

# Ethernet 106Gbps Chip-to-Module (C2M) VSR Simulations and Updates

**For IEEE 802.3ck**

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**Mike Li, Hsinho Wu, Masashi Shimanouchi**

**Intel**

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# Objective and Motivation

New 106/112 Gbps VSR channels and packages became available in recent months

- Several channels have more insertion loss and crosstalk than previous studies VSR channels
- A recent VSR study was presented in OIF CEI
  - “106.25 Gb/s Per Lane VSR Studies: Typical TX FFE + RX CTLE/FFE vs. Longer TX FFE + RX CTLE” by Mike Li, Hsinho Wu, Masashi Shimanouchi, Adeo Ran, October 30, 2018
  - EH, EW, and VEC were worse than expected w/ existing TP1a spec. RX (simulated at BER =  $10^{-5}$ )

Channel	Description	Insertion Loss (dB) @ 26.56 GHz	Simulation Results @ BER = $1e-5$		
			Configure 1: Typical TX FFE + RX CTLE/FFE (4 post-tap)		
			EH (mV)	EW (UI)	VEC (dB)
CH1	Lim_100GEL_C2M 10dB	10.02 + TX Pkg	10.09	0.13	10.26
CH2	Lim_100GEL_C2M 12dB	12.11 + TX Pkg	9.55	0.12	10.69
CH3	Lim_100GEL_C2M 14dB	13.95 + TX Pkg	5.54	0.11	11.94
CH4	Tracy_100GEL_06_0118 RX6	14.58 + TX Pkg	8.21	0.14	10.01
CH5	Tracy_100GEL_06_0118 RX5	14.56 + TX Pkg	9.8	0.18	7.49
CH6	Tracy_100GEL_02_0118 TX6	16.09 + TX Pkg	6.35	0.12	10.67
CH7	Tracy_100GEL_02_0118 TX5	16.45 + TX Pkg	5.81	0.13	11.28

*Note: Simulation configurations are similar to this study but not identical.*

- Need to consider improving Ref EQ to accommodate these more difficult channels

# 106.25 Gb/s VSR TP1a Link Simulations

## Link & Device Configurations

### •Data Rate: 106.25 Gbps, PAM-4

### •Test Pattern:

- QPRBS13-CEI: TP1a simulations

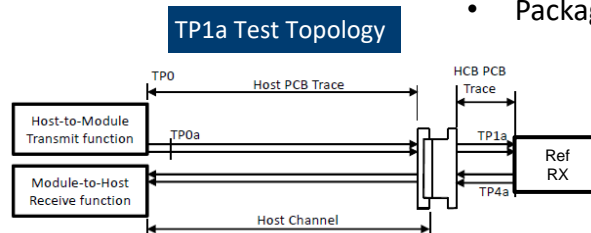
### •TX Die

- VOD: 750 mV-pp
- 20%-80% Rise/Fall Time: 6 ps
- TX FIR:
  - Configuration 1
    - » 4 taps, 2 pre-taps and 1 post-tap
  - Range: Pre-tap 1 and post-tap 1: 0 to -0.20  
other taps: +/- 0.1
  - Step size: 0.02

- RLM (level mismatch): 0.95
- TX termination: 55 ohms
- TX Capacitance: 100 fF (RL~8dB @ Die)
- Jitter:
  - BUJ: 0.04 UI-pp, DCD: 0.019 UI-pp, RJ: 0.01 UI-rms
- Noise:
  - RN: ~8.89mV-rms (TX SNR=32.5dB)
  - Common Mode Noise: 12mV-rms

### TX Package

- Package model (Typ., IL  $\approx$  3.03 dB @ 26.5625 GHz)
- Package crosstalk is < -60 dB (by design)



