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The Impact of Channel Performance to 56G PAM4 Systems

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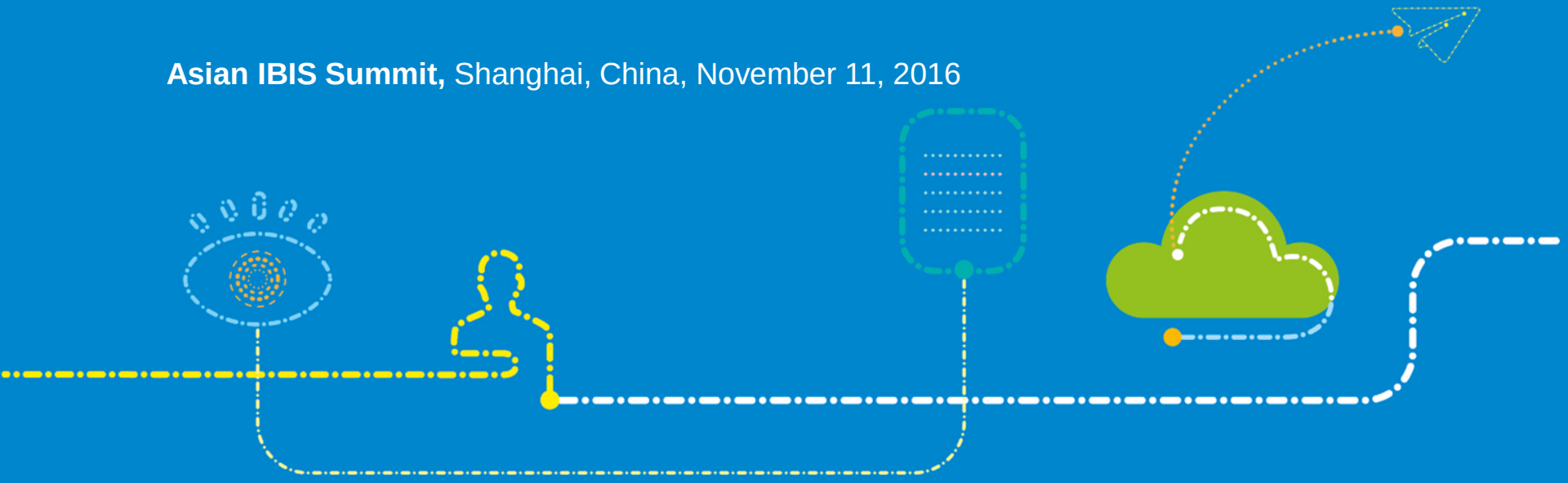
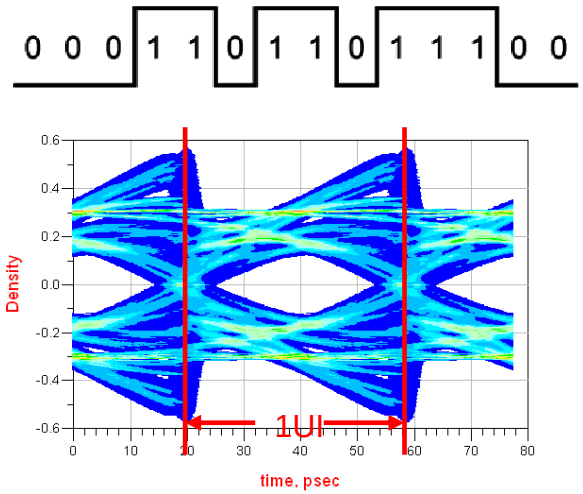
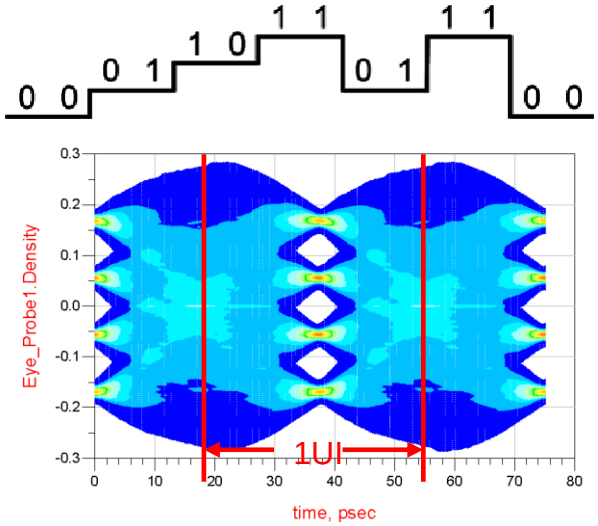


Agenda

- Introduction to PAM4 Modulation
- OIF CEI-56G-LR-PAM4 Specifics
- IBIS-AMI Model Simulation for 56G PAM4 Signals
- The Impact of Channel Characteristics to 56G PAM4 Systems
- Summary

Introduction to PAM4 Modulation





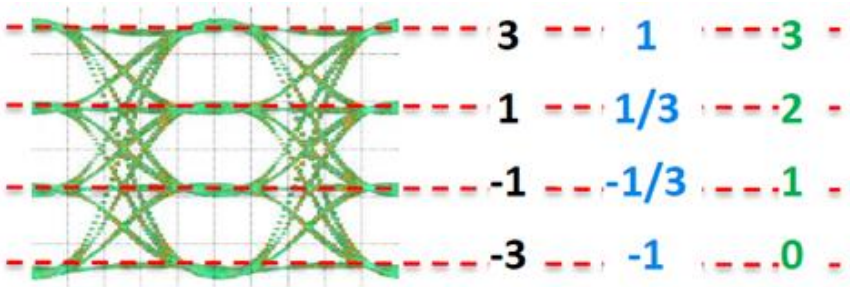
- NRZ(PAM2):
  - ✓ 2 amplitude levels
  - ✓ 1 bit = 1 symbol, one eye in each UI
  - ✓ 56Gbaud for 56 Gbps
    - -Nyquist frequency = 28GHz
  - ✓ BER=1E-15

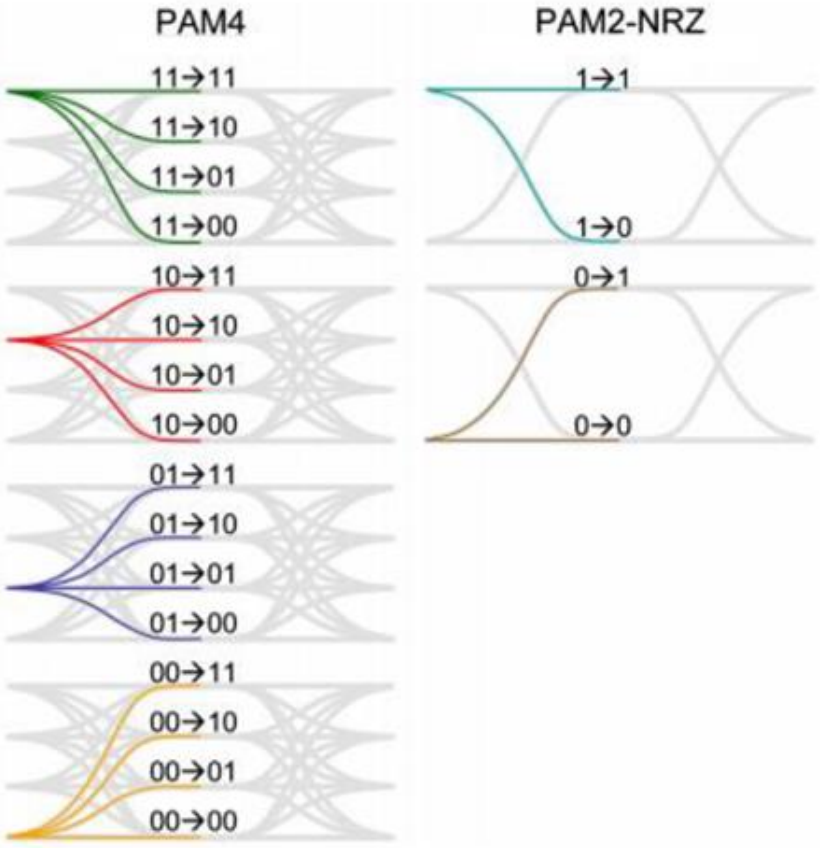
- PAM4:
  - ✓ 4 amplitude levels
  - ✓ 2 bit = 1 symbol, 3 eye in each UI
  - ✓ 28Gbaud for 56 Gbps
    - -Nyquist frequency = 14GHz
  - ✓ BER=1E-15

Introduction to PAM4 Modulation

- Transition Density(TD)
  - 16 traces between 2 symbols
  - Average TD=75%
  - For PAM2,TD is 50%

- Three common amplitude level naming patterns





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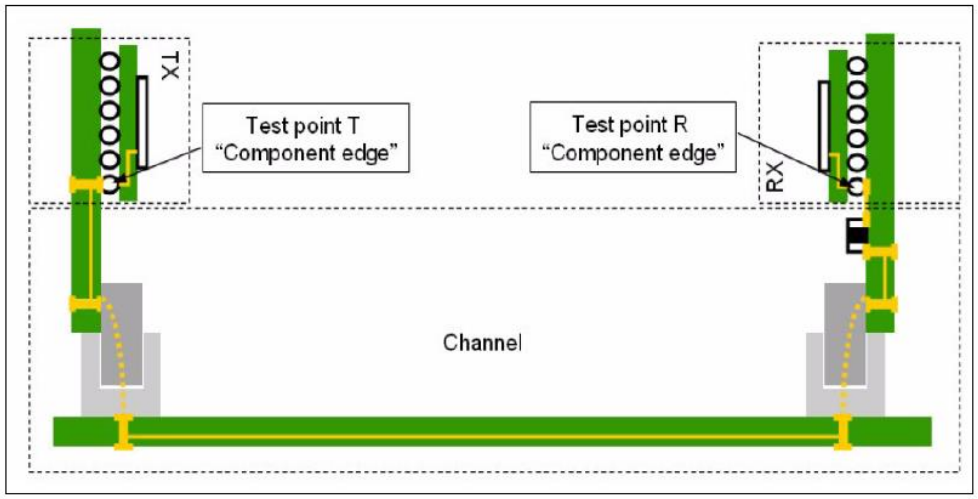
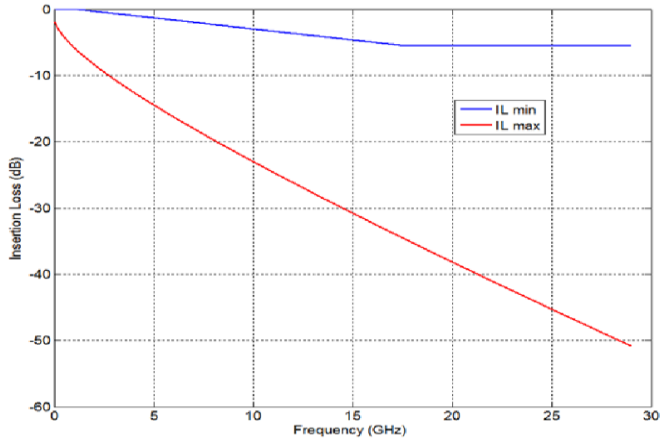
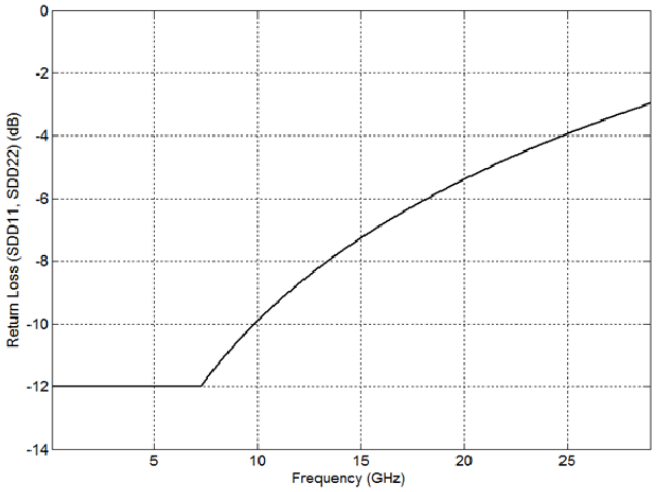
OIF CEI-56G-LR-PAM4 Specifics

- OIF-CEI-4.0（drafting）
- This paper based on OIF CEI-56G-LR-PAM4 (contribute number：OIF2014.380.03)







