224G Electrical Link Bandwidth Considerations

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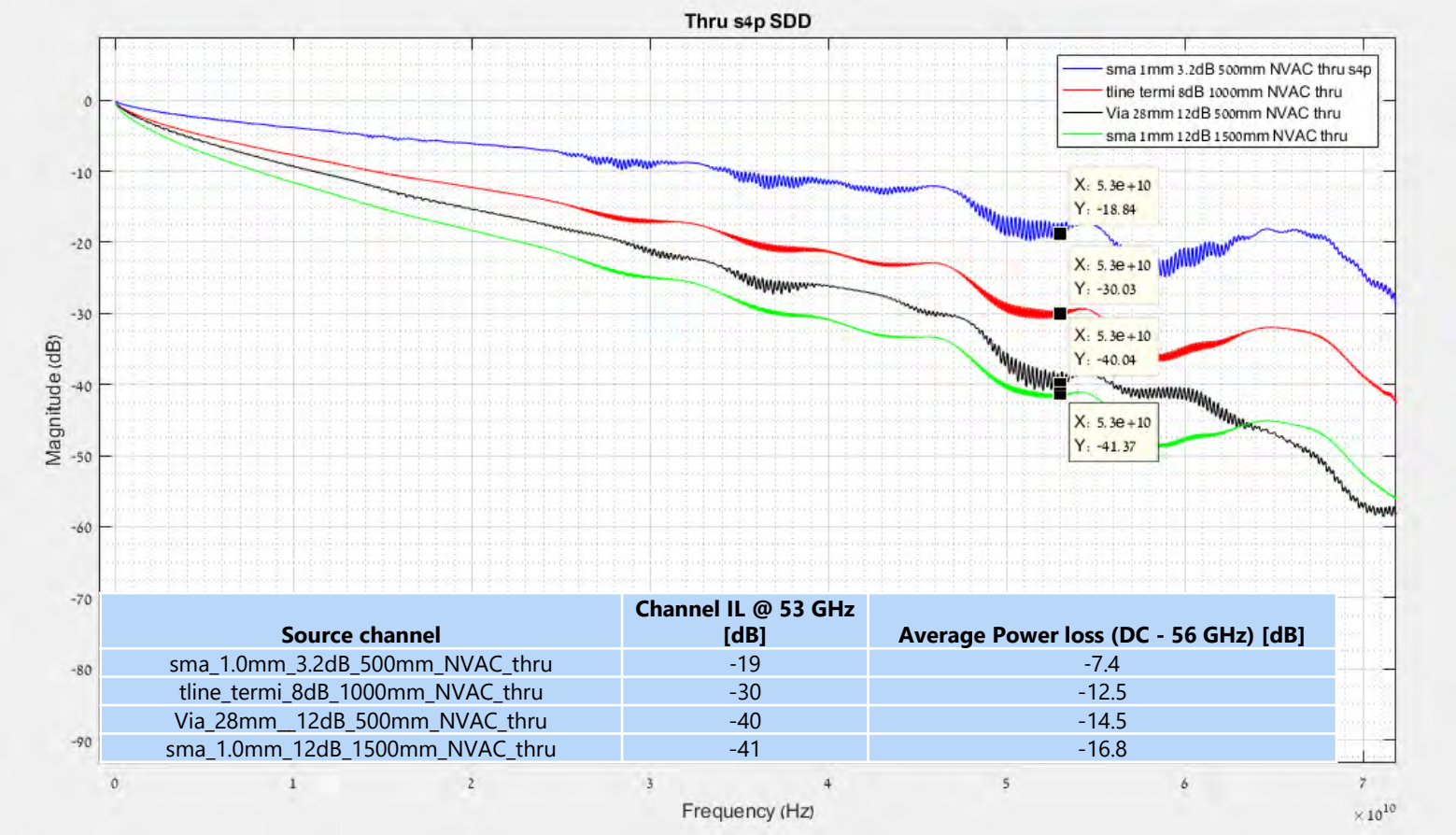
Topics discussion

- PAM 4 receiver sensitivity simulations with different channels and equalizations FFE + DFE
- Compare receiver sensitivity using PAM 4 modulation
  - Simulation of 4 different Mellitz Channels.
  - SER was analyzed for each case (Thru channel)
- The SNR required for several channels is very high (> 34 dB)
- For these channels, other modulation techniques like SE MIMO should be consider

