Lesson AGCD-04-01 Download the pdf slides here

Course AGCD:
Advanced Gigabit Channel Design

With Eric Bogatin,
Signal Integrity Evangelist, Teledyne LeCroy Front Range Signal Integrity Lab
Dean, Teledyne LeCroy Signal Integrity Academy
Adjunct Professor, University of Colorado, Boulder, ECEE

- AGCD-04-01: recorded live, Dec 1, 2013
  - Download a pdf copy of the slides by clicking on the link on this page

Lesson AGCD-04-10 Cross talk can ruin your day

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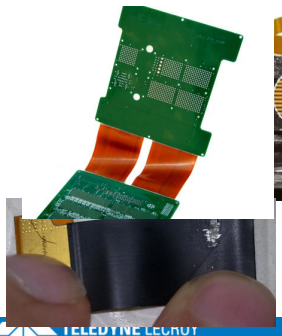
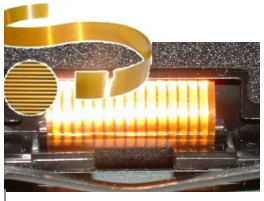
- AGCD-04-10: recorded live, Dec 1, 2013
  - An example of far end noise closing an eye
  - Near end and Far end cross talk
  - How much cross talk is too much: the Signal to Noise Ratio, SNR
  - Signature of the single-bit response for near end cross talk in stripline

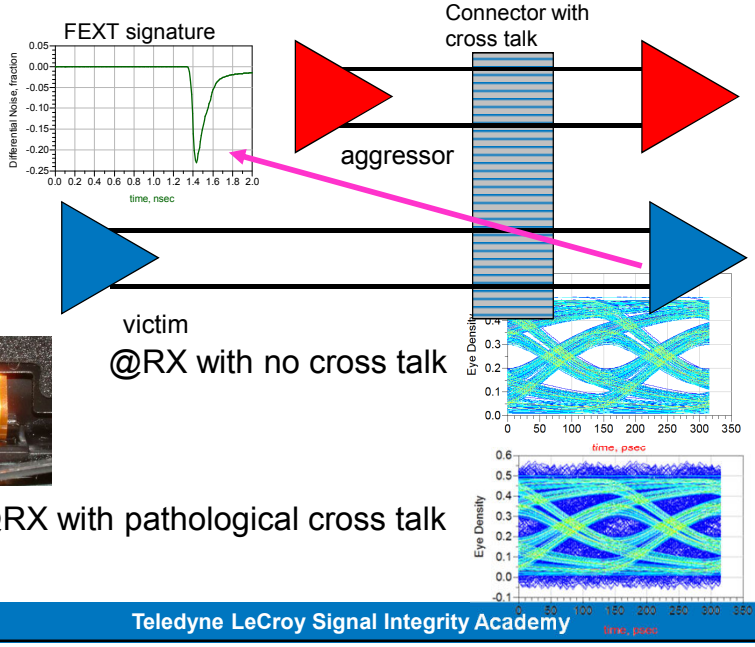
- Day 1
  - ✓ AGCD 1 Opening eyes
  - ✓ AGCD 2 Differential pairs and routing
  - ✓ Lunch
  - ✓ AGCD 3 Lossy Lines and ISI
  - ✓ **AGCD 4 Channel to channel cross talk**
- Day 2
  - ✓ AGCD 5 Mode conversion
  - ✓ AGCD 6 Discontinuities
  - ✓ Lunch
  - ✓ AGCD 7 Transparent Via Design
  - ✓ AGCD 8 Practical consideration

Cross Talk Can Potentially Ruin ANY Channel

- A pathological worst case:
  - 2-layer flex microstrip connector
  - 5 mil line, 5 mil space
  - 2 inches coupled length
  - 5 Gbps
  - 25 psec rise time
  - Asynchronous channels

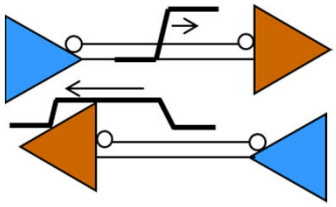






How Much XTK is Too Much?

(interleaved)

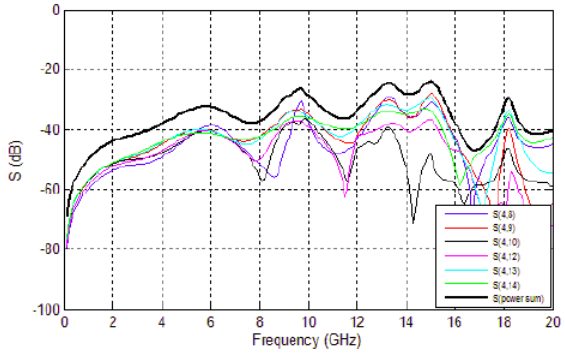


- Acceptable SNR ~ 20 dB (10 Gbase KR spec is -23 dB)
- Short reach channel, signal ~ -10 dB (no equalization)
  - Maximum acceptable xtk might be -30 dB @ Nyquist (3%)
- Worst case signal ~ -25 dB (with equalization)
  - Maximum acceptable xtk might be -45 dB @ Nyquist (0.5%)
- If there are 2 aggressors on either side, then channel to channel XTK ~ -36 dB and -51 dB

ICR: Insertion loss to Cross talk Ratio (~ SNR)

