Exploration feasibility of 200 Gbps/Lane using

Diff PAM4 and SE PAM4

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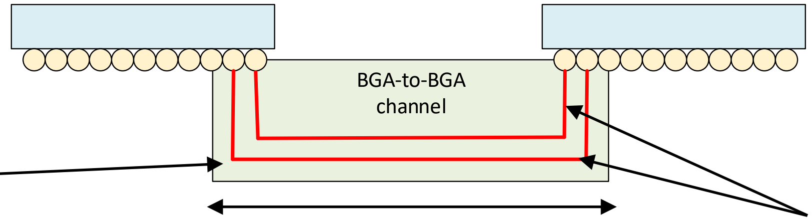
Objectives of the presentation

- **We explore the feasibility of 224 Gbps/Lane using Diff PAM4 and SE PAM4 modulations for different 802.3ck and 802.3df channels.**
- **Demonstrating that for some channels SE PAM4 gives better performance than differential PAM4**
  - **For this goal, the SNR that is required to achieve a certain SER of 10^{-4} is calculated for selected channels**
  - **The SER comparison between the two methods includes FEXT and NEXT crosstalk channels.**
- **Pointing out the channels for which SE PAM4 would be a better fit**
- **Using Single-Ended PAM4 modulation might help in supporting high IL channels and saving power for 224 Gbps/lane chip communications.**

Simulation Setup

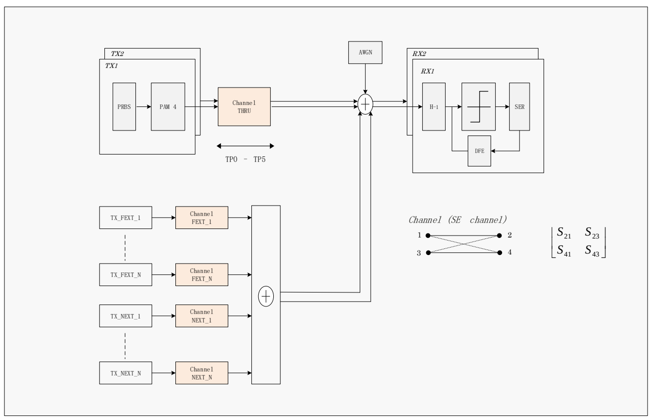


TP0-TP5

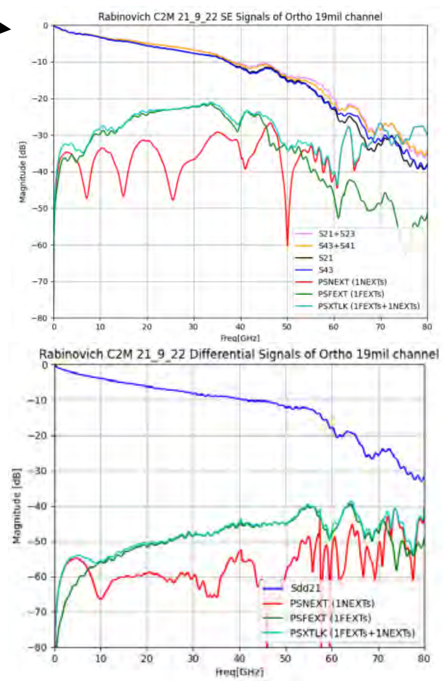
Used for SE PAM4 or differential PAM4 channel

Channel groups:

