Scalability of Duobinary Signaling to 25 Gb/s for 100 GbE Applications

A. Adamiecki, M. Duelk, J. Sinsky, M. Mandich
Bell Labs, Lucent Technologies

Supporters

- **Broadcom**
  - Ali Ghiasi
- **FCI**
  - Dana J. Bergey
- **VITESSE, Corp.**
  - Majid Barazande-Pour
  - John Khoury
  - Nitish Amin
  - Apoorv Srivastava
- **Calispell**
  - Glen Koziuk

Talk Outline:

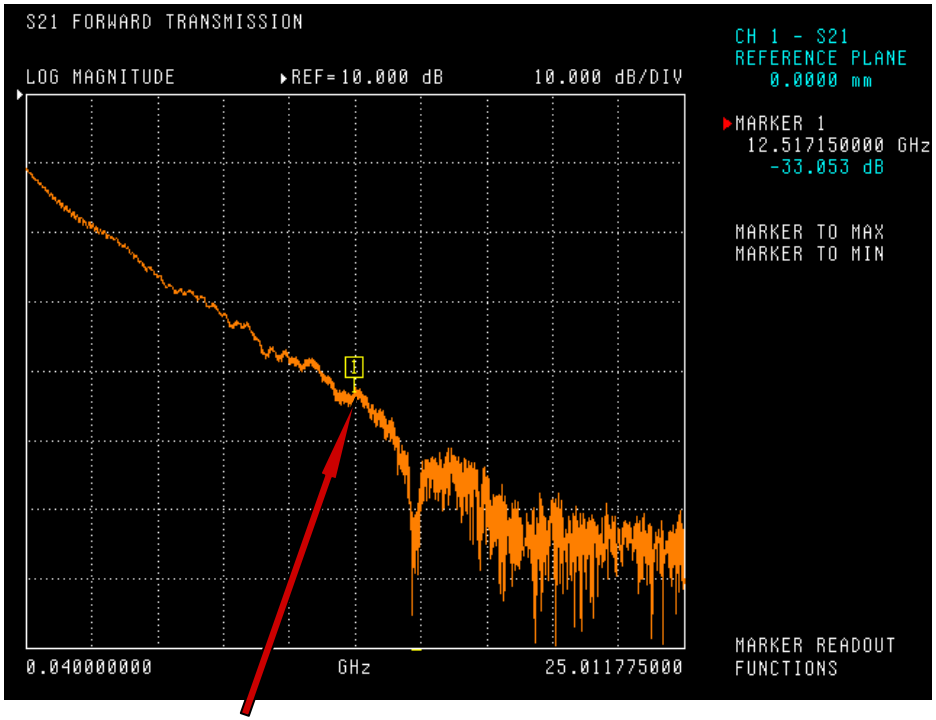
- Introduction - Motivation for 25 Gb/s experiment
- Measurements Test Setup
- Key Hardware Components
  - 25 Gb/s Duobinary-to-NRZ Decoder
  - Backplane designed for 10 Gb/s supplied by FCI
- Measurement Results
- Simulation and Measurements Data Comparison
- Conclusions

Motivation for 25 Gb/s experiment

- Address scalability of 10 Gb/s Ethernet backplane signaling choices to next generation technology
- Next logical rate for Ethernet is 100 Gb/s Ethernet
- Four lane PHY for 100 GbE would be 4 x 25 Gb/s
- NRZ signaling at 10-12.5 Gb/s has been demonstrated over good channels
- Duobinary electrical signaling is the obvious solution for 25 Gb/s electrical transmission because of 2x bandwidth compression

Backplane channel characteristics reveal need for bandwidth compression to achieve 25 Gb/s

Example of back-drilled backplane with improved channels:
24” link where notch due to stub effects moved above 10 GHz

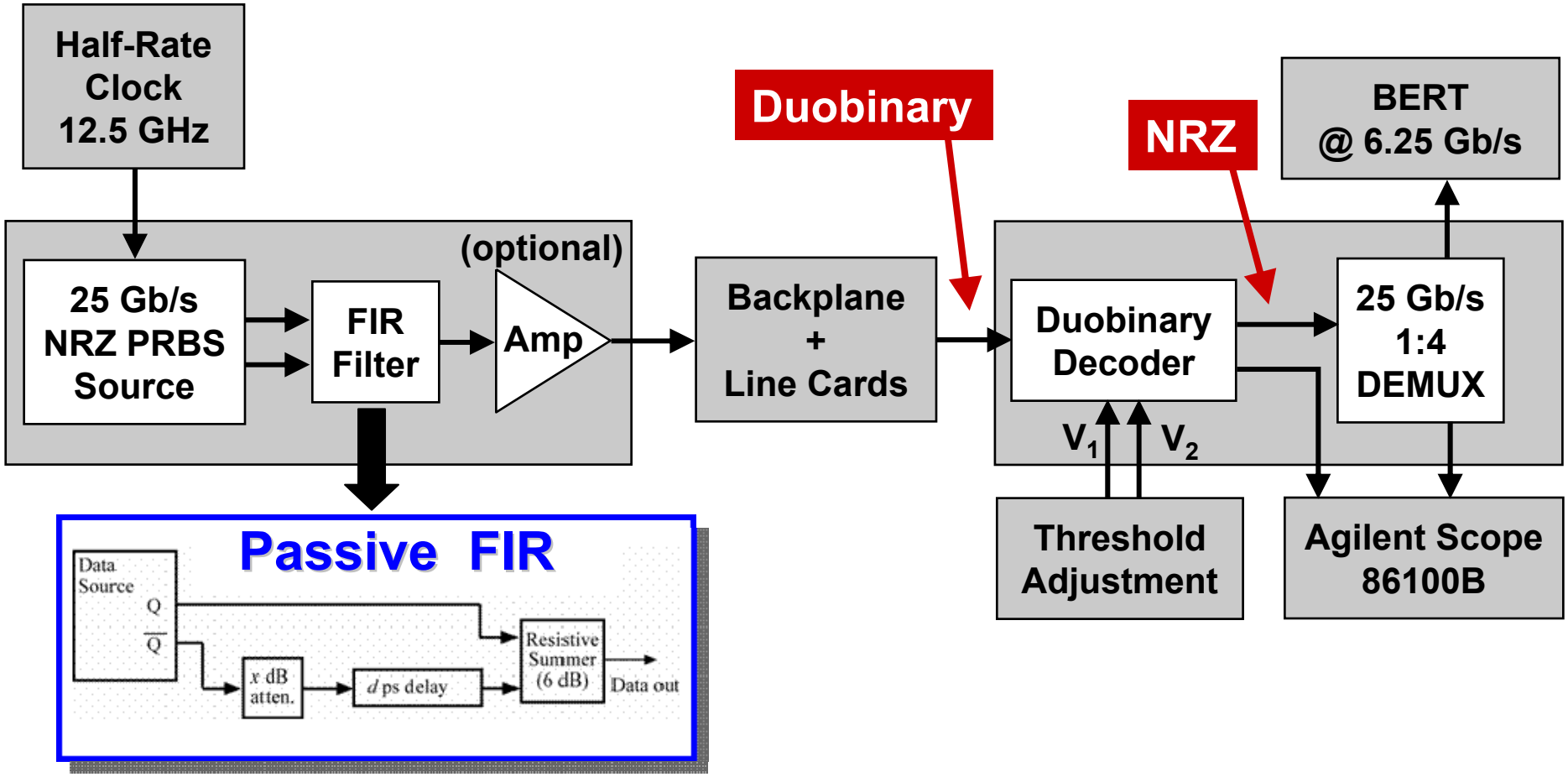


33dB down @ 12.5GHz

Achieving 25 Gb/s over this channel

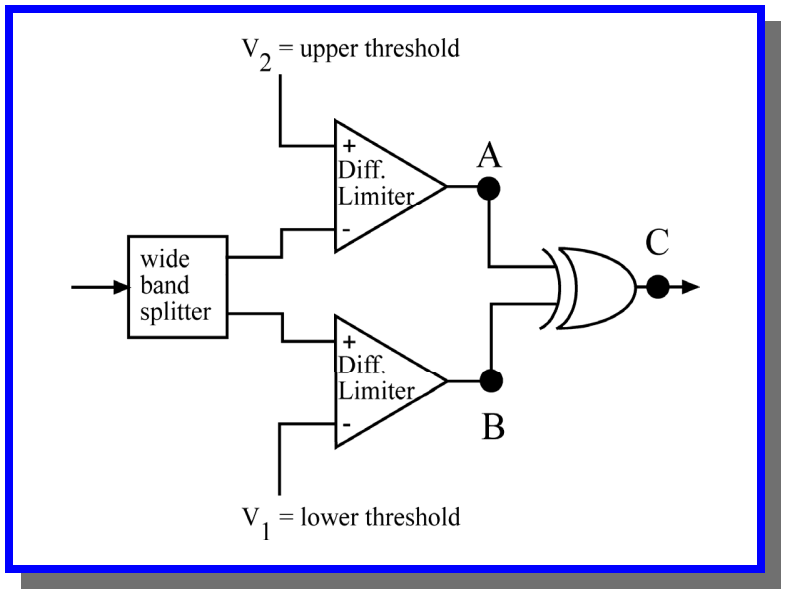
- *Need bandwidth compression*
- *Need maximum eye opening for given voltage swing*
- *Duobinary signaling does both!*

