

PAM-N Eye Diagrams

Next Generation 100Gb/s Ethernet Optics Study Group

IEEE 802.3 Interim Session

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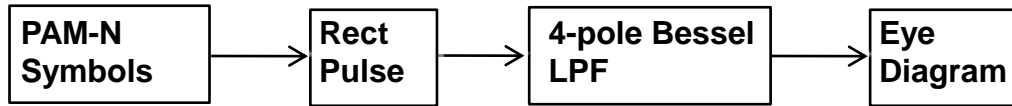
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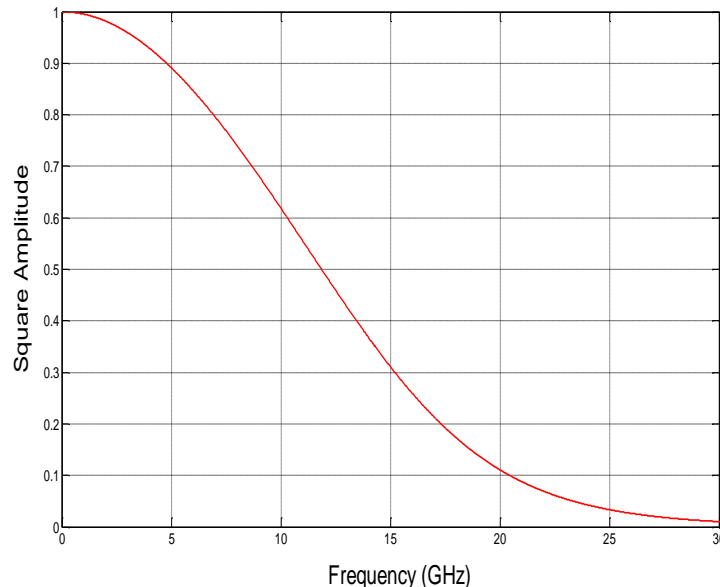
Outline

- Matlab Model
- 7ps Rise/Fall Time Eye Diagrams
- 20ps Rise/Fall Time Eye Diagrams
- Observations
- Appendix

Matlab Model



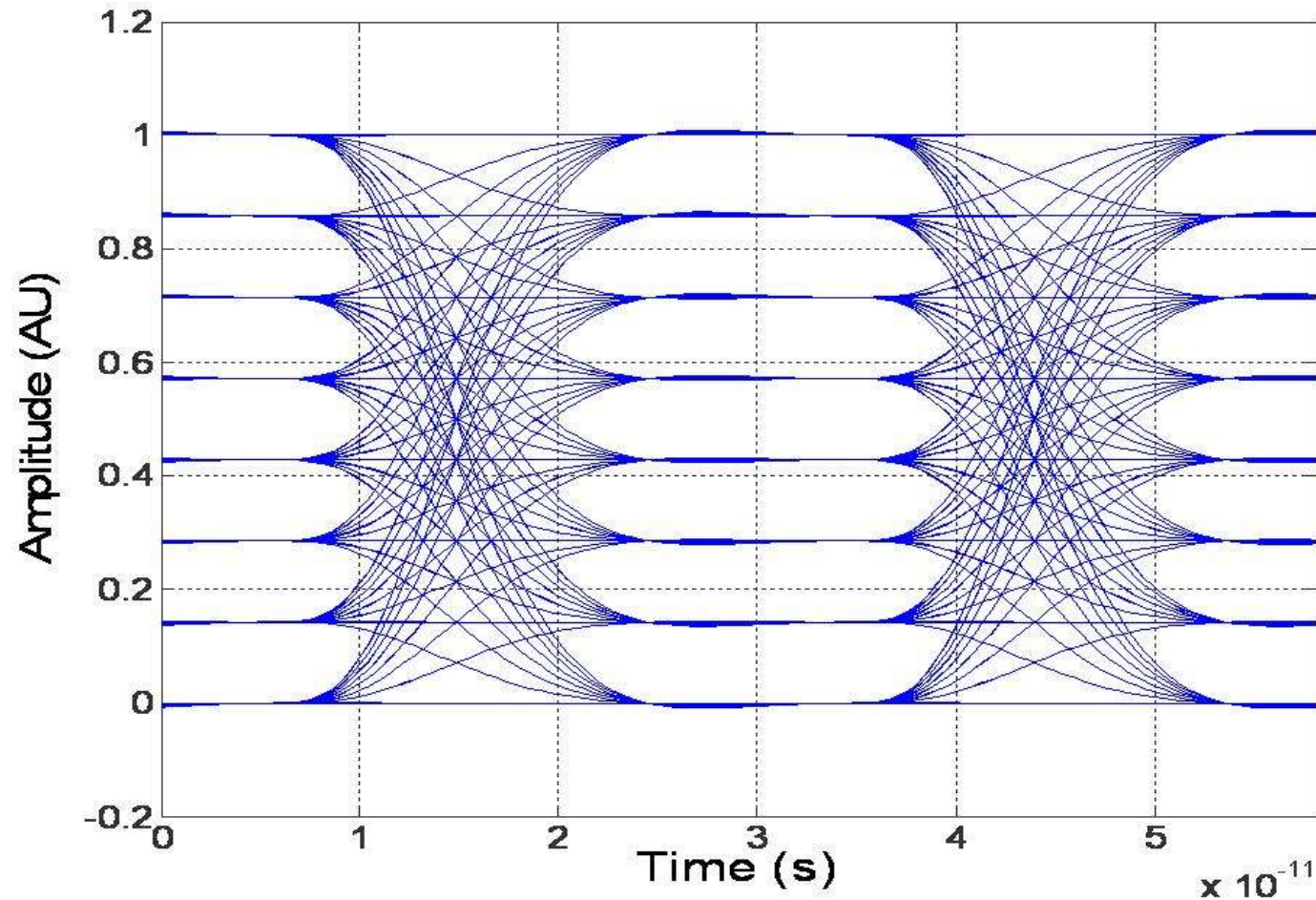
- Simulation variables: N (in PAM-N), data rate, rise/fall time
- Tr defined as 20% to 80% (Tf as 80% to 20%)
- Bessel Filter BW adjusted to match Target response eye diagram rise/fall time (model ER = α since no modulator)