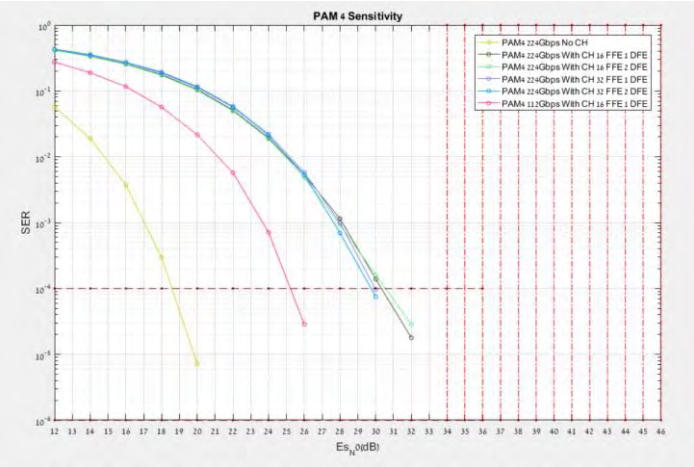
Simulated channels

Simulated source channels, [Contributor : Samtec (Mellitz)]

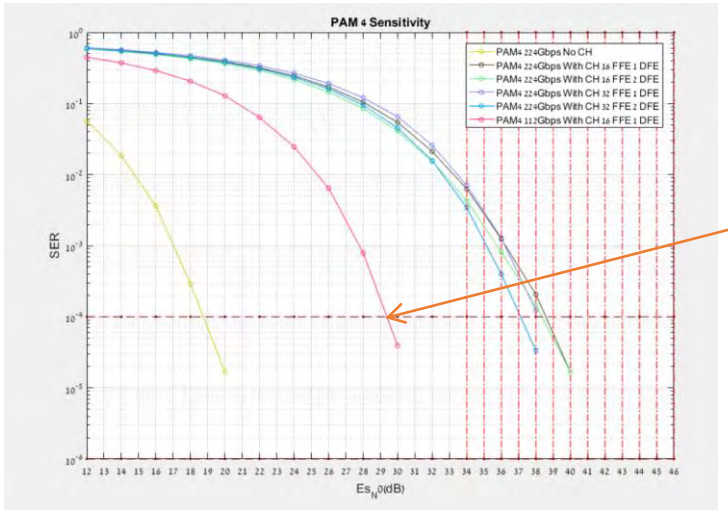


Source channel	Channel IL @ 53 GHz [dB]	Average Power loss (DC - 56 GHz) [dB]
sma_1.0mm_3.2dB_500mm_NVAC_thru	-19	-7.4
tline_termi_8dB_1000mm_NVAC_thru	-30	-12.5
Via_28mm__12dB_500mm_NVAC_thru	-40	-14.5
sma_1.0mm_12dB_1500mm_NVAC_thru	-41	-16.8