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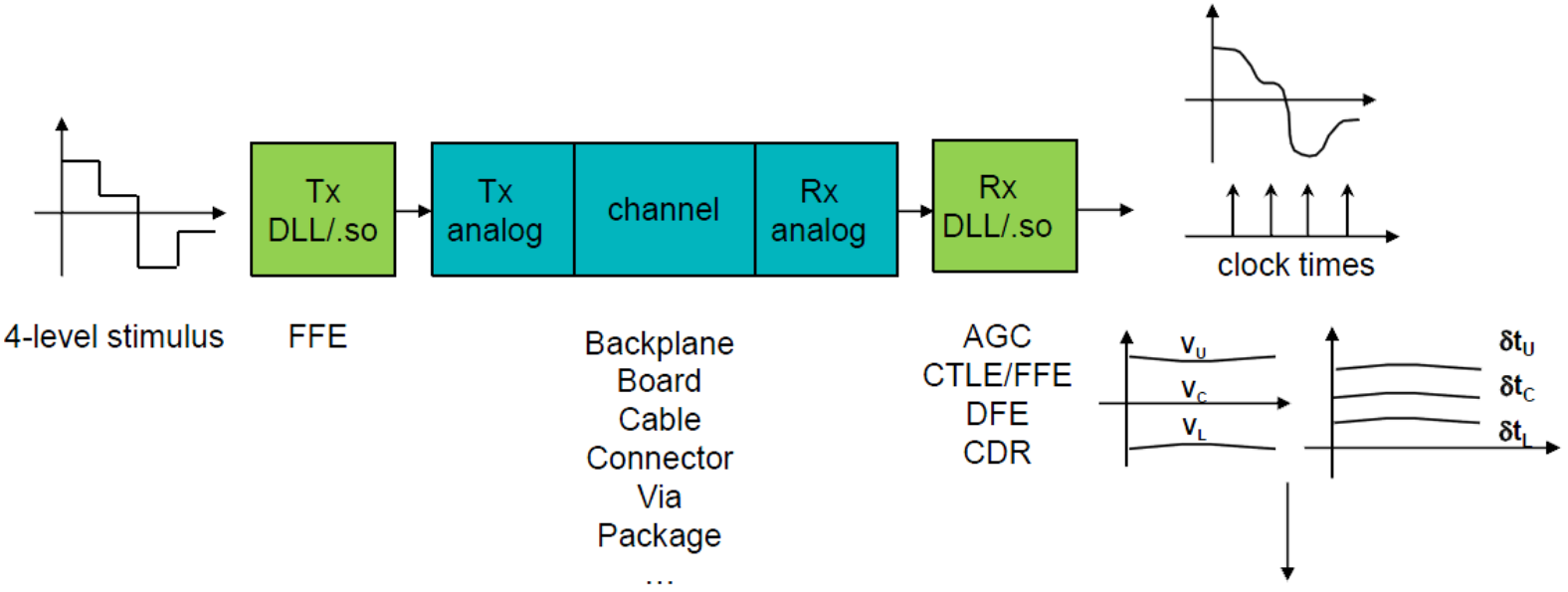
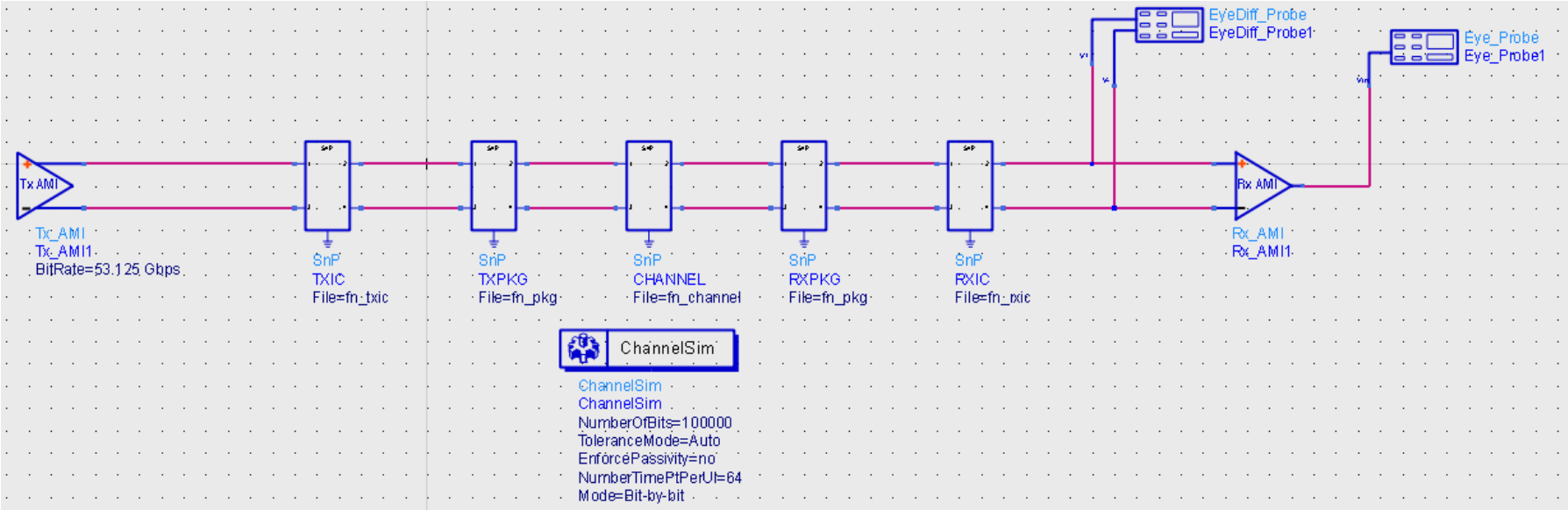
IBIS-AMI Model Simulation for 56G PAM4 Signals

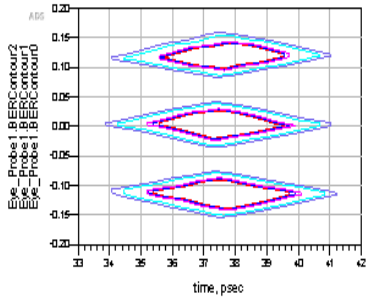
- IBIS-AMI model used for NRZ simulation is widely applied today
- IBIS-AMI model used for PAM4 simulation is still new
- SI engineers are facing new challenges

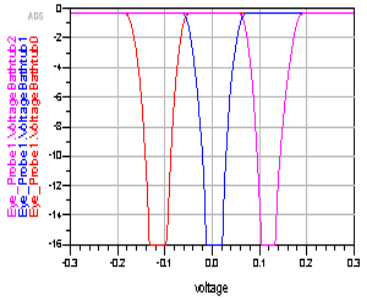


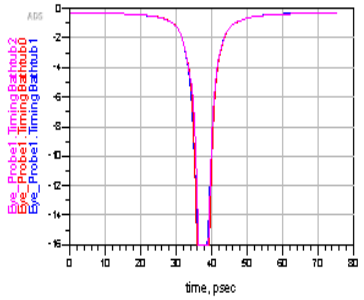
V_U, V_C, V_L: upper, center and lower eye thresholds
δt_U, δt_C, δt_L: upper, center and lower eye sample time offsets

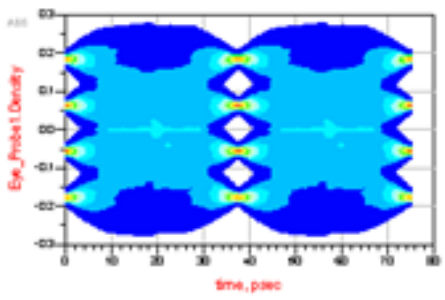
IBIS-AMI Model Simulation for 56G PAM4 Signals











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1.000E-12	0.047	0.046	0.041	4.518E-12	3.953E-12	4.141E-12
1.000E-11	0.050	0.049	0.044	4.894E-12	4.141E-12	4.518E-12
1.000E-10	0.054	0.053	0.049	5.082E-12	4.329E-12	4.894E-12
1.000E-8	0.071	0.071	0.068	6.588E-12	6.400E-12	6.588E-12
1.000E-5	0.077	0.076	0.075	7.341E-12	7.153E-12	7.341E-12

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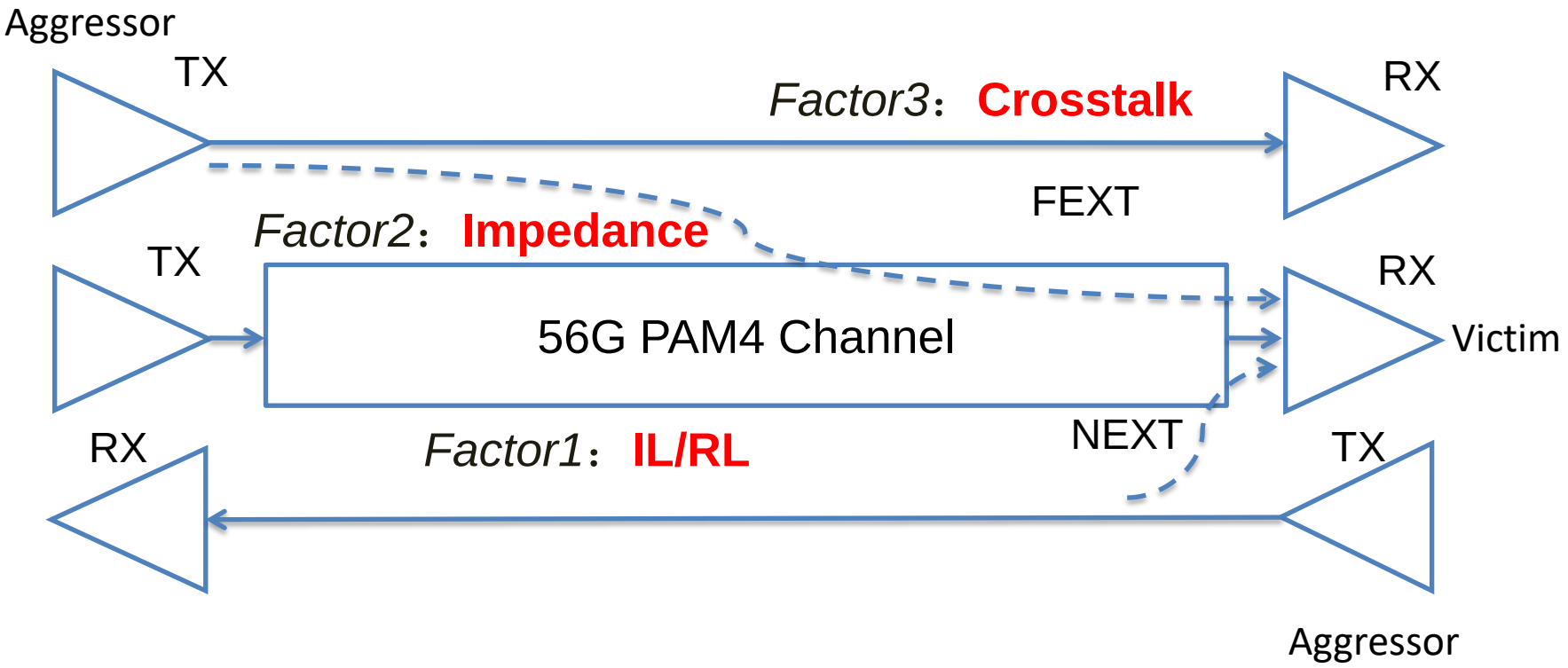
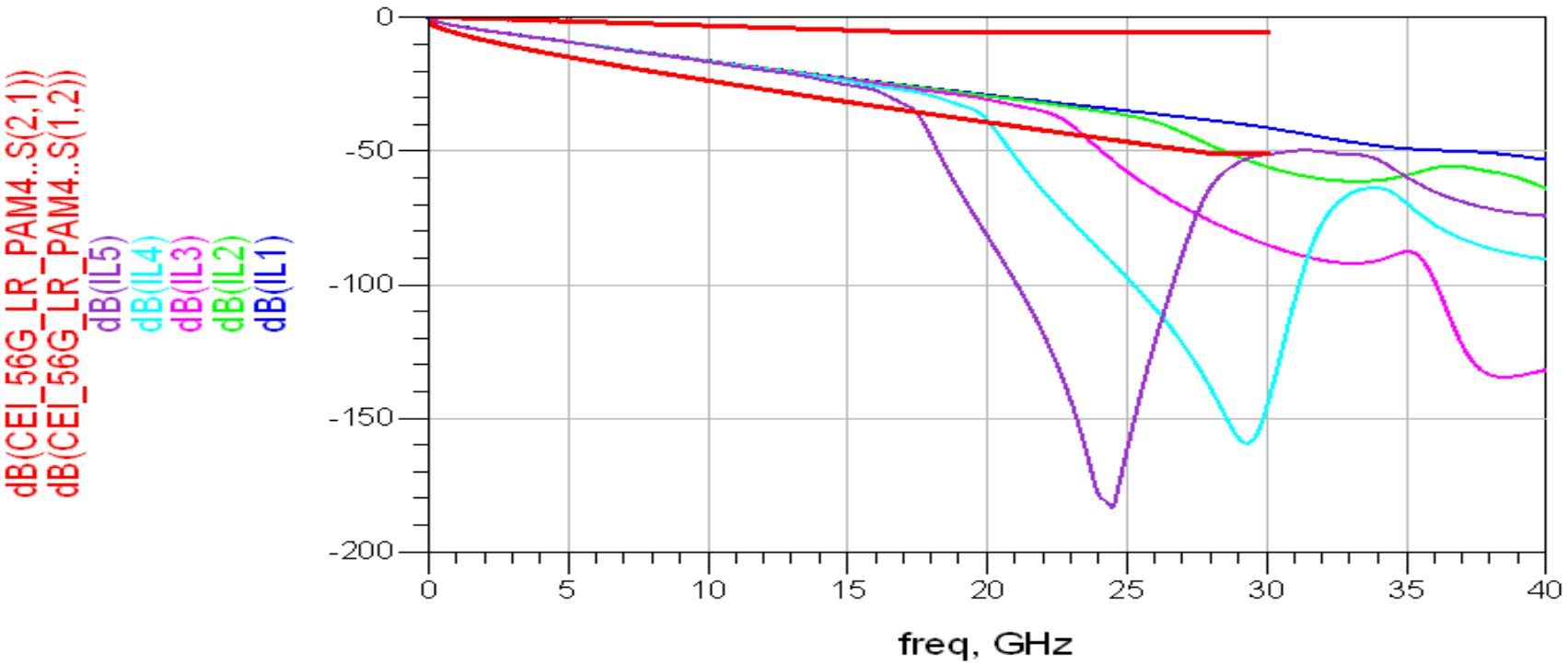
The Impact of Channel Characteristics

- 56G-PAM4 systems performance depends on the channel characteristics including IL/RL, crosstalk, impedance, etc.