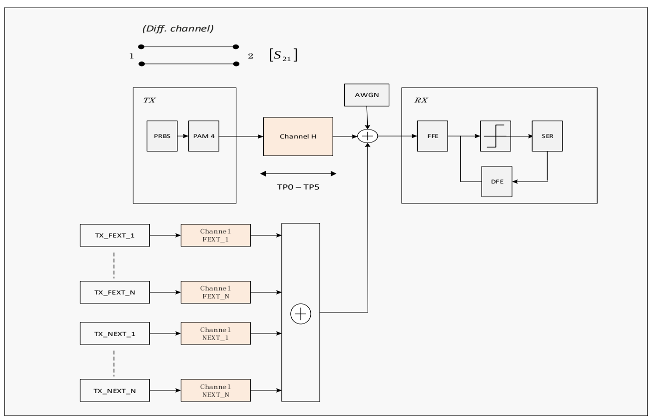
- 802.3ck channels
- 802.3df channels



SE PAM4 simulation Setup



SE s4p df channel Rabinovich 19mil



Differential PAM4 simulation Setup

Channel Scenarios

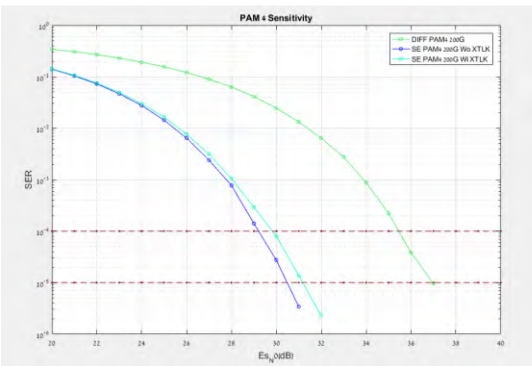
IEEE 802.3.ck channels				
Channel Number	Channel name	Channel contributor	FEXT Channels	NEXT Channels
1	100G C2C-S Channels Estimate 16-18dB channels	Jane Lim Arturo Pachon Pirooz Tooyserkani (14-July-2019)	2	2
2	New Chip to module channel simulation and analysis	Nathan Tracy (11-Nov-2019)	5	0
3	BP OD Channel Analysis	Alex Haser Tom Palkert (14-Jan-2020)	5	3
IEEE 802.3.df channels				
	Channel name	Channel contributor	FEXT Channels	NEXT Channels
4-6	212 Gb/s PAM4 per Lane C2M Channels - Orthogonal 19mil ,67mil, 93mil channel	Rick Rabinovich (19-Sept-2022)	1	1
7	Chip to Chip (C2C) Mezzanine Test Board Channels	Rich Mellitz Brandon Gore Tom Palkert (July 2022)	3	0
8-12	Channel Models for 200 Gbps Lane AUI C2M 93ohms, 20:2:28 dB channel	Femi Akinwale Kusuma Matta Oleg Kashurkin Cesar Mendez-Ruiz Howard Heck Francisco Olguin Tellez (19-Sept-2022)	1	2
13-17	Channel Models for 200 Gbps Lane AUI C2M 100ohms, 20:2:28 dB channel	Femi Akinwale Kusuma Matta Oleg Kashurkin Cesar Mendez-Ruiz Howard Heck Francisco Olguin Tellez (19-Sept-2022)	1	2

- Channels 1-3 were taken from web site "IEEE P802.3ck Task Force - Tools and Channels" : https://www.ieee802.org/3/ck/public/tools/index.html
- Channels 4-17 were taken from web site "IEEE P802.3df 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force Tools and Channel Data Area" https://www.ieee802.org/3/df/public/tools/index.html