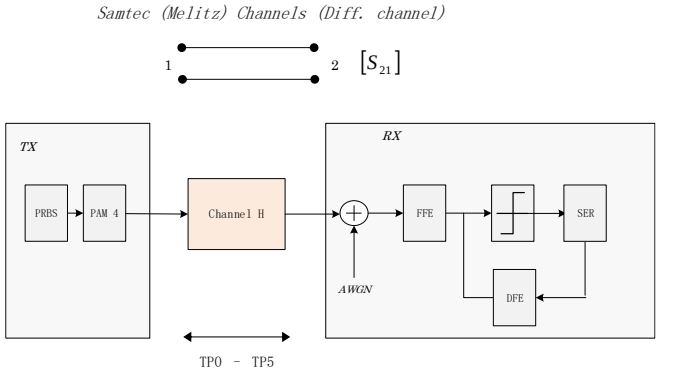
Rx sensitivity simulation results



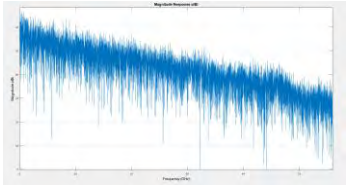
sma_1.0mm_3.2dB_500mm_NVAC_thru



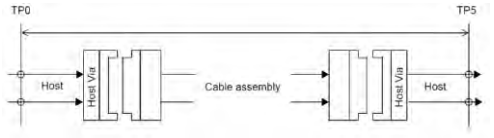
tline_termi_8dB_1000mm_NVAC_thru



Diff. PAM 4



Channel IL

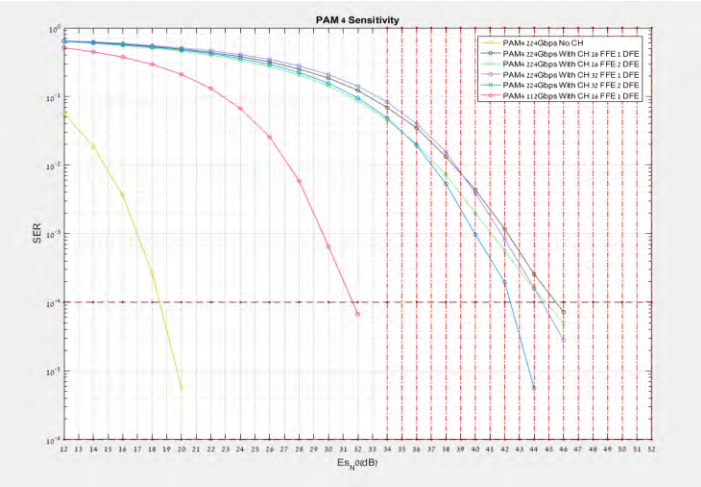


SNR = 29.5 dB for BW= 28 GHZ
2 X 112 GBps = 224 Gbps can be possible using SE MIMO modulation

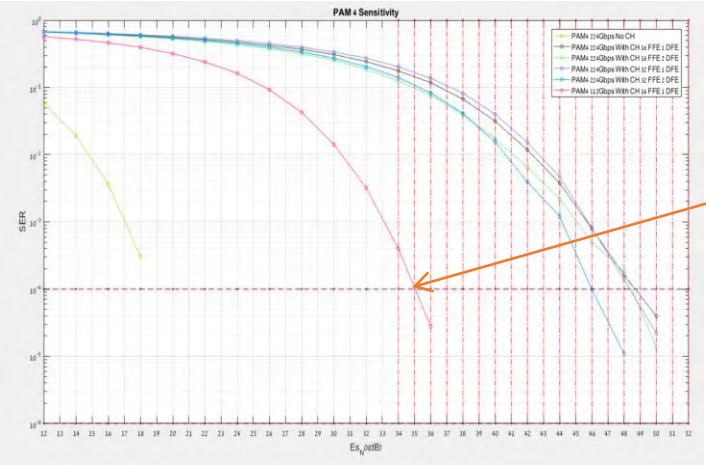
Very difficult to achieve SNR higher than 34-35 dB !!!
Need to increase TX power => More system power

	Equalizer type				
	16 FFE 1 DFE	16 FFE 2 DFE	32 FFE 1 DFE	32 FFE 2 DFE	16 FFE 1 DFE
	224 Gbps per Lane. BW = 56 Ghz				112 Gbps per Lane. BW = 28 Ghz
sma_1.0mm_3.2dB_500mm_NVAC_thru	30.5 dB	30.5 dB	30 dB	29.5 dB	25 dB
Required TX SNR (SER = 1e-4) tline_termi_8dB_1000mm_NVAC_thru	38.5 dB	38 dB	38 dB	37 dB	29.5 dB

Rx sensitivity simulation results

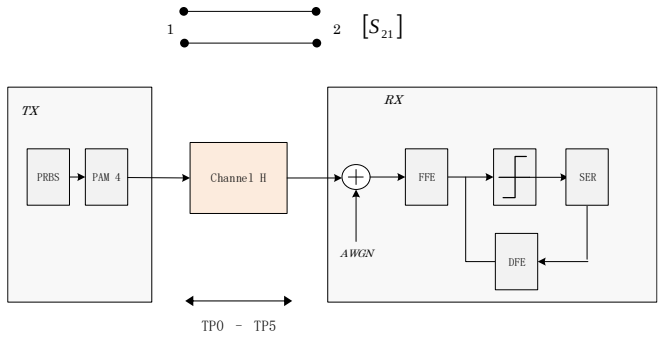


Via_28mm__12dB_500mm_NVAC_thru

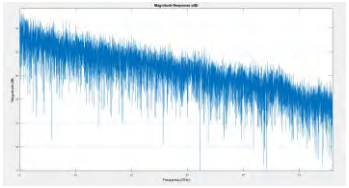


sma_1.0mm_12dB_1500mm_NVAC_thru

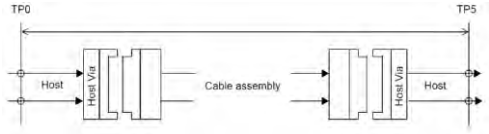
Samtec (Melitz) Channels (Diff. channel)