# 106.25 Gb/s VSR TP1a Link Simulations

## Link & Device Configuration (cont.)

### TP1a Reference RX

- Die Termination: 50 ohms
- Capacitance: 0 fF
- AFE Filter and CTLE
  - Parameter scaled from IEEE 802.3cd ref. CTLE

$$H_r(f) = \frac{1}{1 - 3.414214 \cdot \left(\frac{f}{f_r}\right)^2 + \left(\frac{f}{f_r}\right)^4 + j \cdot 2.613126 \cdot \left(\frac{f}{f_r} - \left(\frac{f}{f_r}\right)^3\right)}$$

$$H_{CTF}(f) = G \cdot \frac{\left(10^{\frac{g_{dc}}{20}} + j \frac{f}{f_{z2}}\right) \cdot \left(10^{\frac{g_{dc}}{20}} + j \frac{f}{f_{z1}}\right)}{\left(1 + j \frac{f}{f_{zp}}\right) \cdot \left(1 + j \frac{f}{f_{p1}}\right) \cdot \left(1 + j \frac{f}{f_{p2}}\right)}$$

- Baud: 53.125 Gsym/s
- $f_{p1} / f_{p2} / f_{z1} / f_{z2} / f_{zp} = \text{Baud} \div 2.5 / 1.0 / 2.5 / 80 / 80$
- $g_{DC}$ : 0 to -15 dB
- $g_{DC2}$ : 0 to -4 dB
- G: 1.0 (constant)

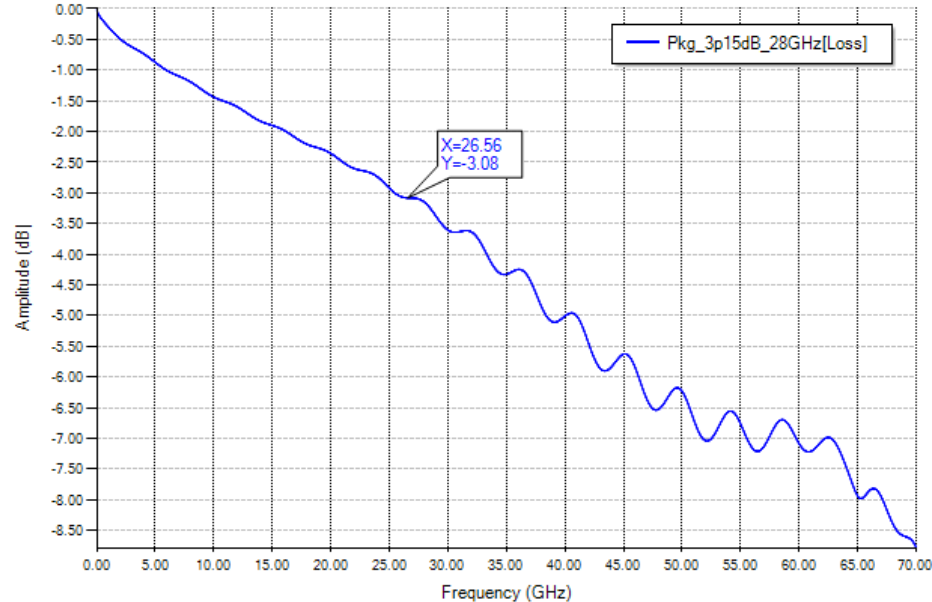
- FFE:
  - 8 Taps: 2 pre-taps, 5 post-taps
  - Range: First 2 post-cursors: +/-0.3 others: +/-0.1
  - Step size: 0.01
- CDR
  - Optimal phase based EH and PAM symbol SNDR
- Noise:
  - Input noise: 8.2e-9 V<sup>2</sup>/GHz
- Jitter: None