Ex: Filter BW for Tr/Tf = 20ps

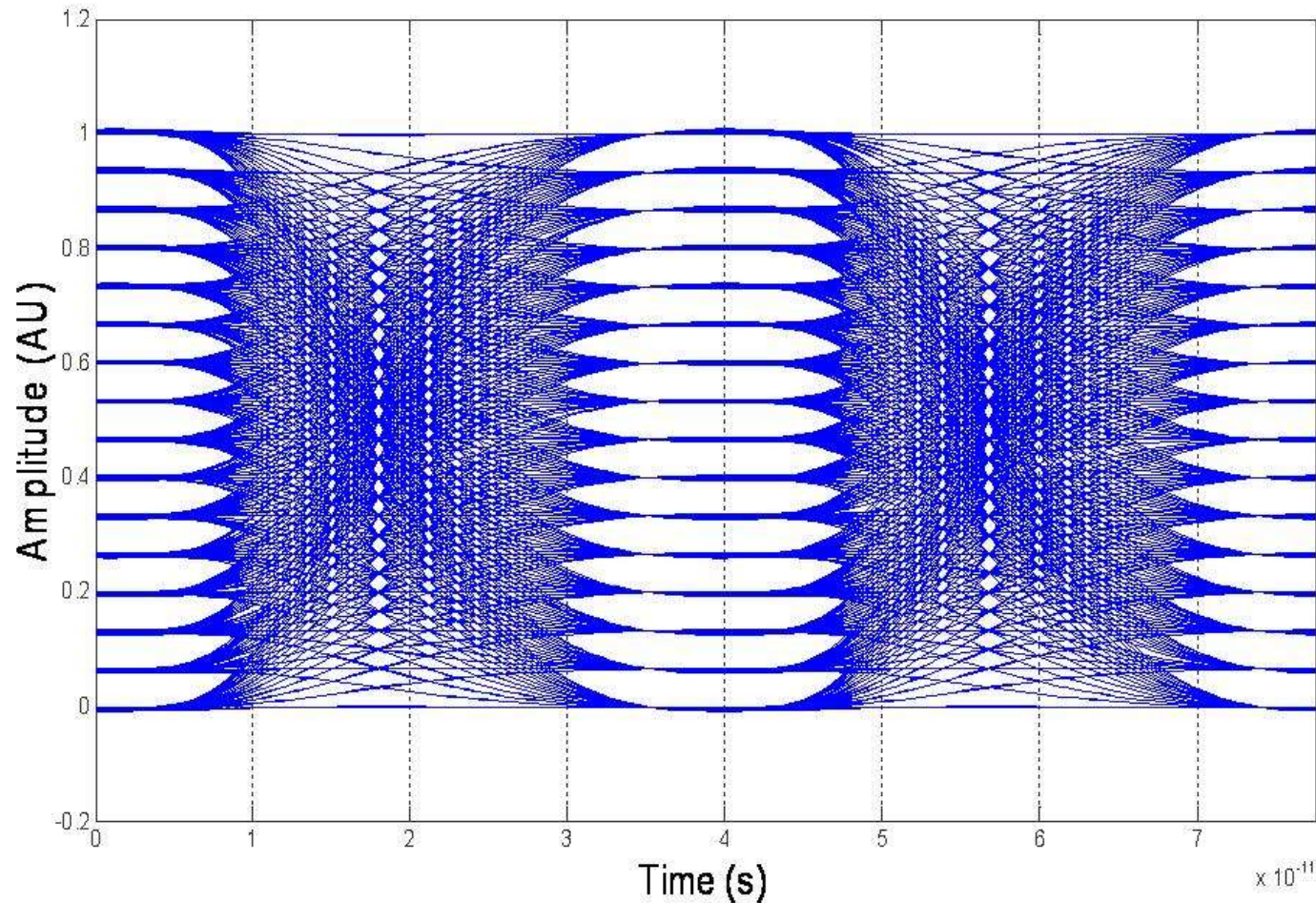
Appendix show Bessel LPF matching examples

