
High Speed Electrical Data Transmission on Long Flex Cables



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Outline

- Introduction
- Tools
- Impedance assessments
- Point-to-Point links
- Driving parallel lines
- Conclusions

Introduction

- A low-mass embedded flexible cable is a natural choice in stave-like concepts being developed in ATLAS to transmit the data from individual modules to the end for aggregation/readout.
- Investigating LVDS signal transmission on flex cable striplines of ~0.5-1m long at speeds of up to 320 Mbps.
- Assuming point-to-point links between hybrids and stave controller for data coming from the detector, at 160 or 320 MHz.
- Multi-tap clock/com lines run at likely lower speed.

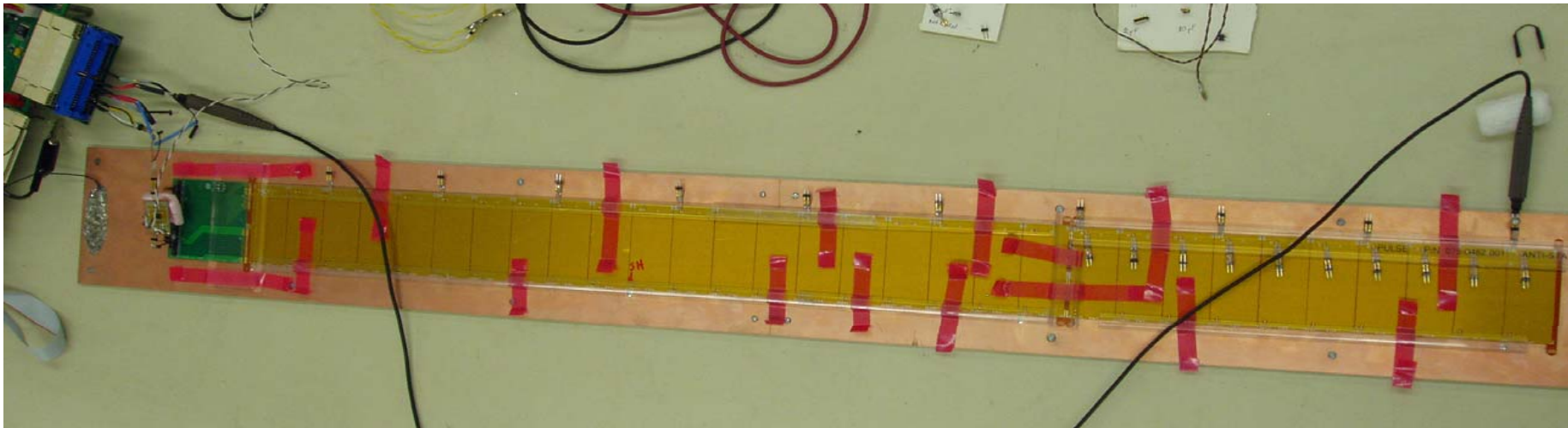
Prototype Stave Cables

A version of ATLAS strip stave's prototype cable from Carl Haber at use at UCSC.

- 1 meter long
- Hybrid locations (taps) every 3.3 cm

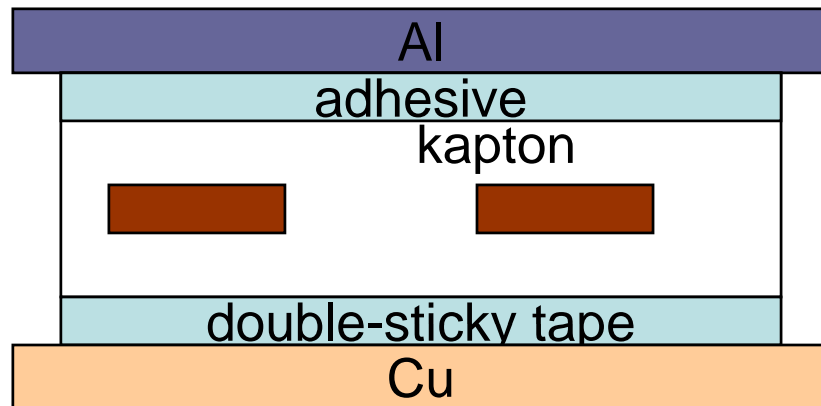
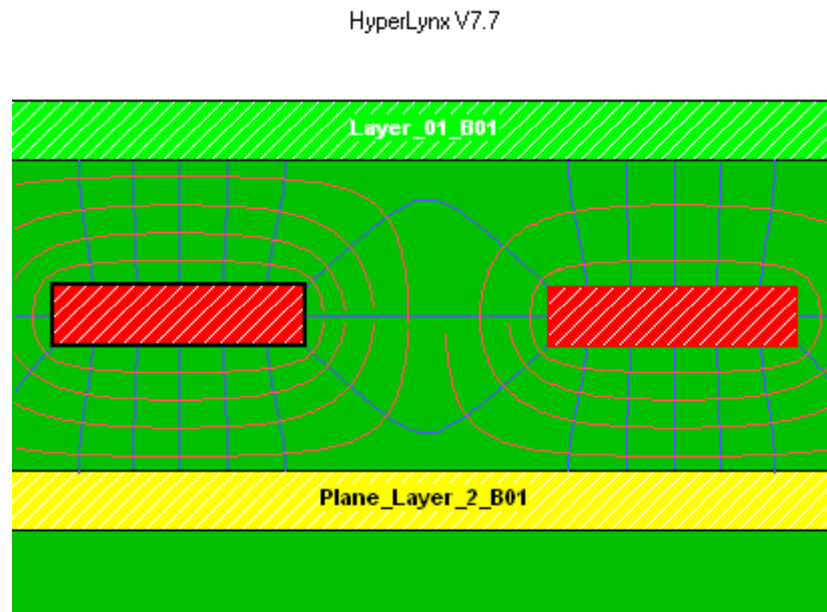
A similar cable (1.2 m, 24 taps, on carbon fibre) is built at Oxford for further prototyping.

Made connections for point-to-point links of up to 1 m long and the last group of 10 clock connections (parallel)



Use oscilloscopes and FPGAs for eye diagrams and bit error rate measurements.

Impedance



Geometry: 4 mill width, separation, 0.7 mill height, 2 mill of dielectric to metal layers.

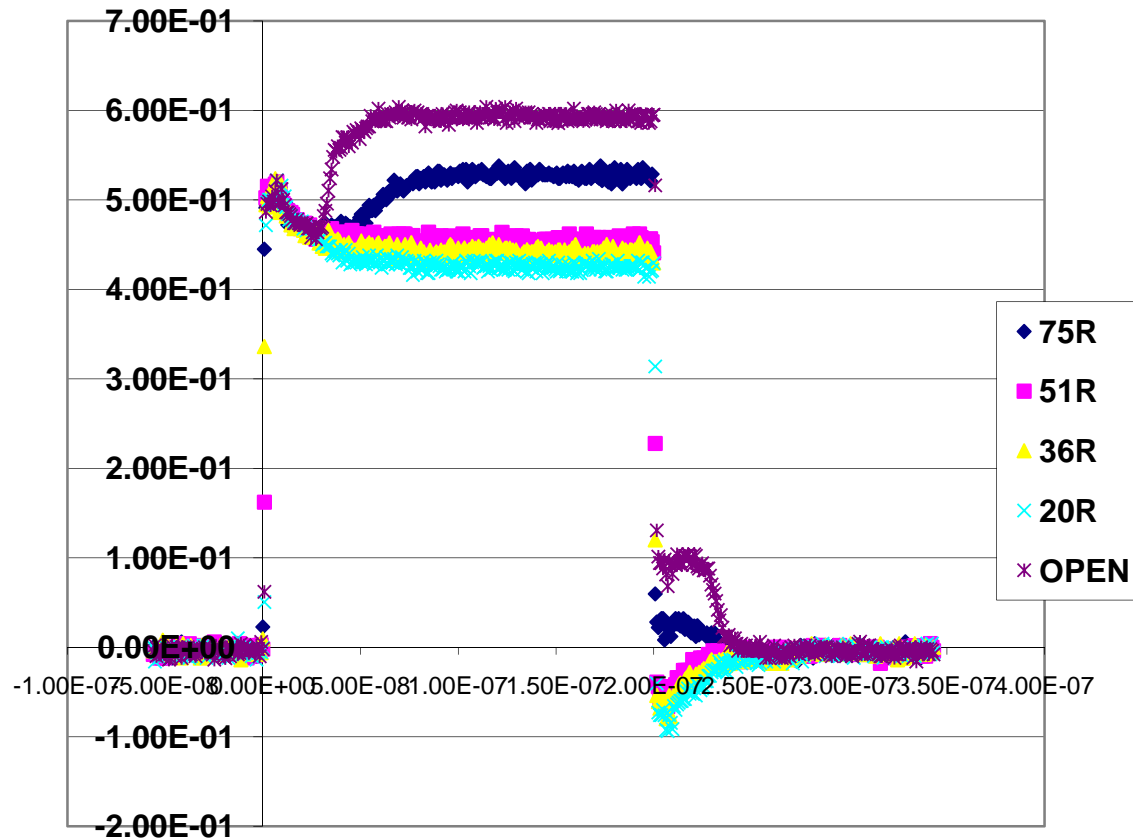
Impedance calculation
⇒ 56 Ohm .