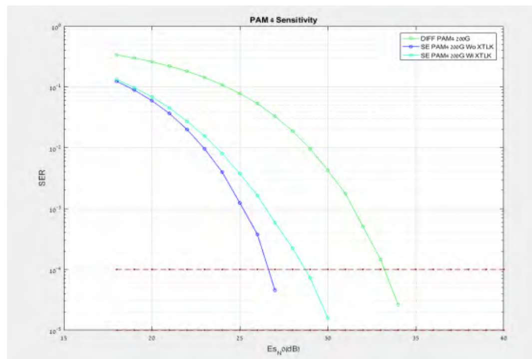
IEEE 802.3ck 200 Gbps Channels

Channels 1-3

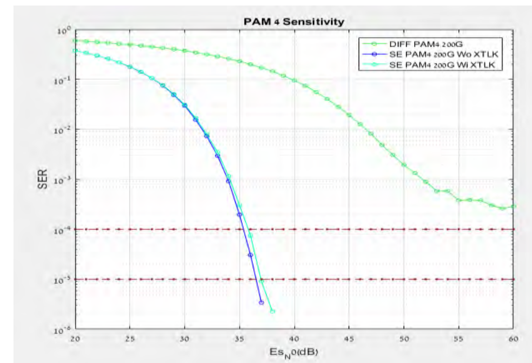
IEEE.ck channels									
Channel Number	Channel name	Channel contributor	FEXT Channels	NEXT Channels	Diff PAM 4 SER 200 Gbps @ 1e-4	SE PAM 4 SER 200 Gbps @ 1e-4	Delta	IL @ 28 GHz	IL @ 56 GHz
1	100G C2C-S Channels Estimate 16-18dB channels	Jane Lim Arturo Pachon Pirooz Tooyserkani (14-July-2019)	2	2	35.5 dB	29.5 dB	6 dB	-20.6	-34
2	New Chip to module channel simulation and analysis	Nathan Tracy (11-Nov-2019)	5	0	33 dB	28.5 dB	4.5 dB	-15.8	-22.1
3	BP OD Channel Analysis	Alex Haser Tom Palkert (14-Jan-2020)	5	3	52 dB @ 1e-3 NA @ 1e-4	33 dB @ 1e-3 36 dB @ 1e-4	19 dB @ 1e-3 NA @ 1e-4	-31.4	-60.2