**RX Package: None**

**Equalization Optimization: SNDR maximization**

# 106.25 Gb/s TX Package Model

Channel Viewer: [0] FR: Sdd21



# Test Channel Summary

Channel	Description	Insertion Loss (dB) @ 26.56 GHz	ICN (mV-rms)*
CH1	Lim_100GEL_C2M 10dB + Tx Pkg	10.02 + TX Pkg	3.90
CH2	Lim_100GEL_C2M 12dB + Tx Pkg	12.11 + TX Pkg	3.48
CH3	Lim_100GEL_C2M 14dB + Tx Pkg	13.95 + TX Pkg	3.16
CH4	Lim_100GEL_C2M 16dB + Tx Pkg	15.89 + TX Pkg	2.88
CH5	Tracy_100GEL_06_0118 RX6 + Tx Pkg	14.58 + TX Pkg	0.92
CH6	Tracy_100GEL_06_0118 RX5 + Tx Pkg	14.56 + TX Pkg	1.09
CH7	Tracy_100GEL_02_0118 TX6 + Tx Pkg	16.09 + TX Pkg	0.99
CH8	Tracy_100GEL_02_0118 TX5 + Tx Pkg	16.45 + TX Pkg	1.00

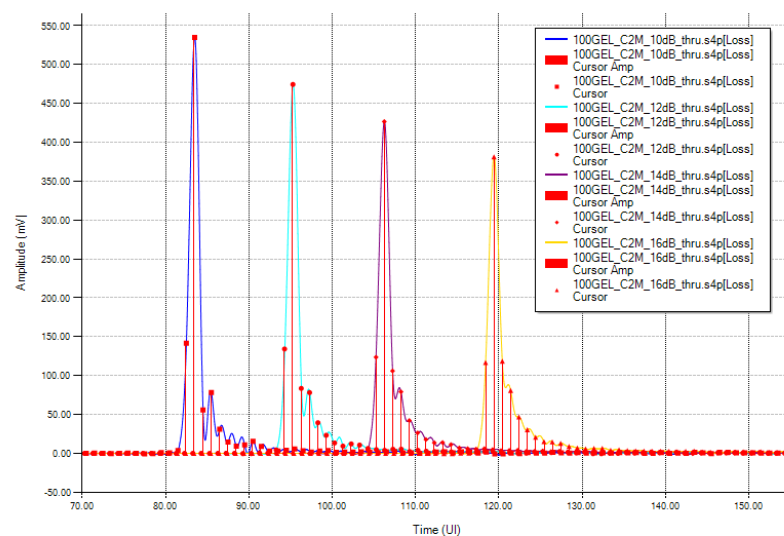
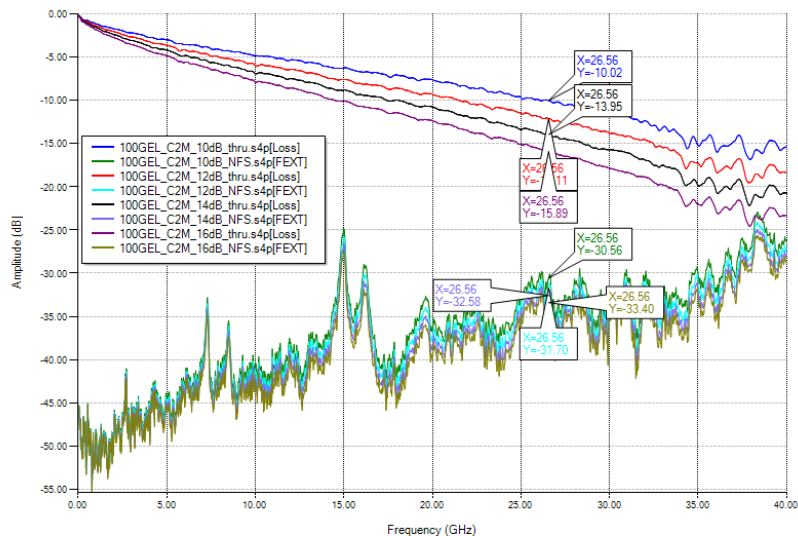
*\*: Channel files' fmax is less than fbaud. ICN results are informative.*