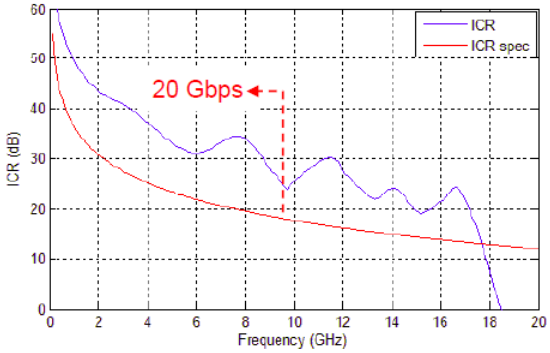
10Gbase-KR spec:
ICR = 37 dB – 20 x log(f[GHz])
@ 5 GHz, ICR > 23 dB

Use the power sum of all the XTK on victim line



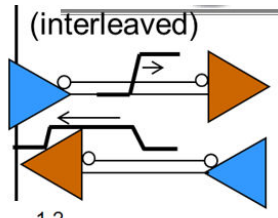
FEXT for via-connector-via
(w/o trace attenuation)

For 12 inch total channel length
(IL is small, so more xtk is tolerated)

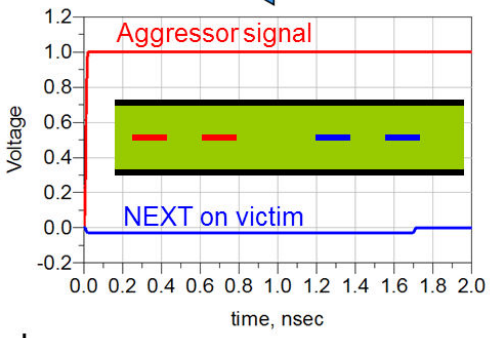


ICR with 6 FEXTs

Near End Cross Talk in Stripline: Step response



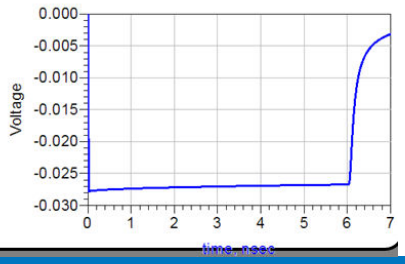
Specs:
Z0_diff = 100 Ohms
W = 7 mils
S = 14 mils
H 1 = H2 = 8.6 mils
½ oz copper
Dk = 4



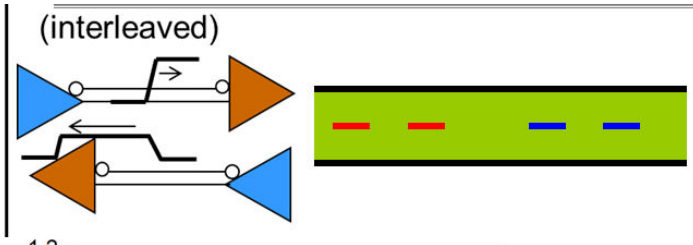
All simulations done with Agilent's ADS

Features:

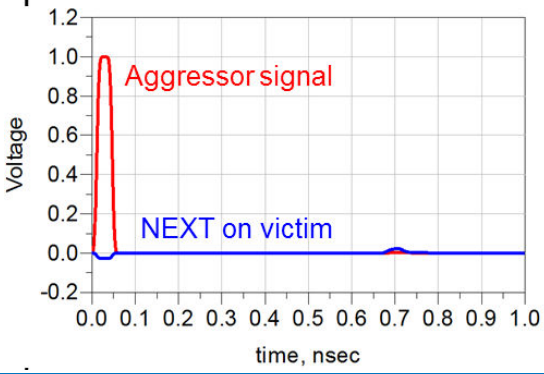
- ✓Turns on with the rise time
- ✓ Lasts for 2 x TD
- ✓ Independent of coupling length
- ✓ Independent of rise time
- ✓ Depends on spacing
- ✓Losses cause slight drop off with coupling length



Near End Cross Talk: Single bit response (SBR)



Specs:
Z0_diff = 100 Ohms
W = 7 mils
S = 14 mils
½ oz copper
Dk = 4
UI < 2 x TD (typical)



Features:

1. First pulse peak is NEXT
2. Lasts for UI
3. Leading edge of bit turns on near end XT
4. Training edge turns it off
5. Second pulse arrives 2 x TD later
6. Some attenuation due to propagation path
7. NEXT will occur throughout UI- for synchronous and asynchronous channels
8. Saturated NEXT is a good FOM of peak noise

Lesson AGCD-04-20 Near end cross talk and coupling

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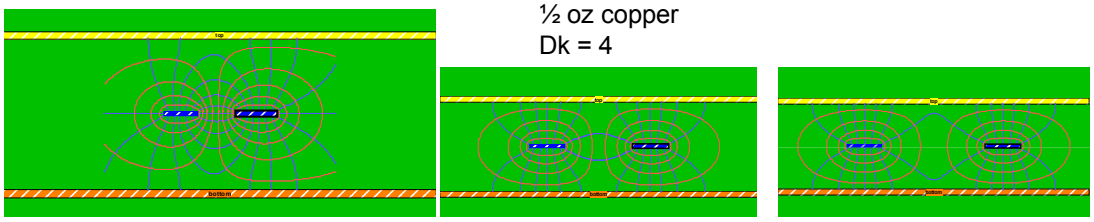
- AGCD-04-20: recorded live, Dec 1, 2013
  - Which has lower NEXT, loosely coupled or tightly coupled differential pairs?
  - Stripline cross sections for constant w and constant impedance
  - Impact on NEXT from the coupling
  - NEXT and design space for stripline

Near End Cross Talk: Design Guidelines

- For the same line width and diff impedance, which has more channel to channel differential cross talk?
  - Tightly coupled stripline differential pairs
  - Loosely coupled stripline differential pairs