This is somewhat idealized model.

In reality is more complicated, with a glue layer etc.

Will test with 50 and 75 Ohm terminations.

**Impedance tests
on the Oxford cable
(does not have to be
exactly the same as
for previous cable).**



TDR scope plots

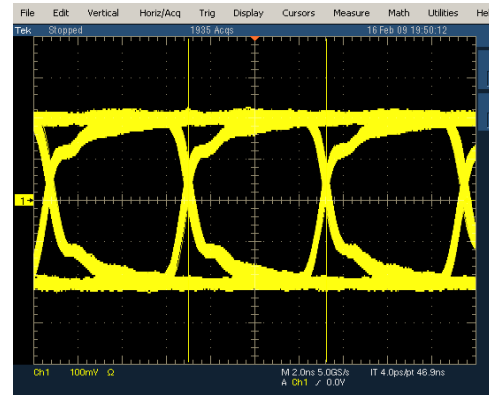
**Clear reflections with 75 Ohms.
Z ~ 30 to 50 Ohms (single ended)**

Point-to-Point Links

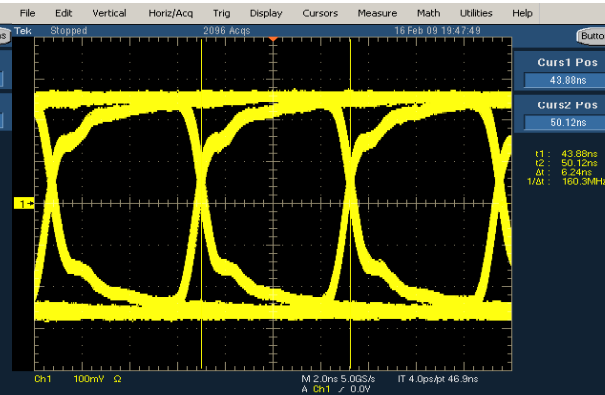
ED on point-to-point links at 160 MHz

LVDS is a current source standard =>
Amplitude =
 $3.5 \text{ mA} \times \text{Termination}$

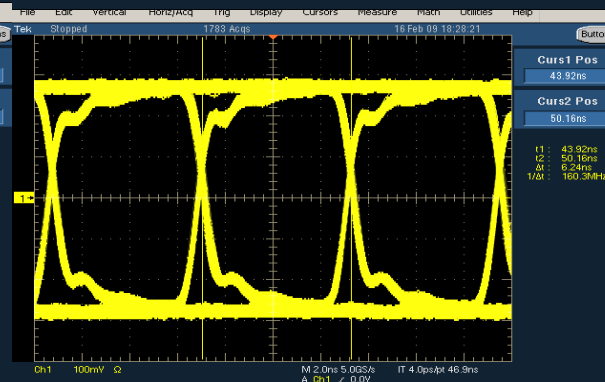
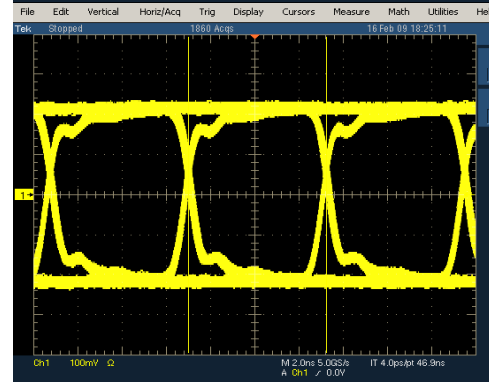
50 Ohm



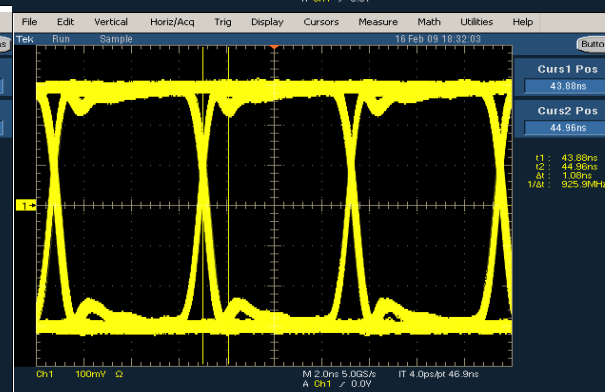
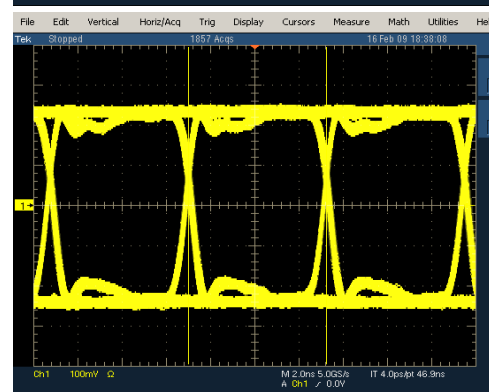
75 Ohm