Diff. PAM 4



Channel IL



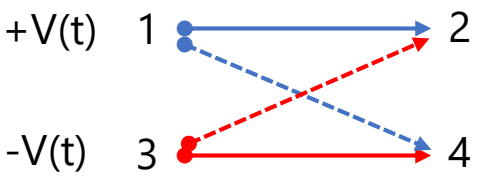
SNR = 35 dB for BW= 28 GHZ
2 X 112 GBps = 224 Gbps can be possible using SE MIMO modulation

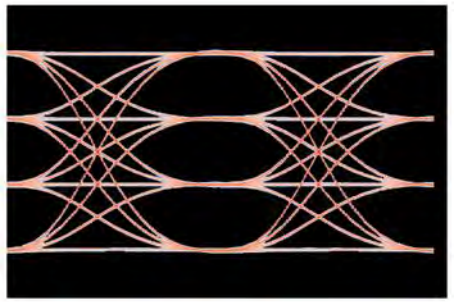
Very difficult to achieve SNR higher than 34-35 dB !!!
Need to increase TX power => More system power

	Equalizer type				
	16 FFE 1 DFE	16 FFE 2 DFE	32 FFE 1 DFE	32 FFE 2 DFE	16 FFE 1 DFE
	224 Gbps per Lane. BW = 56 Ghz				112 Gbps per Lane. BW = 28 Ghz
Required TX SNR (SER = 1e-4) Via_28mm__12dB_500mm_NVAC_thru	45.5	44.5 dB	44.5 dB	42.5 dB	31.5 dB
Required TX SNR (SER = 1e-4) sma_1.0mm_12dB_1500mm_NVAC_thru	48.5 dB	48.5 dB	48.5 dB	46 dB	35 dB

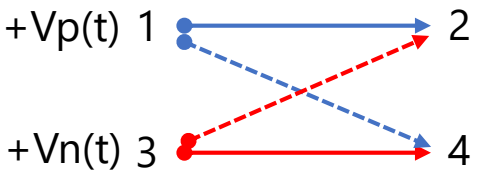
224G PAM vs SE-PAM4 signaling

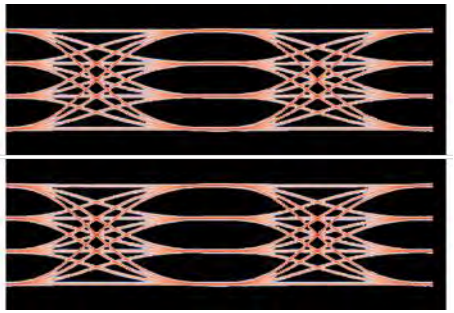
Differential signaling





Single ended signaling





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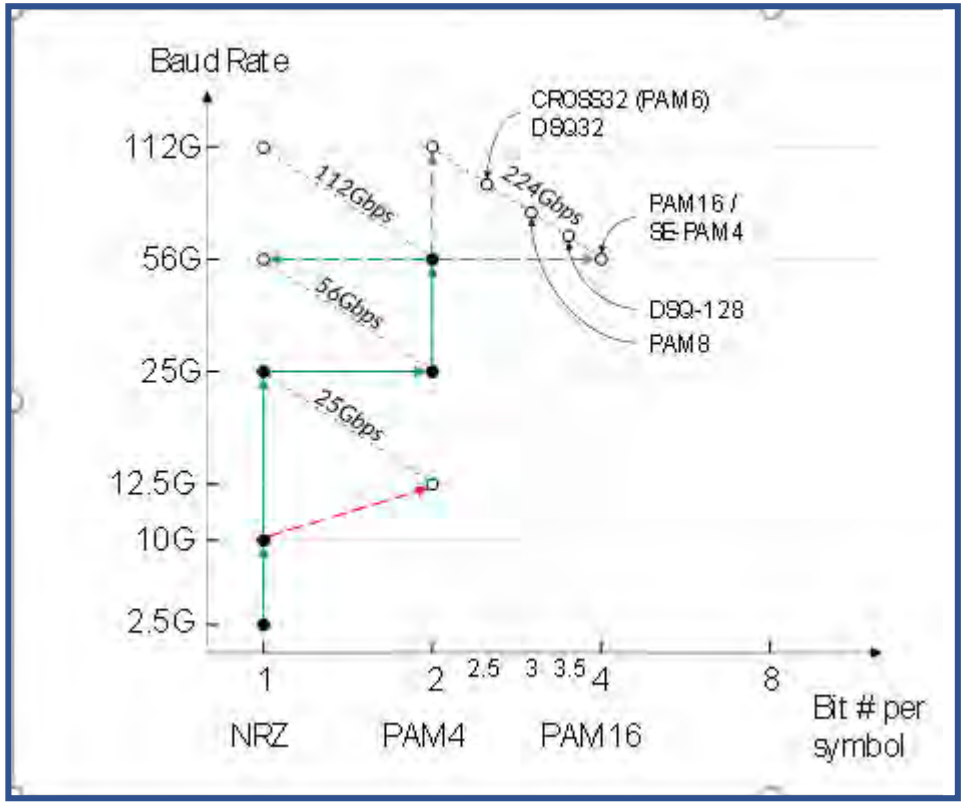
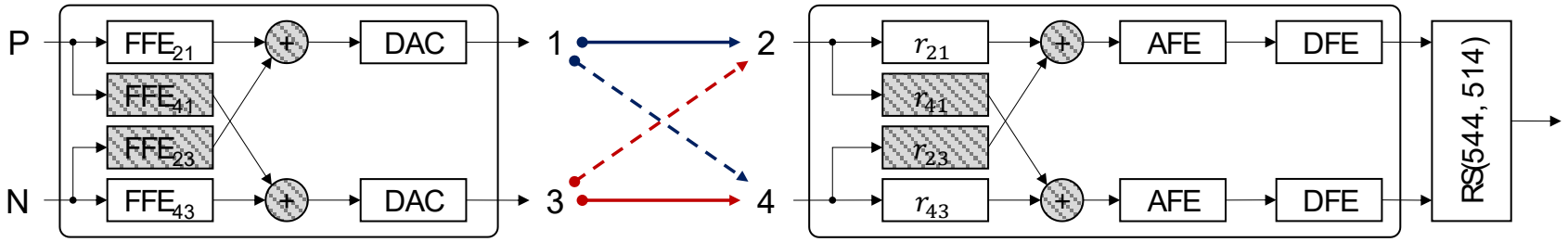