# Channel Characteristics

## CH1-CH4: Lim\_100GEL\_C2M 10/12/14/16dB

Channel Viewer: [23] FR: Sdd21

Channel Viewer: [25] SBR: Sdd21



Channel	IL (dB)	ILD (dB)	RL (dB)	ICN* (mV-rms, PAM4)
Lim_100GEL_C2M 10dB	10.02	+0.3/-2	9.88	3.90
Lim_100GEL_C2M 12dB	12.11	+0.3/-2	9.33	3.48
Lim_100GEL_C2M 14dB	13.95	+0.3/-2	9.44	3.16
Lim_100GEL_C2M 16dB	15.89	+0.3/-2	9.21	2.88

\*: Channel files'  $f_{max}$  is less than  $f_{baud}$ . ICN results are informative.

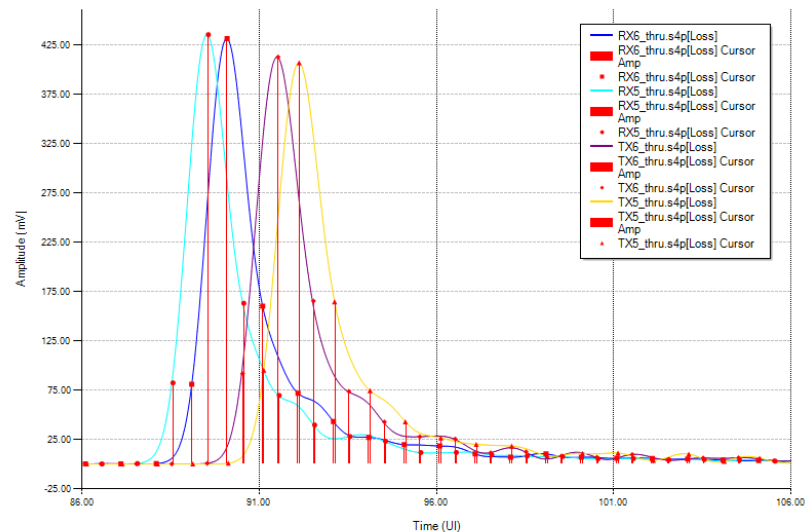
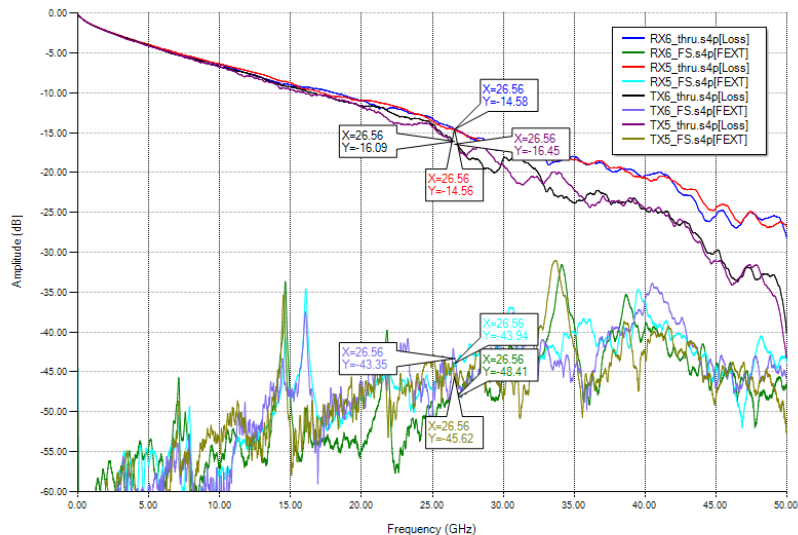