25 Gb/s Measurement Test Setup

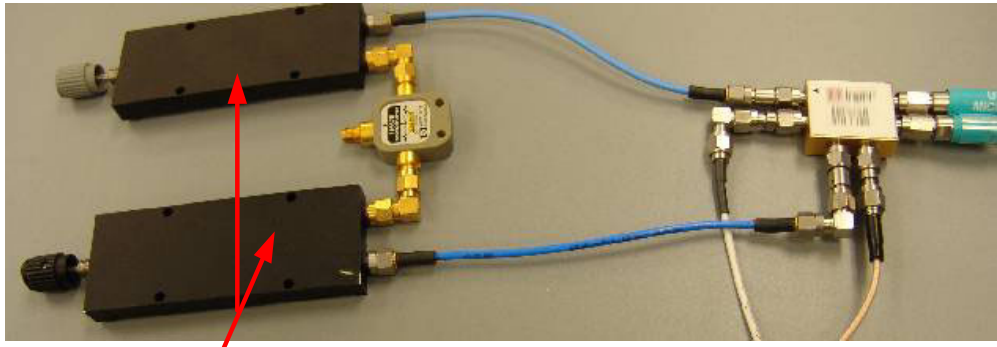


25 Gb/s Duobinary-to-Binary Decoder

Basic Concept

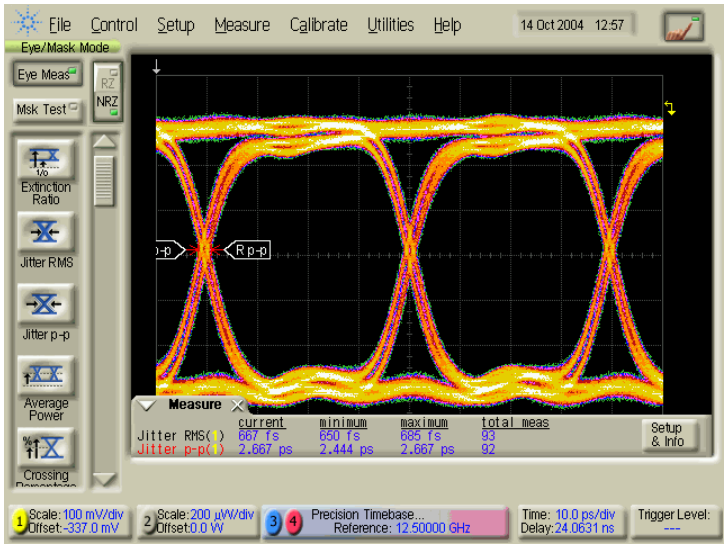


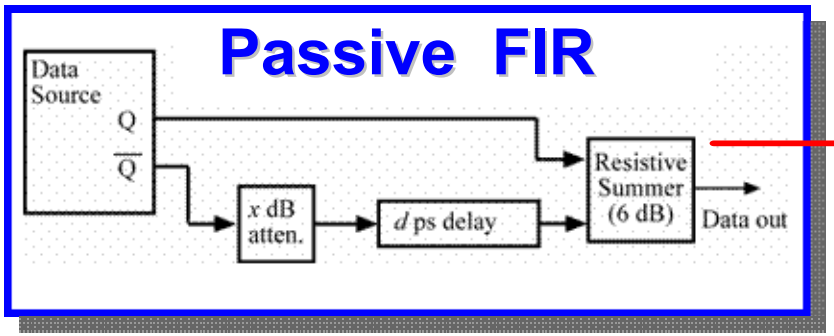
Physical implementation

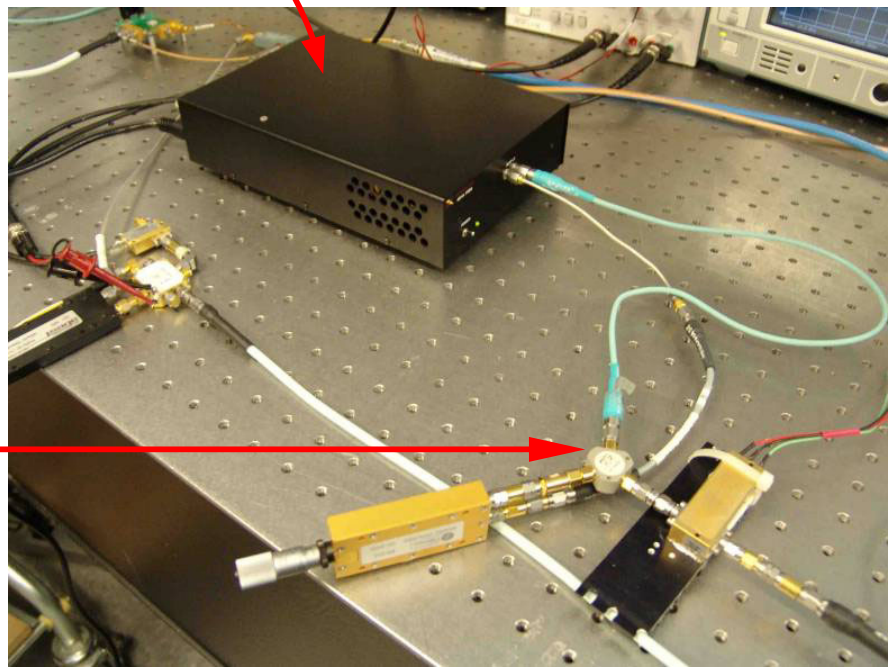


Delay Lines – *used to balance the different electrical lengths of various coaxial components*

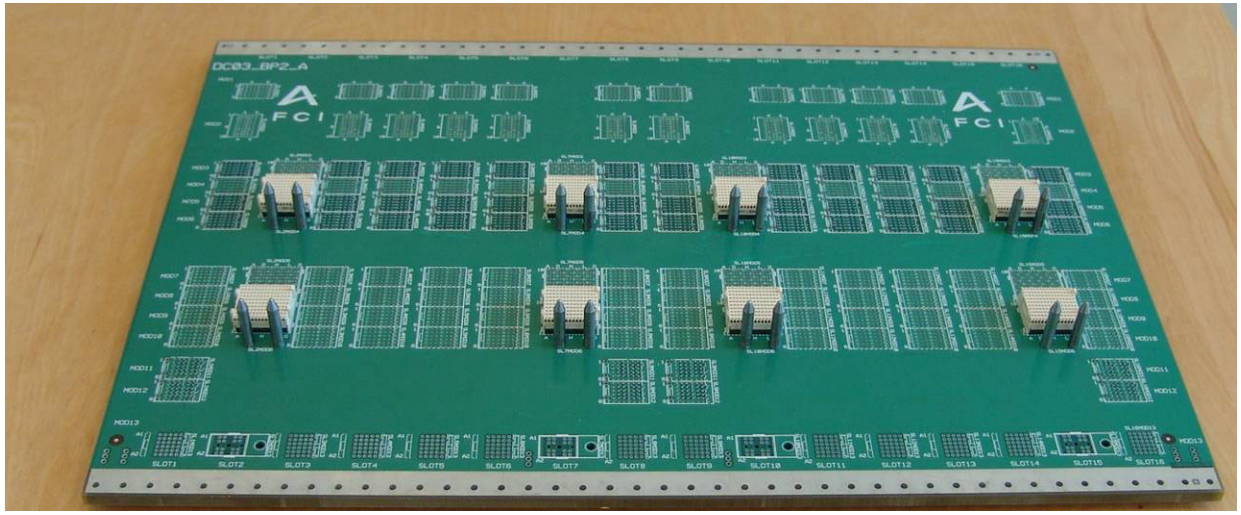
25 Gb/s PRBS Transmitter with 2-tap Passive FIR Filter

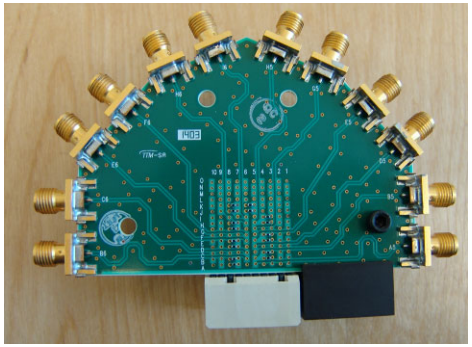






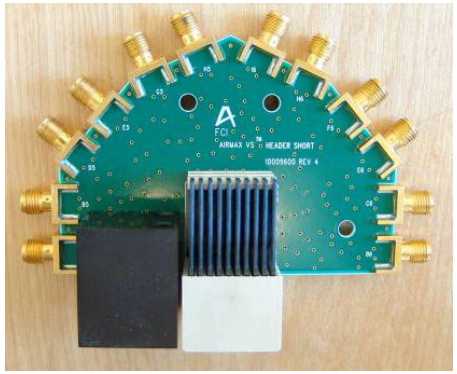
FCI AirMax 10G Demo Backplane + 2 Line Cards