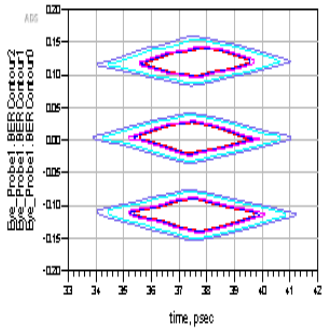
The Impact of Resonance Frequency of Insertion Loss

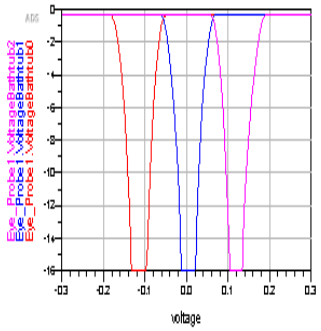


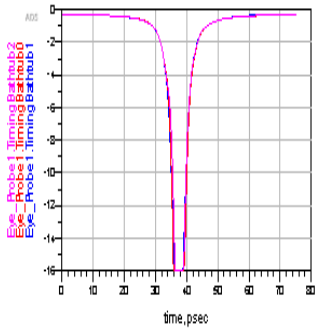
	case1	case2	case3	case4	case5
Resonance f/GHz	98	49	32	29	24

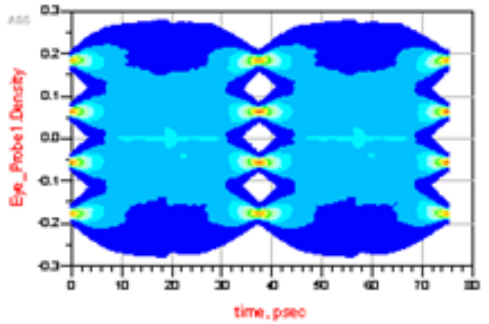
Case Simulations for Different Resonance Frequencies

- Case1



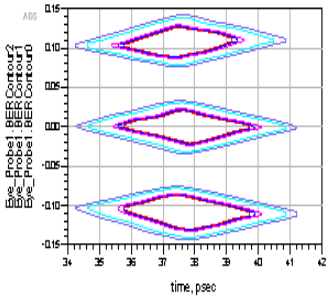


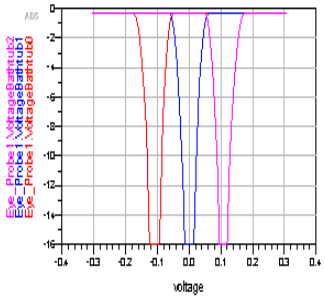


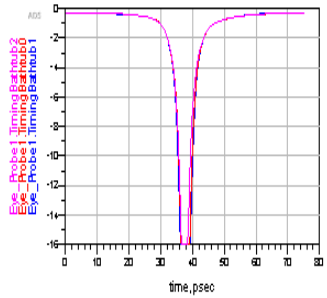


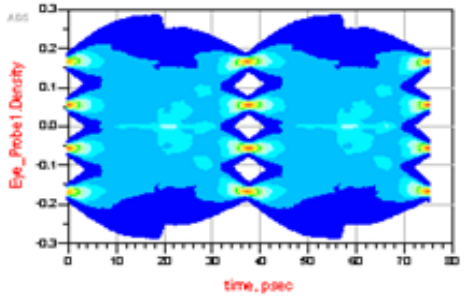
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.047	0.046	0.041	4.518E-12	3.953E-12	4.141E-12
1.000E-11	0.050	0.049	0.044	4.894E-12	4.141E-12	4.518E-12
1.000E-10	0.054	0.053	0.049	5.082E-12	4.329E-12	4.894E-12
1.000E-9	0.071	0.071	0.068	6.588E-12	6.400E-12	6.588E-12
1.000E-8	0.077	0.076	0.075	7.341E-12	7.153E-12	7.341E-12

- Case2









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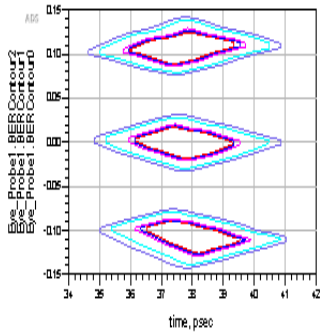
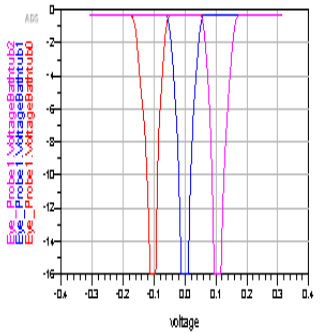
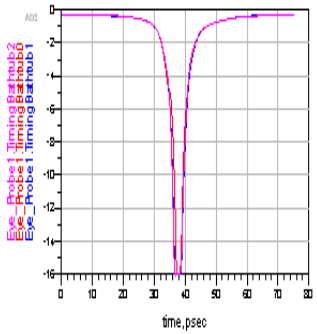
1.000E-12	0.041	0.040	0.037	4.141E-12	3.576E-12	4.141E-12
1.000E-11	0.043	0.043	0.040	4.329E-12	3.953E-12	4.518E-12
1.000E-10	0.046	0.046	0.043	4.706E-12	4.329E-12	4.894E-12
1.000E-9	0.062	0.062	0.060	6.400E-12	6.024E-12	6.400E-12
1.000E-8	0.068	0.067	0.066	7.153E-12	6.776E-12	7.153E-12

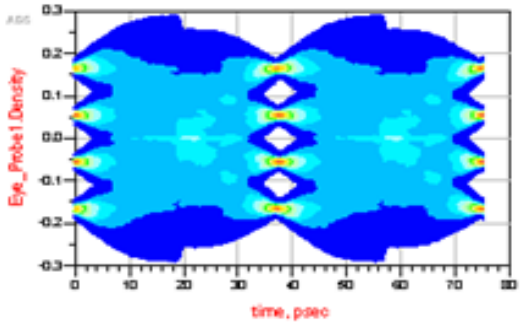
Case Simulations for Different Resonance Frequencies

- Case3









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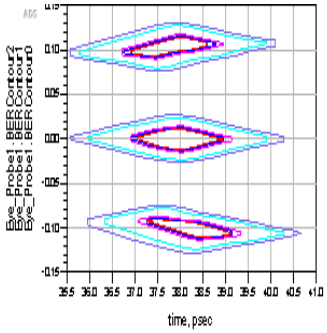
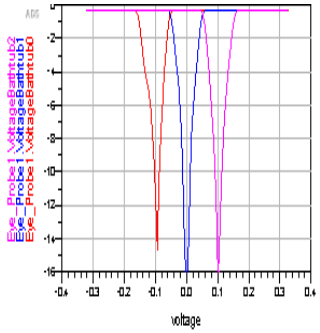
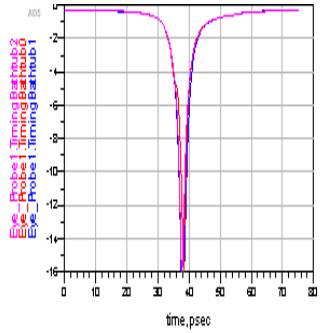
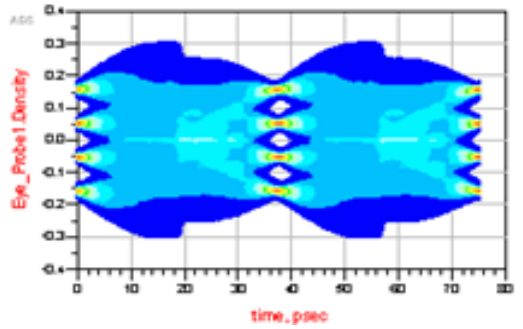
1.000E-12	0.030	0.032	0.033	3.200E-12	3.576E-12	3.388E-12
1.000E-11	0.034	0.036	0.036	3.576E-12	3.765E-12	3.388E-12
1.000E-10	0.038	0.039	0.040	3.953E-12	4.141E-12	3.765E-12
1.000E-8	0.056	0.058	0.059	5.647E-12	5.647E-12	5.459E-12
1.000E-5	0.065	0.065	0.065	6.212E-12	6.400E-12	6.212E-12

- Case4









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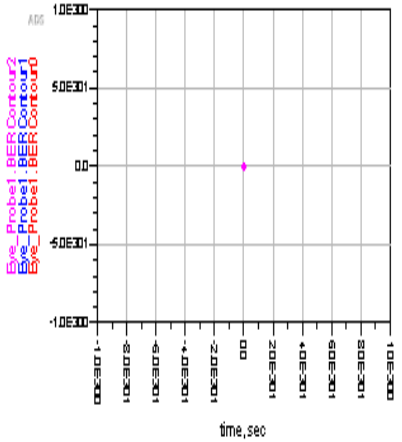
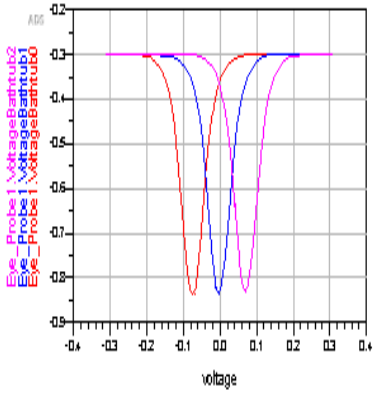
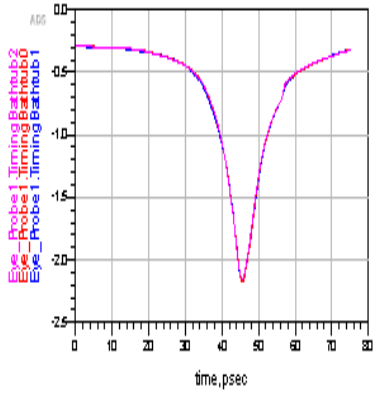
1.000E-12	0.016	0.023	0.016	2.071E-12	1.882E-12	2.071E-12
1.000E-11	0.019	0.027	0.018	2.071E-12	2.259E-12	2.259E-12
1.000E-10	0.022	0.030	0.022	2.447E-12	2.447E-12	2.447E-12
1.000E-8	0.041	0.047	0.045	4.141E-12	4.329E-12	4.141E-12
1.000E-5	0.060	0.063	0.063	4.894E-12	4.706E-12	4.894E-12

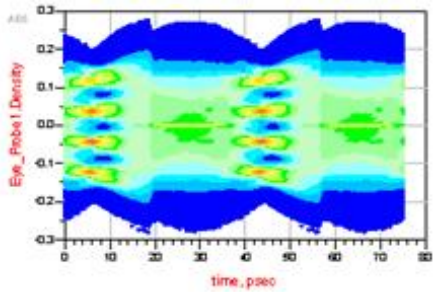
Case Simulations for Different Resonance Frequencies

- Case5





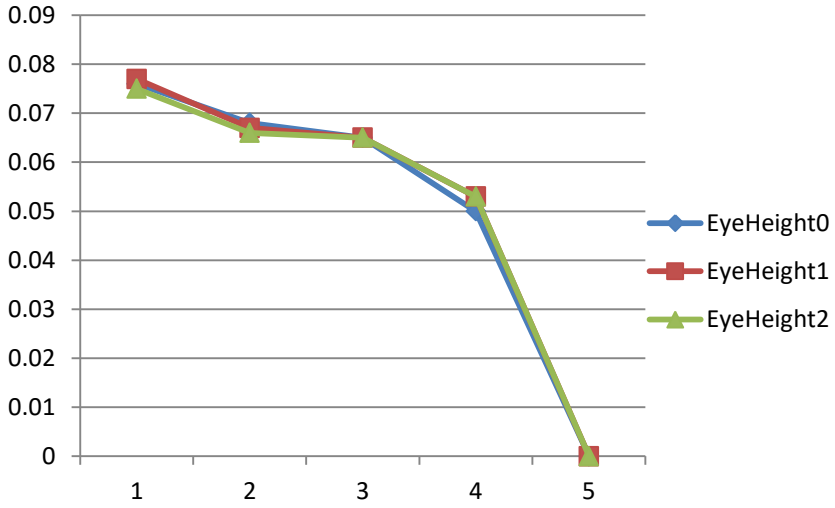


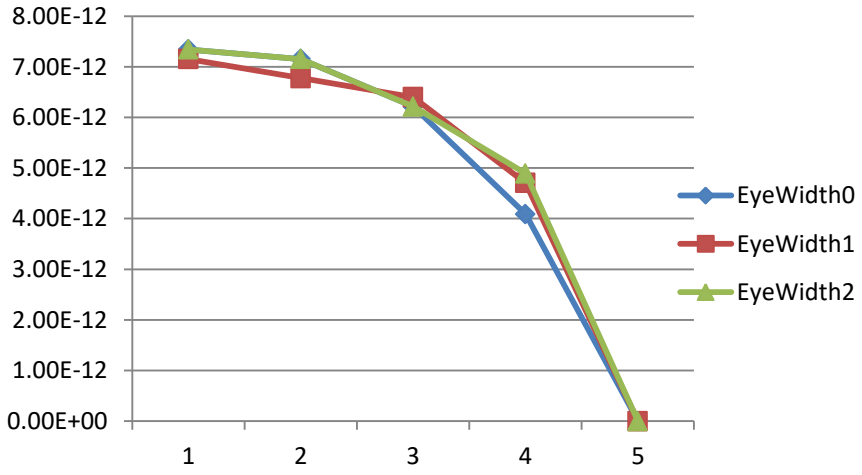


BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	-0.617	-0.607	-0.617	0.000	0.000	0.000
1.000E-11	-0.617	-0.607	-0.617	0.000	0.000	0.000
1.000E-10	-0.617	-0.607	-0.617	0.000	0.000	0.000
1.000E-9	-0.617	-0.607	-0.617	0.000	0.000	0.000
1.000E-8	-0.617	-0.607	-0.617	0.000	0.000	0.000

Factor Analysis for Resonance Frequency of Insertion Loss

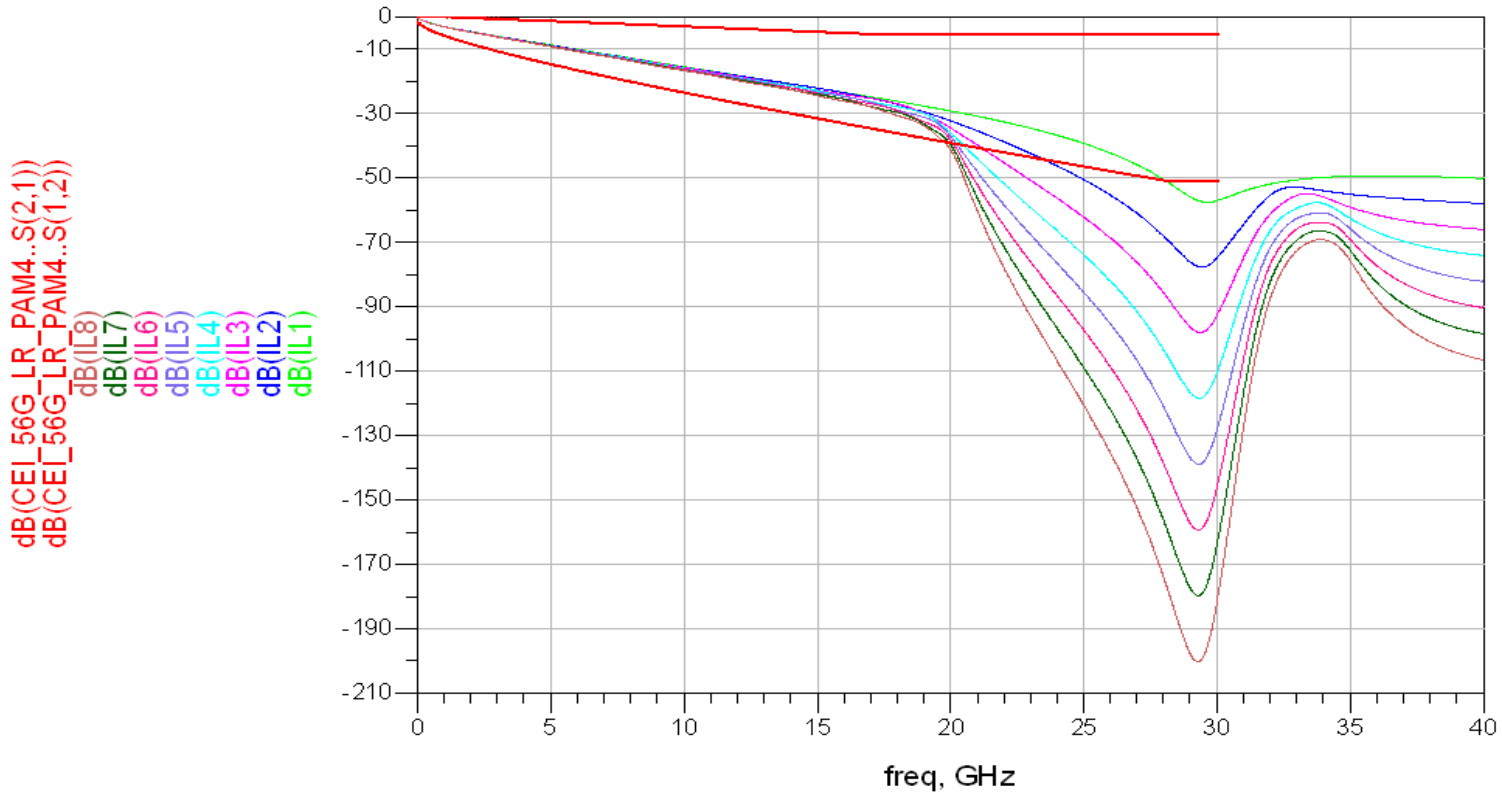
- The resonance frequency affect all the three EyeHeights and EyeWidths
  - -The more close to the Nyquist frequency , the eye getting worse until completely closed
- The resonance frequency should be more than 29GHz in our cases