PAM-8 34.375Gb/s $T_r/f = 6.8\text{ps}$ $E_r = \alpha$



Target response: PAM-8 Eye Diagram bhoja_01_0112 p.10

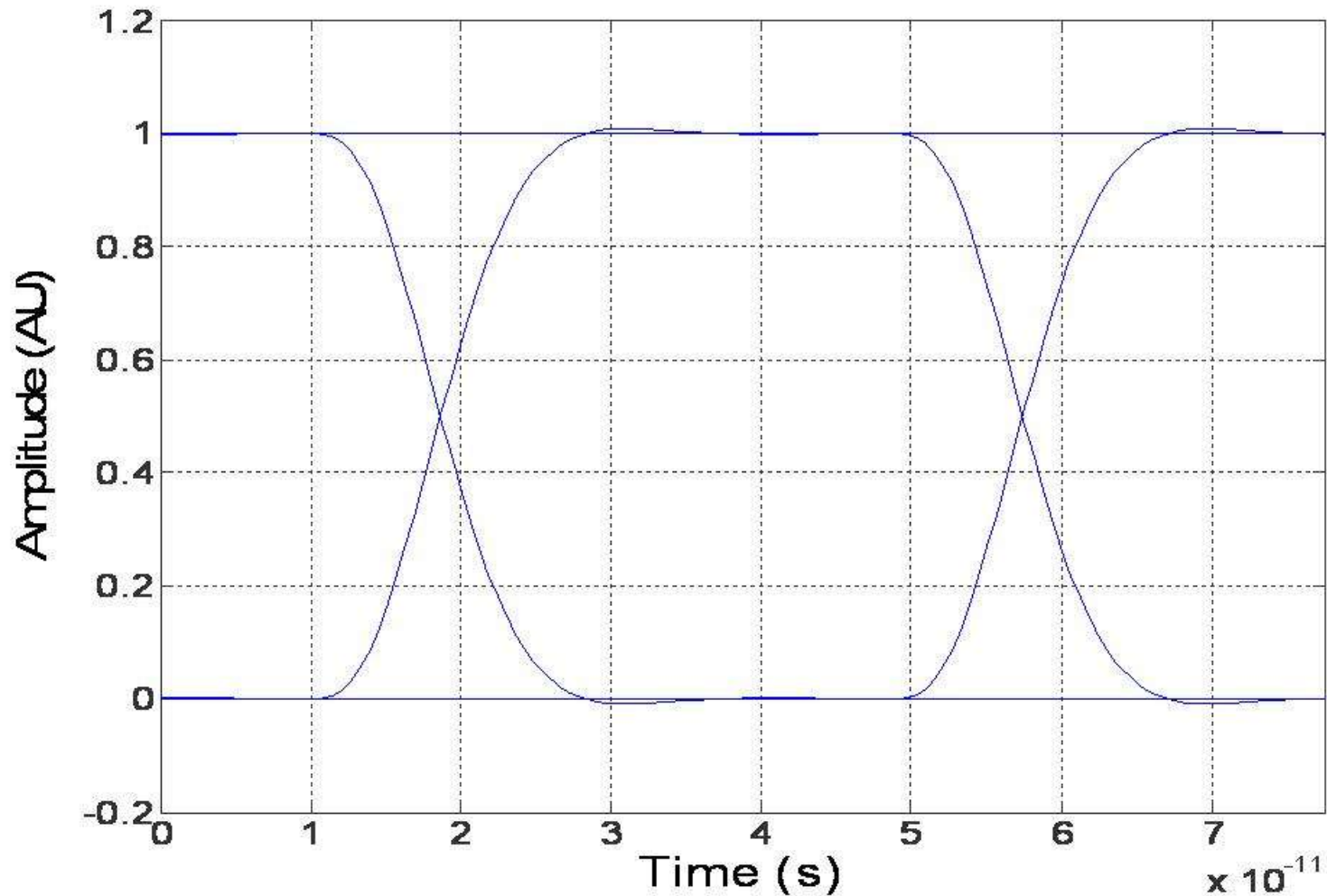
PAM-16 25.781Gb/s $Tr/f = 12ps$ $Er = \alpha$