Cross Talk and Coupling in Stripline for Constant Line Width, 100 Ohm diff impedance

Specs:
Z0_diff = 100 Ohms
W = 7 mils
½ oz copper
Dk = 4



Spacing = 1 x w
H1 = H2 = 13.1 mils

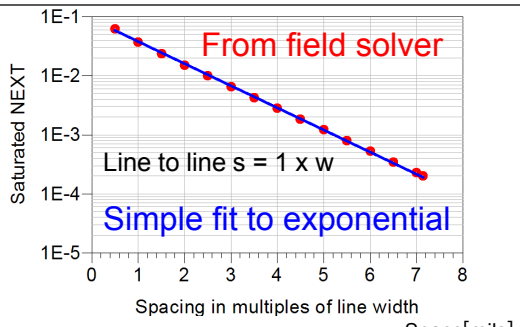
Spacing = 2 x w
H1 = H2 = 8.6 mils

Spacing = 3 x w
H1 = H2 = 8.2 mils

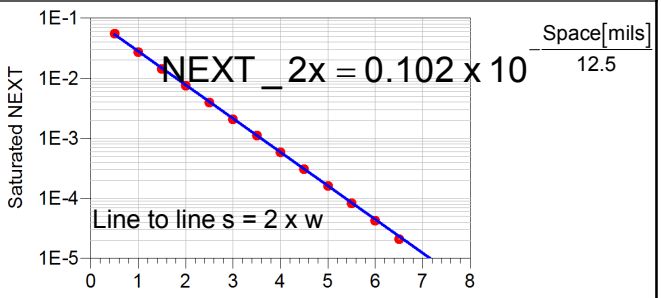
For the same line width and 100 Ohm diff impedance:

Tightly coupled diff pair requires planes farther away → more fringe field coupling to neighbors
Loosely coupled diff pairs enables planes closer→ confines the fringe fields to neighbors

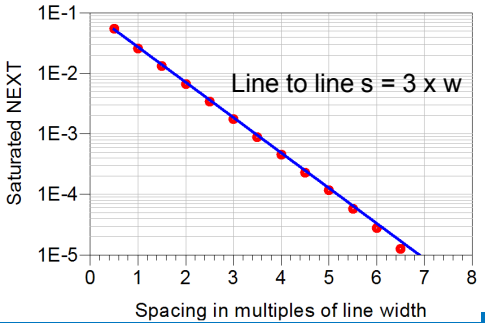
NEXT with Spacing and Coupling



$$NEXT\_1x = 0.09 \times 10^{\frac{Space[mils]}{13.1}}$$



$$NEXT\_2x = 0.102 \times 10^{\frac{Space[mils]}{12.5}}$$



$$NEXT\_3x = 0.105 \times 10^{\frac{Space[mils]}{12}}$$

Lesson AGCD-04-30 Managing NEXT and a Pathological Case

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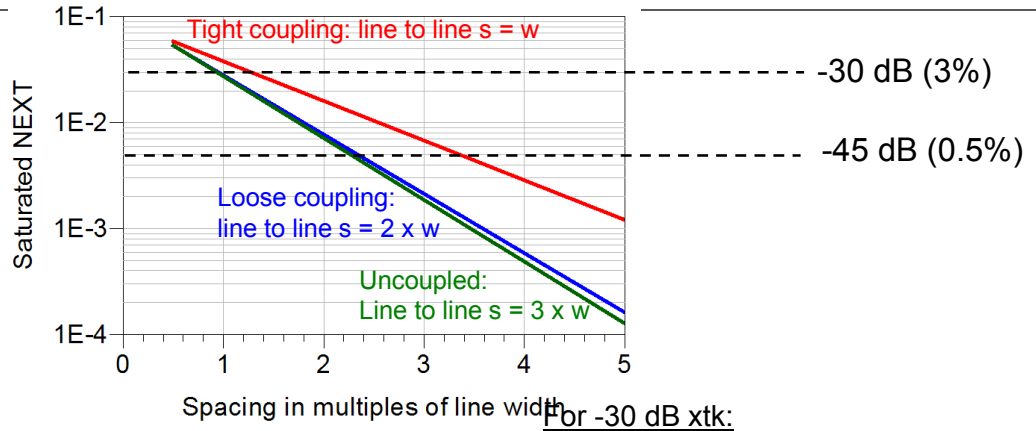
- AGCD-04-30: recorded live, Dec 1, 2013
  - Design rules for NEXT for loosely and tightly coupled differential pairs
  - Easily manage NEXT in stripline with channel to channel spacing
  - A pathological example: broad side coupling
  - Analyzing broad side coupling with a 2D field solver

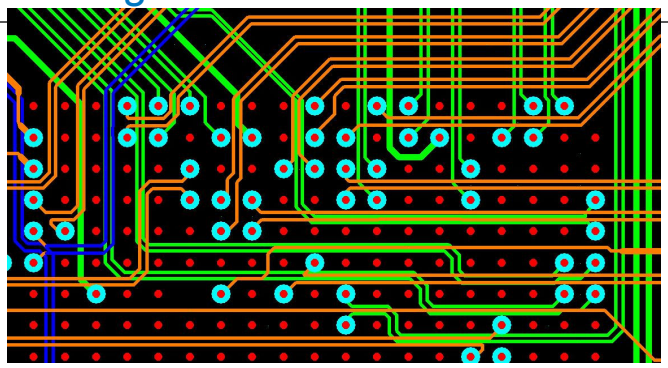
Near End Cross Talk: Design Space



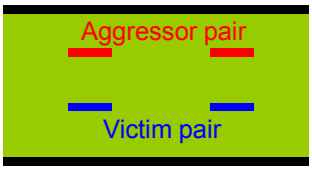
For -30 dB xtk:
Tightly coupled diff pair, pair to pair spacing = 1.5 x w
Loosely coupled diff pair, pair to pair spacing = 1 x w