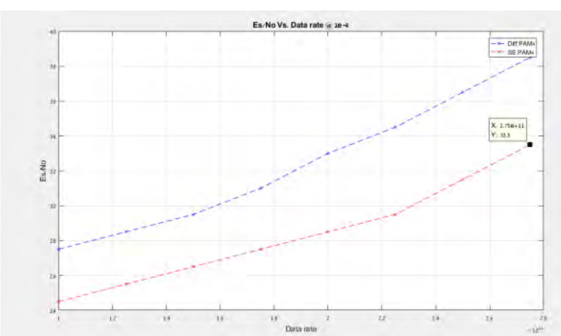
CH1 SER Vs. SNR



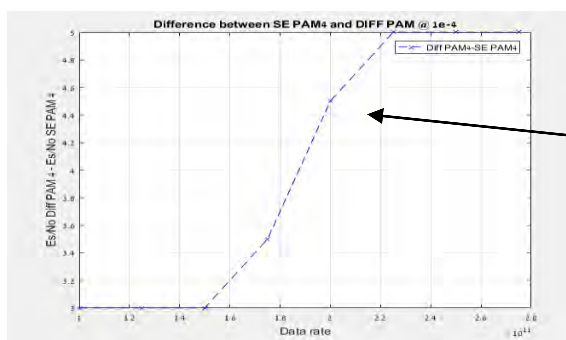
CH2 SER Vs. SNR



CH3 SER Vs. SNR



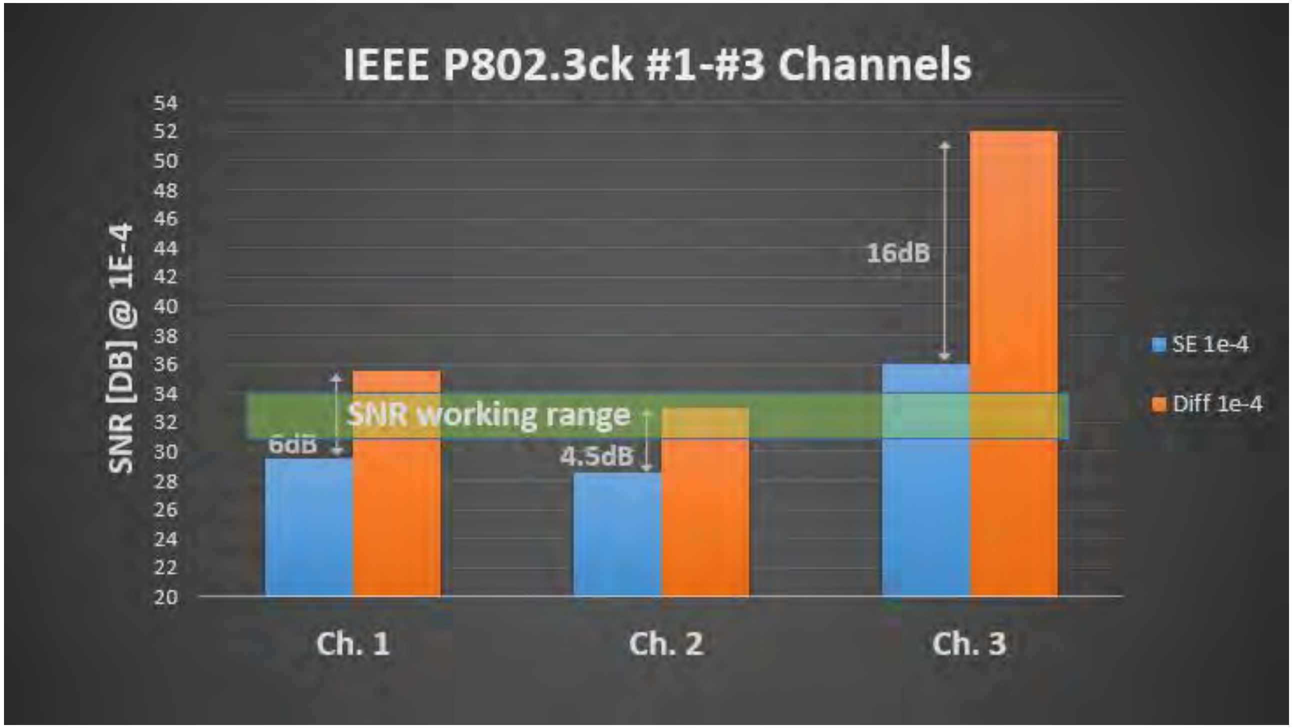
CH2 Es/N0 Vs. Data rate



CH2 difference SER @ 1e-4 between SE PAM4 and Diff PAM4

Increasing the data rate causes SE PAM4 to be better than Diff PAM4.