~1m
Data30

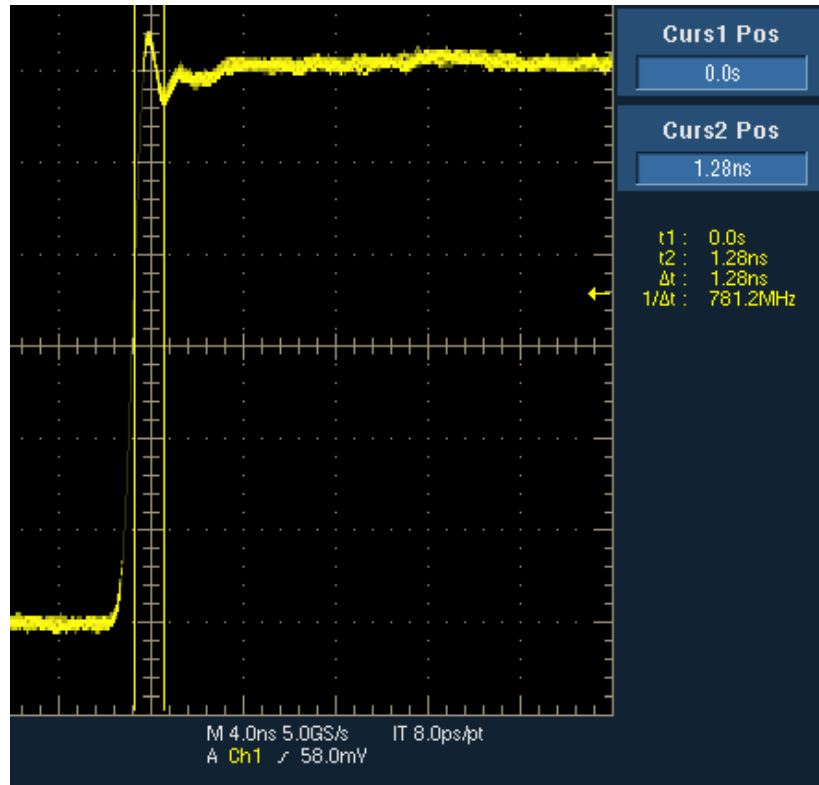


~50cm
Data18

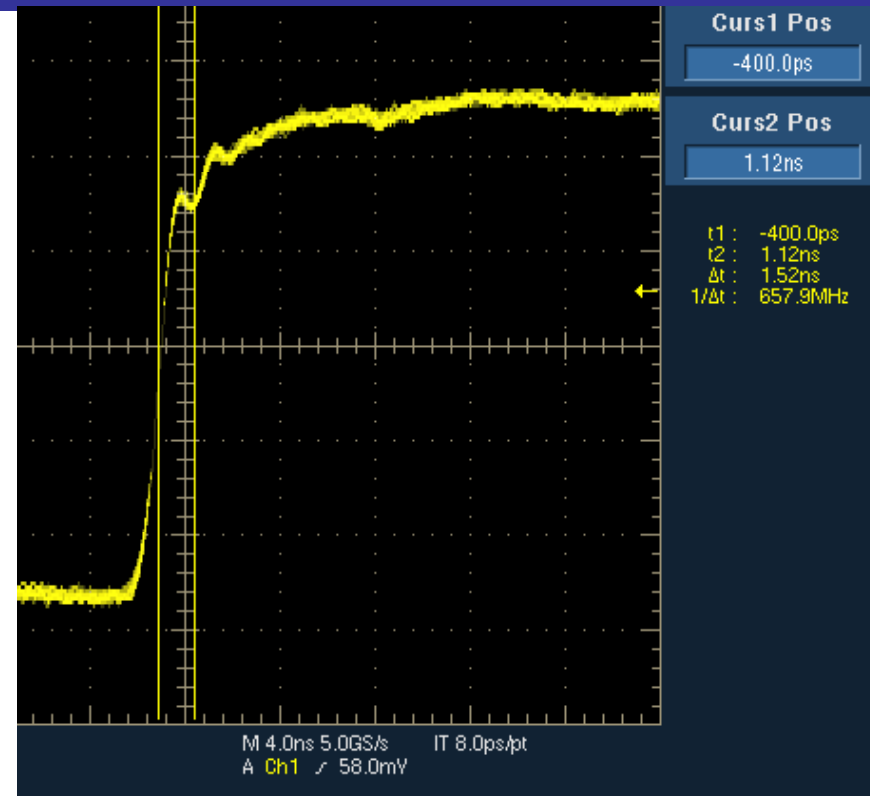


~10cm
Data03

Transitions



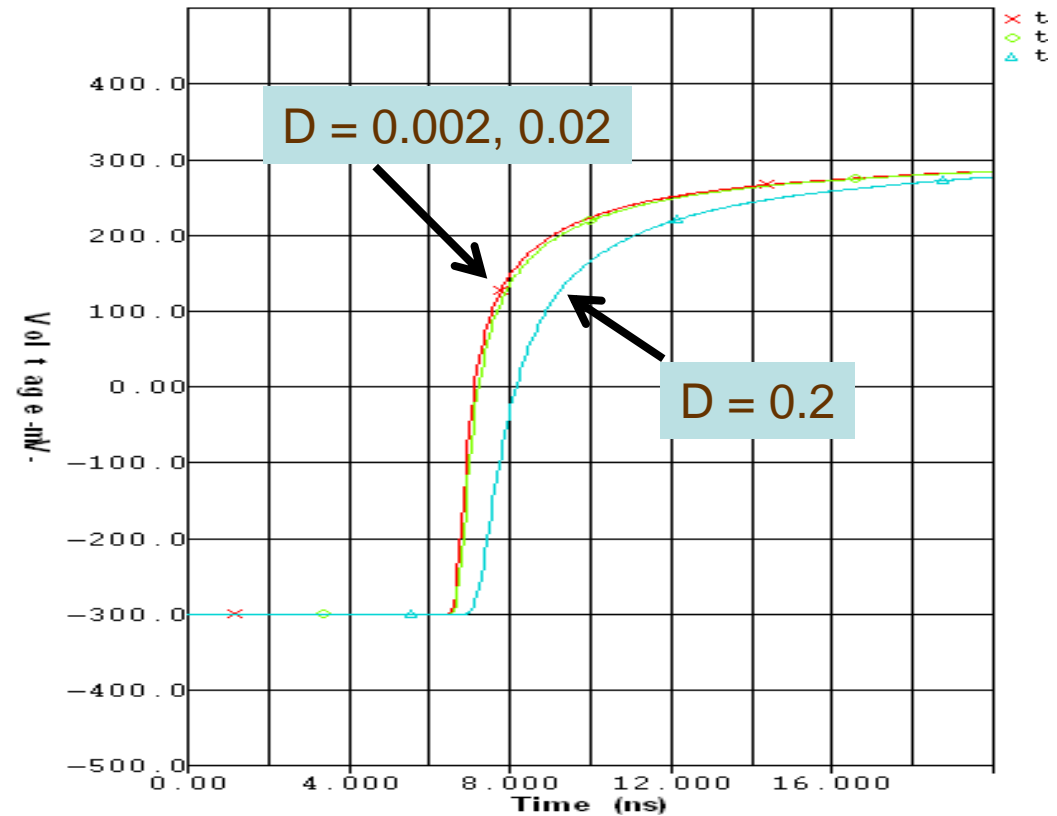
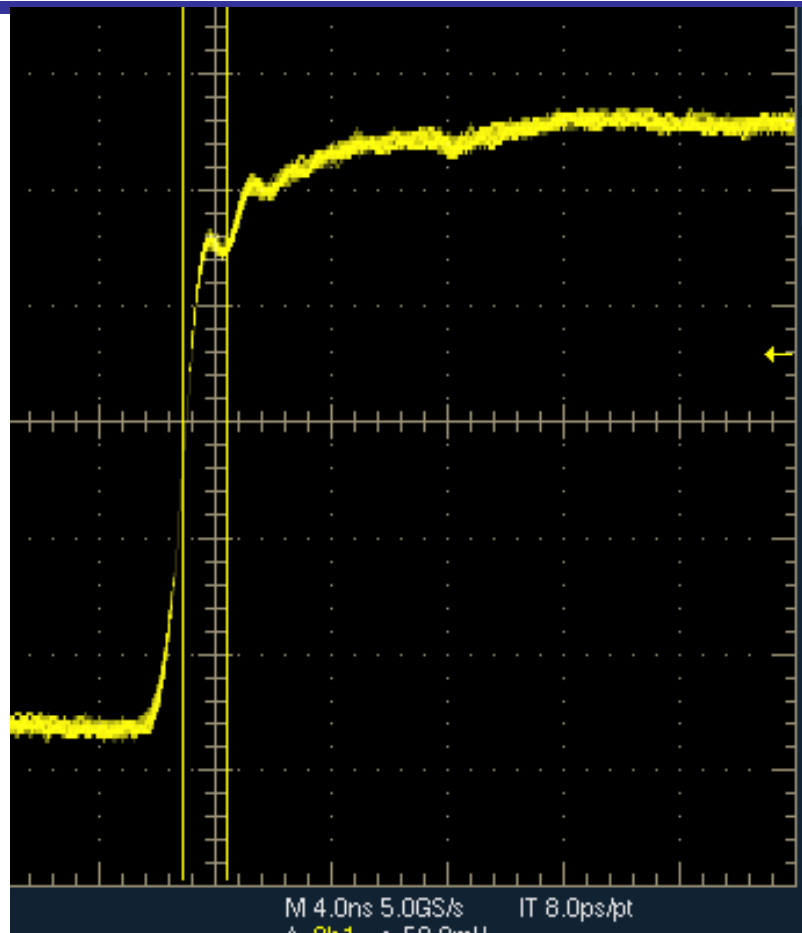
At the driver



After 1m long trace

See a small-scale irregularity, and a slow leveling off after transition. The irregularity is likely to be a property of the driver (SN65LVDS100). The slow transition is a property of the line (next slide).