For -45 dB xtk:
Tightly coupled diff pair, pair to pair spacing = 3.5 x w
Loosely coupled diff pair, pair to pair spacing = 2.5 x w

Pathological Case 1: Broad Side Coupled



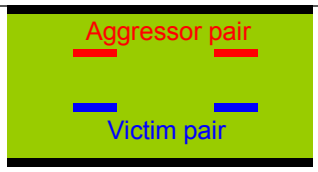
Typically found in BGA escapes, dense connector via fields



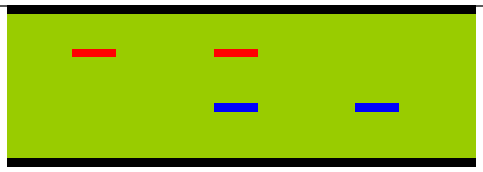
Specs:
100 Ohm diff impedance
w = 7 mils
½ oz copper
Dk = 4
Loosely coupled, s = 2 x w
H1 = H2 = H3 = 7.6 mils

Pathological Case 1: Broad Side Coupled

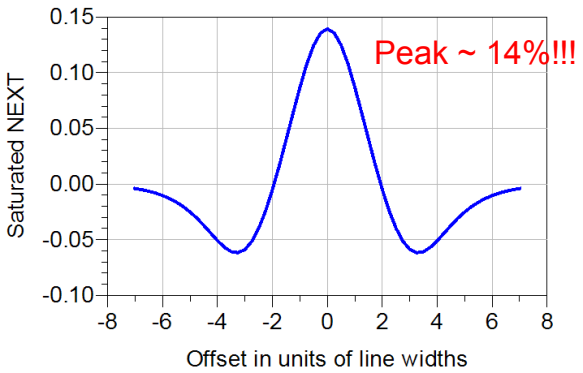
Specs:
w = 7 mils
½ oz copper
Dk = 4
Loosely coupled, s = 2 x w
H1 = H2 = H3 = 7.6 mils

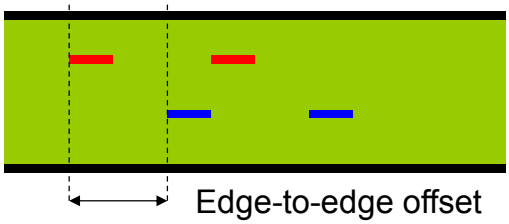


Diff NEXT is positive



Diff NEXT is negative





Peak broadside coupled NEXT ~ 14%

For the case of s = 2 x w
No diff NEXT if offset ~ 2 x w

Lesson AGCD-04-40 Saturated NEXT and Broadside Coupling

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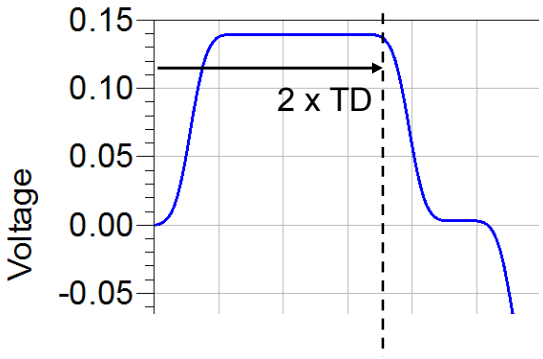
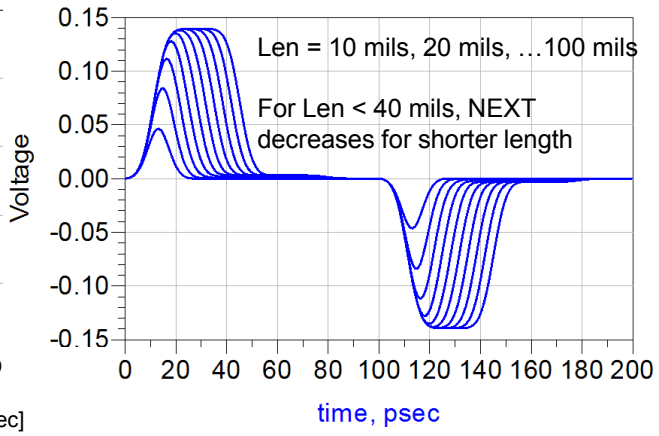
- AGCD-04-40: recorded live, Dec 1, 2013
  - How to reduce the impact of broad side coupled NEXT
  - Rise time and maximum NEXT
  - Saturation length of NEXT and rise time
  - A design rule: maximum broadside coupling length for acceptable cross talk

Features of NEXT and Saturation Length





If 2 x TD < RT, peak NEXT will decrease with smaller TD

When 2 x TD = RT, Length = 6 inches/nsec x ½ x RT[nsec]

Len_{sat}[inches] = 3 x RT[nsec]

If Length < Len_{sat}, decrease NEXT by shorter length,

NEXT = Length/Len_{sat} x $NEXT_{sat}$

Reducing NEXT with Shorter Coupling Length

For RT = 10 psec (~ 28 Gbps)

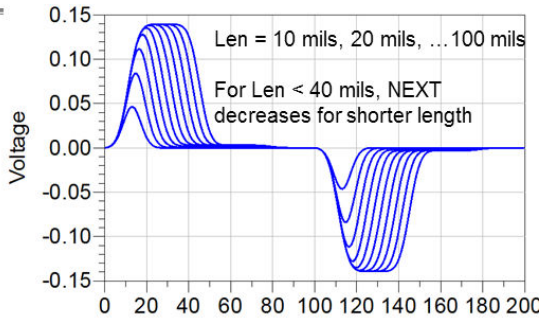
Len_{sat}[inches] = 3 x RT[nsec] = 0.03 inches

If Length < 30 mils, decrease NEXT by shorter length,

$$\frac{Len}{Len_{sat}} = \frac{NEXT}{NEXT_{sat}}$$

$NEXT_{sat}$ = 14%

For NEXT < 3%, Length < 1/5 x 30 mils = 6 mils!!

