102mm **(4.0")**



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- Single ASIC VLC Alternative

➢ **Summary**

HLC Optics vs. Vertical Line Card (VLC) Front Pluggable Optics

Optics		RF Type	$L_{RF\text{-}MAX}$	RF I/O Density	Front Access	Air Flow Obstacles	Mature Tech.	Cost
HLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	9” - 12”	1x	Yes	Cage & Connector	Yes	1x
	Front Pluggable (OSFP, QSFP)	Twinax over PCB	9” - 12”	1x	Yes	Cables & Connector	No	>2x
	Assembled on PCB Near Package (NPO)	Stripline in PCB	3” - 4”	2x	No	ASIC & other NPOs	No	>1x
VLC	Front Pluggable (OSFP, QSFP)	Stripline in PCB	3” - 4”	1x	Yes	None	Yes	1x

VLC Paradigm

- All the advantages of front pluggable HLC paradigm using existing pluggable optics
- Same cost structure and manufacturing maturity as front pluggable HLC
- Ideal airflow with most effective and efficient cooling performance of any approach
- Equivalent or better RF performance than Twinax over PCB, or NPO HLC
- None of the disadvantages of Twinax over PCB, NPO, or CPO HLC
- If you are considering Twinax over PCB, NPO, or CPO, think again
- After an epiphany about VLC, contact Yamaichi Electronics
- For more breakthrough innovations, stay tuned to Nubis Communications

Datacenter Optical Transceivers in the Next Decade

Thank you