Simulations

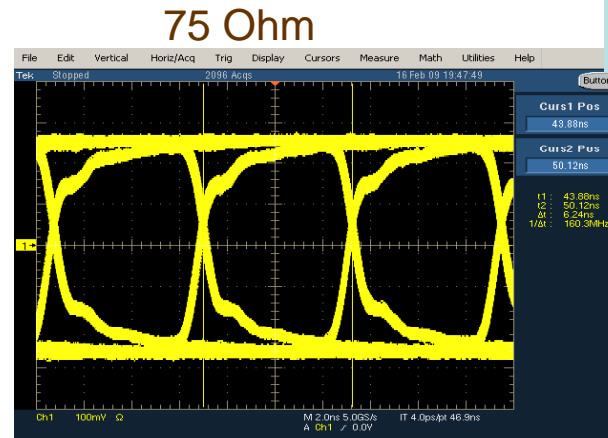
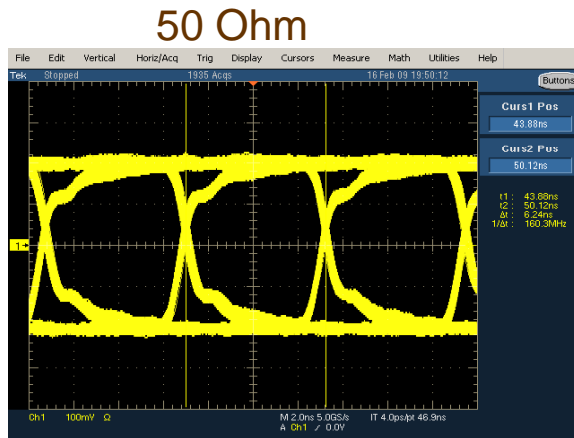


HyperLynx, one of the industry-standard packages from Mentor Graphics. 2D Field solver, works off a PCB/cable layout.

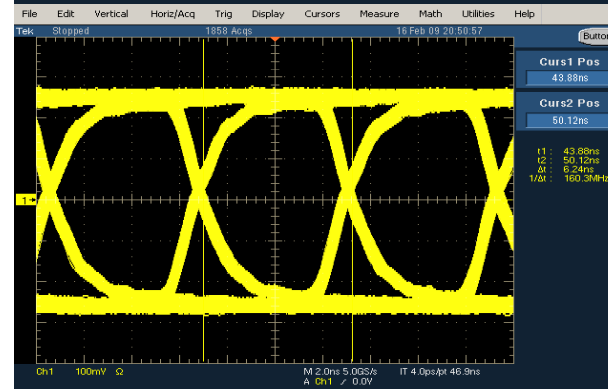
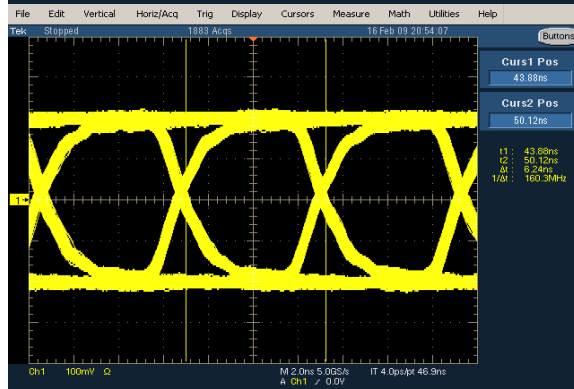
Simulated with loss tangent $D = 0.002, 0.02$ (standard for FR4), 0.2 . Only see a significant difference in the latter (extreme) case. \Rightarrow Most of the “slow rise” effect due to Skin effect?

ED tests with extra capacitance

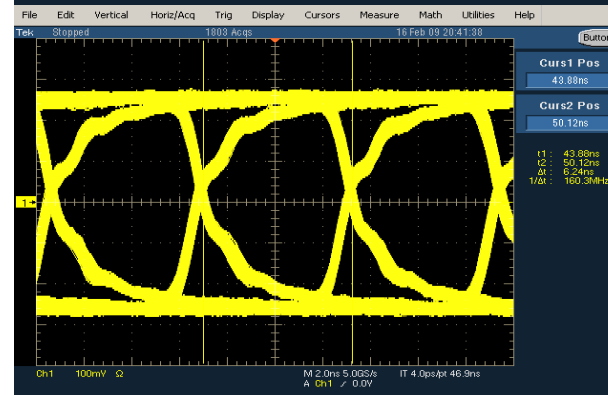
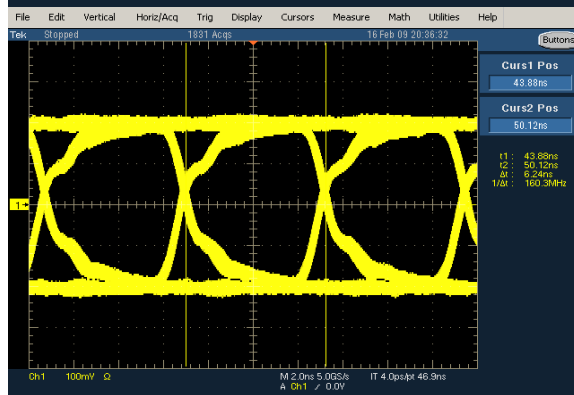
@ 160 MHz



$C = 0$ pF

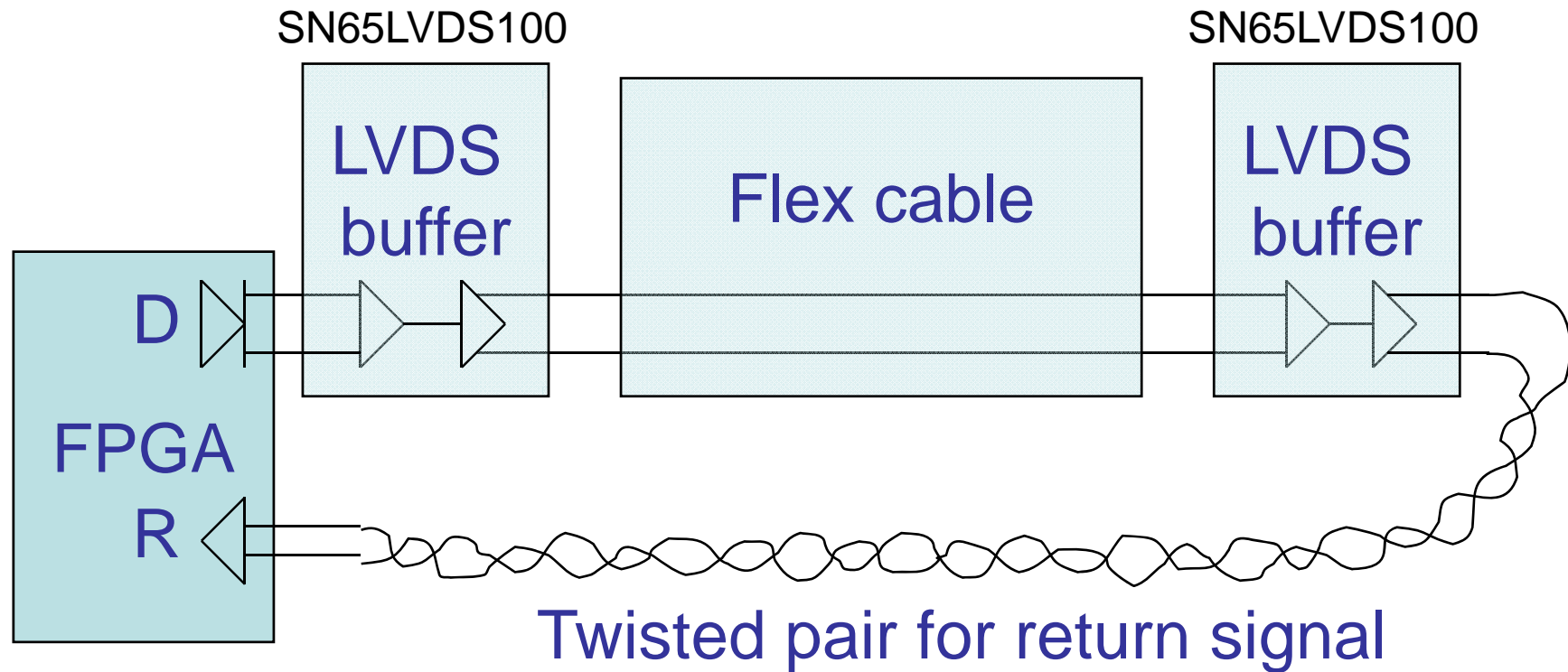


$C = 20$ pF
@ source



$C = 20$ pF
@ Termination

Transmission test at 320 MHz

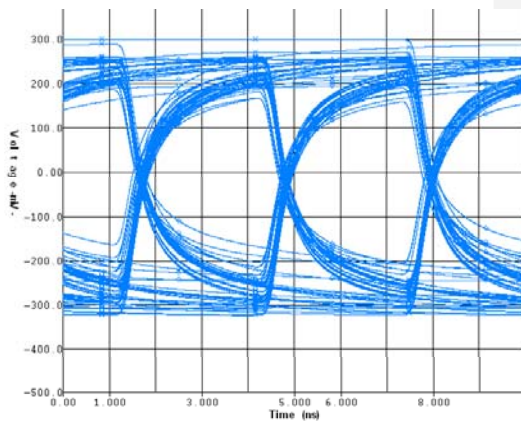


Cable is enclosed between LVDS buffers to limit the effect of other connections.