Line Card: Bottom View

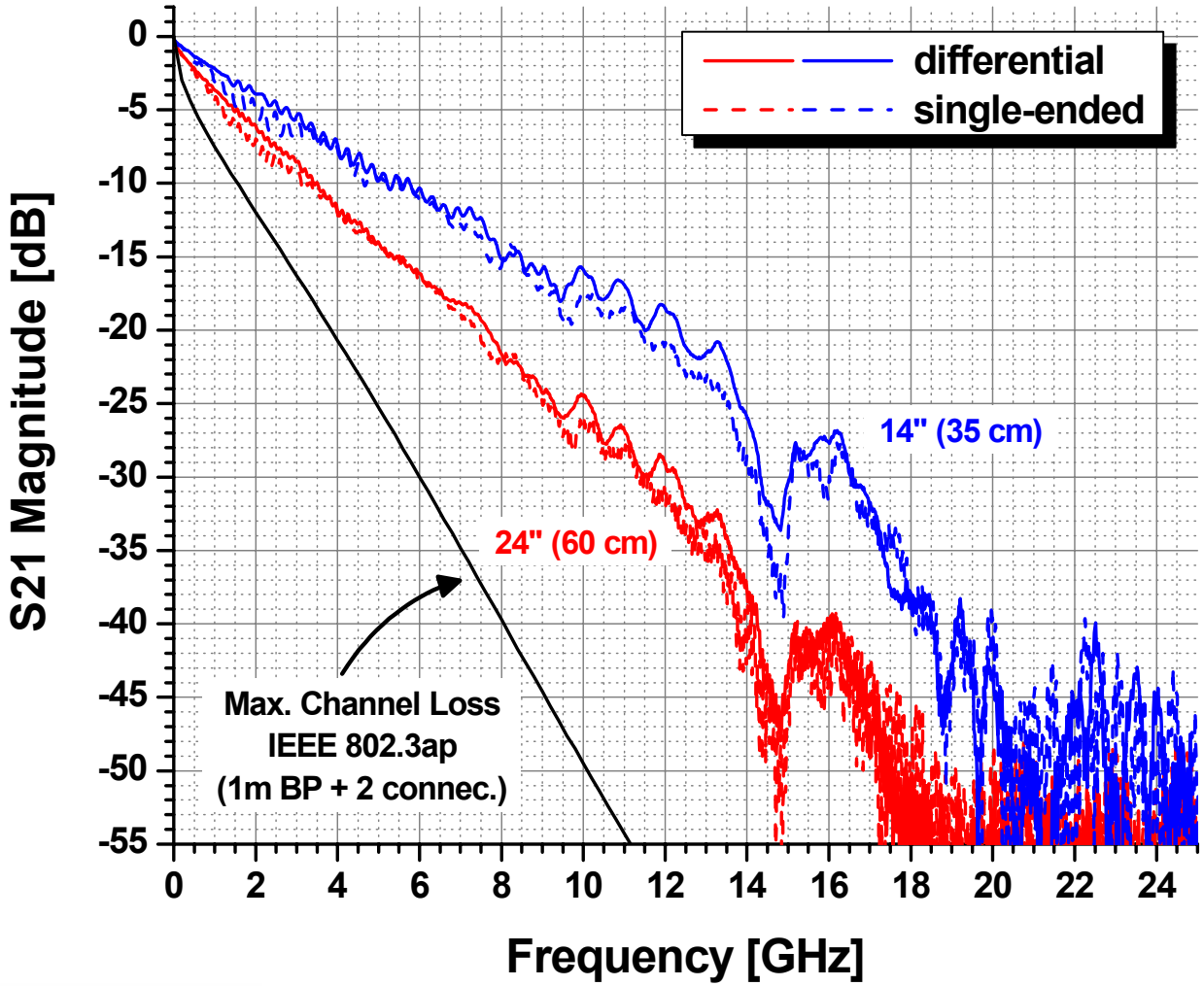
Board Name	PCB Material	Line Lengths	Layers	Connector Type
AIRMAX Backplane	Nelco 4000-6	7.5cm, 25cm 50cm, 75cm	20	AirMax VS®
2 Line Cards	Rogers RO4350	5cm each	2	AirMax VS®



Line Card: Top View

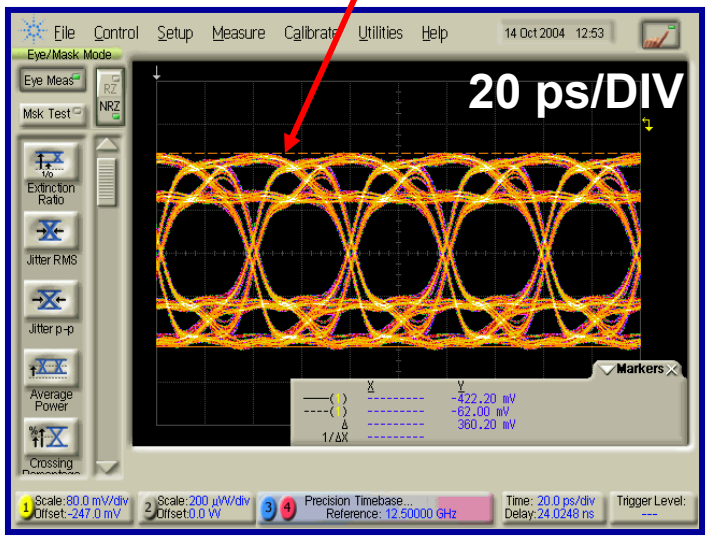
Selected Channels for 25 Gb/s Transmission

14" (35cm) and 24" (60cm)