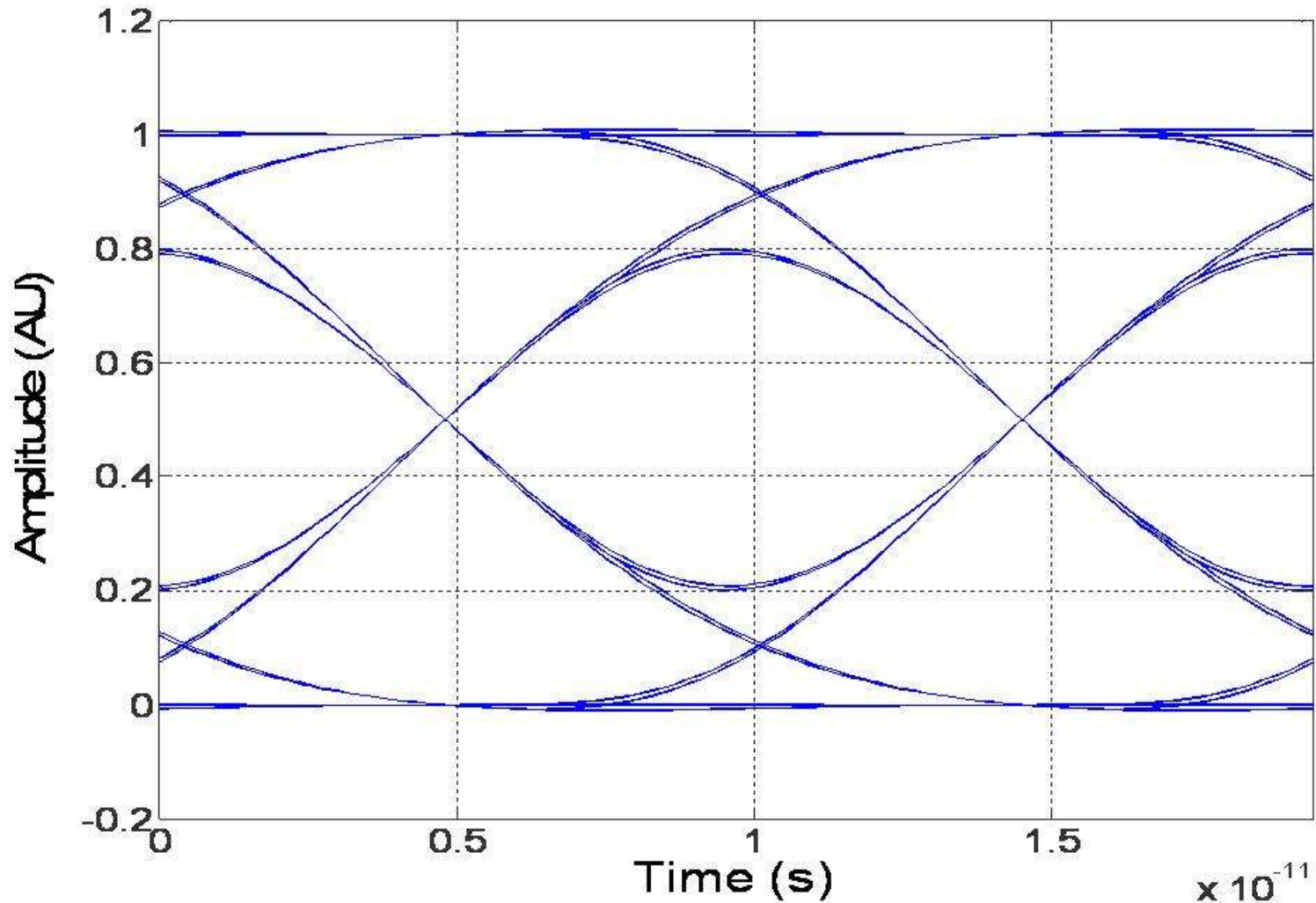
Tr/f changed
from 6.8ps
to 12ps per
request for
correction
from the
floor