224G PAM signaling comparison

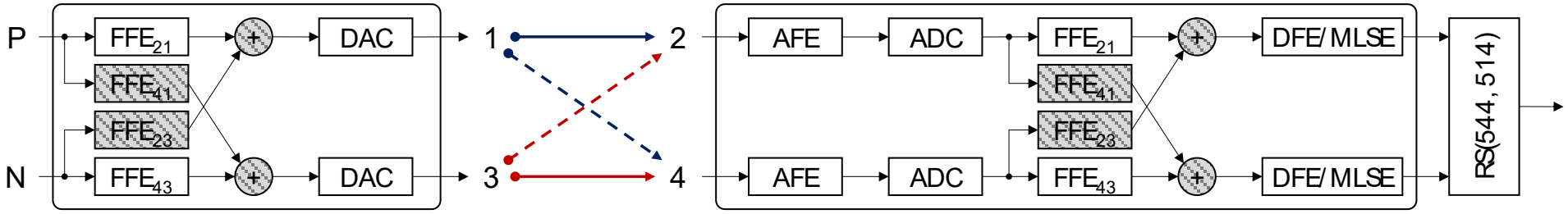
Modulation		Baud Rate (GHz)	Unit Interval (ps)	Nyquist Frequency (GHz)	** Bandwidth Requirements (GHz)	Bits per Symbol	Penalty @SER=1e-4 (Amplitude Normalized)	Penalty @SER=1e-4 (Power Normalized)
4-level	PAM4	**112**	**8.93**	56	**84**	2/1	0.00	0.00
	PR-PAM4	**112**	**8.93**	28*	42	2/1	6.14	3.13
	SE-PAM4	56	17.86	28	42	4/1	6.02	3.01
6-level	CROSS-32 (PAM6)	**89.6**	**11.16**	44.8	**67.2**	5/2	4.89	3.46
8-level	DSQ-32	**89.6**	**11.16**	44.8	**67.2**	5/2	4.81	3.68
	PAM8	**74.7**	13.39	37.3	56	3/1	**7.45**	**6.32**
16-level	DSQ-128	64	15.63	32	48	7/2	**11.46**	**9.78**
	PAM16	56	17.86	28	42	4/1	**14.10**	**12.43**

* Estimated as 1/4 of Baud Rate. ** frequency range with smooth IL or small ILD.