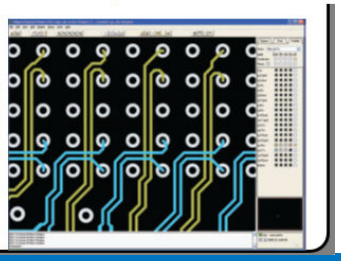


@ 5 Gbps, UI = 200 psec, RT ~ 50 psec

Len_{sat} = 3 x 50 psec = 150 mils

For 1/5 $NEXT_{sat}$, ~ 3%, need to keep Len < 1/5 Len_{sat} = 30 mils!!!

only solution: avoid inadvertent broad side coupling



Courtesy of Altera

Lesson AGCD-04-50 Pathological cross talk: Far End Cross Talk

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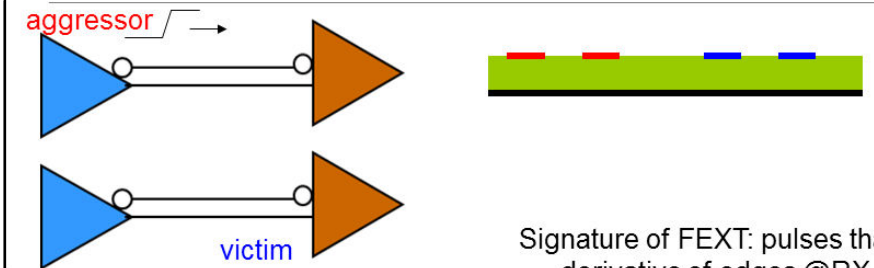
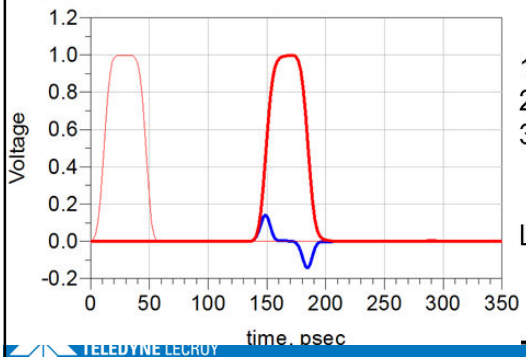
- AGCD-04-50: recorded live, Dec 1, 2013
  - The nature of far end cross talk
  - Exploring design space for far end cross talk
  - Estimating FEXT in microstrip
  - Why surface traces should always be kept short

Pathological Case 2: Far End Cross Talk- SBR





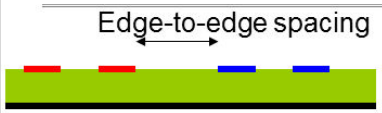
Signature of FEXT: pulses that are ~ derivative of edges @RX

1. Scales with coupled length
2. Scales inversely with RT
3. Contributes noise throughout UI for asynchronous channels

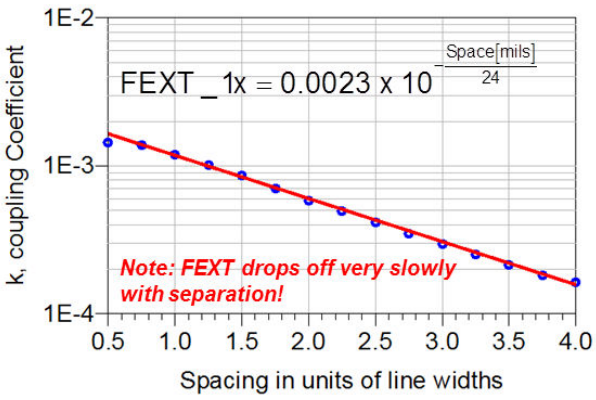
Losses will attenuate FEXT similar to signal

$$FEXT \sim k\frac{Len[inches]}{RT[n\,sec]}$$

Pathological Case 2: Design Space



Specs:
100 Ohm diff impedance
w = 7 mils
½ oz copper
Dk = 4
tightly coupled, s = w
H1 = 4.3 mils
Including low loss interconnect



For spacing ~ 1.5 x w: $FEXT \sim k\frac{Len[inches]}{RT[n\,sec]} = 0.001\frac{Len[inches]}{RT[p\,sec]\times 0.001} = \frac{Len[inches]}{RT[p\,sec]}$

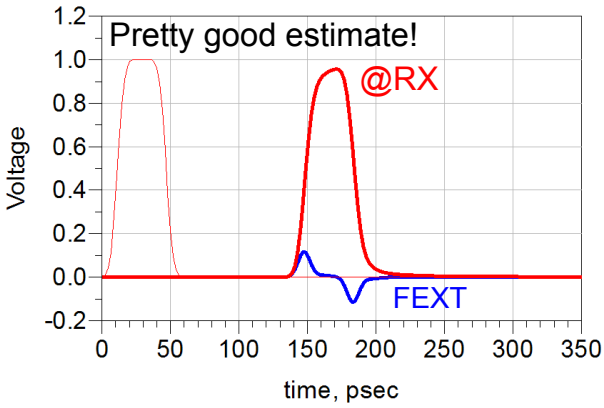
For spacing ~ 3 x w: $FEXT = 0.3\frac{Len[inches]}{RT[p\,sec]}$

Pathological Case 2: 28 Gbps Example

Edge-to-edge spacing

Design Example:
28 Gbps, RT = 0.01 nsec = 10 psec
Len = 1 inch
s = 1.5 x w

$$\text{FEXT} = \frac{\text{Len}[\text{inches}]}{\text{RT}[\text{psec}]} = \frac{1}{10} = 10\%$$



Max coupled length before FEXT < 3%:
Len < 0.3 inches!