Target response: 2nd PAM-16 Eye Diagram bhoja_01_0112 p.22

NRZ 25.781Gb/s $T_r/f = 6.8\text{ps}$ $E_r = \alpha$



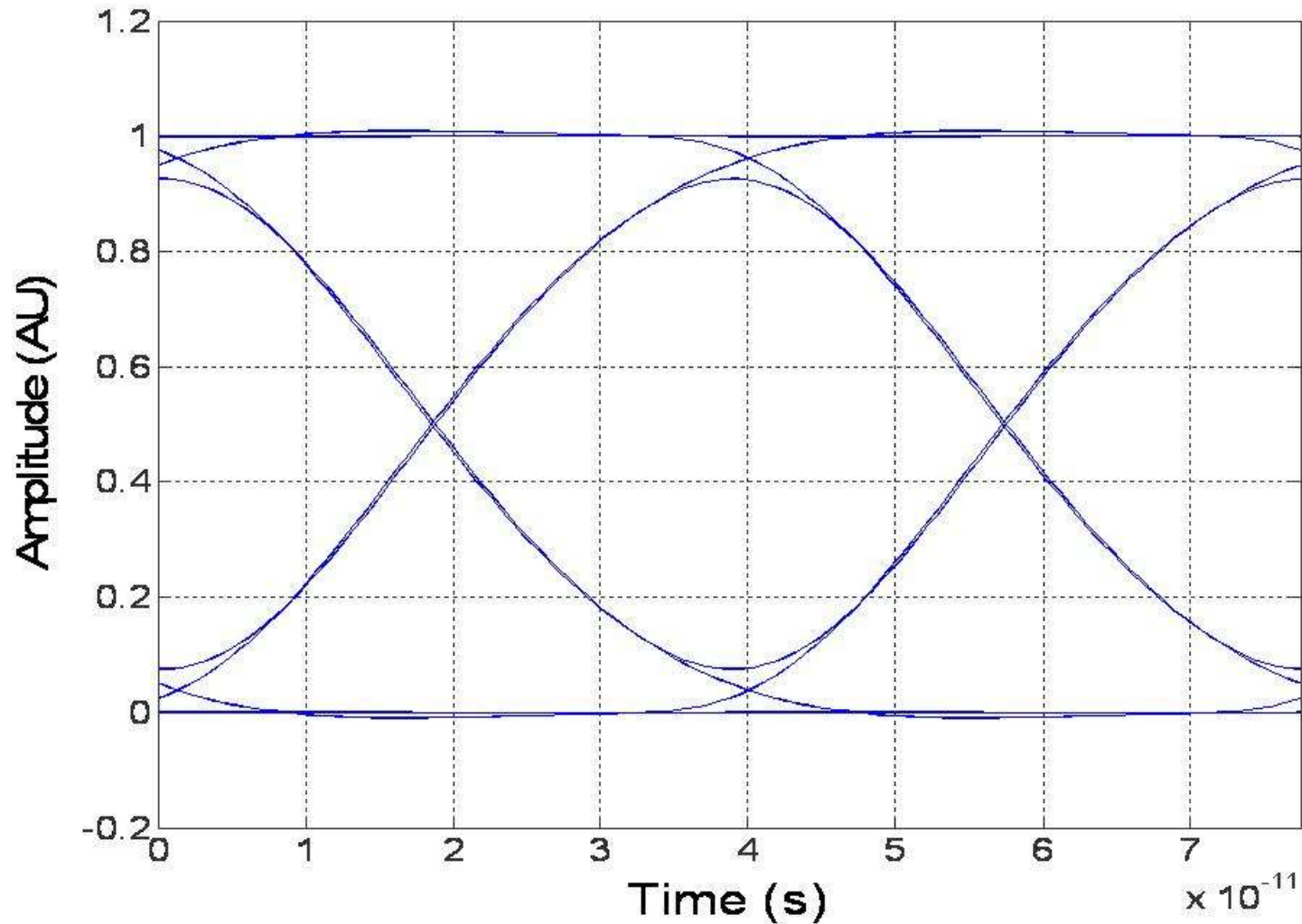
NRZ 103.125Gb/s $T_{r/f} = 6.8\text{ps}$ $E_r = \alpha$