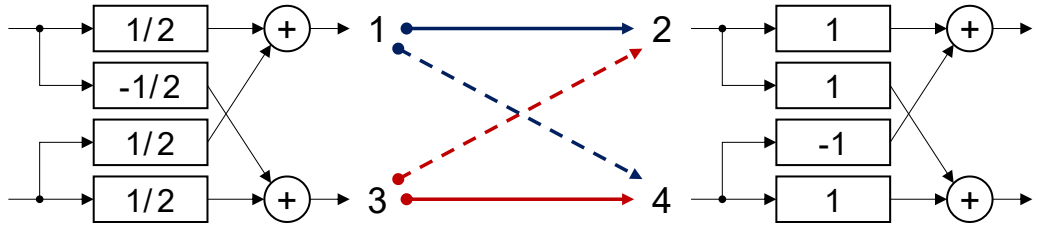
TRX architecture for single-ended signaling



Analog Mixed-Signal based receiver



ADC DSP based receiver



Common (Even) Mode $\begin{bmatrix}+1 & +1\\ -1 & +1\end{bmatrix}/2$

Differential (Odd) Mode

$\begin{bmatrix}s_{21} & s_{23}\\ s_{41} & s_{43}\end{bmatrix}$

$\begin{bmatrix}+1 & -1\\ +1 & +1\end{bmatrix}$

$$\begin{bmatrix}+1 & +1\\ -1 & +1\end{bmatrix}\cdot\begin{bmatrix}s_{21} & s_{23}\\ s_{41} & s_{43}\end{bmatrix}\cdot\frac{1}{2}\cdot\begin{bmatrix}+1 & -1\\ +1 & +1\end{bmatrix}$$

$$\frac{1}{2}\cdot\begin{bmatrix}+s_{21}+s_{23}+s_{41}+s_{43} & -s_{21}+s_{23}-s_{41}+s_{43}\\ -s_{21}-s_{23}+s_{41}+s_{43} & +s_{21}-s_{23}-s_{41}+s_{43}\end{bmatrix}$$

Common (Even) Mode

$$\approx\frac{1}{2}\cdot\begin{bmatrix}+s_{21}+s_{23}+s_{41}+s_{43} & 0\\ 0 & +s_{21}-s_{23}-s_{41}+s_{43}\end{bmatrix}$$