For s = 3 x w, maybe get away with 1 inch max coupled length!

Pathological Case 2: 10 Gbps Example

Edge-to-edge spacing

Design Example:
10 Gbps, RT = 0.025 nsec = 25 psec
Len = 1 inch
s = 1.5 x w

$$\text{FEXT} = \frac{\text{Len}[\text{inches}]}{\text{RT}[\text{psec}]} = \frac{1}{25} = 4\%$$

Max coupled length before FEXT < 3%:
Len < 0.75 inches!

For s = 3 x w, maybe get away with 2.25 inch max coupled length!

Keep microstrip traces short!

Lesson AGCD-04-60 Cross talk in connectors

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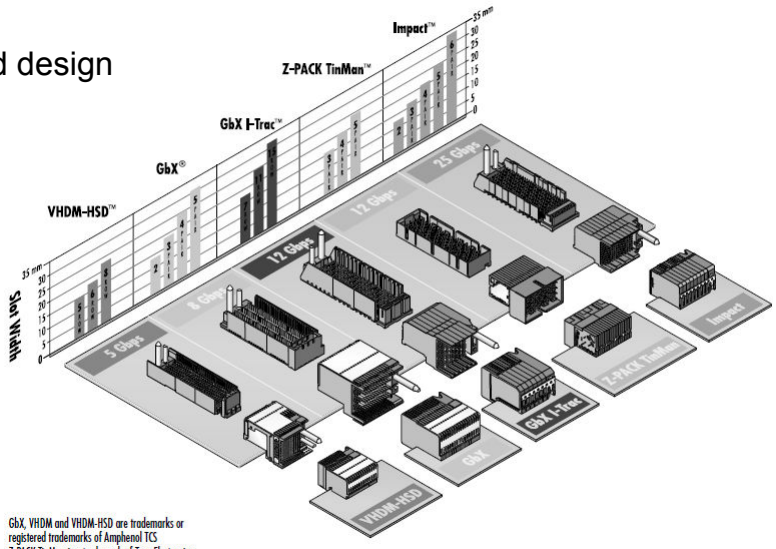
- AGCD-04-60: recorded live, Dec 1, 2013
  - Summary of design guidelines to reduce cross talk in differential pairs
  - Analyzing cross talk in connectors
  - Selecting optimum pin assignments for reduced cross talk
  - Different design guidelines to manage cross talk with and without a return plane

Summary and Recommendations for Differential Pair Design

- NEXT in edge coupled stripline
  - For < -30 dB XTK, loosely coupled, s > w
  - For < -45 dB XTK, loosely coupled, s > 2.5 x w
- Avoid inadvertent broad side coupled stripline (constraint manager)
- Keep microstrip surface traces very short!
  - Try to separate channels as far as possible (> 3 x w)
  - Coupled lengths < 1 inches
- ALWAYS estimate FEXT in ALL microstrip interconnect paths
- Essential to perform channel to channel cross talk simulation with integrated 2D field solver and lossy line model to establish robust design rules

Cross Talk in Connectors

Hard to generalize
Minimum impact from the board design
Many connector vendors
Many connector families

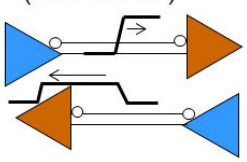


GbX, VHDM and VHDM-HSD are trademarks or registered trademarks of Amphenol TCS
Z-PACK TinMan is a trademark of Tyco Electronics

Molex Connector Families in Perspective

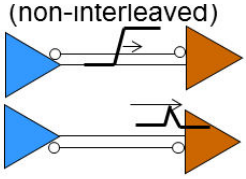
Connector Pin Assignments for Reduced XTK

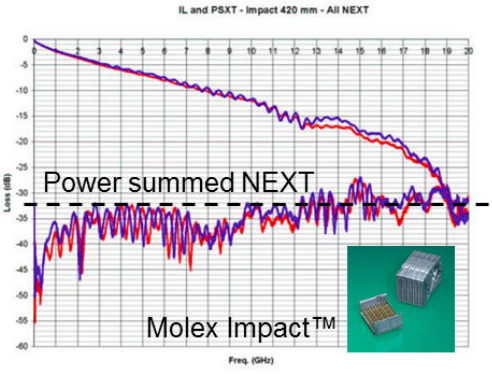
(interleaved)

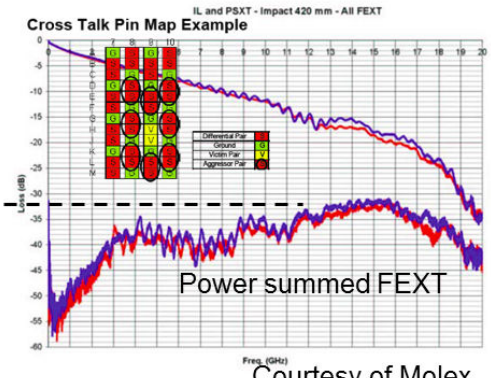


If NEXT > FEXT,
TX adjacent to TX
is lower XTK

(non-interleaved)