# Channel Characteristics

## CH5-CH8: Tracy\_100GEL\_C2M 10/12/14/16dB

Channel Viewer: [38] FR: Sdd21

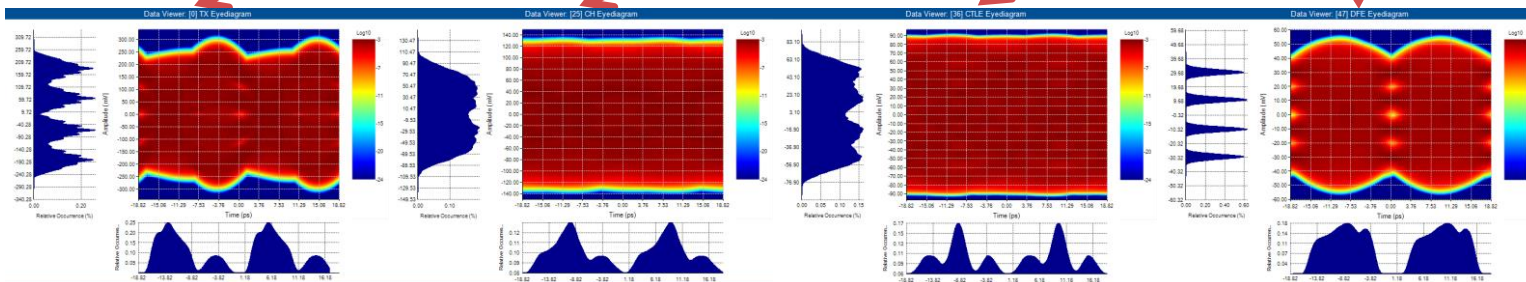
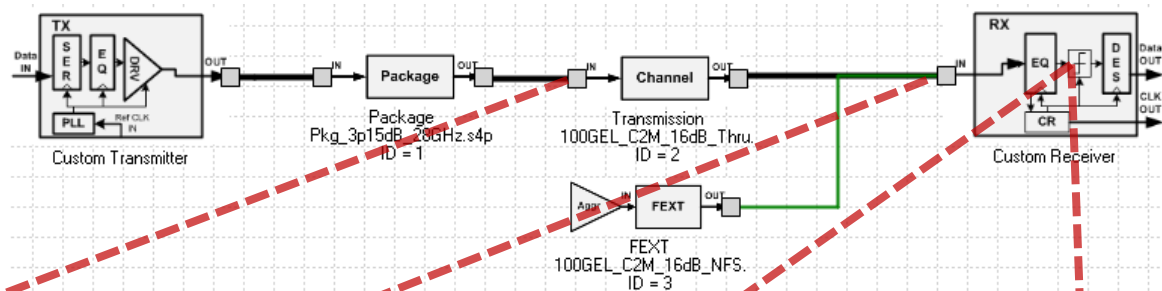
Channel Viewer: [40] SBR: Sdd21



Channel	IL (dB)	ILD (dB)	RL (dB)	ICN* (mV-rms, PAM4)
Tracy_100GEL_06_0118 RX6	14.58	+1.2/-2.3	16.25	0.92
Tracy_100GEL_06_0118 RX5	14.56	+1.2/-2.3	19.72	1.09
Tracy_100GEL_02_0118 TX6	16.09	+1.2/-2.3	24.18	0.99
Tracy_100GEL_02_0118 TX5	16.45	+1.2/-2.3	17.86	1.00

\*: Channel files'  $f_{max}$  is less than  $f_{baud}$ . ICN results are informative.

# CH4 Lim\_100GEL\_C2M\_16dB TP1a Simulation Results



TX Output

CH Output

RX CTLE output

RX FFE output  
EH=5.15mV EW=0.12 UI BER=1e-5  
EH=3.09mV EW=0.08UI BER=1e-6

BER	EW (UI)	EH (V)
$10^{-1}$	0.8010	0.0188
$10^{-2}$	0.3370	0.0136
$10^{-3}$	0.2290	0.0102
$10^{-4}$	0.1670	0.0073
$10^{-5}$	0.1200	0.0052
$10^{-6}$	0.0820	0.0031
$10^{-7}$	0.0498	0.0014
$10^{-8}$	0.0146	0.0000
$10^{-9}$	0.0000	0.0000
$10^{-10}$	0.0000	0.0000
$10^{-11}$	0.0000	0.0000
$10^{-12}$	0.0000	0.0000