“Bathtub” Curve for Data Links

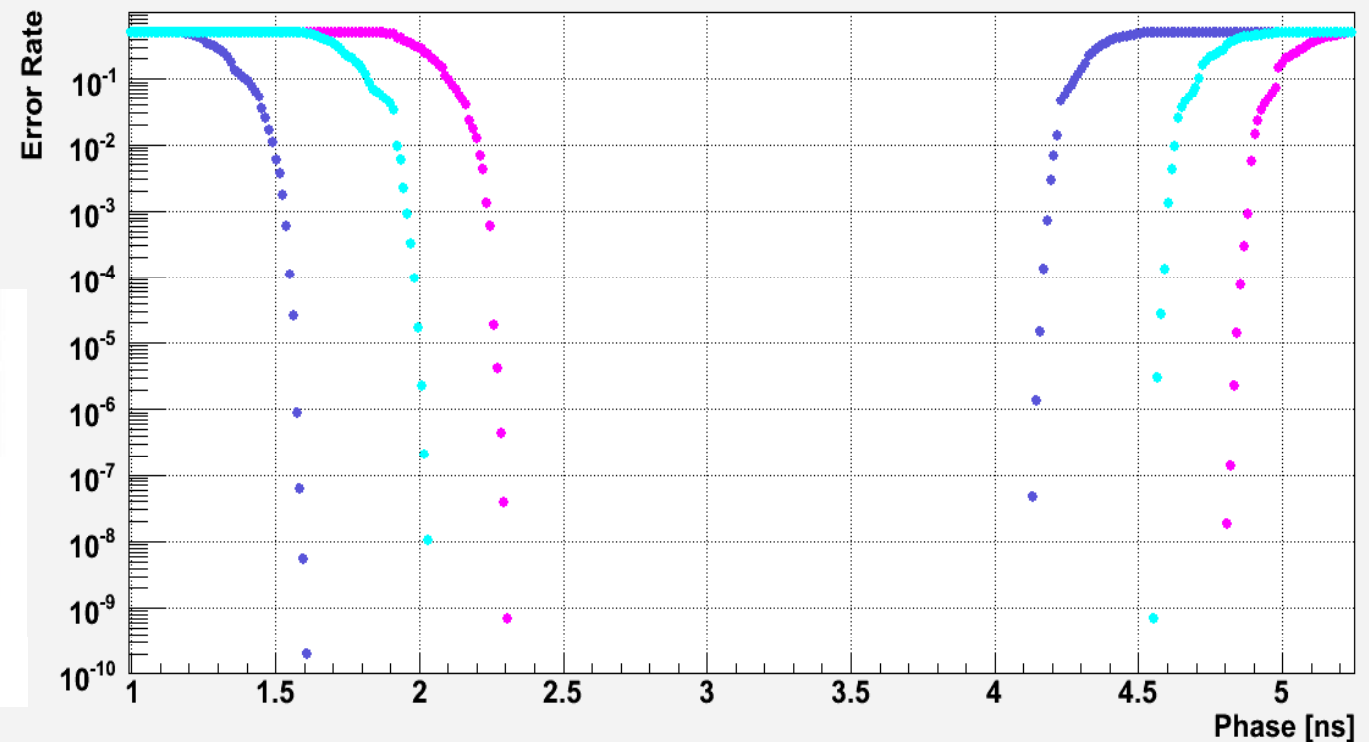
- Error rate as a function of clock phase.
- See a working region of ~ 2.5 ns with 4.16×10^9 samples.
- No significant change in performance with $C = 10$ pF at either source or termination end.

Simulation ED



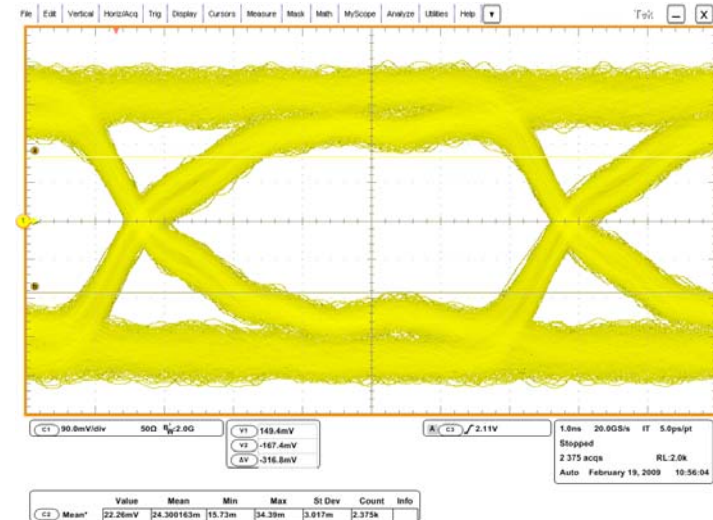
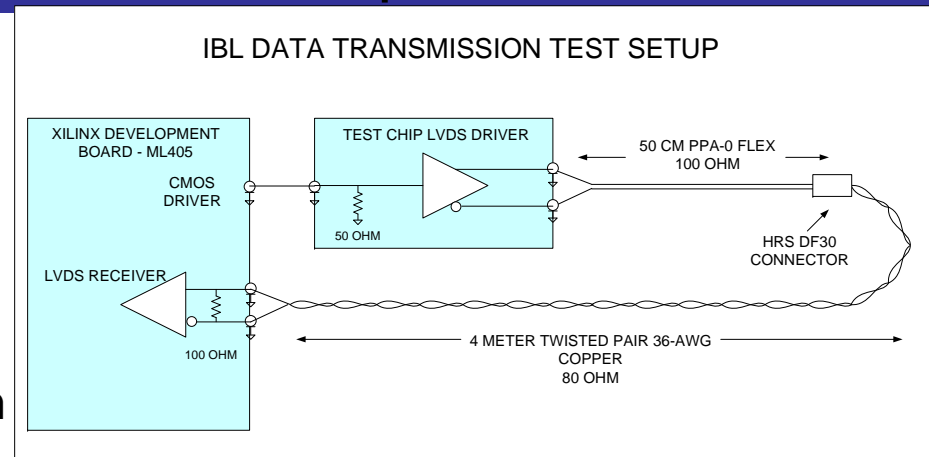
BERT at 325 MHz