@BER=1E-5

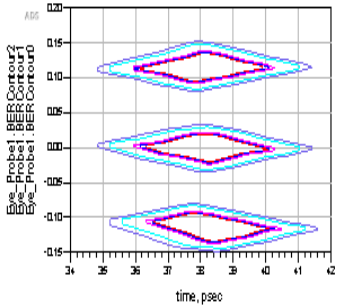
The Impact of Resonance Depth of Insertion Loss

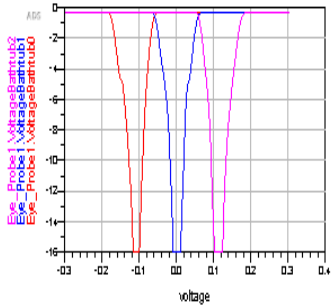


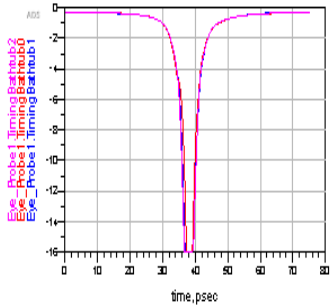
@29.4GHz/dB	case1	case2	case3	case4	case5	case6	case7	case8
Resonance depth	57	78	98	118	139	159	180	200

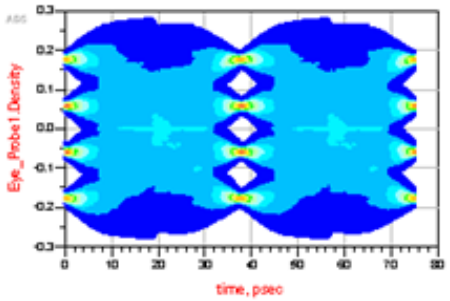
Case Simulations for Different Resonance Depths

- Case1



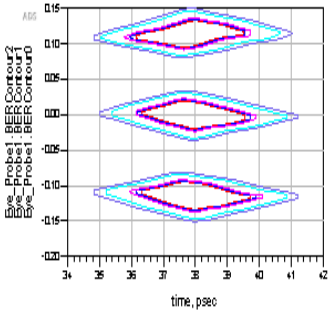


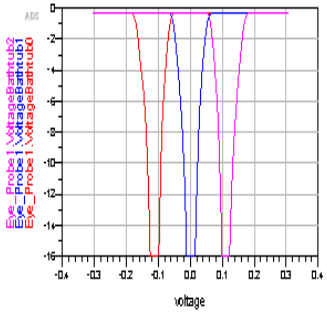


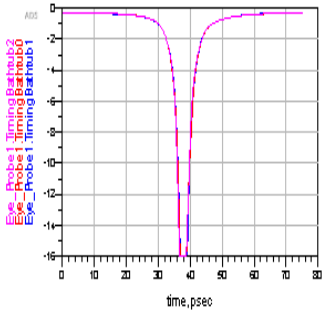


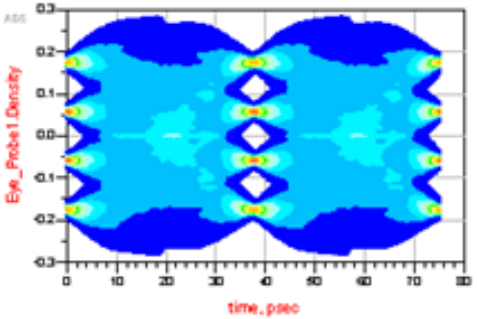
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.036	0.039	0.039	3.765E-12	3.953E-12	3.953E-12
1.000E-11	0.039	0.042	0.042	3.953E-12	4.329E-12	4.141E-12
1.000E-10	0.042	0.046	0.047	4.329E-12	4.518E-12	4.518E-12
1.000E-9	0.059	0.061	0.065	5.835E-12	6.024E-12	6.024E-12
1.000E-8	0.065	0.069	0.071	6.588E-12	6.776E-12	6.776E-12

- Case2





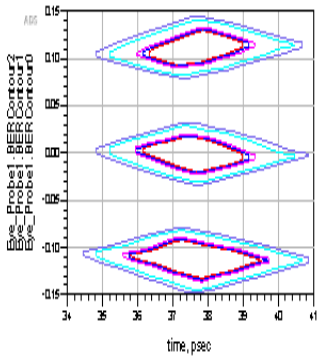


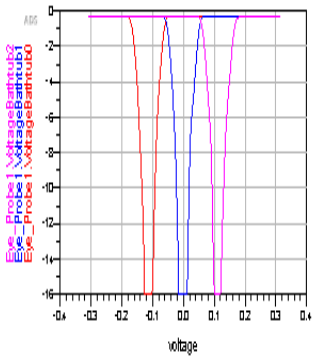


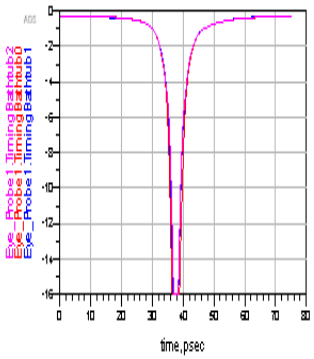
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.038	0.038	0.036	3.576E-12	3.576E-12	3.388E-12
1.000E-11	0.040	0.041	0.040	3.953E-12	3.765E-12	3.765E-12
1.000E-10	0.043	0.044	0.043	4.329E-12	4.141E-12	3.953E-12
1.000E-9	0.060	0.063	0.061	5.835E-12	5.835E-12	5.647E-12
1.000E-8	0.068	0.069	0.069	6.588E-12	6.400E-12	6.400E-12

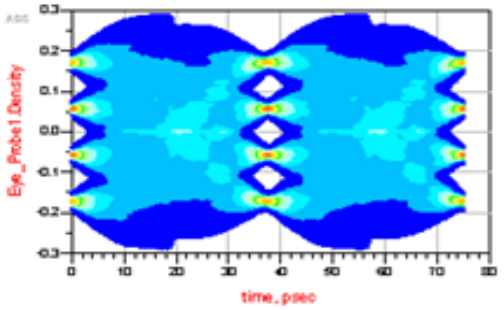
Case Simulations for Different Resonance Depths

- Case3



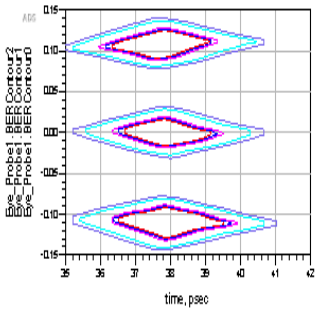


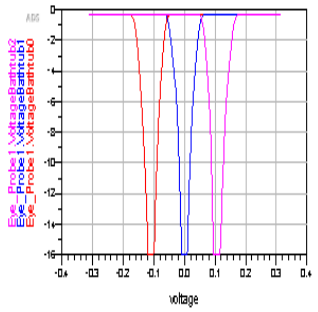


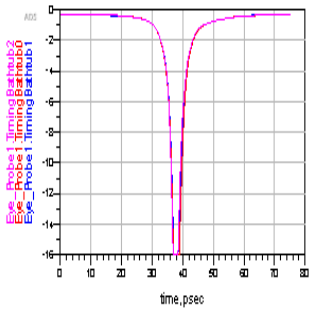


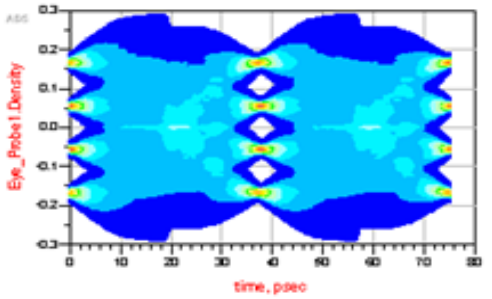
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.035	0.036	0.033	3.963E-12	2.824E-12	3.012E-12
1.000E-11	0.038	0.038	0.036	4.141E-12	3.200E-12	3.388E-12
1.000E-10	0.042	0.041	0.039	4.329E-12	3.576E-12	3.576E-12
1.000E-9	0.060	0.058	0.056	6.024E-12	5.469E-12	5.469E-12
1.000E-8	0.067	0.066	0.064	6.588E-12	6.024E-12	6.212E-12

- Case4





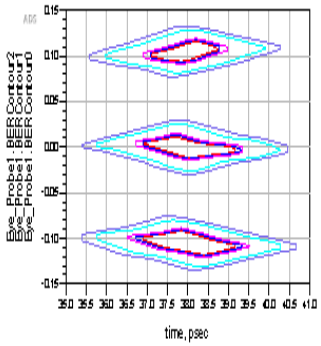


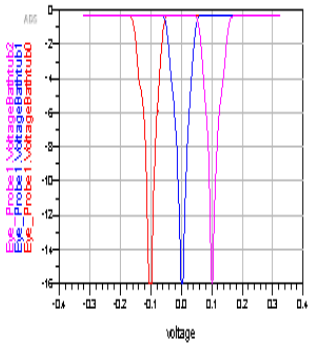


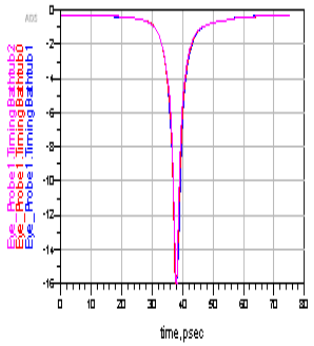
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.037	0.033	0.034	3.200E-12	3.012E-12	2.835E-12
1.000E-11	0.041	0.036	0.036	3.576E-12	3.200E-12	3.012E-12
1.000E-10	0.044	0.039	0.039	3.765E-12	3.576E-12	3.388E-12
1.000E-9	0.060	0.055	0.056	5.469E-12	5.469E-12	4.894E-12
1.000E-8	0.066	0.063	0.063	6.024E-12	5.835E-12	5.647E-12

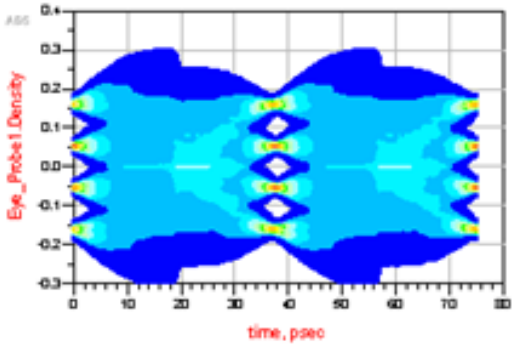
Case Simulations for Different Resonance Depths

- Case5



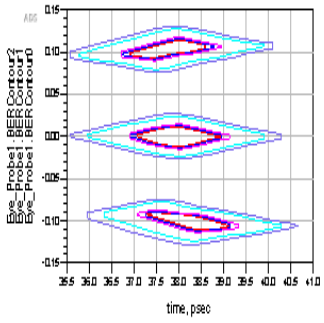


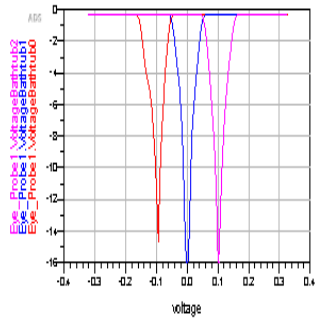


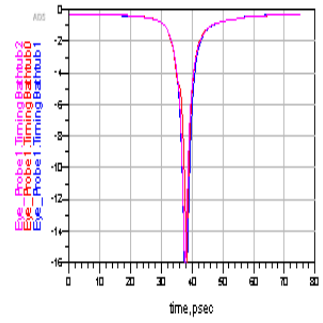


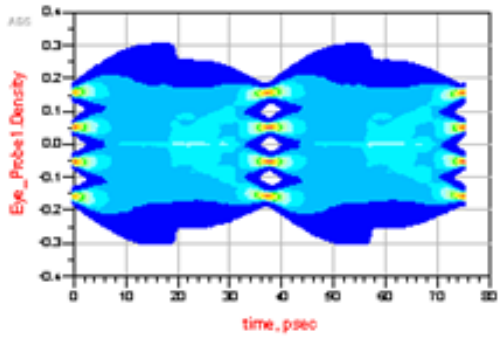
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERLis
1.000E-12	0.021	0.019	0.019	2.447E-12	1.882E-12	2.447E-
1.000E-11	0.024	0.024	0.022	2.824E-12	1.882E-12	2.635E-
1.000E-10	0.027	0.027	0.026	3.200E-12	2.259E-12	2.824E-
1.000E-8	0.047	0.051	0.046	4.706E-12	4.141E-12	4.706E-
1.000E-6	0.058	0.059	0.054	5.459E-12	4.894E-12	5.271E-