# TP1a Simulation Results Summary

Channel	Description	Insertion Loss (dB) @ 26.56 GHz	Simulation Results					
			BER 10 <sup>-5</sup>			BER 10 <sup>-6</sup>		
			EH (mV)	EW (UI)	VEC (dB)	EH (mV)	EW (UI)	VEC (dB)
CH1	Lim_100GEL_C2M 10dB	10.02 + TX Pkg	10.58	0.14	7.82	7.77	0.11	9.51
CH2	Lim_100GEL_C2M 12dB	12.11 + TX Pkg	8.60	0.13	8.26	6.20	0.10	10.57
CH3	Lim_100GEL_C2M 14dB	13.95 + TX Pkg	5.80	0.13	9.10	3.51	0.08	11.50
CH4	Lim_100GEL_C2M 16dB	15.89 + TX Pkg	5.15	0.12	9.19	3.09	0.08	11.90
CH4s	Lim_100GEL_C2M 16dB w/ 1/3 XTLK	15.89 + TX Pkg	7.25	0.14	6.76	5.60	0.11	8.55
CH5	Tracy_100GEL_06_0118 RX6	14.58 + TX Pkg	10.30	0.17	6.64	8.41	0.13	8.00
CH6	Tracy_100GEL_06_0118 RX5	14.56 + TX Pkg	7.64	0.16	6.62	6.01	0.13	7.77
CH7	Tracy_100GEL_02_0118 TX6	16.09 +TX Pkg	6.51	0.13	7.59	4.75	0.09	9.40
CH8	Tracy_100GEL_02_0118 TX5	16.45 + TX Pkg	6.36	0.13	8.35	4.33	0.10	10.32

# 106.25 Gb/s VSR Whole Link Simulation

## Link & Device Configurations

- **Data Rate: 106.25 Gbps, PAM-4**

- **Test Pattern:**

- QPRBS31

- **TX Die**

- VOD: 750 mV-pp
- 20%-80% Rise/Fall Time: 6 ps
- TX FIR:
  - Configuration 1
    - » 4 taps, 2 pre-taps and 1 post-tap
  - Range: Pre-tap 1 and post-tap 1: 0 to -0.20  
other taps: +/- 0.1
  - Step size: 0.02

- RLM (level mismatch): 0.95
- TX termination: 55 ohms
- TX Capacitance: 100 fF (RL~8dB @ Die)
- Jitter:
  - BUJ: 0.04 UI-pp, DCD: 0.019 UI-pp, RJ: 0.01 UI-rms
- Noise:
  - RN: 1mV-rms
  - Common Mode Noise: 12mV-rms

### TX Package

- IL  $\approx$  3.03 dB @ 26.5625 GHz
- Package crosstalk is < -60 dB (by design)

# 106.25 Gb/s VSR Whole Link Simulation

## Link & Device Configuration (cont.)

### RX

- Die Termination: 45 ohms
- Capacitance: 100 fF
- AFE Filter and CTLE
  - Parameter scaled from IEEE 802.3cd ref. CTLE

$$H_r(f) = \frac{1}{1 - 3.414214 \cdot \left(\frac{f}{f_r}\right)^2 + \left(\frac{f}{f_r}\right)^4 + j \cdot 2.613126 \cdot \left(\frac{f}{f_r} - \left(\frac{f}{f_r}\right)^3\right)}$$

$$H_{CTF}(f) = G \cdot \frac{\left(10^{\frac{g_{dc}}{20}} + j \frac{f}{f_{z2}}\right) \left(10^{\frac{g_{dc}}{20}} + j \frac{f}{f_{z1}}\right)}{\left(1 + j \frac{f}{f_{zp}}\right) \left(1 + j \frac{f}{f_{p1}}\right) \left(1 + j \frac{f}{f_{p2}}\right)}$$