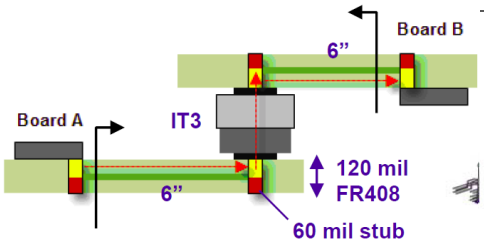


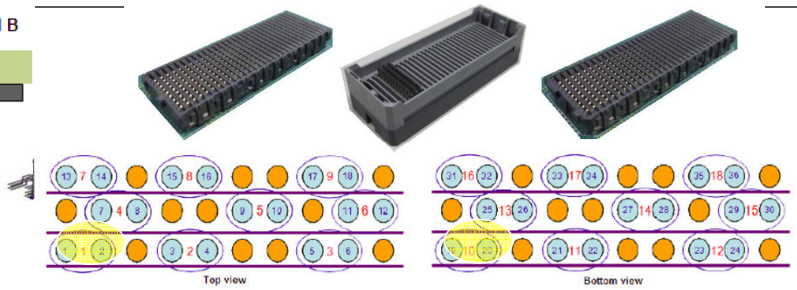


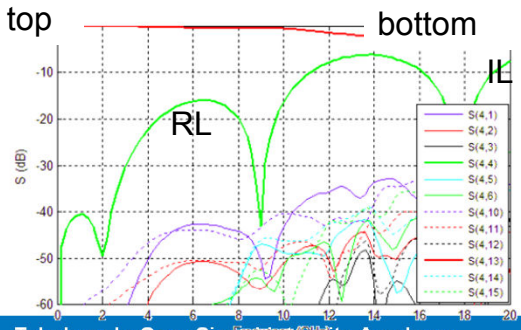


Courtesy of Molex

Hirose IT3-17 mm, Mezzanine Connector

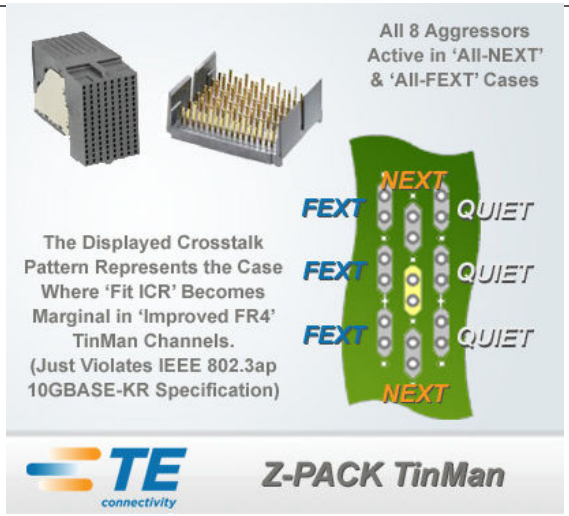


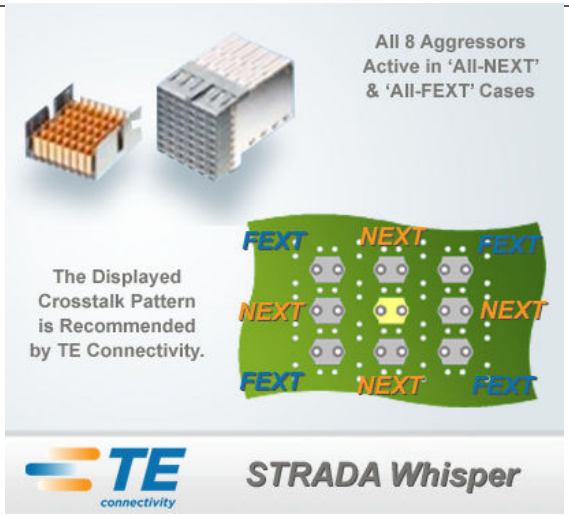




1. NEXT ~ FEXT
2. Spacing strongest factor in XTK
3. Worse case FEXT ~ -45 dB @ 5 GHz

Tyco Electronics: XTK Improvements From Old to New Generation





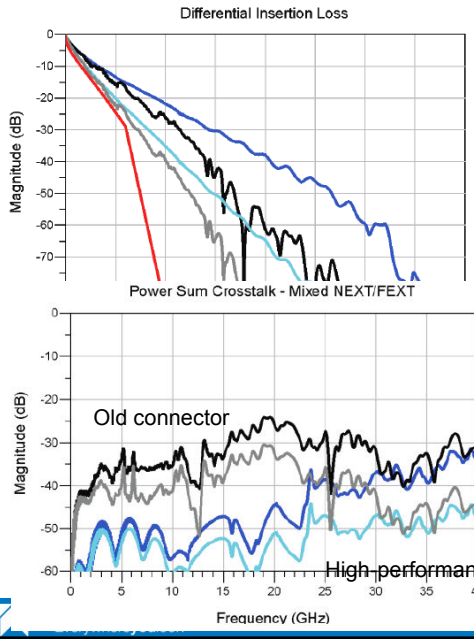
Insertion Loss and XTK

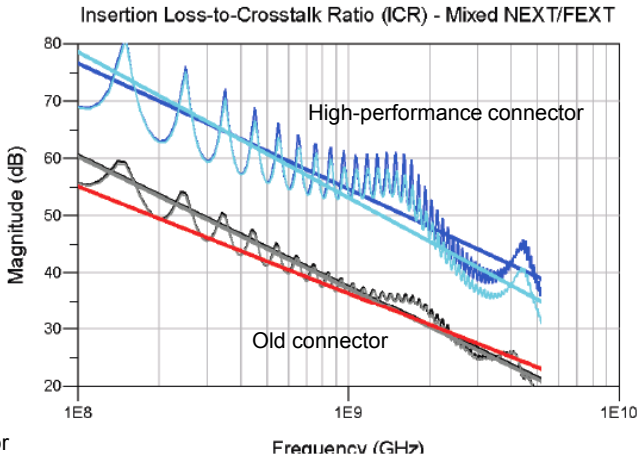
Blue Waveforms = STRADA Whisper & Megtron6