- Case6





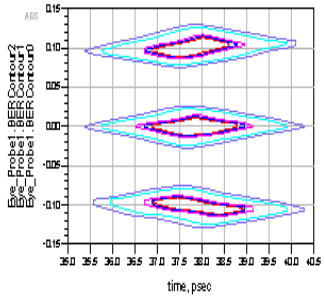


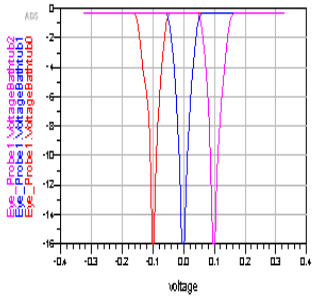


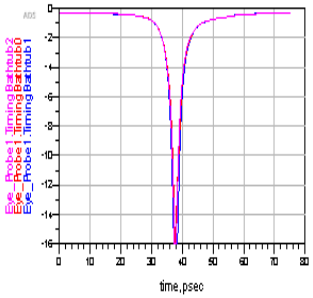
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.016	0.023	0.016	2.071E-12	1.882E-12	2.071E-12
1.000E-11	0.019	0.027	0.018	2.071E-12	2.259E-12	2.259E-12
1.000E-10	0.022	0.030	0.022	2.447E-12	2.447E-12	2.447E-12
1.000E-8	0.041	0.047	0.046	4.141E-12	4.329E-12	4.141E-12
1.000E-6	0.050	0.053	0.053	4.894E-12	4.706E-12	4.894E-12

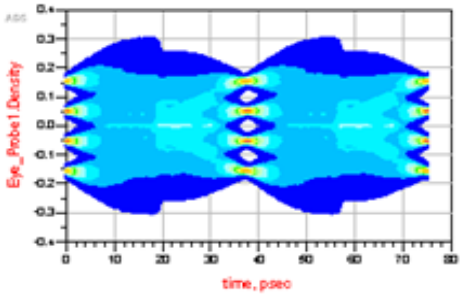
Case Simulations for Different Resonance Depths

- Case7



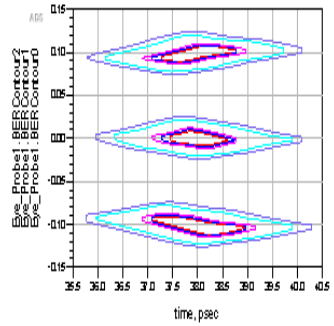


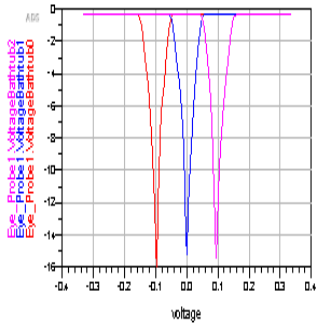


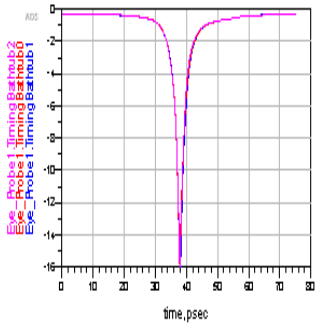


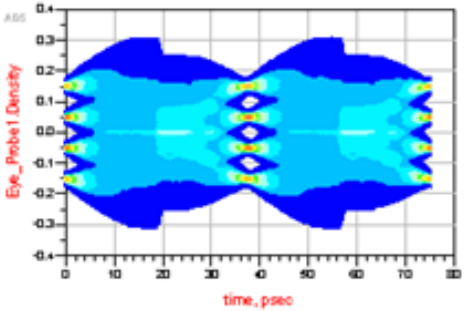
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.015	0.021	0.019	2.259E-12	1.882E-12	2.071E-12
1.000E-11	0.017	0.025	0.023	2.259E-12	2.259E-12	2.447E-12
1.000E-10	0.020	0.028	0.027	2.635E-12	2.447E-12	2.824E-12
1.000E-8	0.042	0.047	0.046	4.141E-12	4.329E-12	4.329E-12
1.000E-6	0.051	0.054	0.053	4.894E-12	4.894E-12	5.082E-12

- Case8





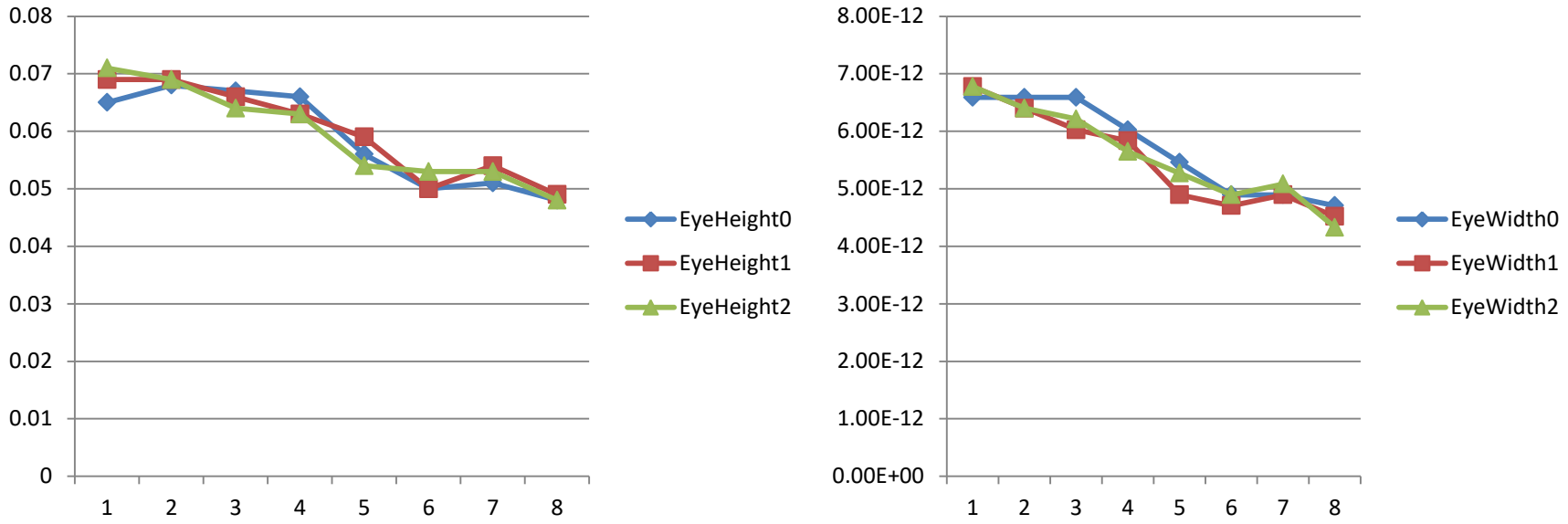




BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.014	0.015	0.013	2.071E-12	1.694E-12	1.318E-12
1.000E-11	0.018	0.018	0.017	2.071E-12	1.882E-12	1.694E-12
1.000E-10	0.022	0.022	0.021	2.447E-12	2.259E-12	1.882E-12
1.000E-8	0.039	0.041	0.041	4.141E-12	3.765E-12	3.765E-12
1.000E-5	0.048	0.049	0.048	4.706E-12	4.518E-12	4.329E-12

Factor Analysis for Resonance Depth of Insertion Loss

- The deeper of the resonance, the eye getting worse
- The depth of the resonance is less impact to the eye diagram than the frequency of the resonance

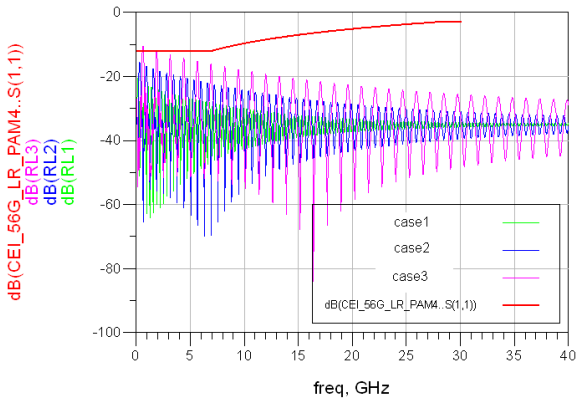


@BER=1E-5

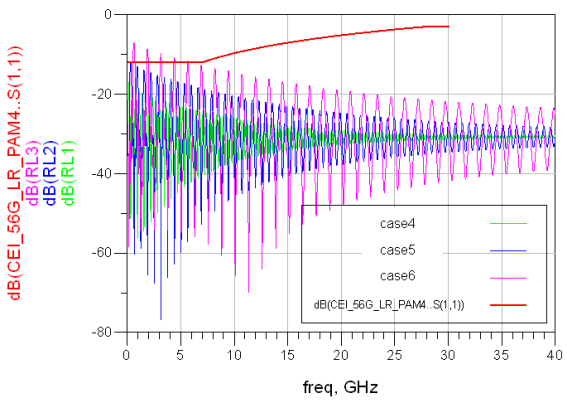
The Impact of Impedance Discontinuity

- Channel length： 20in, differential impedance： 100ohm

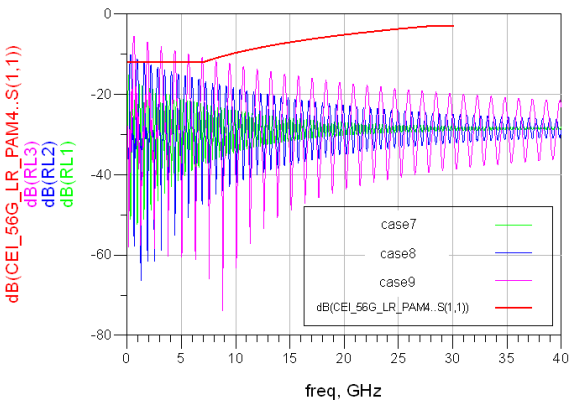
Case1-10in 105ohm +10 in 95ohm
Case2-(5in 105ohm +5 in 95ohm)*2
Case3-(2.5in 105ohm +2.5 in 95ohm) *4



Case4-10in 108ohm +10 in 92ohm
Case5-(5in 108ohm +5 in 92ohm)*2
Case6-(2.5in 108ohm +2.5 in 92ohm) *4

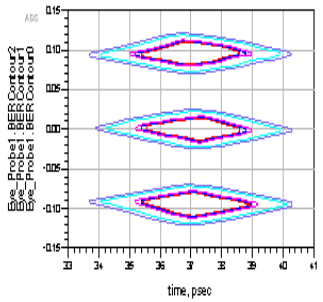


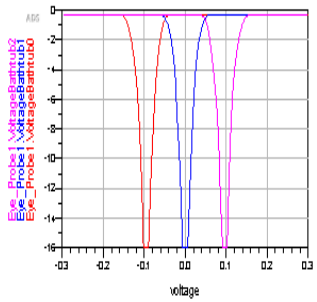
Case7-10in 110ohm +10 in 90ohm
Case8-(5in 110ohm +5 in 90ohm)*2
Case9-(2.5in 110ohm +2.5 in 90ohm) *4

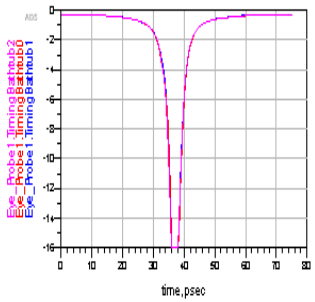


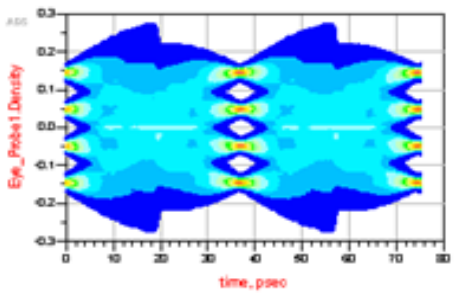
Case Simulations for Impedance Discontinuity

- Case1



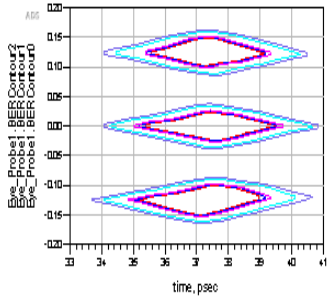


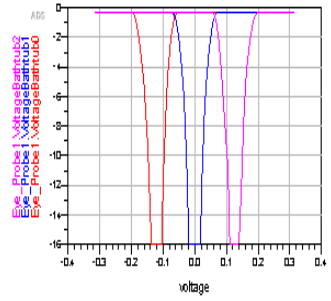


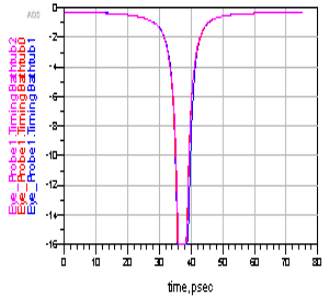


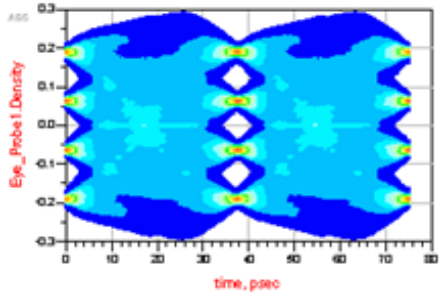
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.029	0.028	0.028	3.765E-12	3.388E-12	3.200E-12
1.000E-11	0.032	0.031	0.030	3.765E-12	3.765E-12	3.576E-12
1.000E-10	0.034	0.034	0.032	4.141E-12	4.141E-12	3.953E-12
1.000E-9	0.047	0.045	0.046	6.212E-12	6.024E-12	5.835E-12
1.000E-5	0.051	0.049	0.051	6.776E-12	6.776E-12	6.588E-12

- Case2





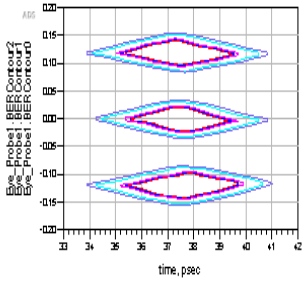


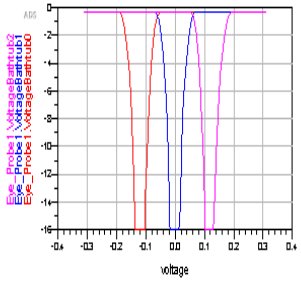


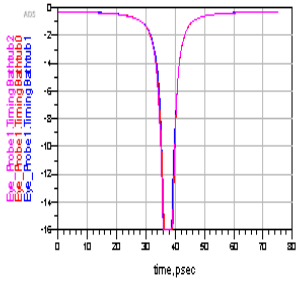
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.047	0.047	0.046	3.953E-12	3.765E-12	4.329E-12
1.000E-11	0.050	0.050	0.050	4.329E-12	3.953E-12	4.518E-12
1.000E-10	0.054	0.053	0.054	4.706E-12	4.141E-12	4.894E-12
1.000E-9	0.070	0.070	0.070	6.212E-12	6.024E-12	6.588E-12
1.000E-5	0.076	0.076	0.078	7.153E-12	6.588E-12	6.965E-12