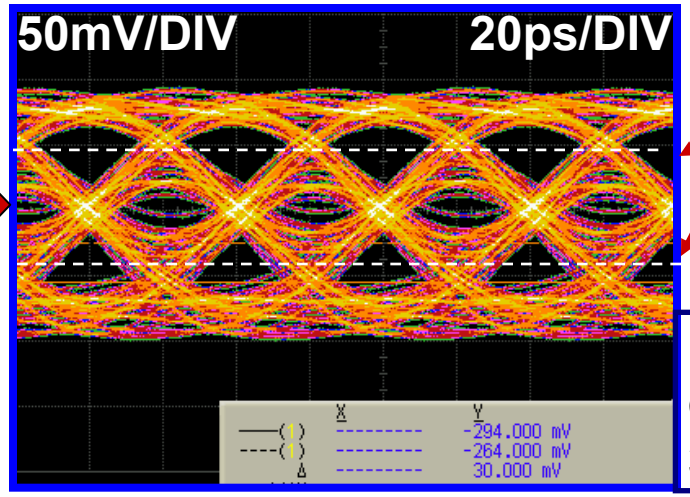
Measurement Results: 14” (35cm) Link

Pre-emphasized data.
Backplane input amplitude: 360 mV_{pp}



2-tap FIR Filter: -9.4 dB, 60 ps

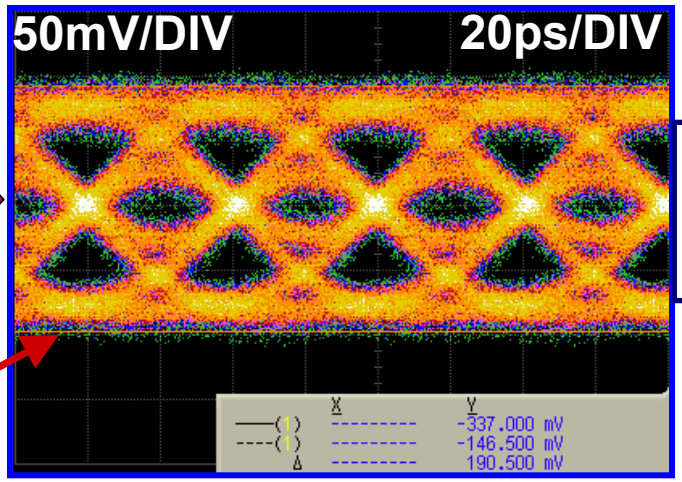
Backplane output for PRBS 7



decision thresholds

Eye openings: 30/40 mV

Backplane output for PRBS 15

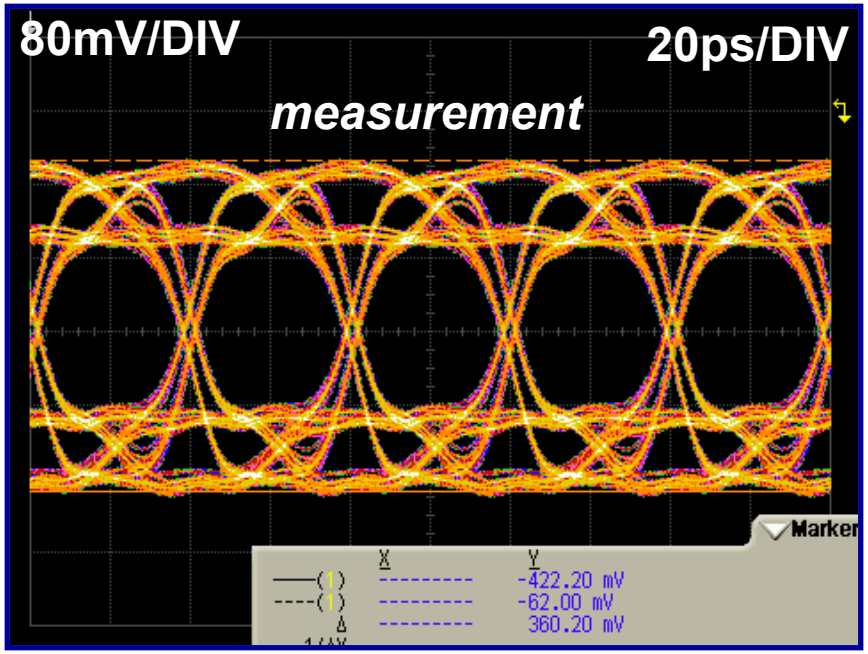


Eye openings: 2x26 mV

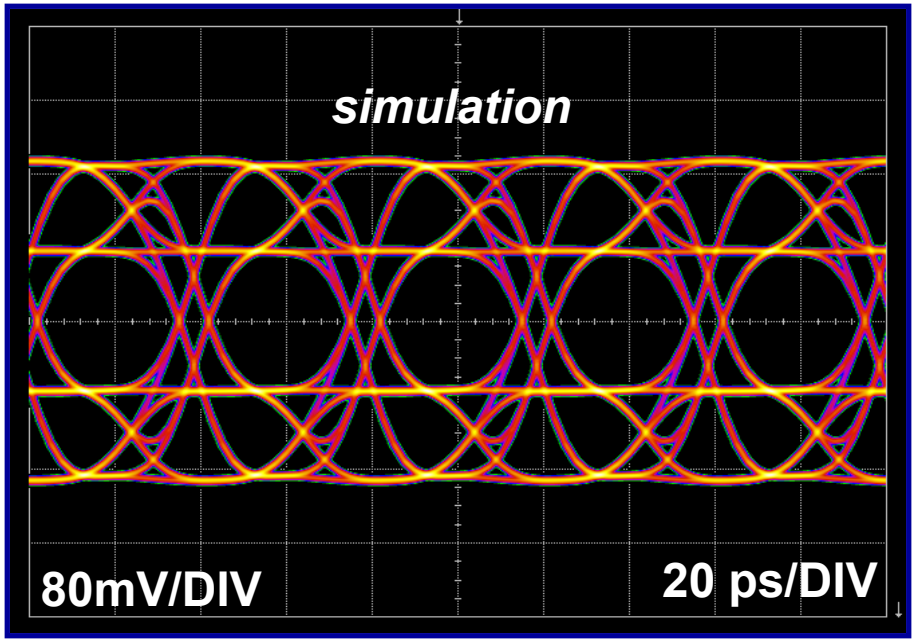
Amplitude 190 mV_{pp}

Backplane Input: 14” (35cm) Link

PRBS 7, single-ended



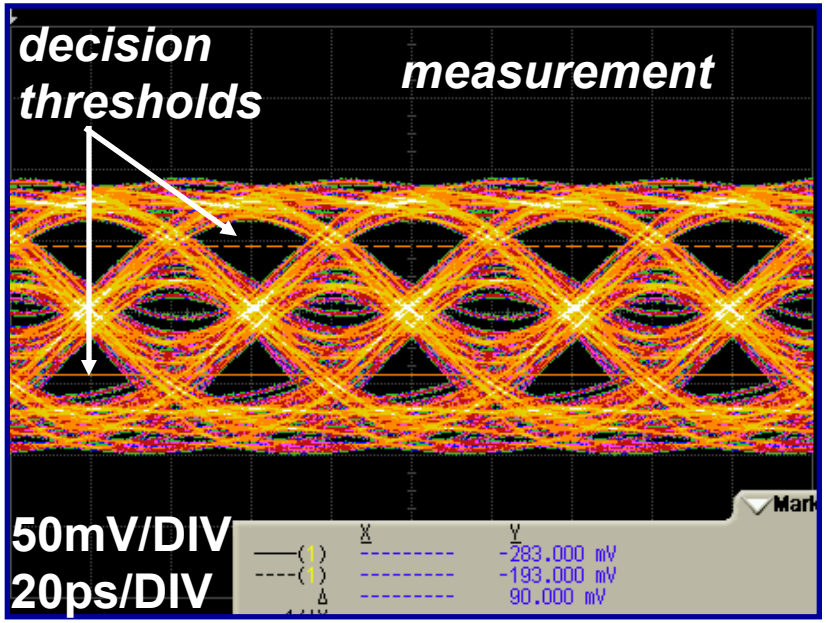
2-tap FIR: -9.4 dB, 60 ps,
Amplitude: 360 mV_{pp}

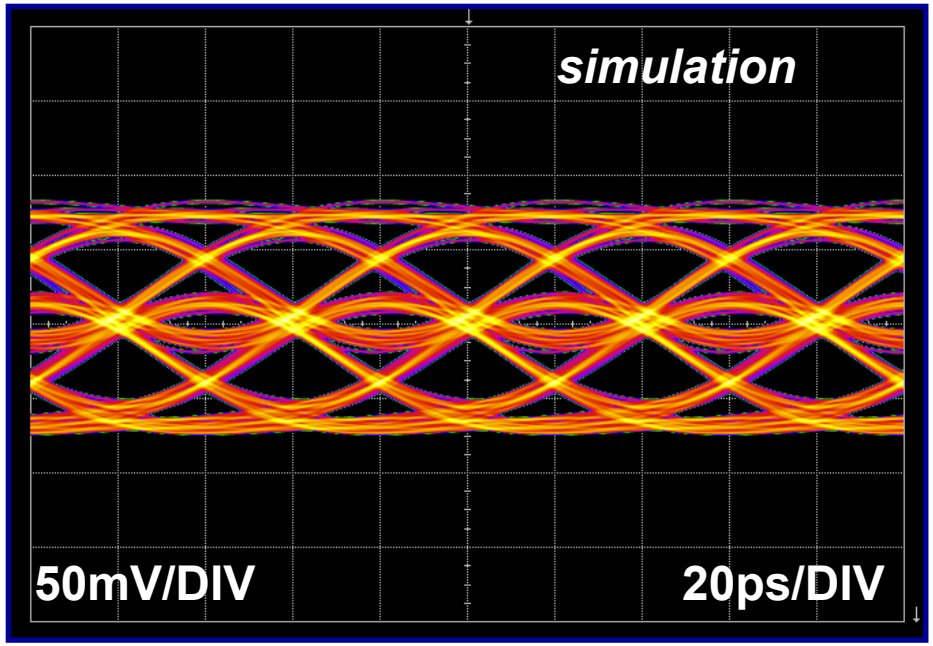


2-tap FIR: -8.0 dB, 65 ps
Amplitude: 340 mV_{pp}

Backplane Output: 14” (35cm) Link

PRBS 7, single-ended



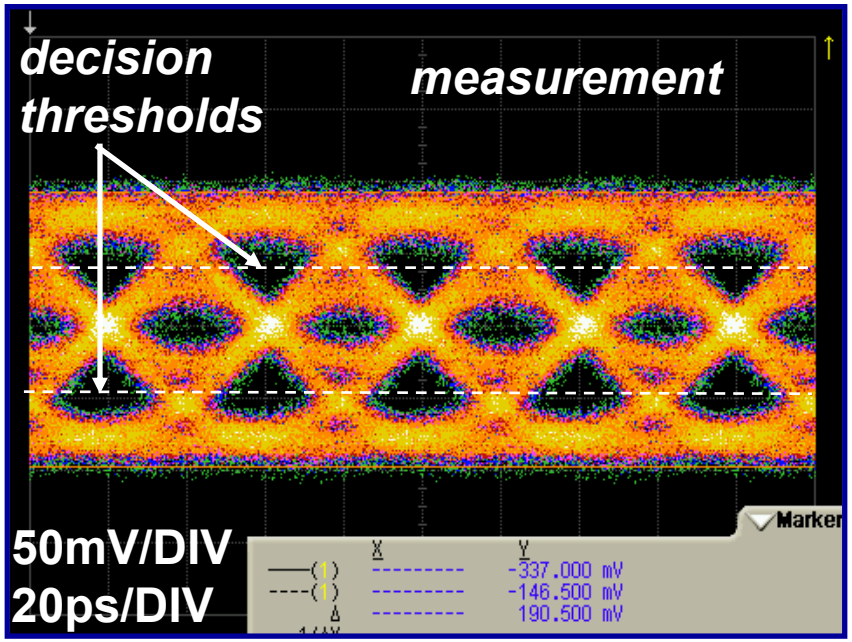


2-tap FIR: -9.4 dB, 60 ps
Output Amplitude: 190 mV_{pp}
Eye Openings: 30mV_{pp} / 40mV_{pp}

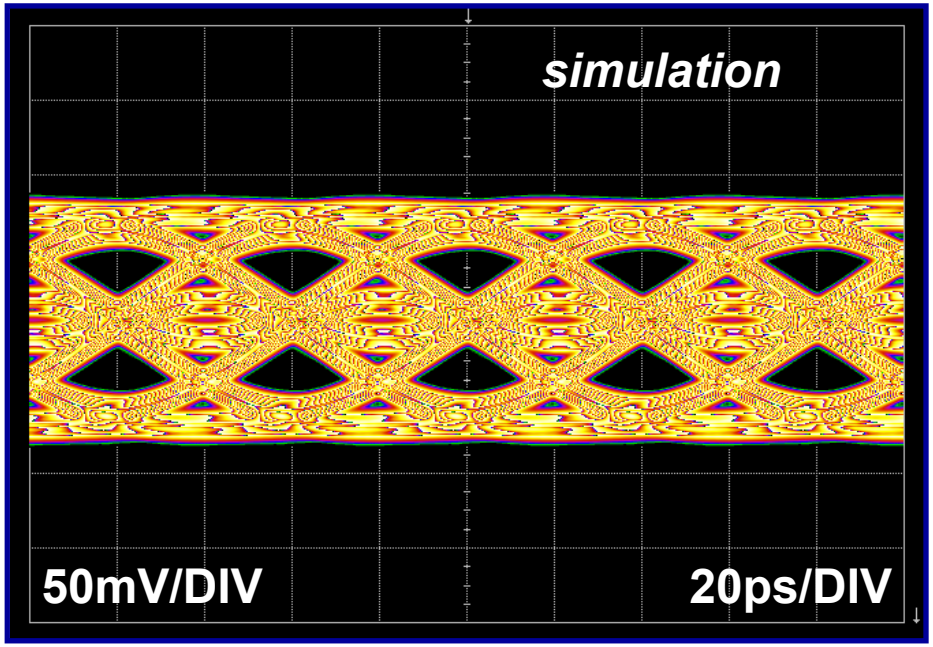
2-tap FIR: -8 dB, 65 ps
Eye Openings: 2x42 mV_{pp}