IEEE.CK channels summary

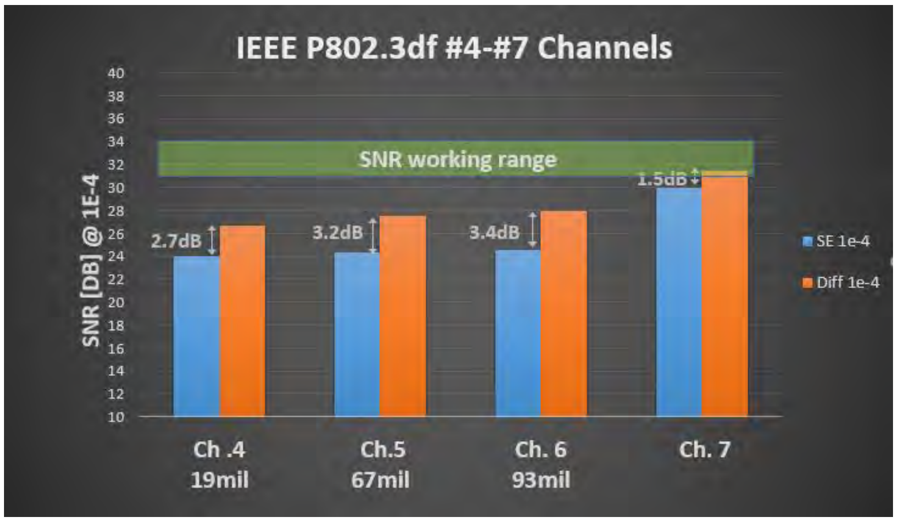


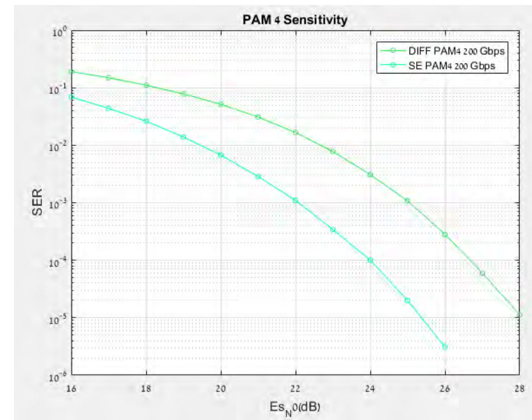
- **SE performs better for all 802.3ck channels**
- **Difference of 6dB in low IL channels and > 10 dB for high IL channels**

IEEE 802.3df 224 Gbps Channels

Channels 4-7

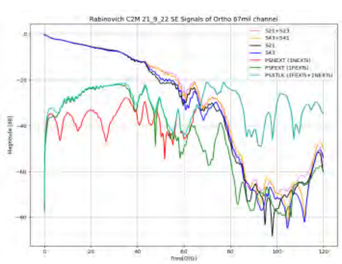
	Channel name	Channel contributor	FEXT Channels	NEXT Channels	Diff PAM 4 SER 200 Gbps @ 1e-4	SE PAM 4 SER 200 Gbps @ 1e-4	Delta
4	212 Gb/s PAM4 per Lane C2M Channels - Orthogonal 19mil channel	Rick Rabinovich (19-Sept-2022)	1	1	26.7 dB	24 dB	2.7 dB
5	212 Gb/s PAM4 per Lane C2M Channels - Orthogonal 67mil channel	Rick Rabinovich (19-Sept-2022)	1	1	27.5 dB	24.3 dB	3.2 dB
6	212 Gb/s PAM4 per Lane C2M Channels - Orthogonal 93mil channel	Rick Rabinovich (19-Sept-2022)	1	1	27.9 dB	24.5 dB	3.4 dB
7	Chip to Chip (C2C) Mezzanine Test Board Channels	Rich Mellitz Brandon Gore Tom Palkert (July 2022)	3	0	31.5 dB	30 dB	1.5 dB

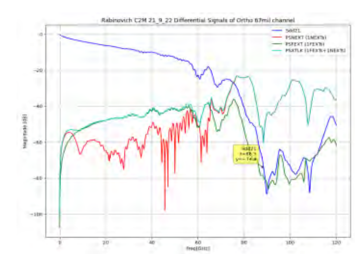




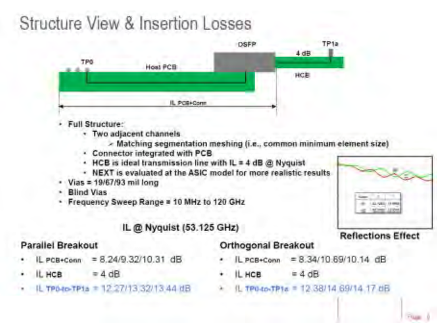
CH5 SER Vs. SNR

- **SE performs better all channels**
- **For channels 4, 5, 6 both SE and differential have high margin from SNR limit**