Differential (Odd) Mode

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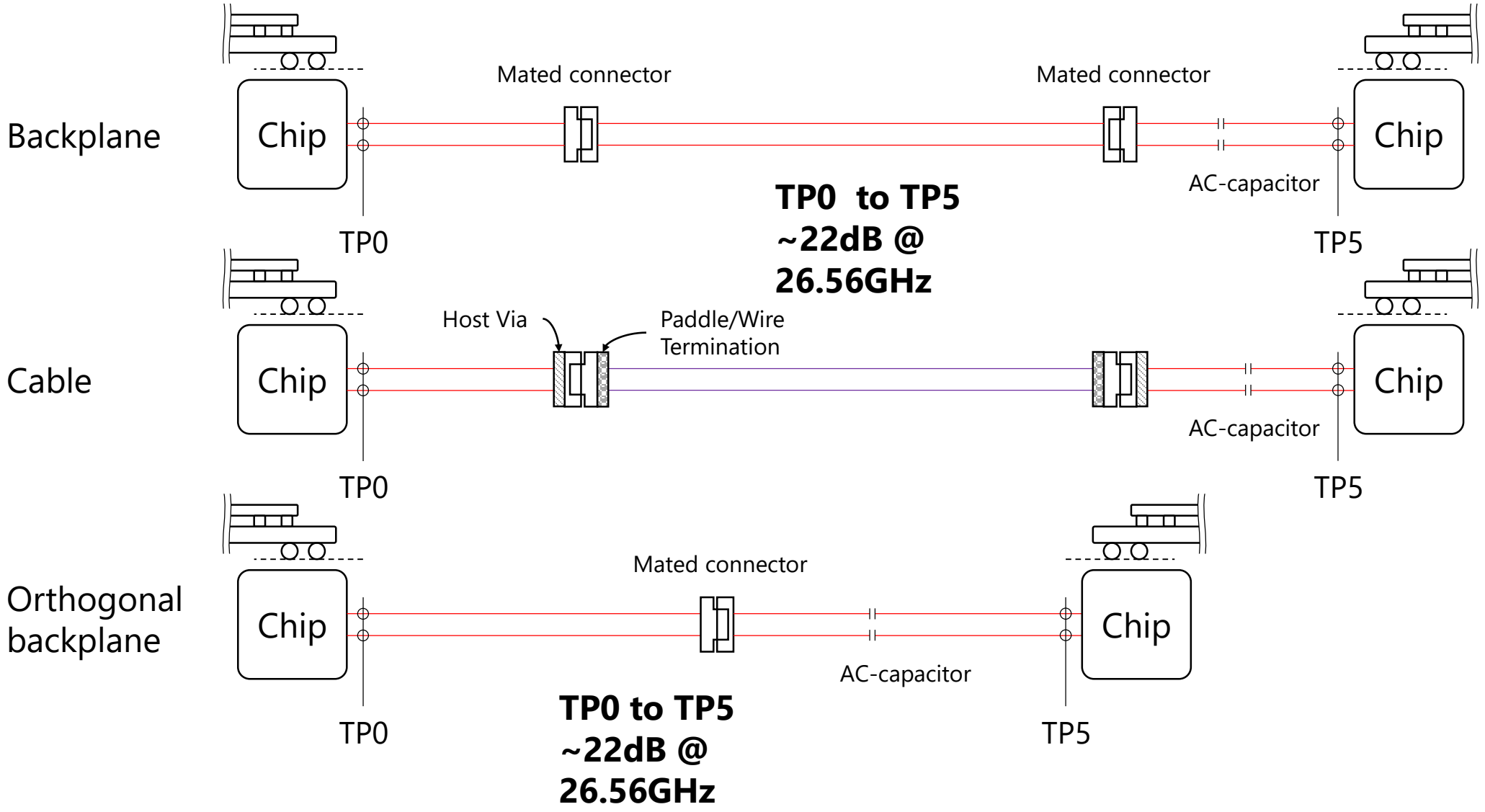
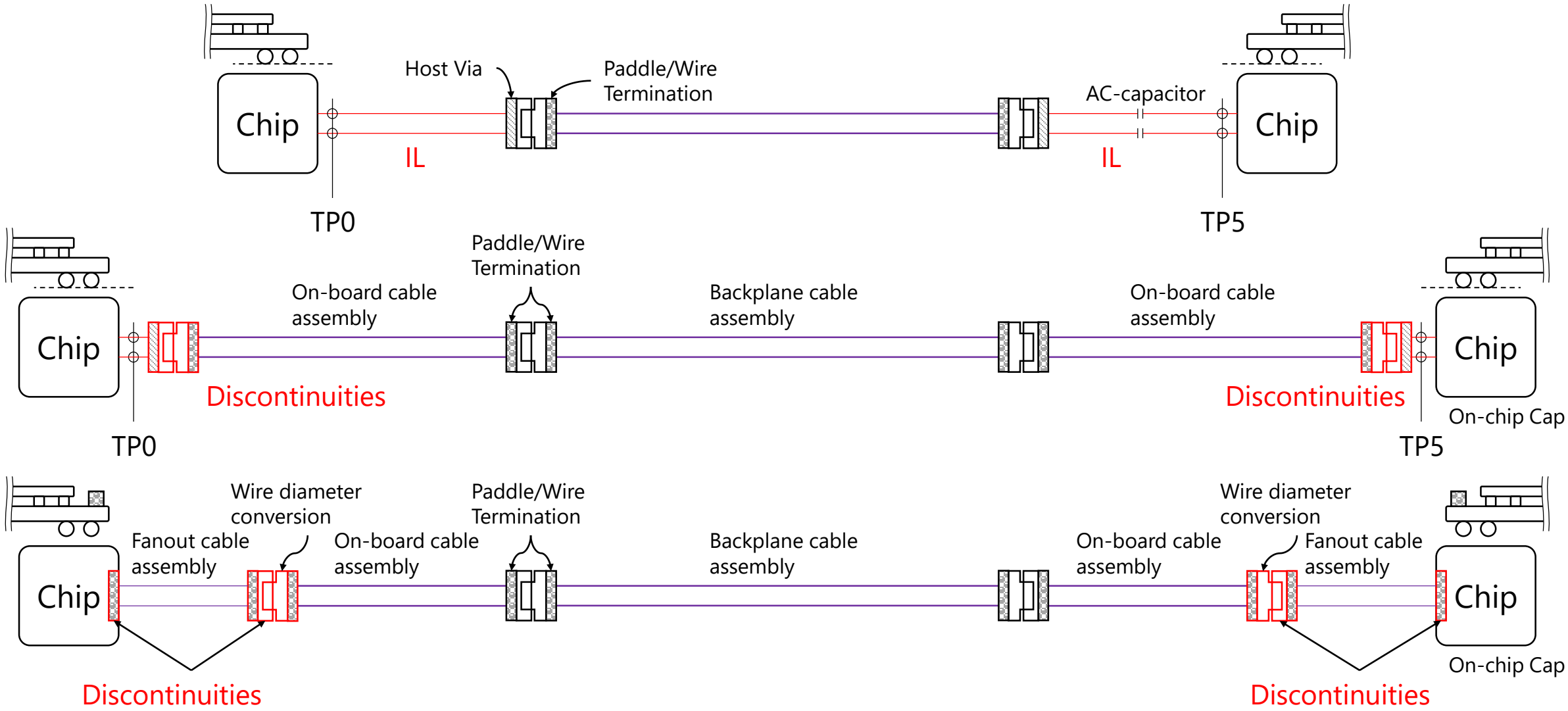
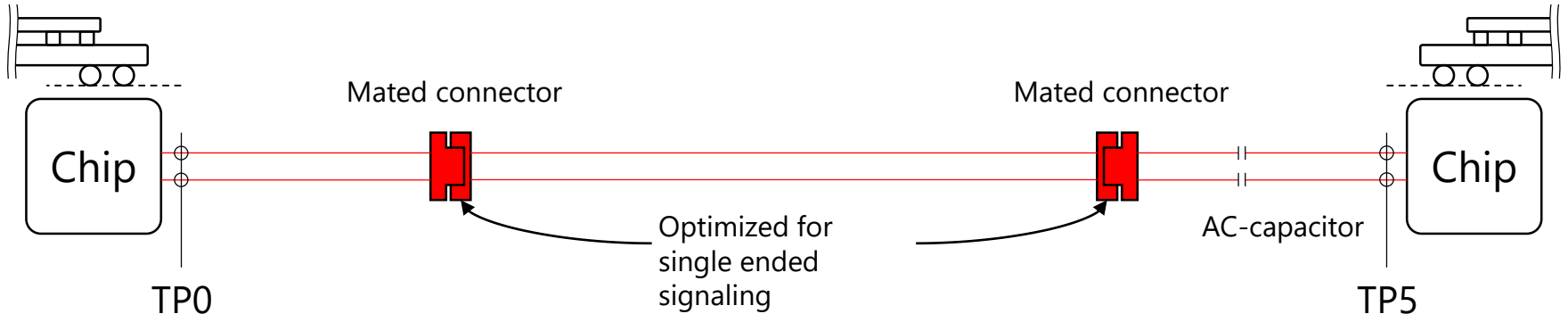
SE-PAM4 can support PCB solutions