Backplane Output: 14” (35cm) Link

PRBS 15, single-ended

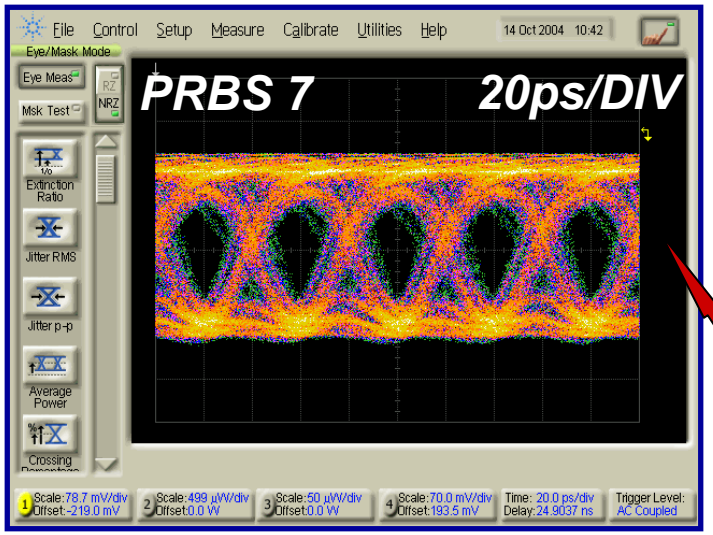


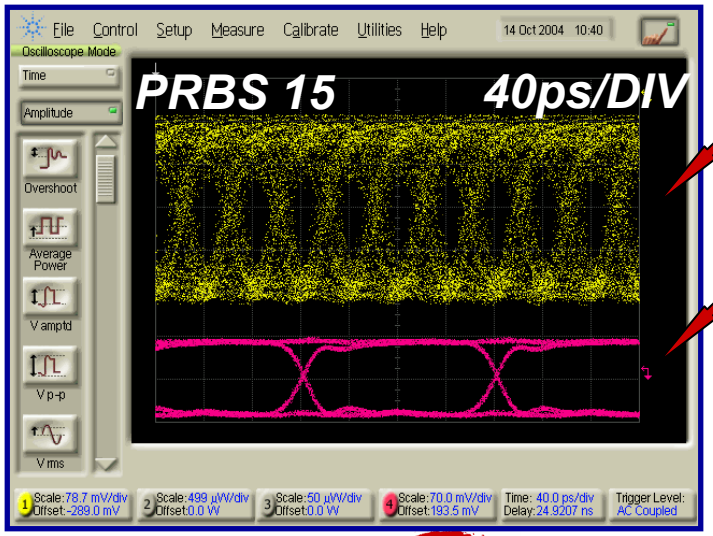
2-tap FIR: -9.4 dB, 60 ps
Output Amplitude: 190 mV_{pp}
Eye Openings: 2x26 mV_{pp}



2-tap FIR: -8.0 dB, 65 ps
Eye Openings: 2x31 mV_{pp}

Decoder Output: 14” (35cm) Link





NOTE: Duobinary decoder was working at the sensitivity limit since the backplane input was only 360 mV_{pp} single-ended !

Duobinary-to-NRZ Decoder Output @ 25 Gb/s

Demuxed NRZ Data @ 6.25 Gb/s

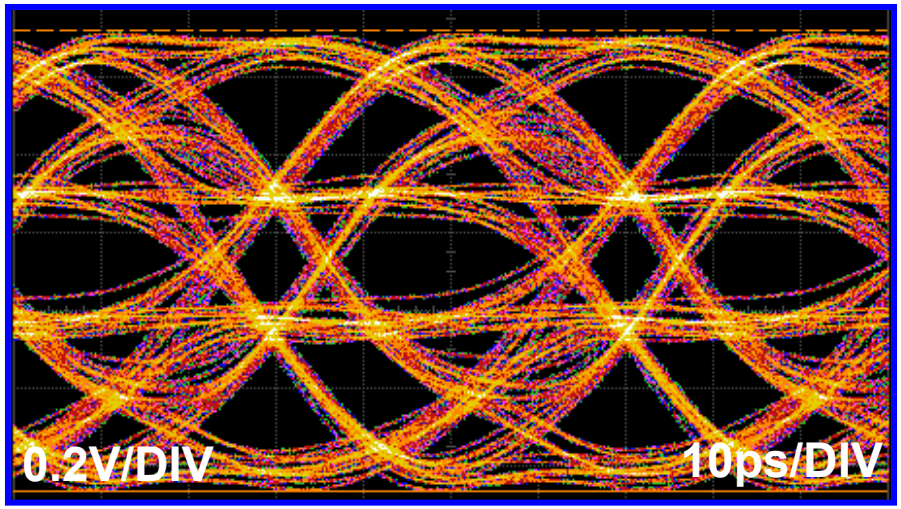
- BER @ PRBS 7 $< 10^{-13}$ *
- BER @ PRBS 15 $< 10^{-13}$ *