Error rate measurement



IBL Data Transmission using the ATPIX Transceiver Chip

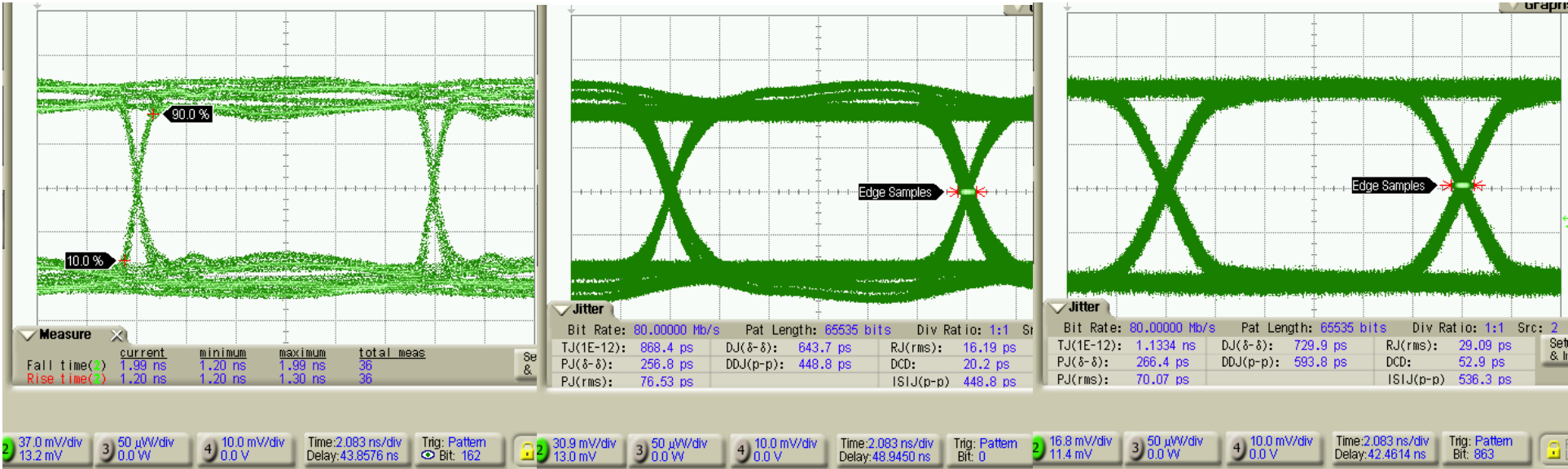
- Test-up includes:
 - Xilinx ML-405 development board
 - Random pattern test code Martin Kocian
 - ATPIX LVDS test chip
 - Two PPA-0 flex circuits – 50 cm
 - One HRS connector
 - One – 4 meter twisted pair 36 AWG wire
 - 160 Mbps data rate
 - Eye pattern is 317mV, need > 200mV
 - Cross talk measurement OK
 - We should consider MLVDS receivers
 - Eye requirement is 100mV
 - No errors @ 150 Mbps or 350 Mbps
 - Error rate better than $2 \cdot 10^{-13}$ @ 350 Mbps



SLAC test of data transmission through 50 cm flex + 4 m twisted pair.

Driving Parallel Connections

Eye Diagrams at 80 MHz



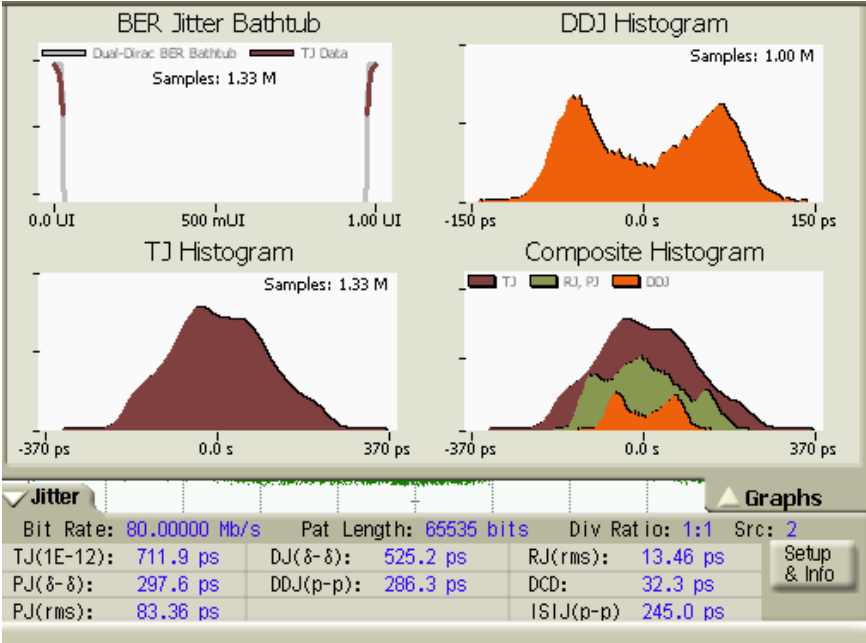
Source

Middle

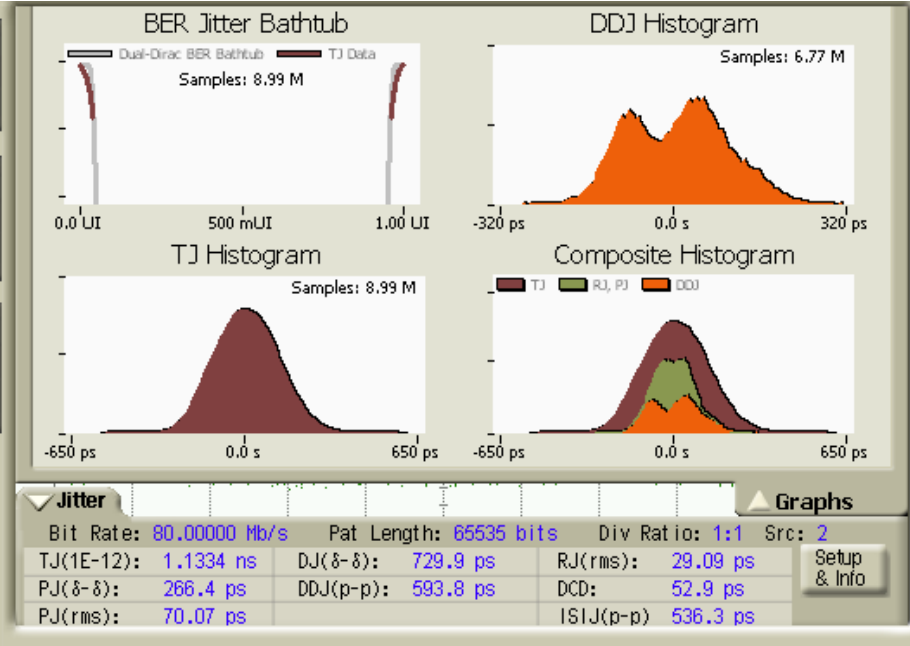
Termination
(75 Ohm)

Eye diagrams on Oxford cable (L=1.2m) with 24 x DS91D180 (M-LVDS receivers with C = ~2.5 pF).