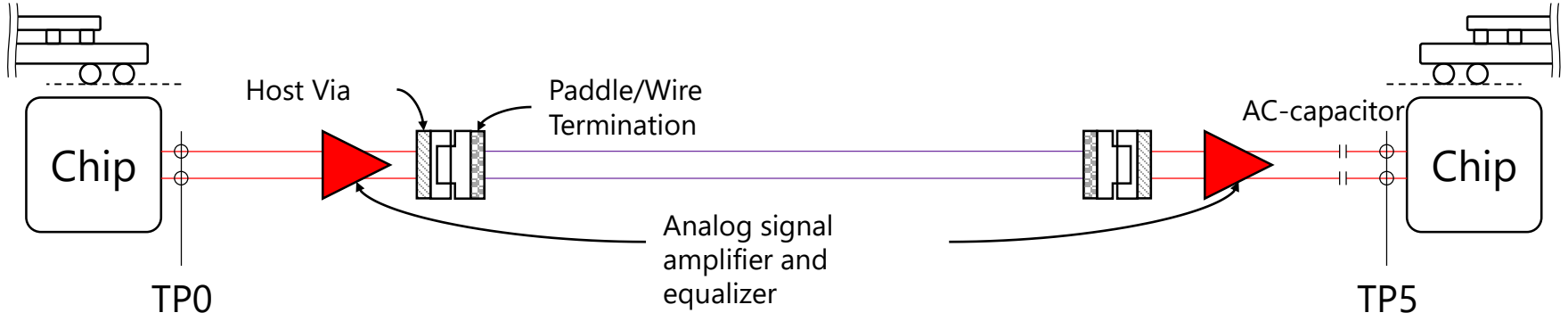
PAM4 relies more on cable solutions



Optimizations of SE-PAM4 and PAM4



SE-PAM4 requires optimization of passive channels for single-ended signaling.



PAM4 requires optimization of passive channels for 112GBd signal.
Analog signal amplifier and equalizer may be the key enabling technology.

Future work

- SE-PAM4 simulation with different channels
- Add bump to ball channel
- Find optimal equalization architecture
- Investigate specific penalties related with SE

Thanks