* time-limited measurement

Measurement Results: 24” (60cm) Link

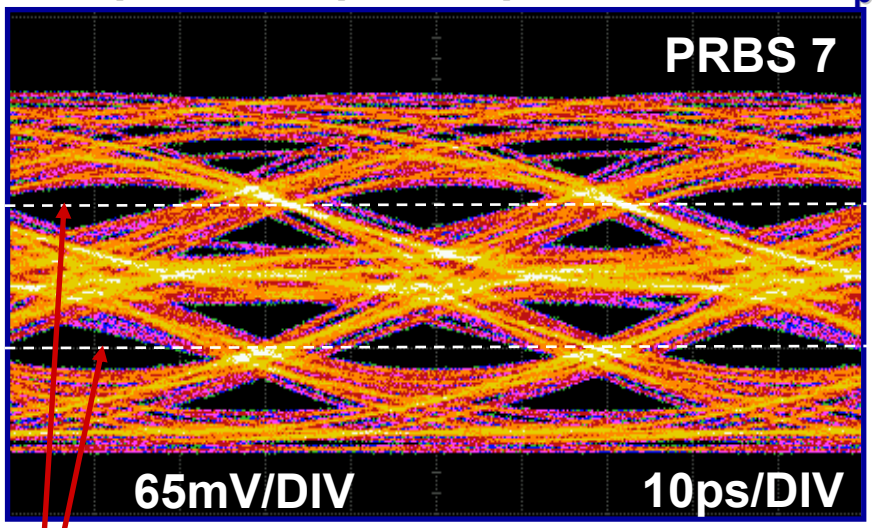
Pre-emphasized TX data

Backplane Input Amplitude 1200 mV_{pp}



2-tap FIR Filter: -6 dB, 60 ps

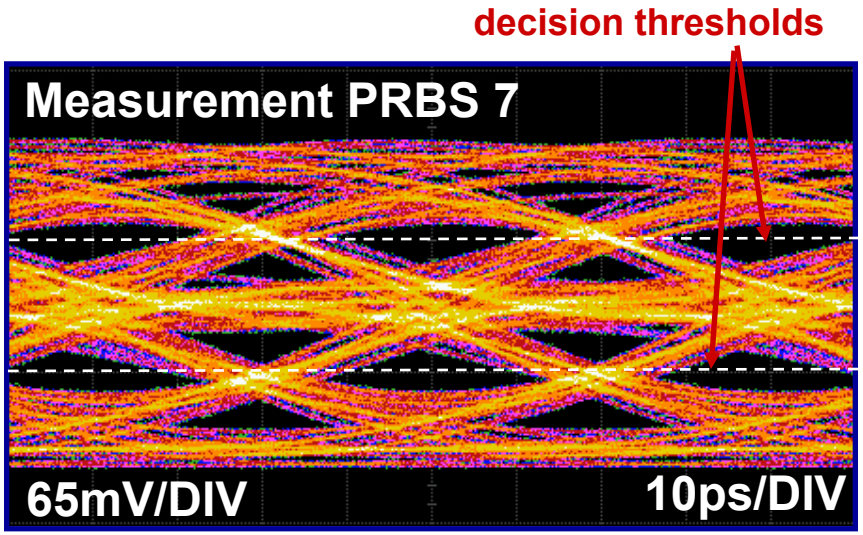
Backplane Output Amplitude: 270 mV_{pp}

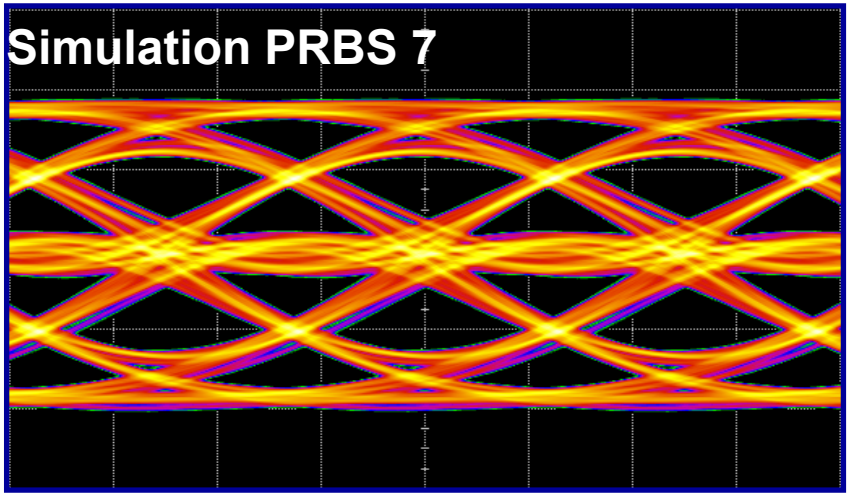


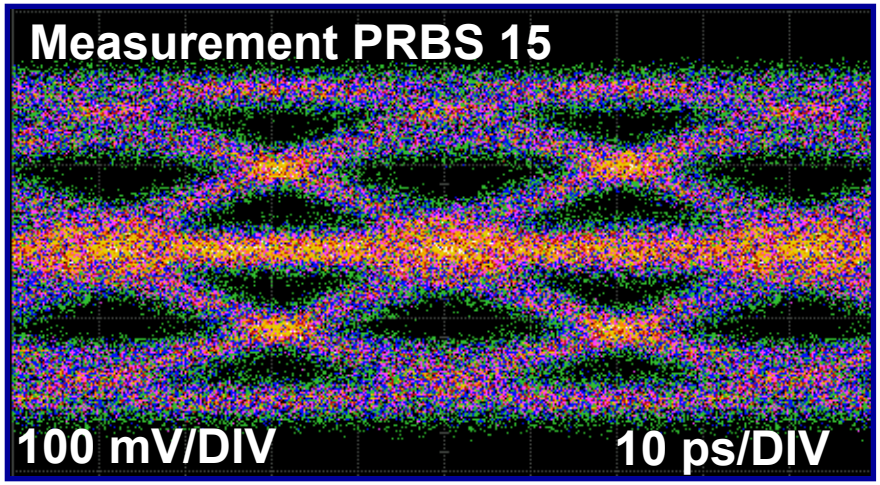
Eye opening: 2x30 mV_{pp}

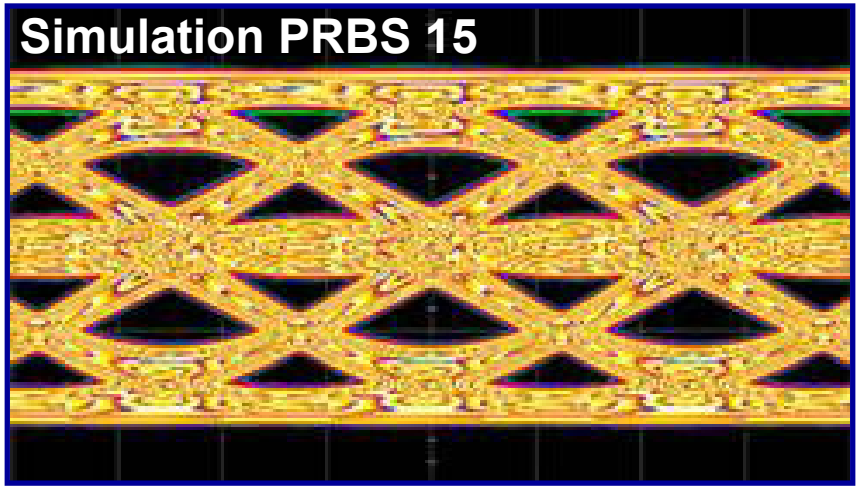
decision thresholds

Backplane Outputs : 24” (60cm) Link

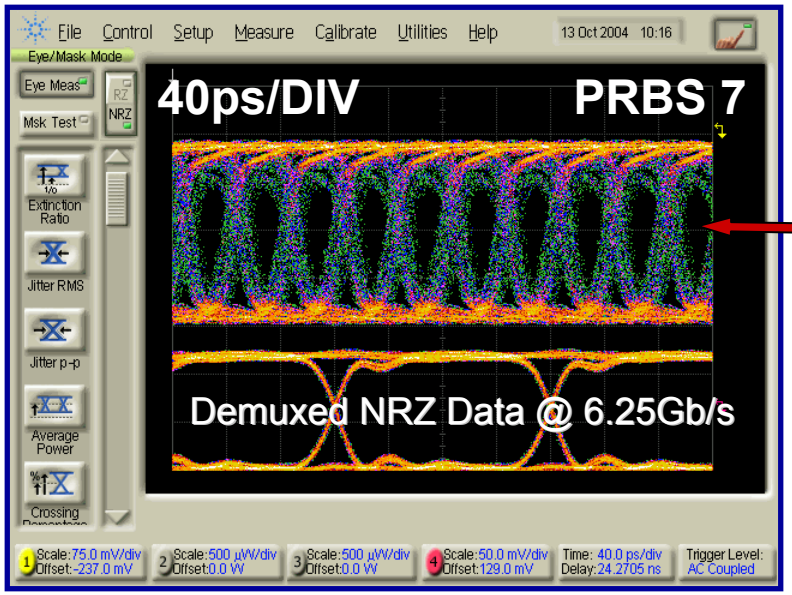




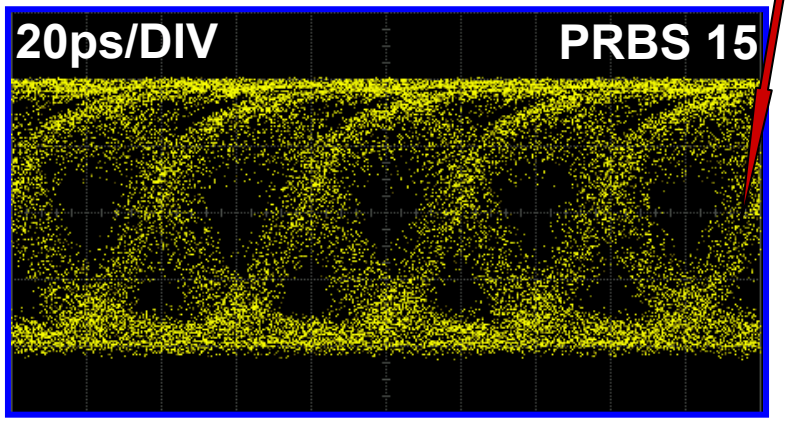




Decoder Output: 24” (60cm) Link



Duobinary-to-NRZ Decoder Output @ 25 Gb/s

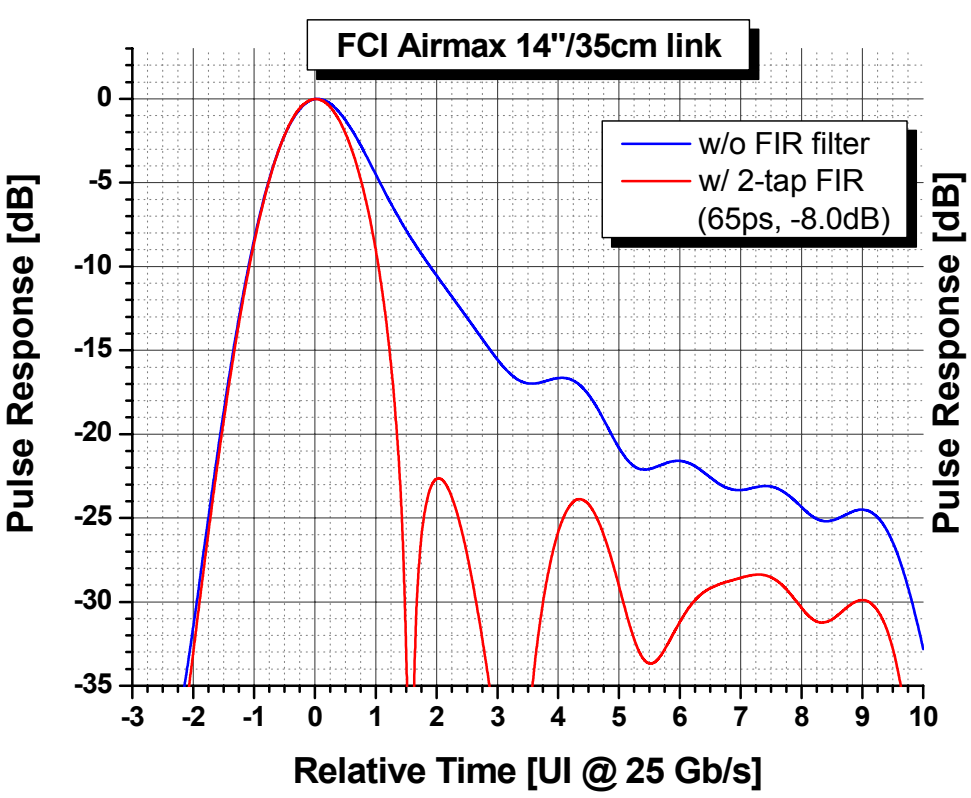


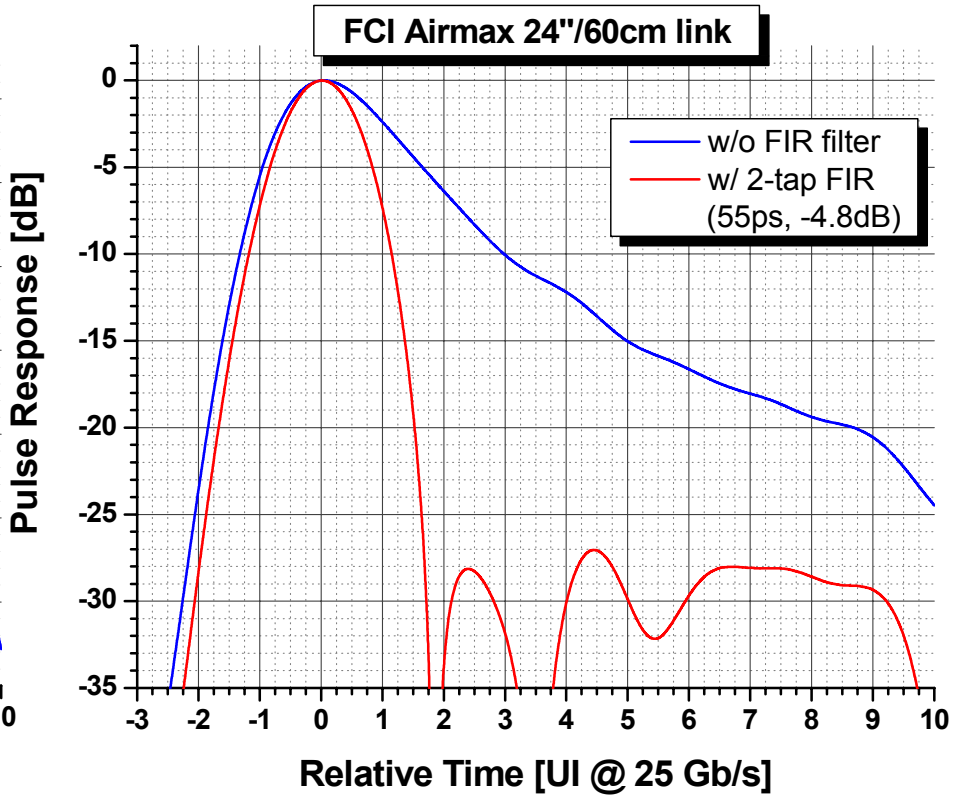
- **BER @ PRBS 7 < 10^{-13} ***
- **BER @ PRBS 15 < 3×10^{-10} ****

*** time-limited measurement**

**** BER could be improved by using further suppression of pre- and post-cursors using more taps at pre-emphasis FIR filter or FFE/DFE @ Rx. Not an issue in IC implementation !**

S21 – Single-ended Log10 Pulse Responses





→ -13 dB suppression of first (±1 UI) pre-/post-cursor required for ~10% eye closure !

→ 2-tap FIR filter yields only -9 dB (14'' link) and -7 dB (24'' link) ⇒ eye closure !

Test Results Summary @ 25 Gb/s

Trace Length	14 inches (35cm)		24 inches (60cm)	
PRBS Sequence	2^7-1	2^{15}-1	2^7-1	2^{15}-1
Single-ended Backplane Input (rail-to-rail)	360 mV_{pp}		1200 mV_{pp}	