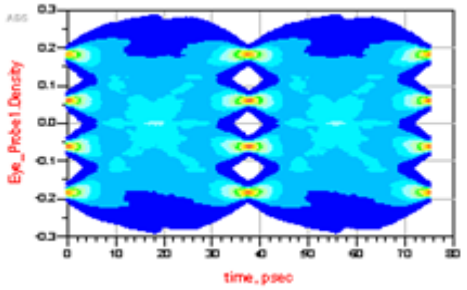
Case Simulations for Impedance Discontinuity

- Case3



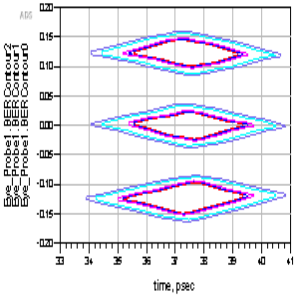


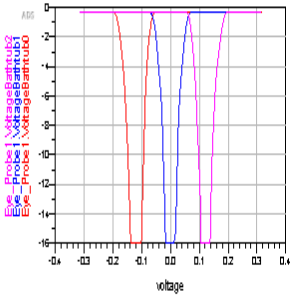


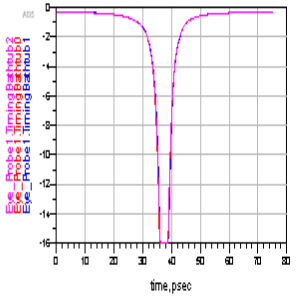


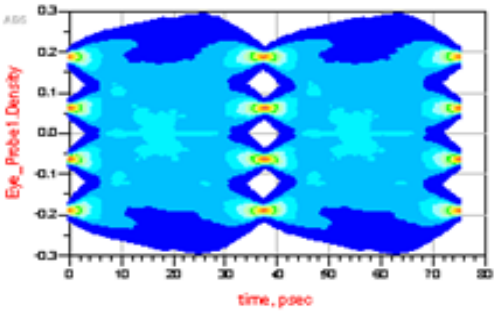
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.044	0.042	0.043	4.518E-12	4.329E-12	3.953E-12
1.000E-11	0.047	0.045	0.046	4.518E-12	4.518E-12	4.141E-12
1.000E-10	0.050	0.047	0.050	4.894E-12	4.894E-12	4.518E-12
1.000E-8	0.068	0.063	0.065	6.588E-12	6.588E-12	6.212E-12
1.000E-6	0.071	0.070	0.070	7.341E-12	7.153E-12	6.776E-12

- Case4





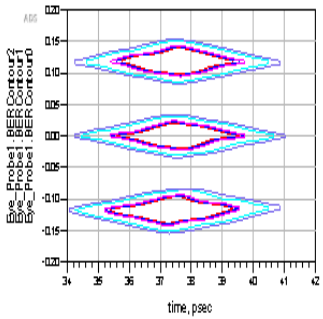


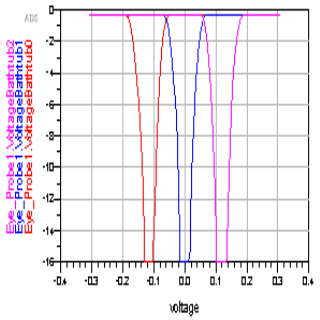


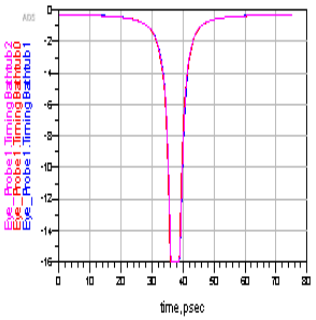
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.049	0.045	0.042	4.329E-12	3.765E-12	3.953E-12
1.000E-11	0.052	0.047	0.046	4.518E-12	4.141E-12	4.141E-12
1.000E-10	0.056	0.050	0.049	4.894E-12	4.518E-12	4.518E-12
1.000E-8	0.071	0.068	0.067	6.400E-12	6.212E-12	6.212E-12
1.000E-6	0.077	0.074	0.074	7.153E-12	6.776E-12	6.965E-12

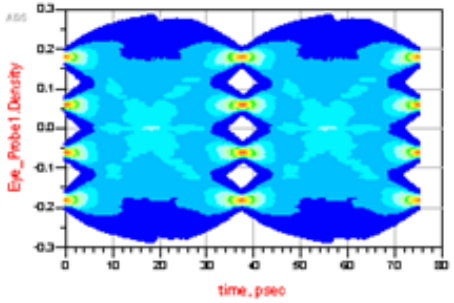
Case Simulations for Impedance Discontinuity

- Case5



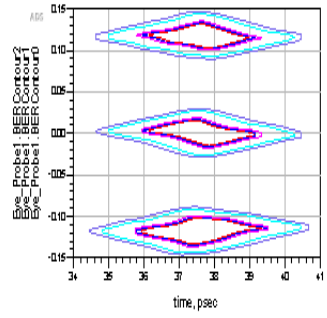


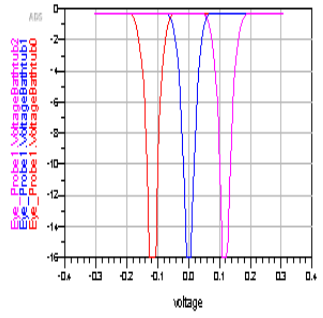


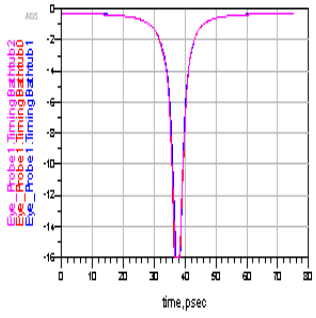


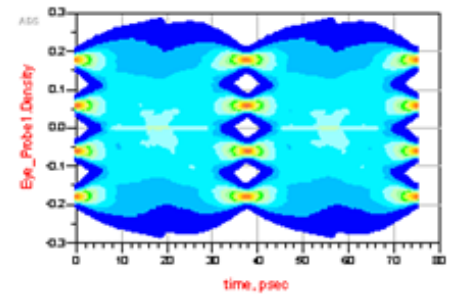
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.041	0.039	0.042	4.141E-12	3.765E-12	4.141E-12
1.000E-11	0.044	0.042	0.045	4.518E-12	4.141E-12	4.518E-12
1.000E-10	0.048	0.046	0.049	4.518E-12	4.518E-12	4.518E-12
1.000E-8	0.064	0.062	0.065	6.400E-12	6.024E-12	6.400E-12
1.000E-6	0.070	0.068	0.070	6.965E-12	6.776E-12	6.965E-12

- Case6





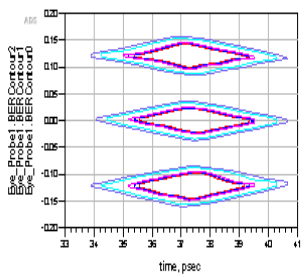


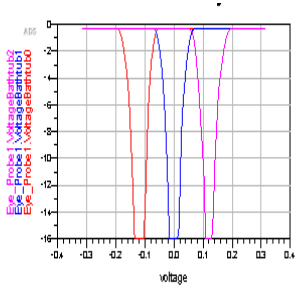


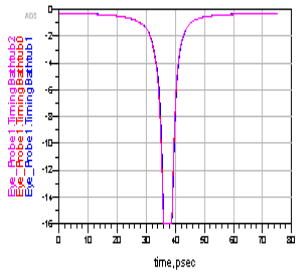
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.032	0.027	0.028	3.576E-12	3.012E-12	3.200E-12
1.000E-11	0.035	0.031	0.032	3.953E-12	3.388E-12	3.388E-12
1.000E-10	0.038	0.035	0.035	3.953E-12	3.765E-12	3.576E-12
1.000E-8	0.052	0.053	0.050	5.835E-12	5.459E-12	5.459E-12
1.000E-6	0.057	0.058	0.056	6.400E-12	6.024E-12	6.024E-12

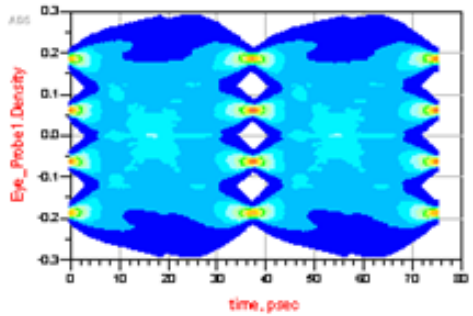
Case Simulations for Impedance Discontinuity

- Case7



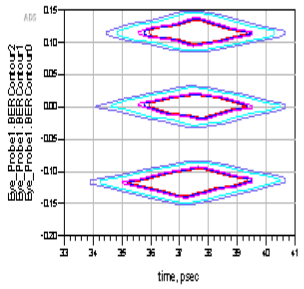


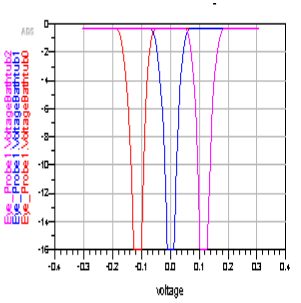


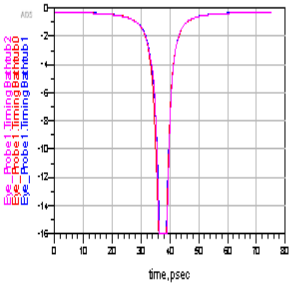


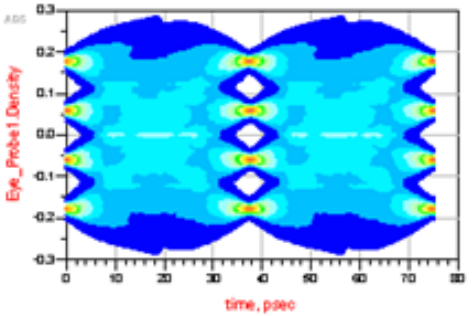
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.047	0.043	0.044	3.765E-12	4.141E-12	3.953E-12
1.000E-11	0.051	0.046	0.047	4.141E-12	4.329E-12	4.329E-12
1.000E-10	0.054	0.048	0.050	4.518E-12	4.706E-12	4.518E-12
1.000E-8	0.068	0.068	0.064	6.212E-12	6.212E-12	6.024E-12
1.000E-6	0.074	0.073	0.070	6.965E-12	6.965E-12	6.776E-12

- Case8





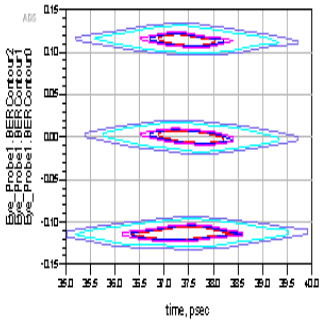


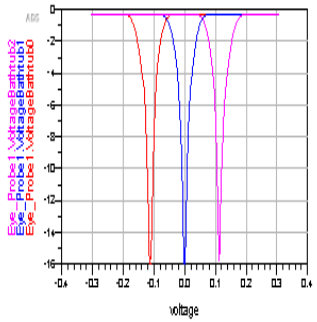


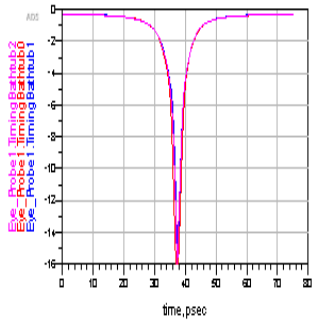
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.039	0.034	0.037	4.329E-12	3.576E-12	3.576E-12
1.000E-11	0.042	0.037	0.040	4.518E-12	3.953E-12	3.765E-12
1.000E-10	0.045	0.041	0.044	4.706E-12	4.141E-12	4.141E-12
1.000E-8	0.062	0.059	0.058	6.400E-12	5.647E-12	6.024E-12
1.000E-6	0.067	0.065	0.064	6.965E-12	6.400E-12	6.776E-12

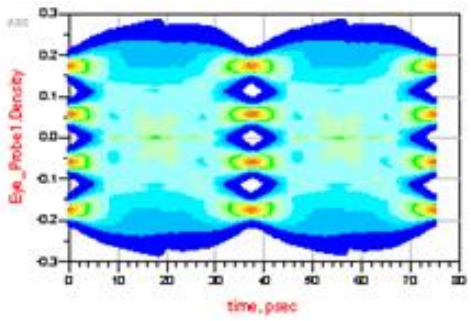
Case Simulations for Impedance Discontinuity

- Case9





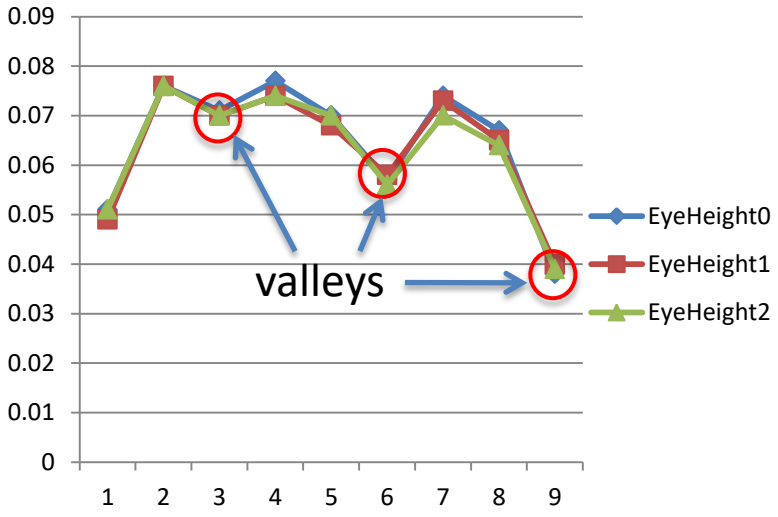


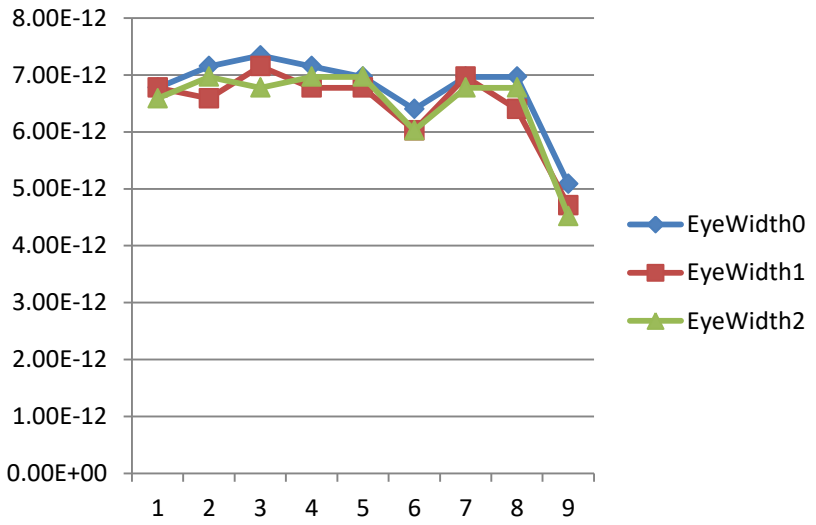


BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.015	0.013	0.012	2.259E-12	1.318E-12	1.506E-12
1.000E-11	0.017	0.015	0.015	2.447E-12	1.694E-12	1.882E-12
1.000E-10	0.020	0.017	0.017	2.635E-12	2.071E-12	2.071E-12
1.000E-8	0.033	0.033	0.032	4.518E-12	3.953E-12	3.765E-12
1.000E-5	0.038	0.040	0.039	5.082E-12	4.706E-12	4.518E-12