Cyan Waveforms = STRADA Whisper & FR4

Black Waveforms = Z-PACK TinMan & Megtron6

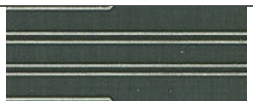
Grey Waveforms = Z-PACK TinMan & FR4

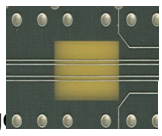


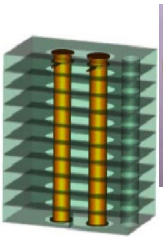


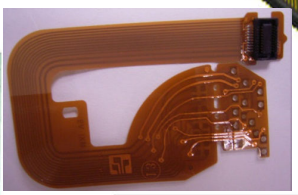
Coupling and Differential Cross Talk

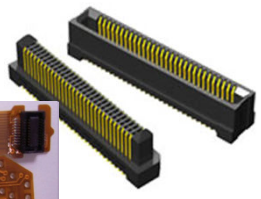
- When the return path is a wide, uniform plane, tighter coupling has little impact on differential cross talk (ie, in controlled impedance board traces)
- When the return path is not a uniform plane, tighter coupling can significantly decrease differential cross talk
- Always use tight coupling between lines in a differential pair when the return path is not a wide uniform plane:
  - Gaps
  - Vias
  - Connectors
  - Leaded, 2 layer packag
  - Sockets/interposers
  - Flex/ribbon cable

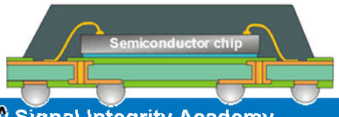


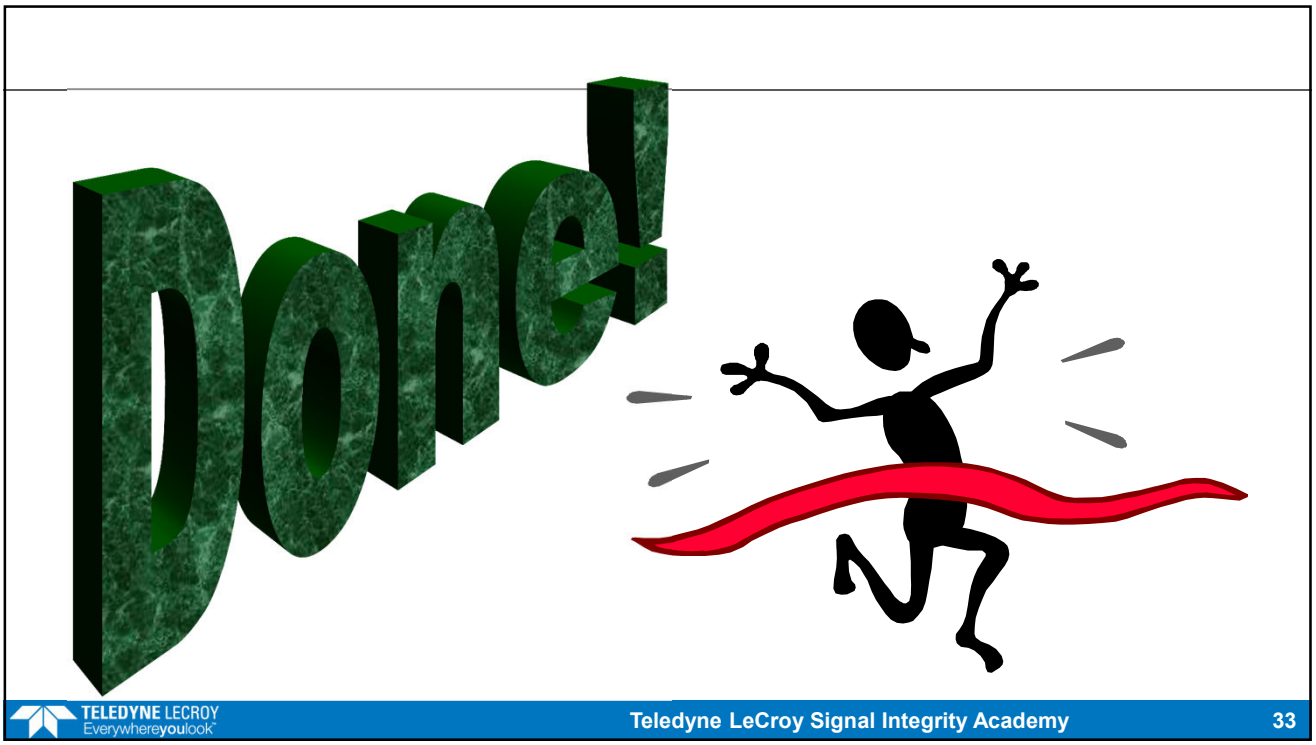











Done!
TELEDYNE LECROY
Everywhereyoulook
Teledyne LeCroy Signal Integrity Academy
33