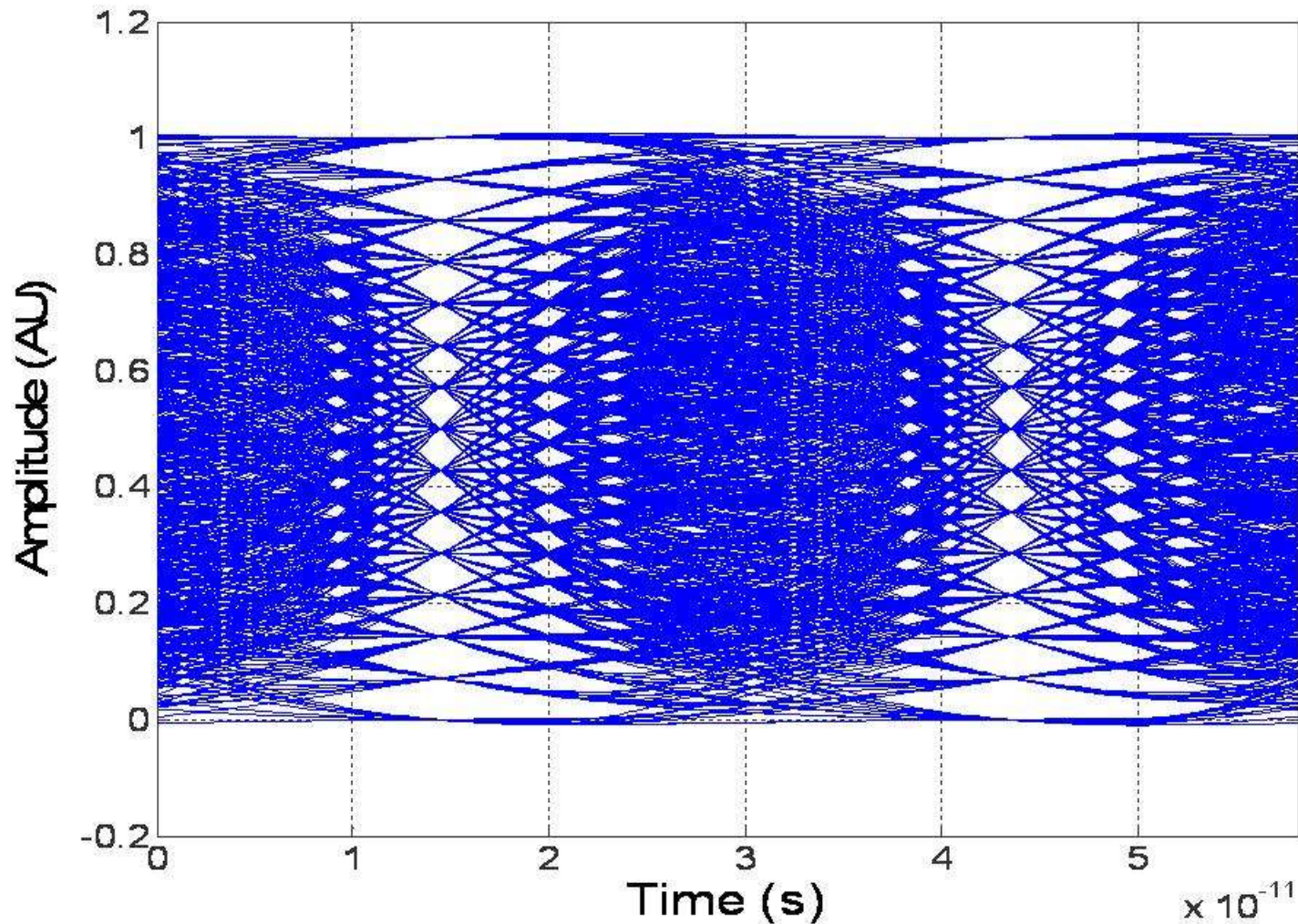
Si Modulator Tr/f Reported Results

- L. Chen, et al., (ALU Bell Labs), "... Silicon ... Modulator ...", Optics Express, Vol. 19, No. 26, pp. 946-951 (2011)
Tr/f = ~20ps ER = 7.2dB (*Tr/f = 18ps Bessel 4p LPF best match*)
- K. Ogawa, et al., (Fujikura), "Silicon MZ Modulator ...", ECOC 2011
Tr/f = ~22ps ER = ~10dB (*Tr/f = 22ps Bessel 4p LPF best match*)
- J. Rosenberg, et al., (IBM), "... Silicon ... Modulator", CLEO 2011
Tr/f = ~22ps ER = 1-4dB (*Tr/f = 20ps Bessel 4p LPF best match*)
- A Narasimha, et al., (Luxtera), "... Silicon Modulator", OFC 2008
Tr/f = ~21ps ER = ~4dB (*Tr/f = 18ps Bessel LPF best match*)
- L. Liao, et al., (Intel), "... silicon modulator", Electronics Letters 2007
Tr/f = ~15ps ER = 1.1dB (*Tr/f = 15ps Bessel LPF best match*)