- Baud: 53.125 Gsym/s
- $f_{p1} / f_{p2} / f_{z1} / f_{z2} / f_{zp} = \text{Baud} \div 2.5 / 1.0 / 2.5 / 80 / 80$
- $g_{DC}$ : 0 to -16 dB
- $g_{DC2}$ : 0 to -4 dB
- DC Gain from CTLE+VGA : up to 25dB

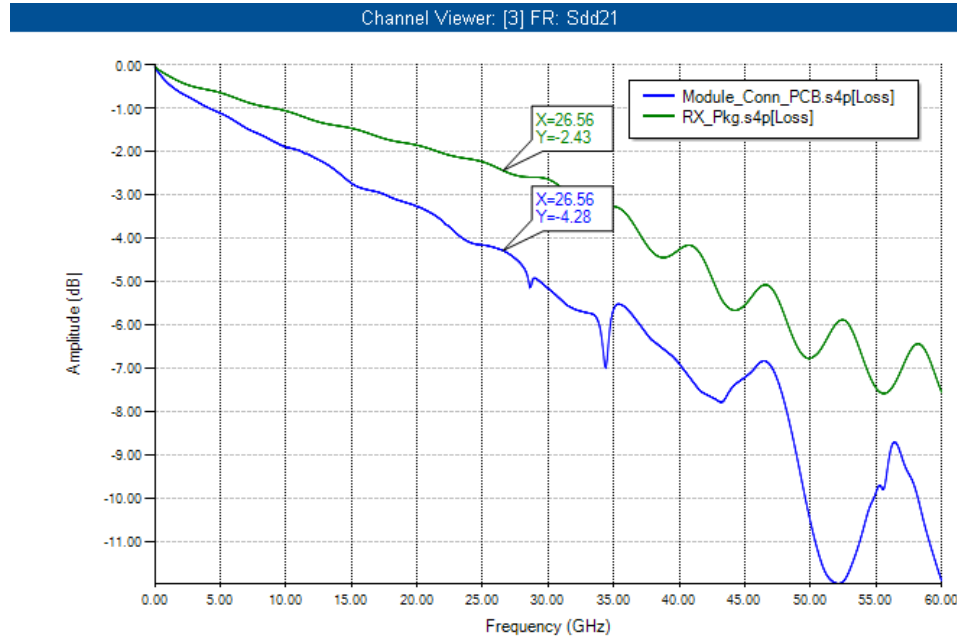
- FFE:
  - 8 Taps: 2 pre-taps, 5 post-taps
    - Range: First 2 post-cursors: +/-0.3 others: +/-0.1
  - Step size: 0.01
- CDR
  - Optimal phase based EH and PAM symbol SNDR
- Noise:
  - RN: 4 mV-rms
- Jitter:
  - DJ: 0.05 UI-pp
  - RJ: 0.01 UI-rms