BERT and Jitter at 80 MHz



At Source

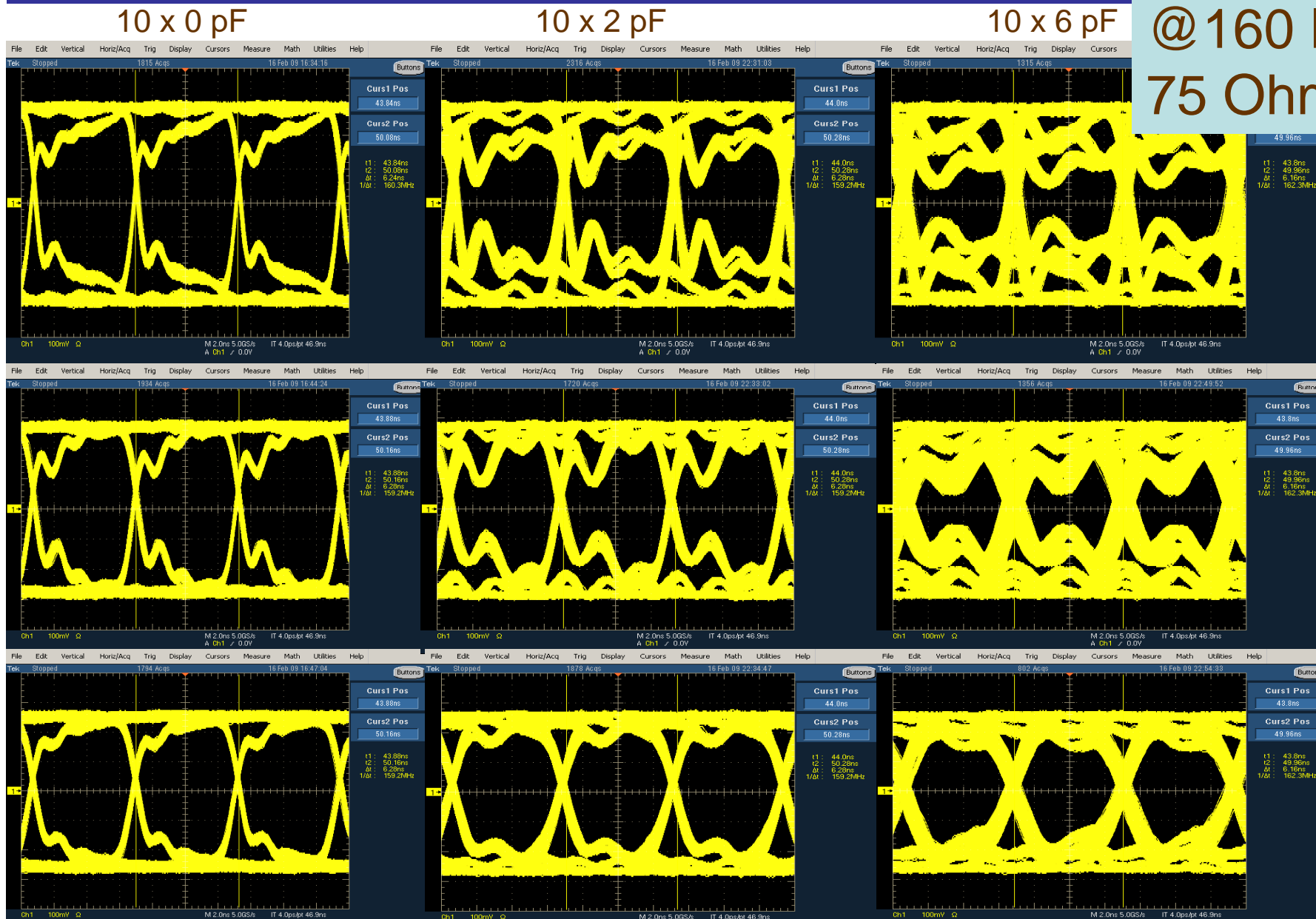


At termination
(75 Ohm)

BERT and jitter measurements on Oxford cable (L=1.2m) with 24 x DS91D180 (M-LVDS receivers with C = ~2.5 pF).

Parallel loading of multiple receivers

@ 160 MHz
75 Ohm

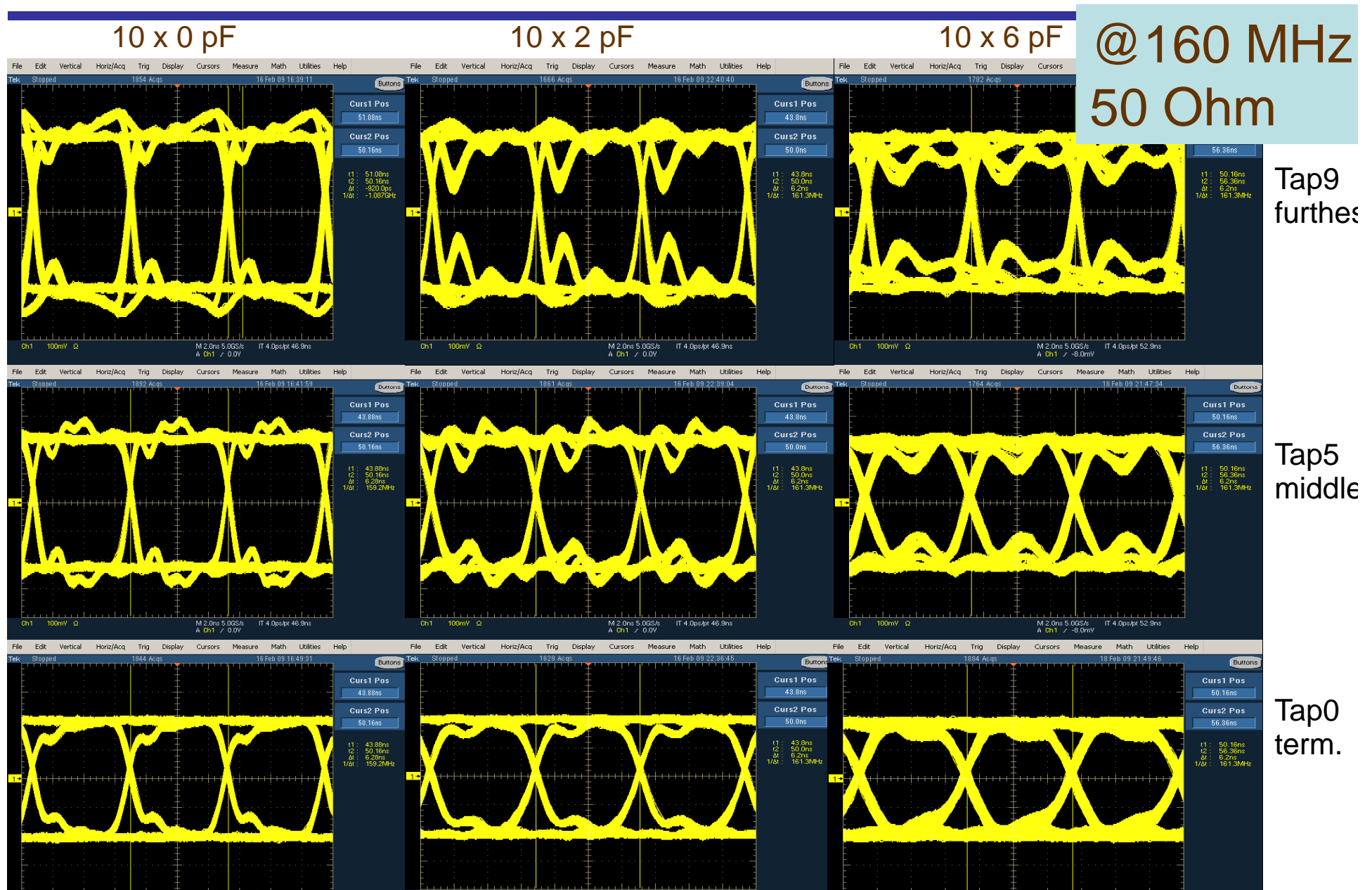


Tap9
further

Tap5
middle

Tap0
term

Parallel loading of multiple receivers



Conclusions

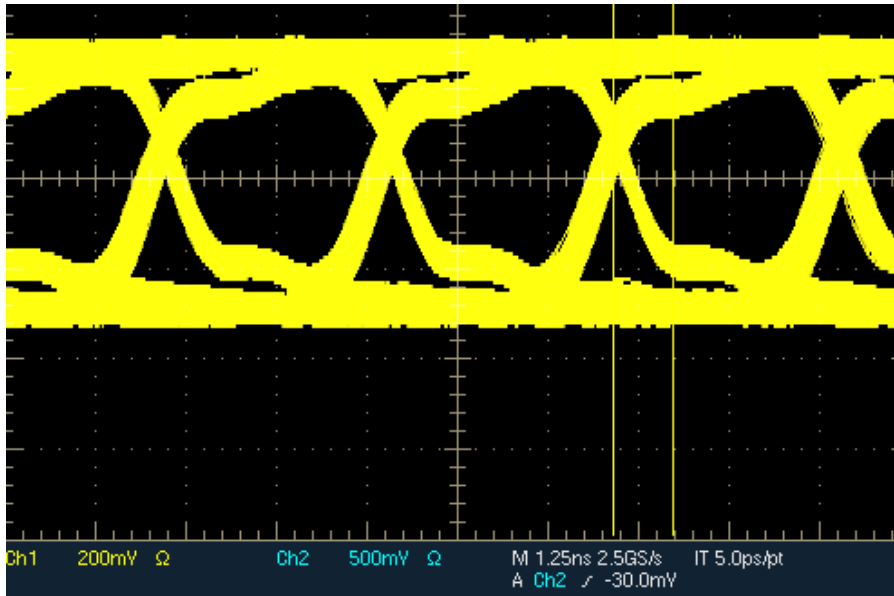
- Data transmission on point-to-point links is ok at 320 MHz. Extra capacitance of 10 pF does not deteriorate the performance. A combination of flex cable + long twisted pair works as well.
- Driving a group of parallel loads looks possible at 160 MHz when each load is ~few pF. Verified at 80 MHz with commercial receivers with $C = 2.5$ pF.
- Have a simulation tool that could be useful with cable design and engineering.
- Work is in progress, more system-level testing to be done.