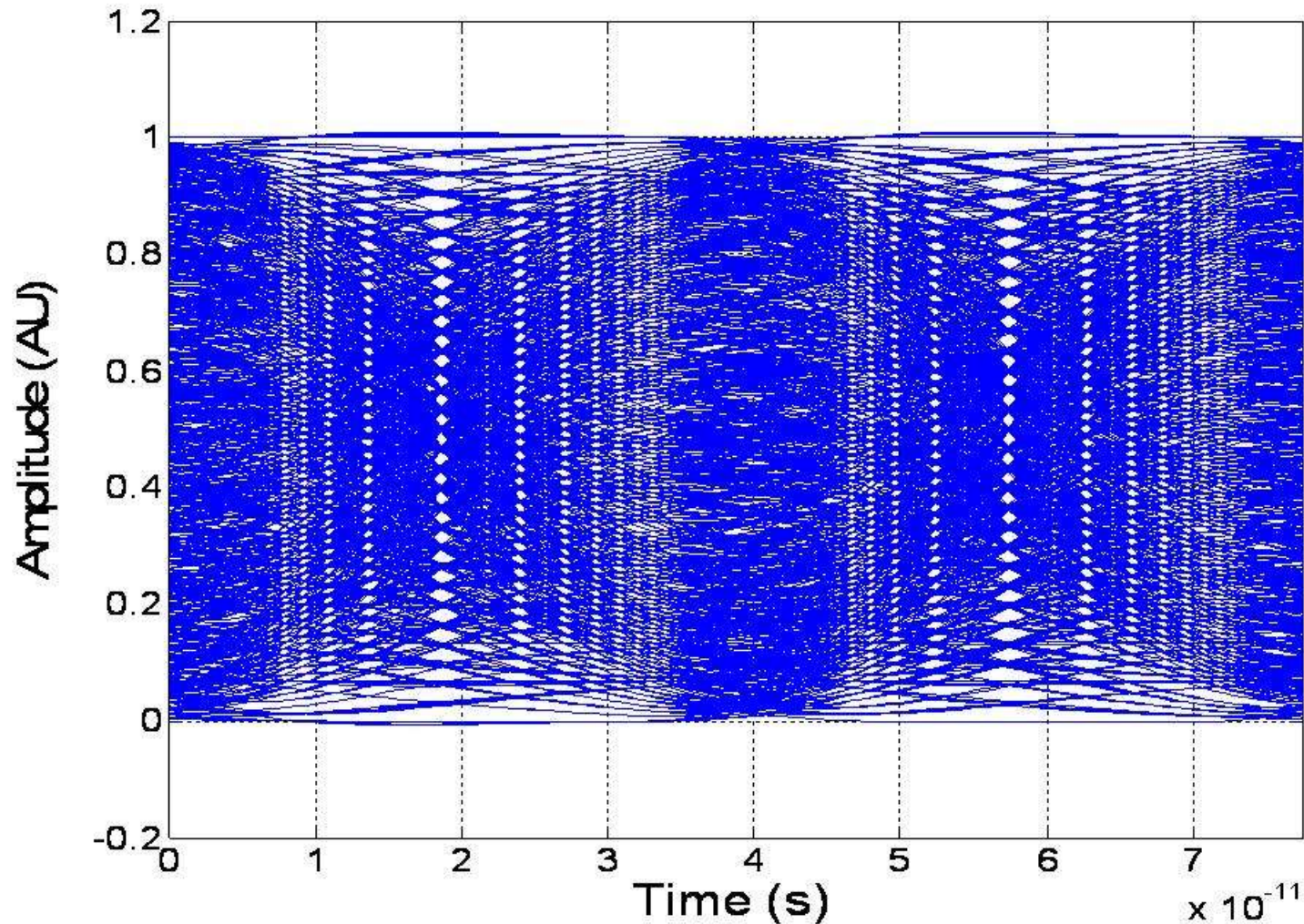
NRZ 25.781Gb/s $T_{r/f} = 20\text{ps}$ $E_r = \alpha$



PAM-8 34.375Gb/s $T_r/f = 20\text{ps}$ $E_r = \alpha$



PAM-16 25.781Gb/s $T_r/f = 20\text{ps}$ $E_r = \alpha$



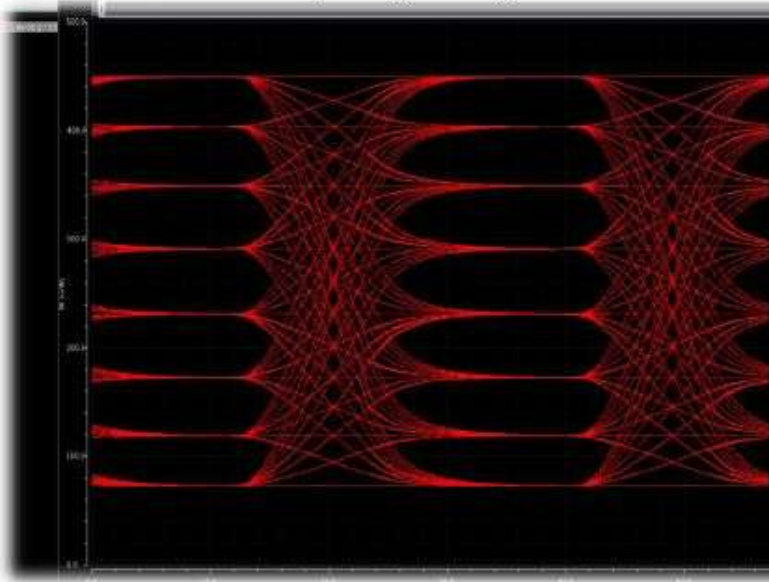
Observations

- PAM-N technical feasibility is primarily determined by MZ Si Modulator performance
- PAM-N economic feasibility is driven by MZ Si Modulator yield and IC complexity and power consumption
- Publically reported Si Modulator performance suggests PAM-8 and PAM-16 modulation is not yet feasible for 100Gb/s duplex SMF applications
- Significantly more study is required to understand PAM-8 and PAM-16 performance limitations before use in support of 100Gb/s duplex SMF Technical Feasibility