Single-ended Backplane Output (eye opening)	40 mV_{pp} 30 mV_{pp}	2x26 mV_{pp}	2x30 mV_{pp}	2x20 mV_{pp}
Bit Error Rate	< 10^{-13}	< 10^{-13}	< 10^{-13}	< $3x10^{-10}$
FCI Backplane Link	Slot7Mod6_D5 to Slot10Mod6_J5		Slot7Mod6_D5 to Slot10Mod6_J5	
FIR Architecture	2-tap (-9.4dB, 60ps)		2-tap (-6dB, 60ps)	

Conclusions

- Using duobinary signaling, we have demonstrated 25 Gb/s electrical transmission over 14” and 24” links that include a backplane, 2 connectors and 2 line cards
- Duobinary signaling will enable 25 Gb/s signaling over higher performance backplanes and connectors
- Improved performance at 25 Gb/s should be realizable using, e.g., receiver equalization and lower loss backplane materials
- Duobinary signaling offers realistic possibility for scaling 10 GbE backplane signaling technology to 100 GbE

Backup Slides

FCI AIRMAX DEMO Backplane : Trace selection

- 35cm (Slot7Mod6_D5 to Slot10Mod6_J5 Signal Layer7)

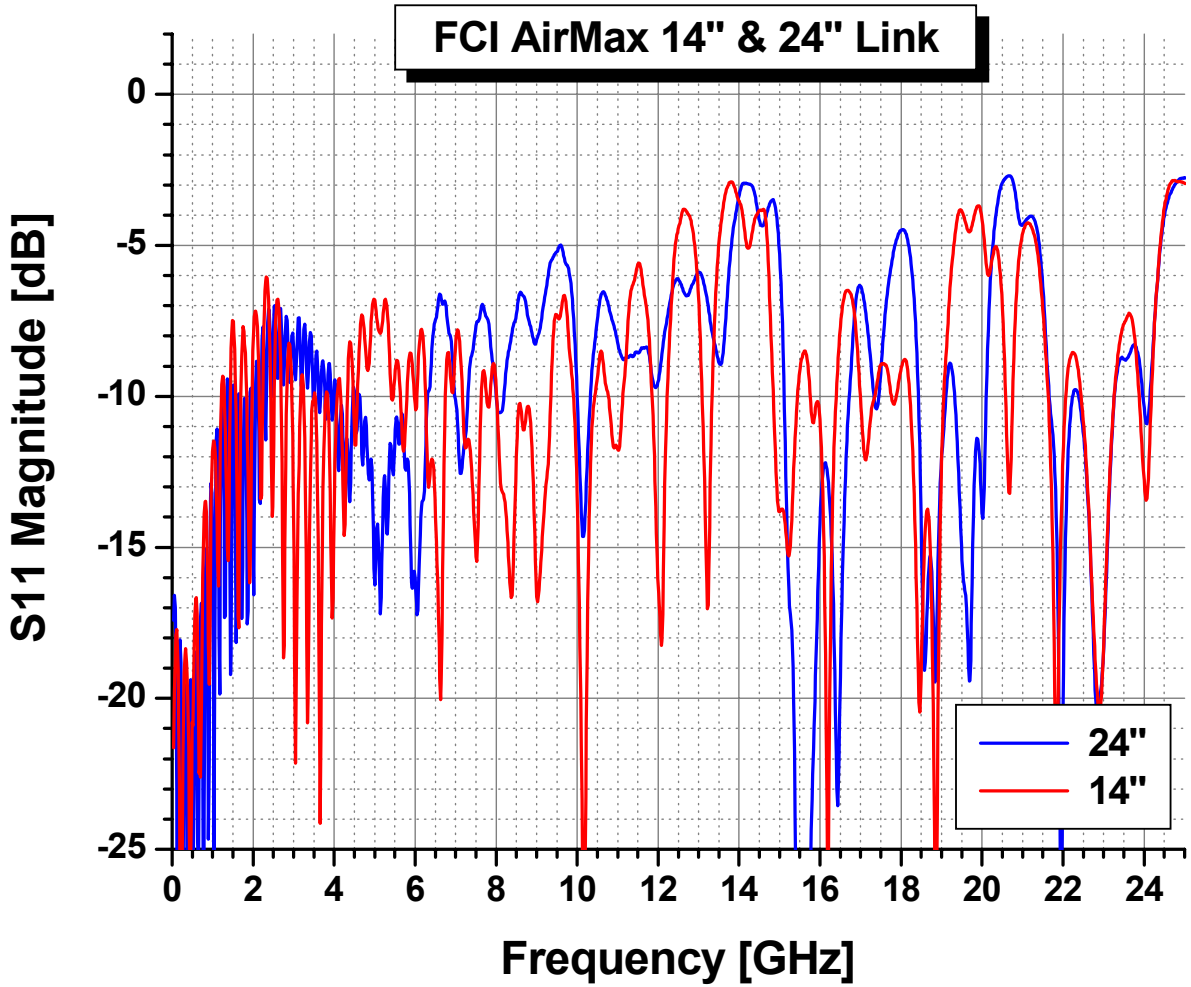
  Total length: 14” (25cm backplane + 2 Line cards, each 5cm)

- 60cm (Slot2Mod4_D5 to Slot15Mod4_J5 Signal Layer7)

  Total length: 24” (50cm backplane + 2 Line Cards, each 5cm)

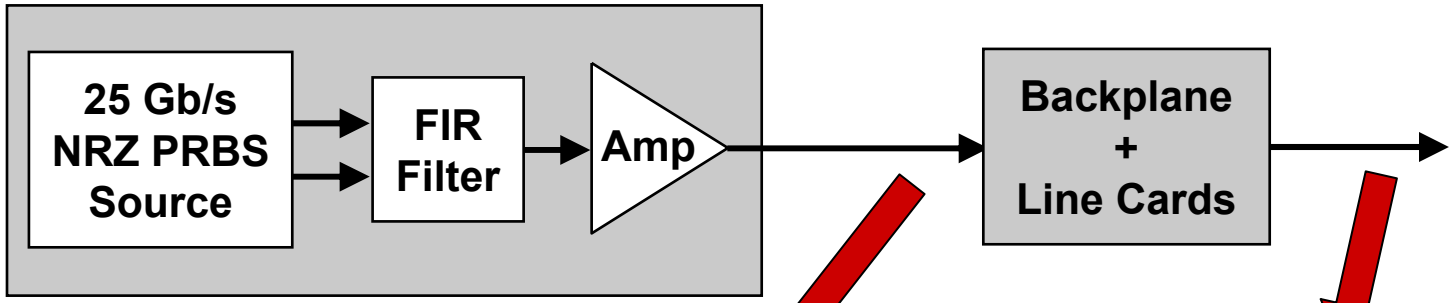
AIRMAX Demo Backplane	Board Thickness	Total Number of Layers	Number of Signal Layers	Back drilling On Selected Links
Nelco 4000-6	0.25”	20	7	0.038”

S11 – Single-ended Return Loss

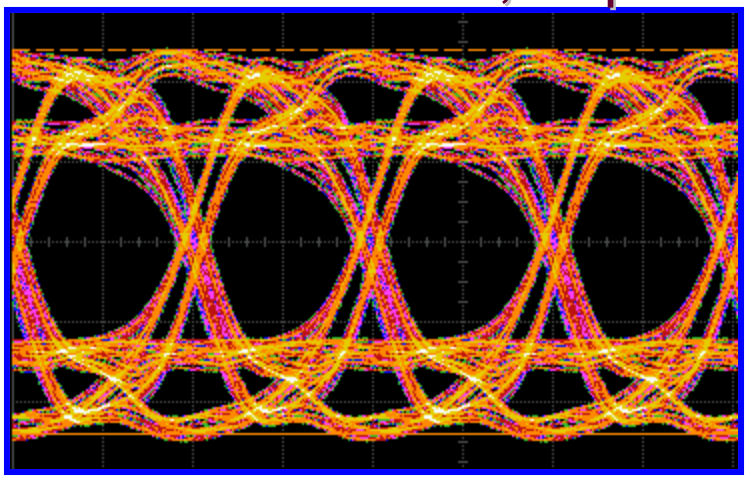


→ Return Loss larger than -10 dB above ~1 GHz (Sdd11 slightly better) !