Factor Analysis for Impedance Discontinuity

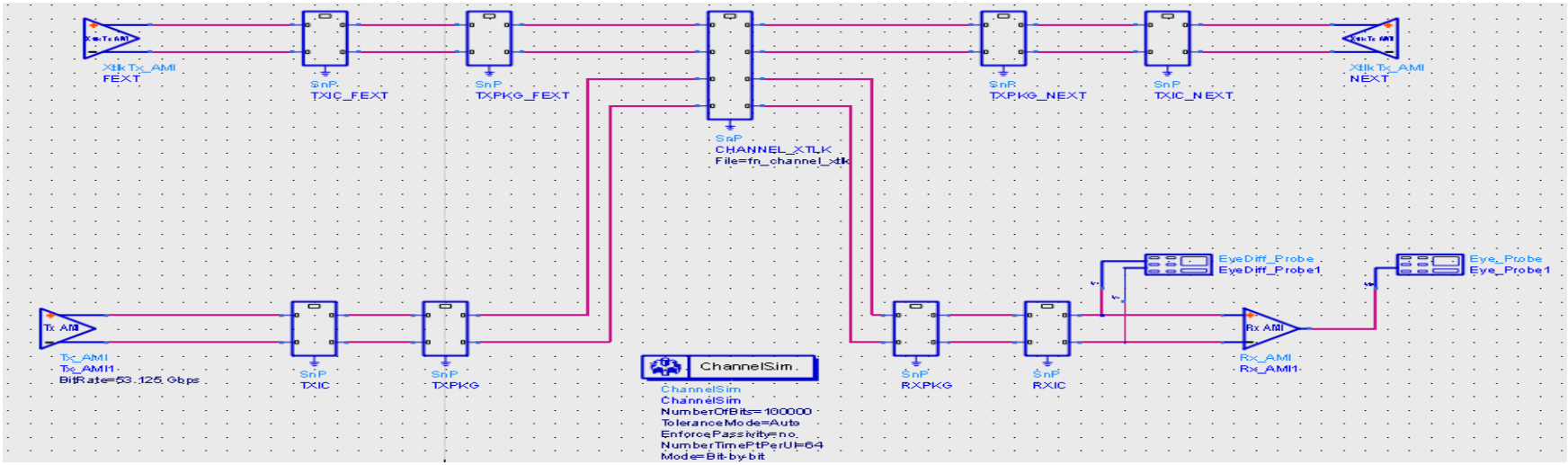
- The diagrams including 3 valleys and the depth is greater in turn
  - The impedance fluctuations of the signal channel affect the EyeHeight more than the EyeWidth
  - Common impedance tolerance +/-10% is not acceptable in the 56G PAM4 systems
  - The impedance tolerance is recommend to be less than or equal to +/-8%
  - Reduce the discontinuity points as possible as you can





@BER=1E-5

The Impact of Channel Crosstalk



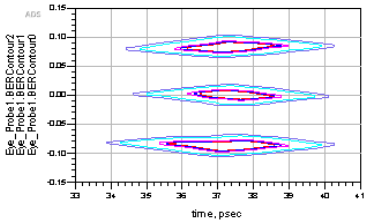
@IL=30dB	case1	case2	case3	case4
ICN/mV	1	2	3	4
XTK=NEXT				

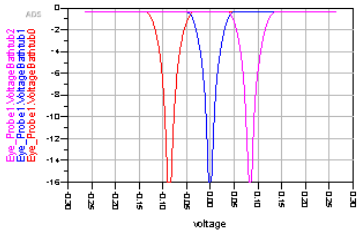
@IL=30dB	case5	case6	case7	case8
ICN/mV	1	2	3	4
XTK=FEXT				

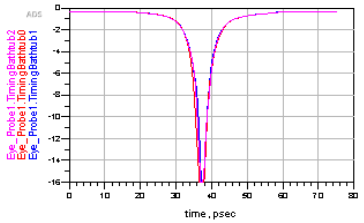
@IL=30dB	case9	case10	case11	case12
ICN/mV	1	2	3	4
XTK=FEXT 50%+NEXT 50%				

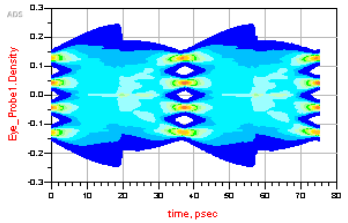
Case Simulations for Channel Crosstalk

- Case1



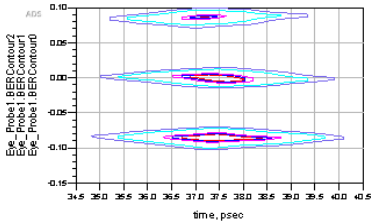


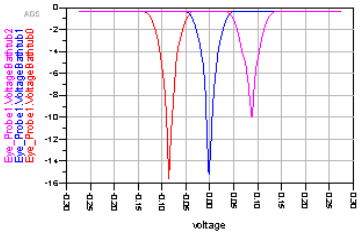


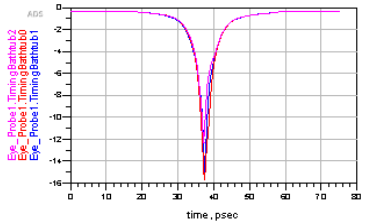


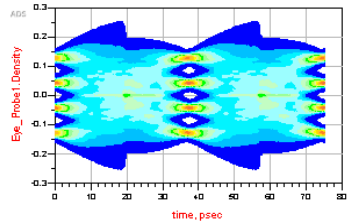
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList
1.000E-12	0.015	0.013	0.016	3.200E-12	2.259E-12	2.635E-12
1.000E-11	0.017	0.015	0.018	3.388E-12	2.447E-12	3.012E-12
1.000E-10	0.019	0.018	0.021	3.765E-12	2.824E-12	3.388E-12
1.000E-6	0.032	0.032	0.034	5.835E-12	4.894E-12	5.271E-12
1.000E-5	0.038	0.037	0.038	6.588E-12	5.647E-12	6.024E-12

- Case2





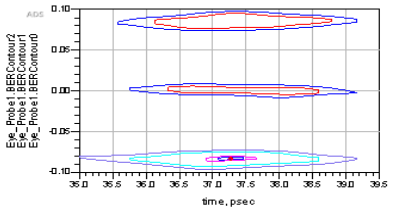


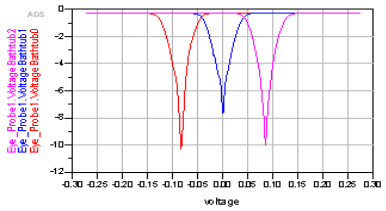


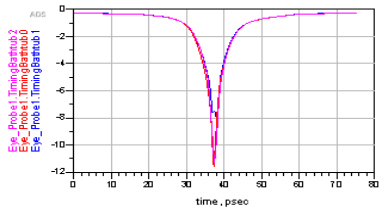
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList
1.000E-12	0.009	0.009	0.001	1.882E-12	1.318E-12	3.765E-13
1.000E-11	0.012	0.011	0.004	2.259E-12	1.506E-12	7.529E-13
1.000E-10	0.014	0.013	0.006	2.635E-12	1.882E-12	1.129E-12
1.000E-6	0.028	0.025	0.021	4.518E-12	4.141E-12	3.388E-12
1.000E-5	0.032	0.029	0.028	5.459E-12	5.082E-12	4.329E-12

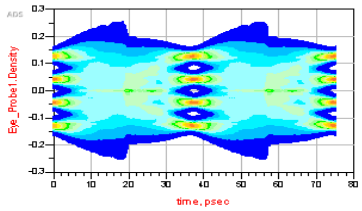
Case Simulations for Channel Crosstalk

- Case3



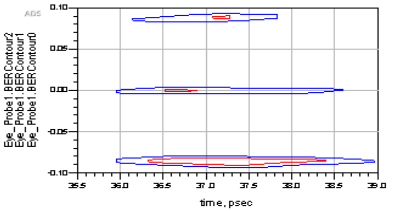


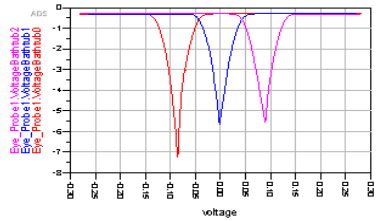


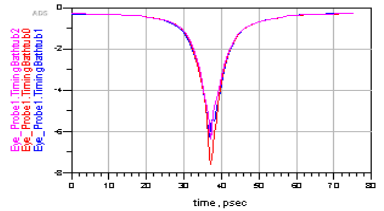


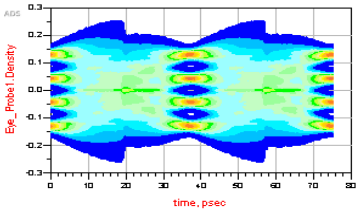
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList
1.000E-12	3.894E-4	-0.513	-0.545	1.882E-13	0.000	0.000
1.000E-11	0.003	-0.513	-0.545	5.647E-13	0.000	0.000
1.000E-10	0.006	-0.513	0.003	9.412E-13	0.000	7.529E-13
1.000E-9	0.018	0.009	0.018	3.012E-12	2.447E-12	2.824E-12
1.000E-8	0.023	0.016	0.023	4.329E-12	3.576E-12	3.765E-12

- Case4





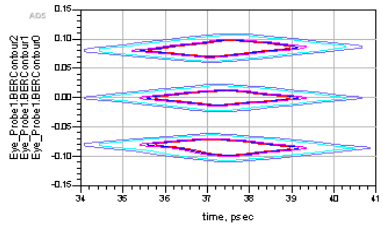


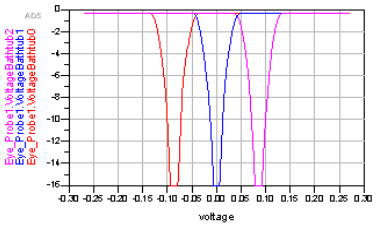


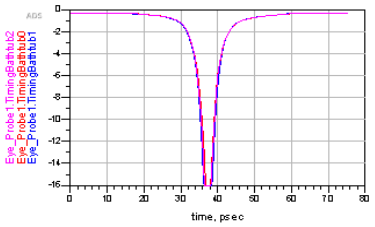
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList
1.000E-12	-0.560	-0.534	-0.560	0.000	0.000	0.000
1.000E-11	-0.560	-0.534	-0.560	0.000	0.000	0.000
1.000E-10	-0.560	-0.534	-0.560	0.000	0.000	0.000
1.000E-9	0.008	0.002	0.003	2.259E-12	5.647E-13	3.765E-13
1.000E-8	0.014	0.008	0.009	3.200E-12	2.824E-12	1.882E-12

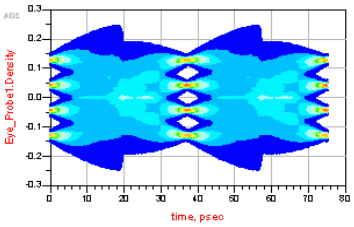
Case Simulations for Channel Crosstalk

- Case5



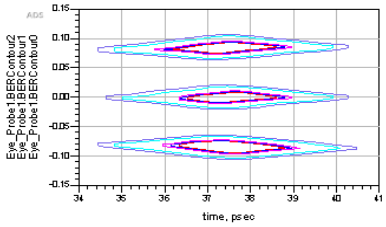


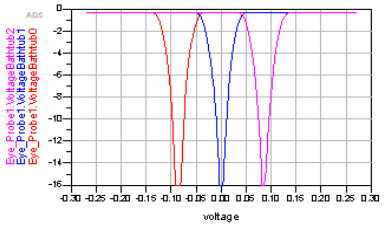


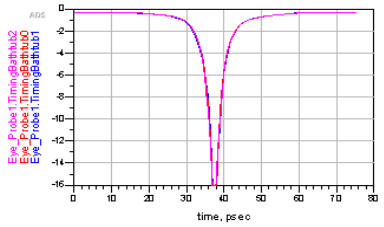


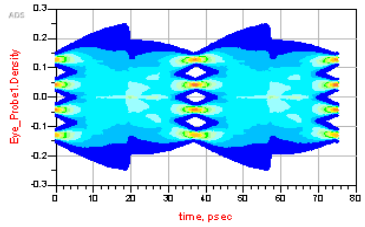
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.025	0.023	0.025	3.388E-12	3.576E-12	3.388E-12
1.000E-11	0.027	0.026	0.027	3.765E-12	3.953E-12	3.765E-12
1.000E-10	0.030	0.028	0.030	4.141E-12	4.329E-12	4.141E-12
1.000E-9	0.043	0.043	0.043	6.212E-12	6.024E-12	6.024E-12
1.000E-5	0.047	0.047	0.048	6.965E-12	6.776E-12	6.776E-12

- Case6





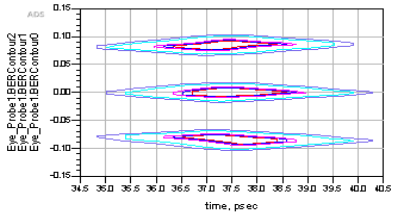


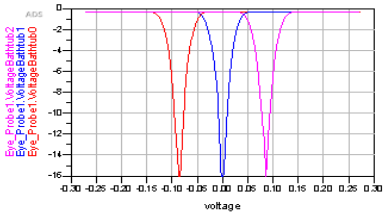


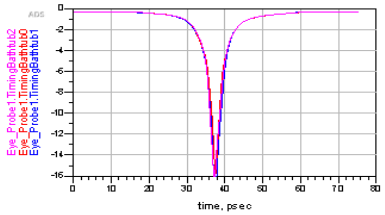
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.020	0.016	0.017	2.635E-12	2.635E-12	2.259E-12
1.000E-11	0.022	0.018	0.020	3.012E-12	3.012E-12	2.635E-12
1.000E-10	0.024	0.021	0.023	3.388E-12	3.388E-12	2.824E-12
1.000E-9	0.037	0.036	0.037	5.459E-12	5.271E-12	5.082E-12
1.000E-5	0.041	0.041	0.042	6.212E-12	6.024E-12	5.835E-12