Rick Rabinovich February 24, 2022 67mil channel



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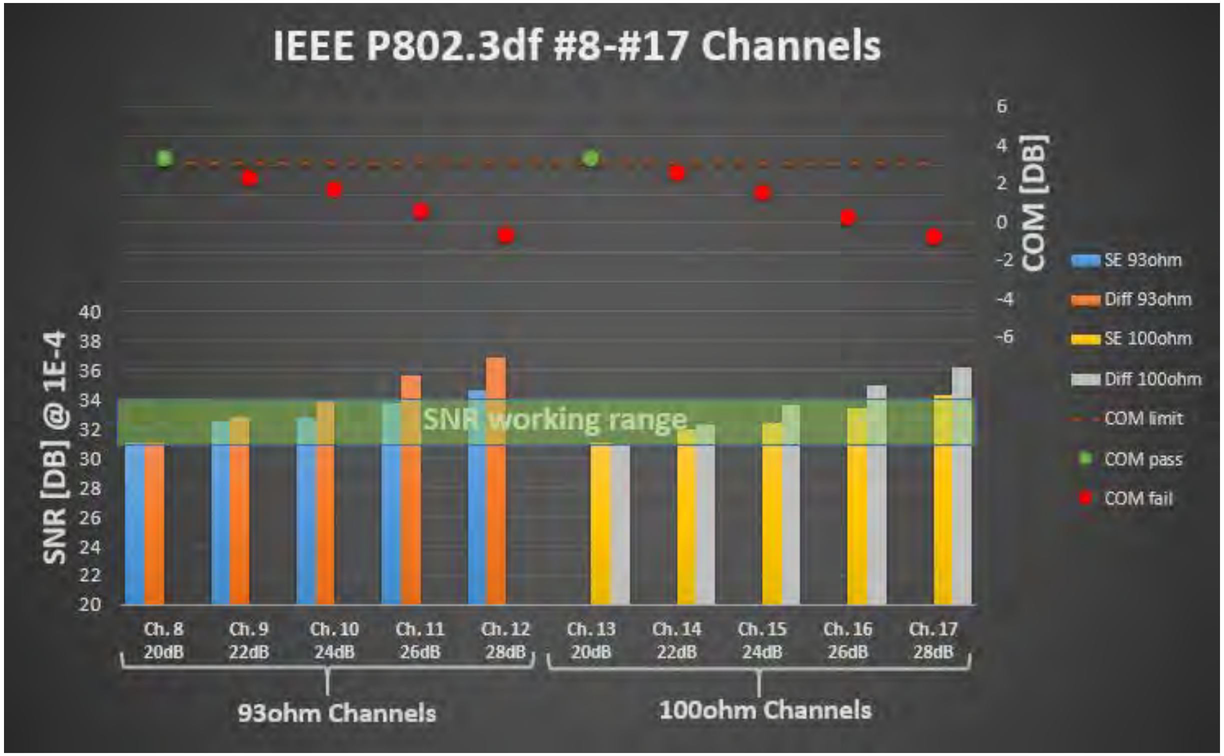
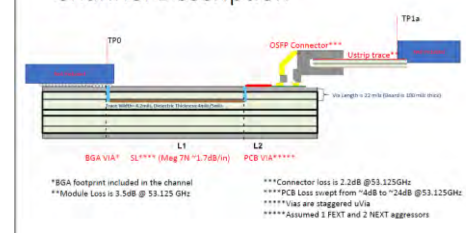
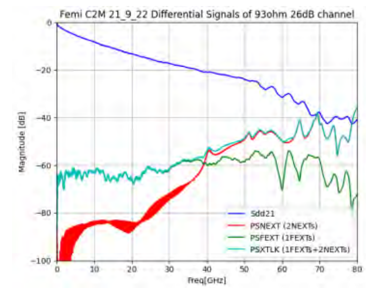
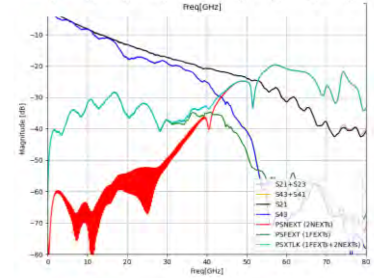
Channels 8-17