Measurement results : 14” Link with FIR filter + amplifier (single-ended)

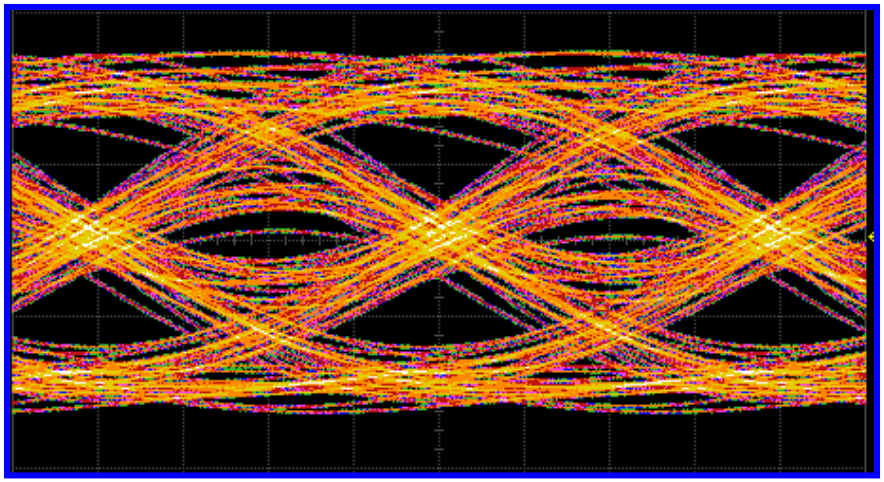


FIR Filter: -9.4dB, 60ps



Amplitude: 920 mV_{pp}

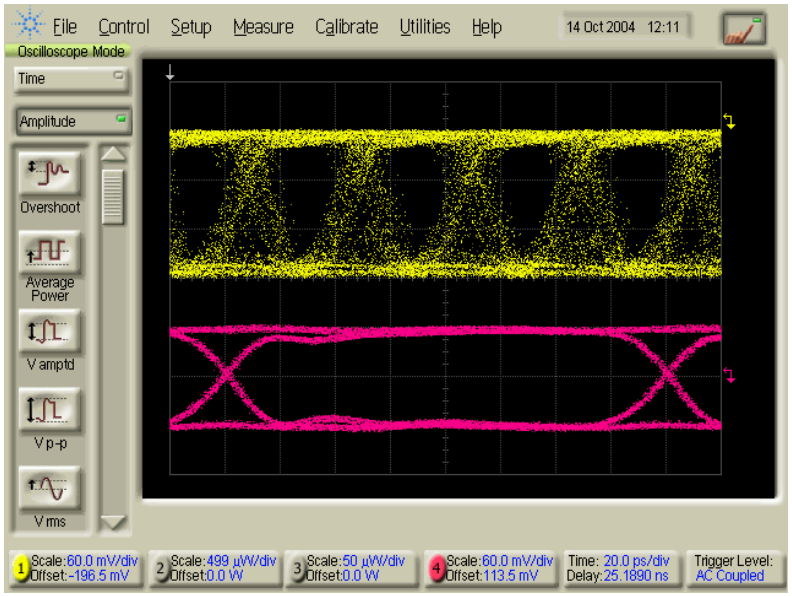
Backplane output

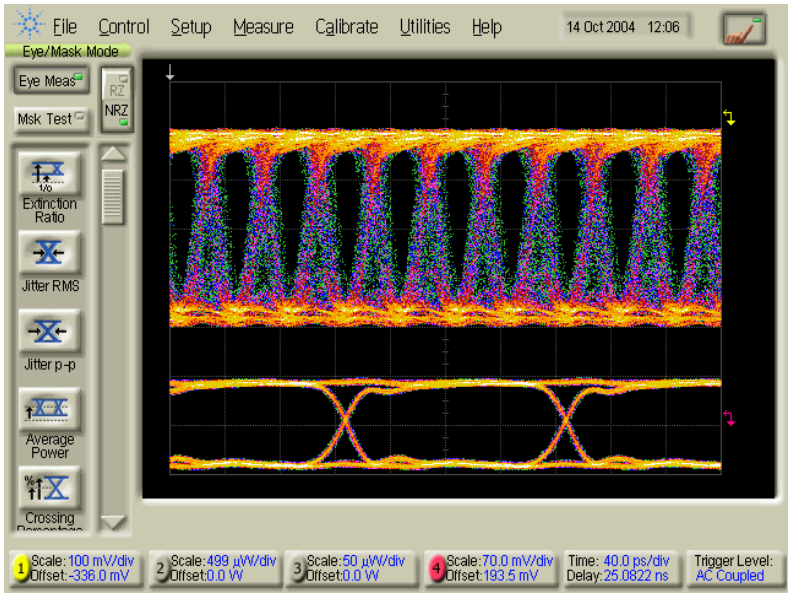


Amplitude: 460 mV_{pp}
Eye openings: 2x80 mV_{pp}

Measurement results : 14” Link with FIR filter + amplifier (single-ended)

Duobinary decoder output shown with demuxed NRZ data



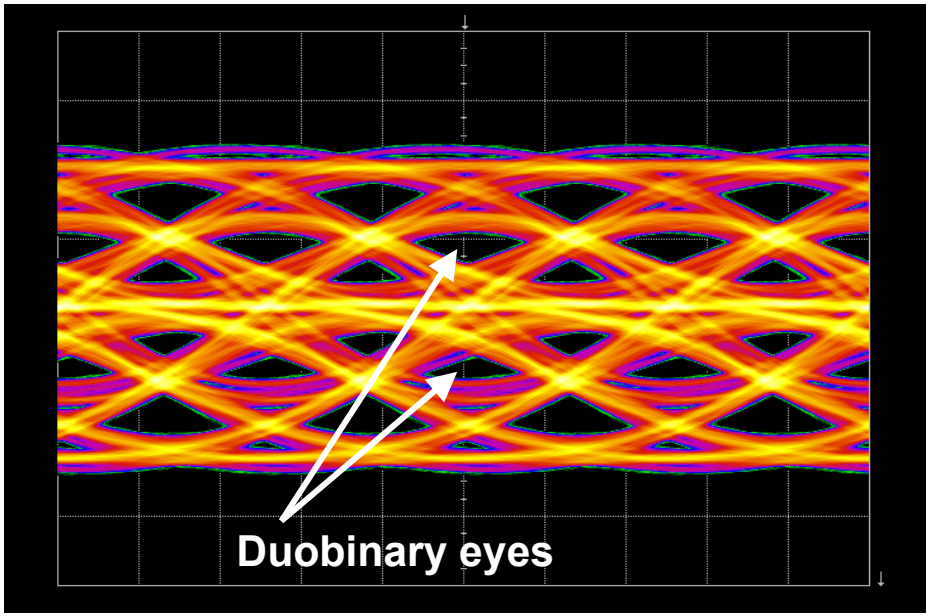


- BER @ PRBS 7 $< 10^{-13}$ *
- BER @ PRBS 15 $< 10^{-13}$ *

* time-limited measurement

25 Gb/s Duobinary Simulations through Proposed 10G IEEE 802.3ap Max. Loss Compliance Channel

- Channel: Proposed IEEE 802.3ap model for maximum loss of 10GE backplane channel (1m backplane + 2 connectors)
- Channel response S21 w/o phase information, 50 dB loss @ 10G
- Simulations with 3-tap integer-delay FIR filter: ±1 UI with -6.8 dB weight
  → more taps will open up eyes !
- 1000 mV_{pp} input into BP incl. pre-emphasis
- PRBS 7



10 mV/DIV
16ps/DIV

Notes on Simulations

- Differential transmission would have benefited mainly from reduced return loss (less reflections) and not so much from improved transmission loss Sdd21
- Simulations were carried out using only forward transmission Sdd21, Sdd11/Sdd22 were not considered
- Simulations with 0.5 ps_{rms} jitter and 2.0 mV_{rms} amplitude noise @ driver
- NRZ performs worse than Duobinary (assuming limited amplitude @ Tx and pre-emphasis only) even for shorter 14'' link, i.e. eye openings @ Rx for 600 mV_{pp} @ Tx:
  → NRZ ~ 1x40 mV_{pp}
  → DUO ~ 2x65 mV_{pp}