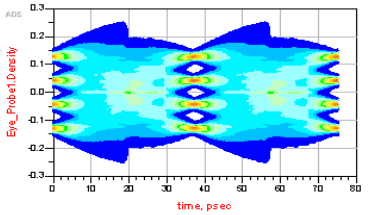
Case Simulations for Channel Crosstalk

- Case7



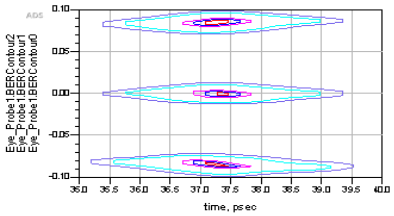


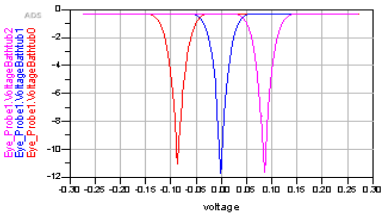


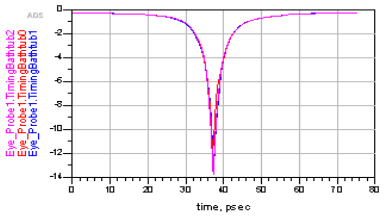


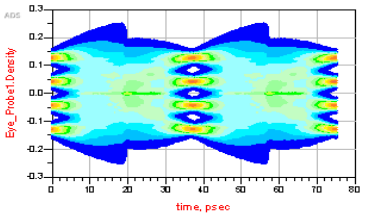
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.013	0.015	0.014	2.071E-12	2.259E-12	2.071E-12
1.000E-11	0.016	0.017	0.017	2.447E-12	2.635E-12	2.447E-12
1.000E-10	0.019	0.019	0.019	2.824E-12	3.012E-12	2.824E-12
1.000E-6	0.032	0.031	0.032	4.706E-12	4.706E-12	4.706E-12
1.000E-5	0.036	0.035	0.036	5.647E-12	5.271E-12	5.459E-12

- Case8





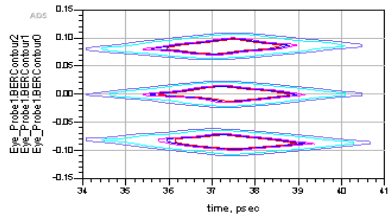


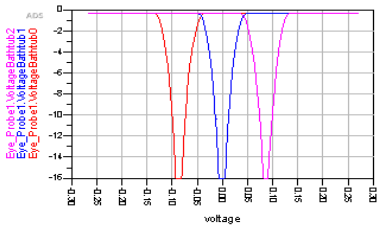


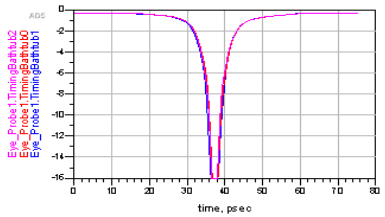
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.002	0.004	0.005	5.647E-13	5.647E-13	3.765E-13
1.000E-11	0.005	0.007	0.007	9.412E-13	9.412E-13	7.529E-13
1.000E-10	0.008	0.009	0.010	1.318E-12	1.318E-12	1.129E-12
1.000E-6	0.021	0.022	0.024	3.765E-12	3.388E-12	3.388E-12
1.000E-5	0.027	0.026	0.028	4.518E-12	4.141E-12	4.141E-12

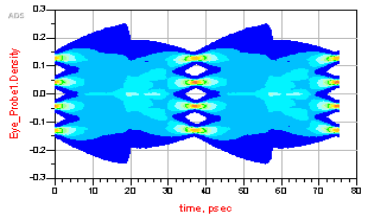
Case Simulations for Channel Crosstalk

- Case9



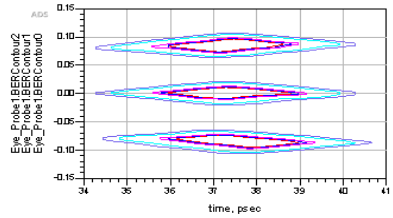


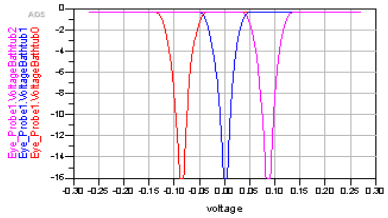


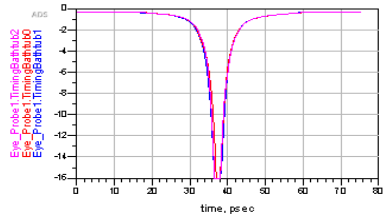


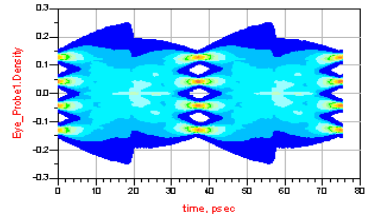
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.023	0.025	0.023	3.012E-12	2.824E-12	3.200E-12
1.000E-11	0.026	0.028	0.026	3.388E-12	3.388E-12	3.576E-12
1.000E-10	0.029	0.031	0.029	3.765E-12	3.765E-12	3.953E-12
1.000E-6	0.042	0.043	0.042	6.024E-12	5.835E-12	6.647E-12
1.000E-5	0.047	0.048	0.047	6.776E-12	6.588E-12	6.588E-12

- Case10





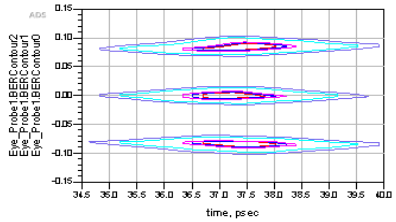


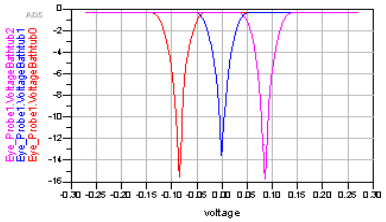


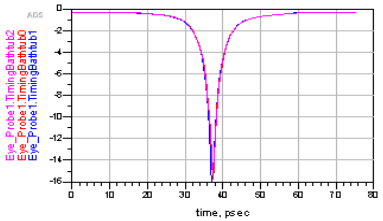
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.017	0.019	0.021	3.012E-12	2.824E-12	3.012E-12
1.000E-11	0.020	0.021	0.024	3.388E-12	3.012E-12	3.388E-12
1.000E-10	0.023	0.024	0.026	3.765E-12	3.576E-12	3.765E-12
1.000E-6	0.035	0.037	0.038	5.647E-12	5.459E-12	5.459E-12
1.000E-5	0.041	0.042	0.042	6.400E-12	6.212E-12	6.212E-12

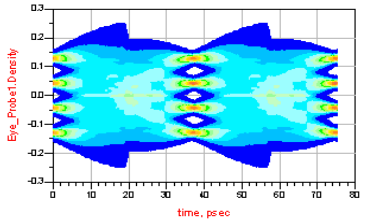
Case Simulations for Channel Crosstalk

- Case11



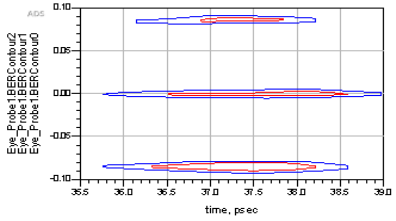


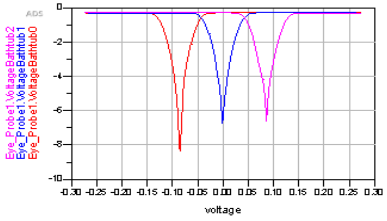


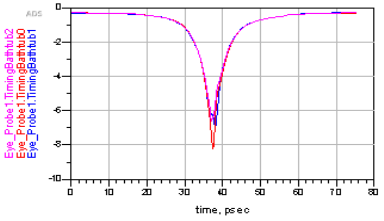


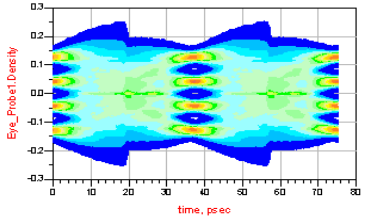
BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	0.009	0.010	0.011	1.506E-12	1.506E-12	1.318E-12
1.000E-11	0.010	0.012	0.013	1.882E-12	1.882E-12	1.694E-12
1.000E-10	0.012	0.015	0.016	2.259E-12	2.259E-12	2.071E-12
1.000E-6	0.026	0.028	0.030	4.518E-12	4.518E-12	4.141E-12
1.000E-5	0.032	0.032	0.035	5.459E-12	5.271E-12	5.082E-12

- Case12





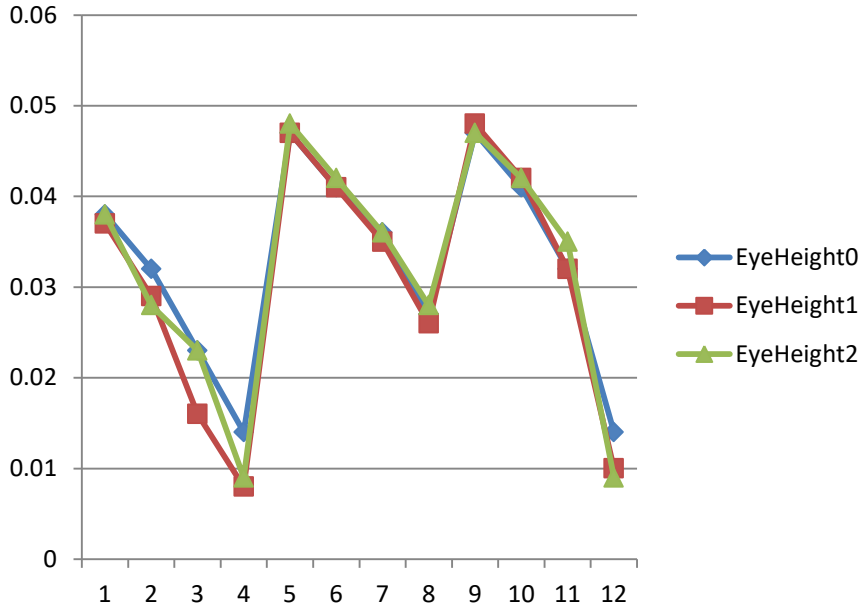


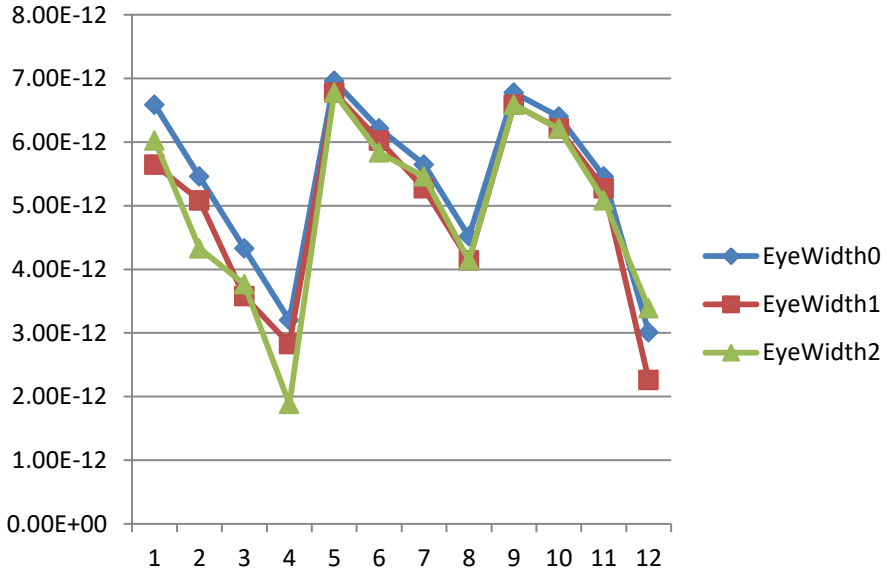


BER	BERHeightList0.Eye_Probe1.HeightAtBERList	BERHeightList1.Eye_Probe1.HeightAtBERList	BERHeightList2.Eye_Probe1.HeightAtBERList	BERWidthList0.Eye_Probe1.WidthAtBERList	BERWidthList2.Eye_Probe1.WidthAtBERList	BERWidthList1.Eye_Probe1.WidthAtBERList
1.000E-12	-0.544	-0.529	-0.544	0.000	0.000	0.000
1.000E-11	-0.544	-0.529	-0.544	0.000	0.000	0.000
1.000E-10	-0.544	-0.529	-0.544	0.000	0.000	0.000
1.000E-6	0.009	0.005	0.004	2.071E-12	1.129E-12	2.259E-12
1.000E-5	0.014	0.010	0.009	3.012E-12	2.259E-12	3.388E-12

Factor Analysis for Channel Crosstalk

- NEXT is more influential to the 56G-PAM4 systems than FEXT
- ICN limited:
  - To be less than 4mV for all crosstalk is NEXT
  - To be 4mV is OK for all crosstalk is FEXT
  - To be less than 4mV for half of crosstalk is FEXT and the other half of crosstalk is NEXT





@BER=1E-5

Agenda

- Introduction to PAM4 Modulation
- OIF CEI-56G-LR-PAM4 Specifics
- IBIS-AMI Model Simulation for 56G PAM4 Signals
- The Impact of Channel Characteristics to 56G PAM4 Systems
- Summary

Summary

- The 56G-PAM4 standard is still in continuous update
- IBIS-AMI model works well for 56G PAM4 systems simulation, although the PAM4 modeling is new until today
- After the analysis, we obtain some conclusions about the impact of channel characteristics to the 56G-LR PAM4 systems
  - —The IL resonance frequency should be more than 29GHz
  - —The IL resonance depth should be as smaller as possible
  - —The impedance tolerance is recommended to be less than or equal to +/-8%, and to reduce the discontinuity points as possible as you can
  - —NEXT is playing the leading role in the crosstalk and you might pay more attention to NEXT than FEXT
  - —ICN of crosstalk must be less than 4mV and is recommended to be less than 3mV

Thank you

Tomorrow never waits