Backup Slides

BERT Development

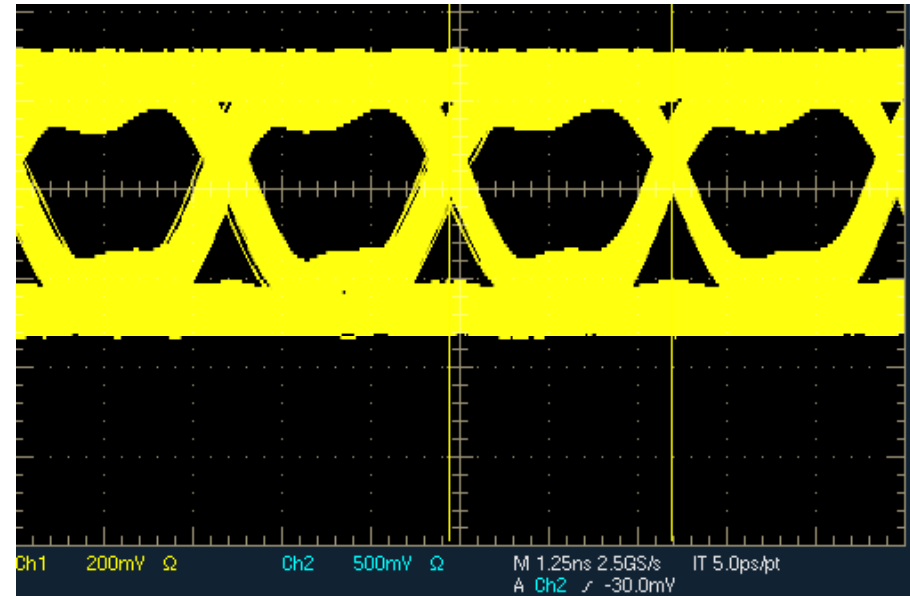
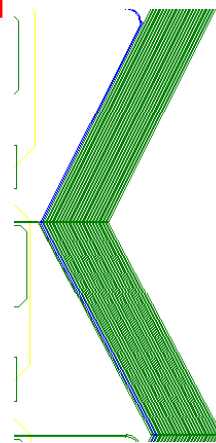
- Got a firmware error-counting design at 320 MHz with Virtex-5 FPGA board to work.
- An option to scan the phase of in-coming data latch to find the working phase margin and amount of jitter in the system.
- “Raw” bit error counting from PRBS:
 - No packets/framing.
 - No DC-balancing (8/10 or 64/66 or else) encoding
- No pre/de-emphasis on LVDS lines.

Effect of Multiple trace bends



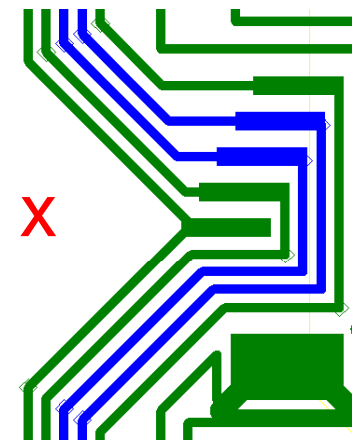
PRBS data (320 MHz) after longest "dataout" trace of the long cable.

15 x



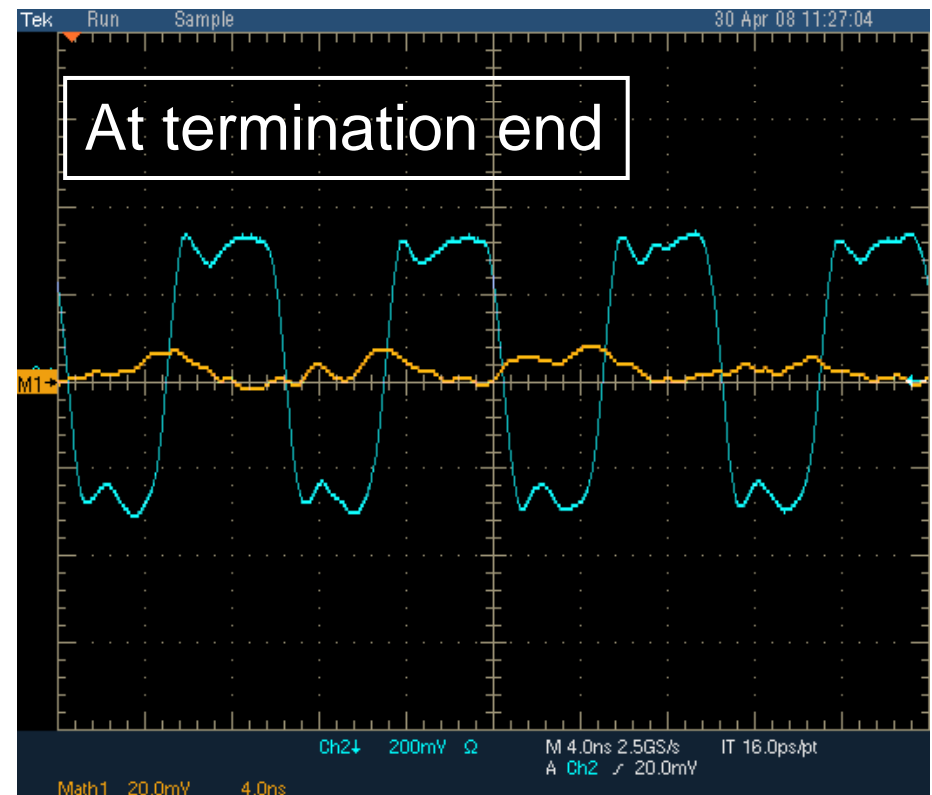
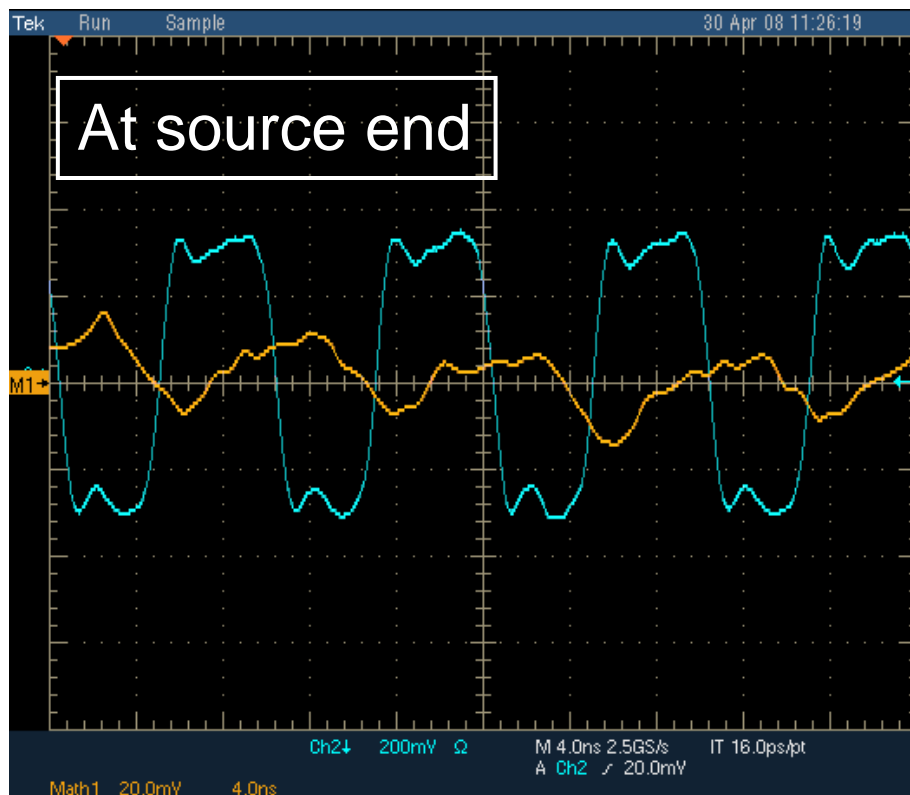
PRBS data (320 MHz) after longest "clock" trace of the long cable.

30 x



Cross-Talk

Drive differential pair with 100 MHz clock (blue)
Measure cross-talk signal on adjacent terminated trace (orange)
separated by 100 microns (same as stripline width)



Note different scales: *cross-talk amplitude is less than 5% .*

"Bathtub" Curves for Parallel Loads

- Our LVDS buffers have built-in 100 Ohm termination => Can only look at the error rate on the last tap.
- Do scans for no C loads, and 2, 4, ..., 10 loads of 2 pF.
- The working region contracts from ~ 5.0 ns to 4.5 ns.