Channel Description



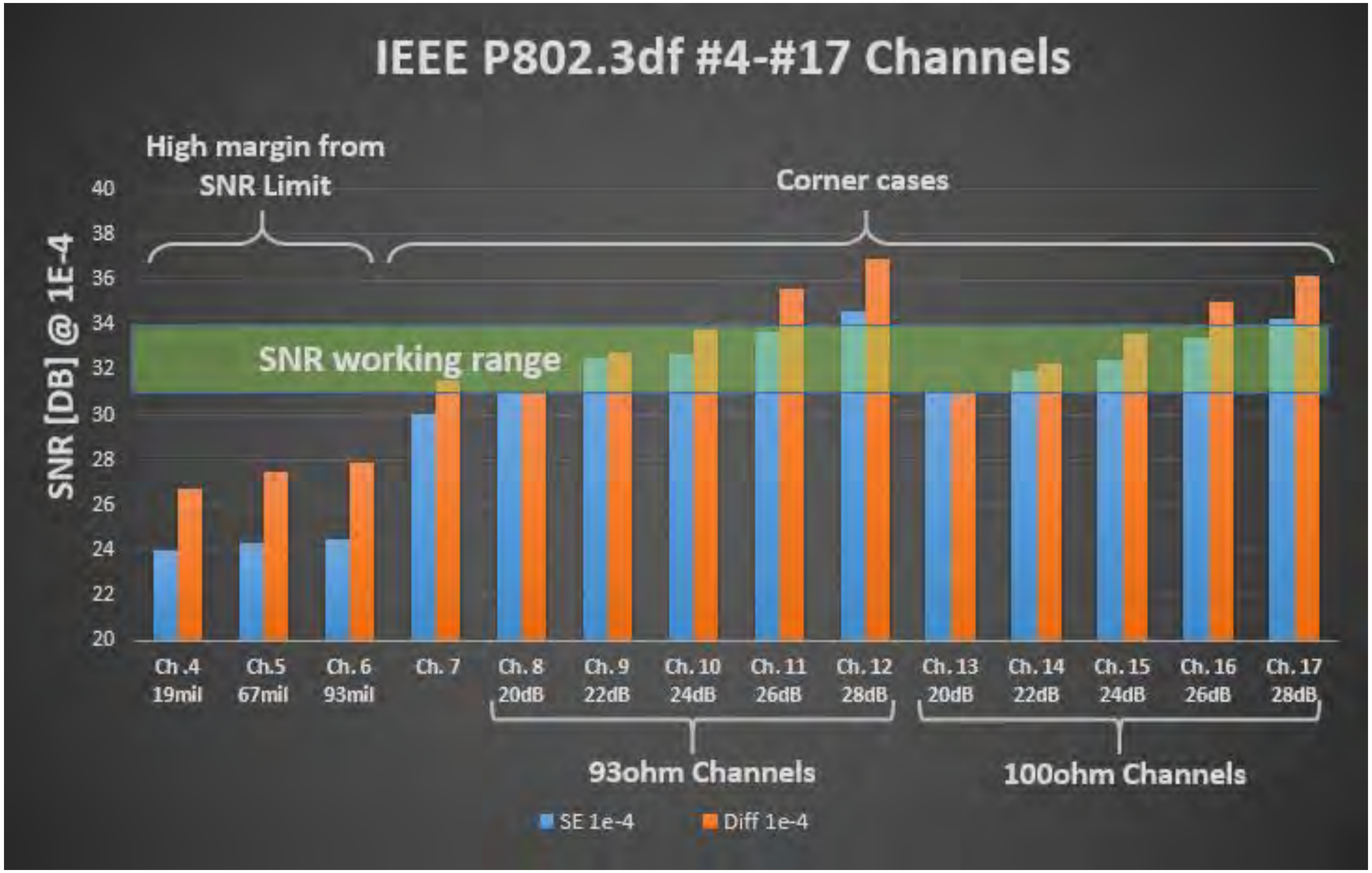




- **SE performs better for higher IL channels, cases 9-12 and 14-17.**
- **For high IL channels, differential implementation does not pass COM**
- **SE advantage increases with high IL**