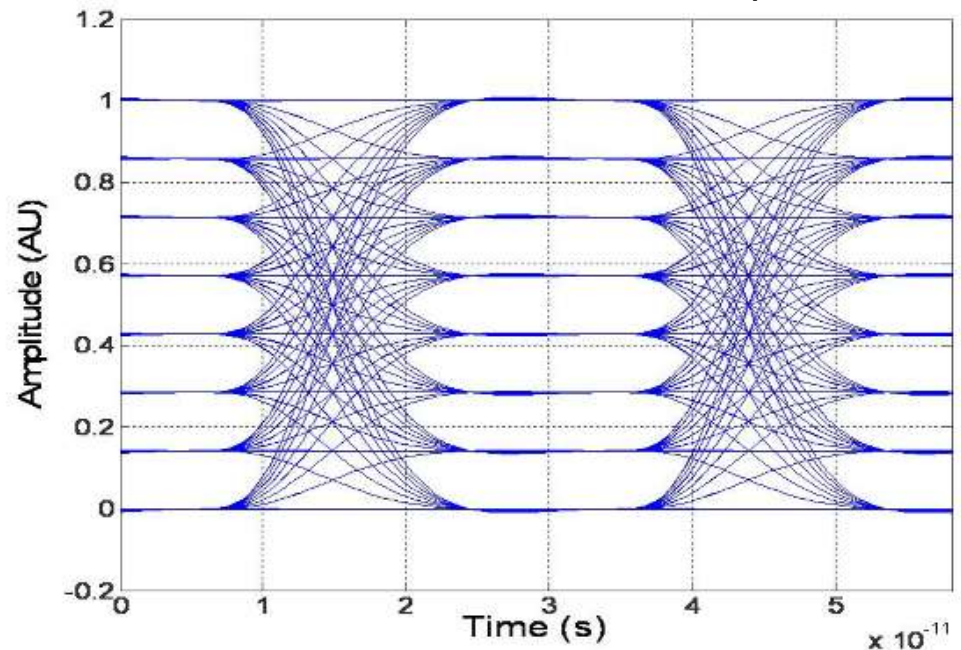
Appendix: Ex. PAM Study to LPF Matching

- J. Bhoja, et al., “Study of PAM modulation for 100GE over a single laser”, IEEE 802.3 Interim Meeting, Jan. 24th-25th, 2012
- Finisar Matlab Model Bessel LPF best eye match $T_r/f = 6.8\text{ps}$

PAM-8 at 35 Gbps signaling rate

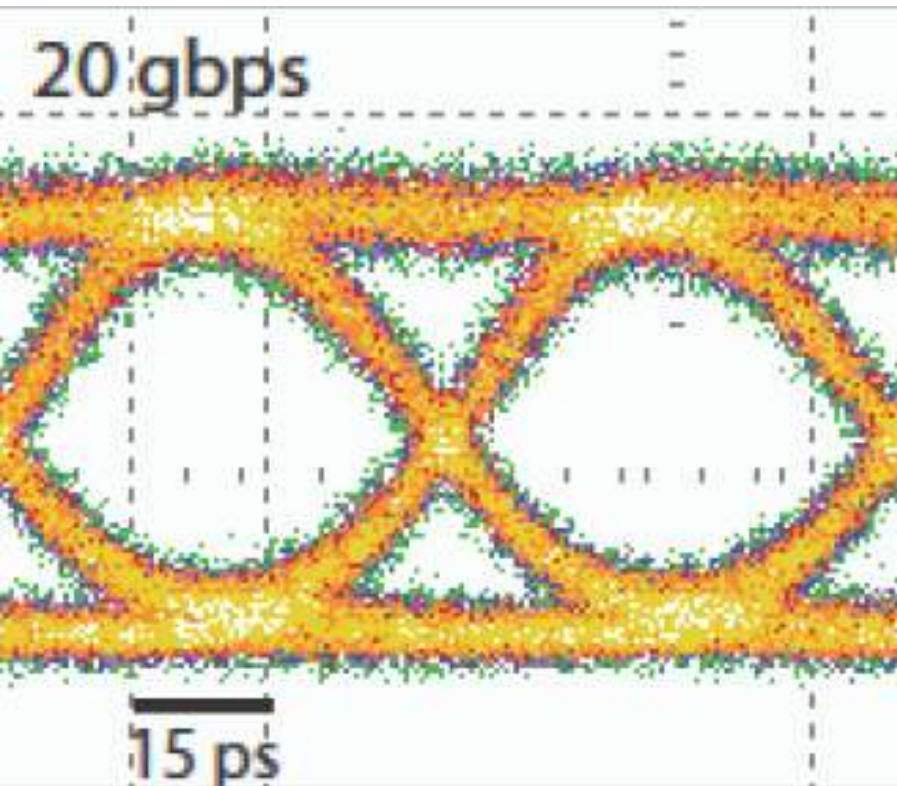


Bessel LPF PAM-8 35 Gb/s 6.8ps



Appendix: Ex. Reference to LPF Matching

- J. Rosenberg, et al., (IBM), “Low-Power 30 Gbps Silicon Microring Modulator”, PDPB9, OSA/CLEO 2011
- IBM Reference Reported $T_r/f = 22\text{ps}$
- Finisar Matlab Model Bessel LPF best eye match $T_r/f = 20\text{ps}$



Bessel LPF NRZ 20 Gb/s 20ps