### RX Package

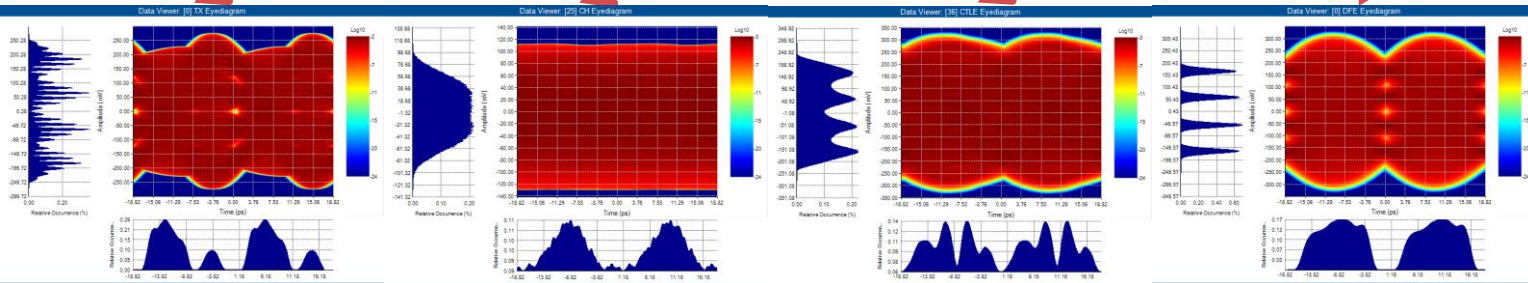
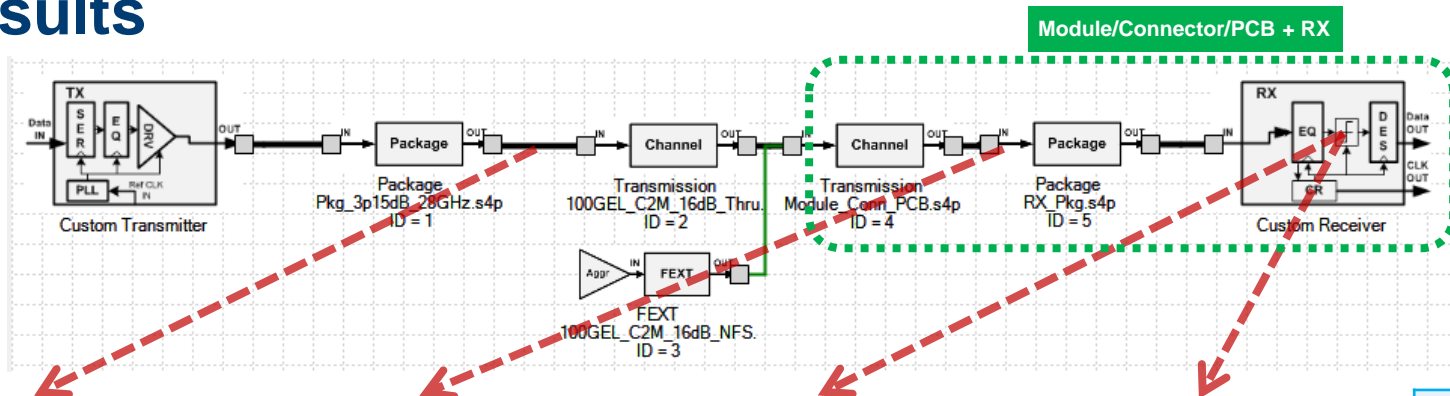
- IL  $\approx$  2.4 dB @ 26.5625 GHz
- Package crosstalk is < -60 dB (by design)

**Equalization Optimization: SNDR maximization**

# 106.25 Gb/s Module & RX Package Model



# CH4s Lim\_100GEL\_C2M\_16dB Whole Link Simulation Results



TX Output

CH Output

RX CTLE output

RX FFE output  
EH=26.60mV EW=0.09UI BER=1e-5  
EH=15.01mV EW=0.05UI BER=1e-6

BER	EW (UI)	EH (V)
$10^{-1}$	0.7940	0.1040
$10^{-2}$	0.3110	0.0750
$10^{-3}$	0.1990	0.0552
$10^{-4}$	0.1360	0.0402
$10^{-5}$	0.0898	0.0266
$10^{-6}$	0.0508	0.0150
$10^{-7}$	0.0117	0.0048
$10^{-8}$	0.0000	0.0000
$10^{-9}$	0.0000	0.0000
$10^{-10}$	0.0000	0.0000
$10^{-11}$	0.0000	0.0000
$10^{-12}$	0.0000	0.0000

# Summary and Conclusion

What takes to accommodate the new 16 dB C2M VSR channel (i.e., Lim\_100GEL\_C2M\_16dB)

- Enhance the receiver equalizer
  - Extend RX FFE to 8 taps: 2-pre-taps + 5 post-taps with step size 0.01
- Improve the channel
  - Reduce the channel crosstalk ICN from ~3.5 mV-rms to ~1 mV-rms