Femi Akinwale, Cesar Mendez-Ruiz, Arturo Pachon, Kusuma Matta and Howard Heck.
Channel 26 dB, 93 ohm

Summary results 802.3df channels



- **For channels 4-6 both SE and differential have good results and have high margin from SNR limit**
- **For channels 7-17 which are important corner cases, SE performs better results than differential**

Conclusions and summary

- **It was demonstrated that SE PAM4 has clear advantage over Diff PAM4 for some channels**
- **In general, differential pair is the implementation of choice for channels with high XTK and low IL, and SE PAM4 is the preferred choice for channels with low XTK and high IL.**
  - **Similarly, the advantage of SE increases with BW.**
- **The Diff PAM4 implementation requires low IL channels. Such channels needs higher design effort and are more expensive.**
- **Based on these results we propose to consider SE PAM4 implementation in addition to Diff PAM 4 implementation.**

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Thank you !

Appendix

Channels IL

channel no.	IL @ 28GHz [dB] for SE	IL @ 56GHz [dB] for Diff	Notes	Channel Name	Channel Contributor
#1	-20.6	-34	ck	100G C2C-S Channels Estimate 16-18dB channels	Jane Lim Arturo Pachon Pirooz Tooyserkani (14-July-2019)
#2	-15.8	-22.1	ck	New Chip to module channel simulation and analysis	Nathan Tracy (11-Nov-2019)
#3	-31.4	-60.2	ck	BP OD Channel Analysis	Alex Haser Tom Palkert (14-Jan-2020)
#4 19mil	-6.3	-13	df	212 Gb/s PAM4 per Lane C2M Channels - Orthogonal 19mil channel	Rick Rabinovich (19-Sept-2022)
#5 67mil	-6.9	-15.6	df	212 Gb/s PAM4 per Lane C2M Channels - Orthogonal 67mil channel	Rick Rabinovich (19-Sept-2022)
#6 93mil	-7.3	-19.3	df	212 Gb/s PAM4 per Lane C2M Channels - Orthogonal 93mil channel	Rick Rabinovich (19-Sept-2022)
#7	-14	-25.9	df	Chip to Chip (C2C) Mezzanine Test Board Channels	Rich Mellitz Brandon Gore Tom Palkert (July 2022)
#8 12dB	-8.2	-12.3	df	Channel Models for 200 Gbps Lane AUI C2M 93ohms, 12 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#9 16dB	-11.3	-17.4	df	Channel Models for 200 Gbps Lane AUI C2M 93ohms, 16 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#10 20dB	-13.3	-20.7	df	Channel Models for 200 Gbps Lane AUI C2M 93ohms, 20 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#11 24dB	-16	-25.2	df	Channel Models for 200 Gbps Lane AUI C2M 93ohms, 24 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#12 28dB	-18.7	-29.3	df	Channel Models for 200 Gbps Lane AUI C2M 93ohms, 28 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#13 12dB	-7.9	-12.9	df	Channel Models for 200 Gbps Lane AUI C2M 100ohms, 12 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#14 16dB	-10.9	-17.3	df	Channel Models for 200 Gbps Lane AUI C2M 100ohms, 16 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#15 20dB	-13.2	-21.1	df	Channel Models for 200 Gbps Lane AUI C2M 100ohms, 20 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#16 24dB	-15.9	-25.2	df	Channel Models for 200 Gbps Lane AUI C2M 100ohms, 24 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)
#17 28dB	-18.7	-29.5	df	Channel Models for 200 Gbps Lane AUI C2M 100ohms, 28 dB channel	Femi AkinwaleKusuma MattaOleg KashurkinCesar Mendez-RuizHoward HeckFrancisco Olguin Tellez (19-Sept-2022)