Lesson EPSI-07-01 Download the pdf slides here

Course EPSI: Essential Principles of Signal Integrity

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

- EPSI-07-01: recorded live, Dec 1, 2013
  - cross talk in uniform transmission lines: NEXT and FEXT
  - Download a pdf copy of the slides here

Lesson EPSI-07-10 Near and Far End Cross Talk

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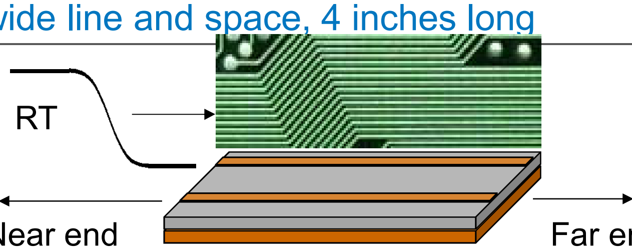
- EPSI-07-10: recorded live, Dec 1, 2013
  - Cross talk when the return path is a solid plane
  - Measuring the cross talk to an adjacent transmission line
  - The signature of near end and far end cross talk
  - Finding the root cause of near and far end cross talk

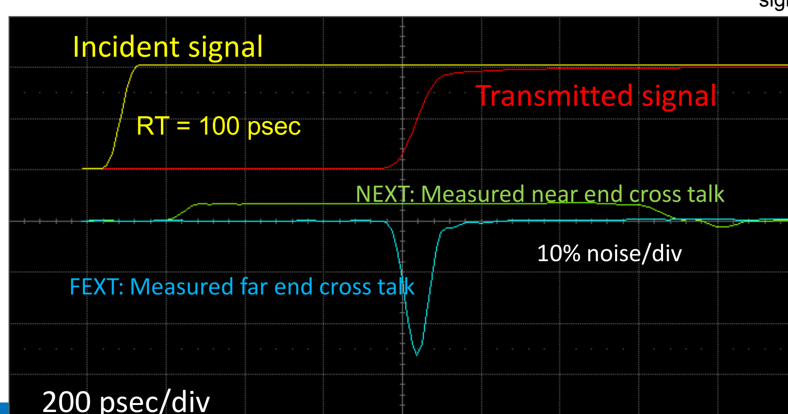
- Day 1
  - EPSI 1 Transmission Lines
  - EPSI 2 Differential Pairs and Lossy Lines
  - Lunch
  - EPSI 3 Reflections and Terminations
  - EPSI 4 Routing Topologies and Discontinuities
- Day 2
  - EPSI 5 Eliminating Ground Bounce
  - EPSI 6 Navigating Return Path Discontinuities
  - Lunch
  - **EPSI 7 NEXT and FEXT Features**
  - EPSI 8 PDN and EMI Design

The Problem: Measured Near and Far End XTK in Two Uniform Microstrips: 5 mil wide line and space, 4 inches long



$$\text{NEXT} = \frac{V_{near}}{V_{signal}}$$

$$\text{FEXT} = \frac{V_{far}}{V_{signal}}$$



Very different signatures
Very different magnitudes

Lesson EPSI-07-20 Cross talk and fringe fields

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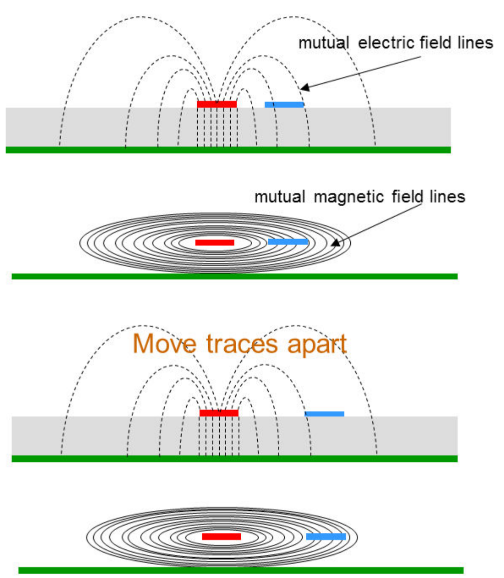
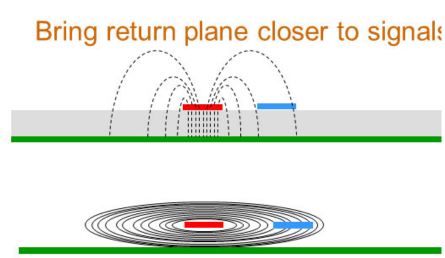
- EPSI-07-20: recorded live, Dec 1, 2013
  - Fringe electric and magnetic fields
  - The important role of planes for impedance and cross talk control
  - The root cause of cross talk
  - Two important design features to reduce cross talk

Fundamental Root Cause of Cross Talk: Fringe Electric and Magnetic Fields



- Induced cross talk noise:
  - ✓ Changing mutual electric field
  - ✓ Changing mutual magnetic fields
- Two general ways of reducing mutual field lines
  - ✓ Move the traces farther apart
  - ✓ Bring return plane closer to the signal lines



Lesson EPSI-07-30 Why NEXT is different from FEXT

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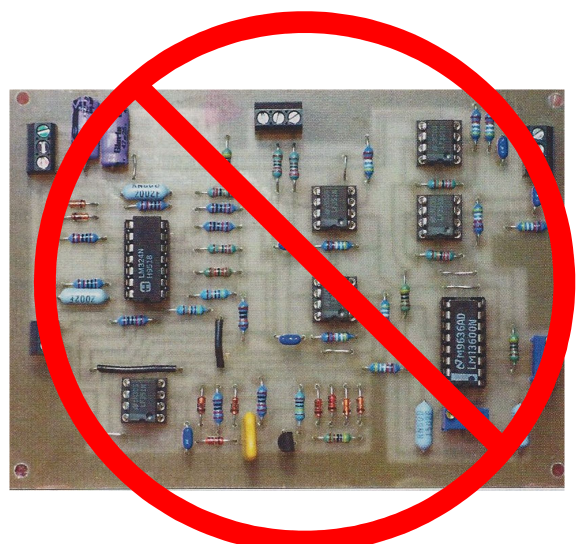
- EPSI-07-30: recorded live, Dec 1, 2013
  - Two essential principles of NEXT and FEXT
  - Changing fields is what drives cross talk
  - Signal propagation is what shapes NEXT and FEXT
  - Based on the root cause, the way to reduce far end cross talk

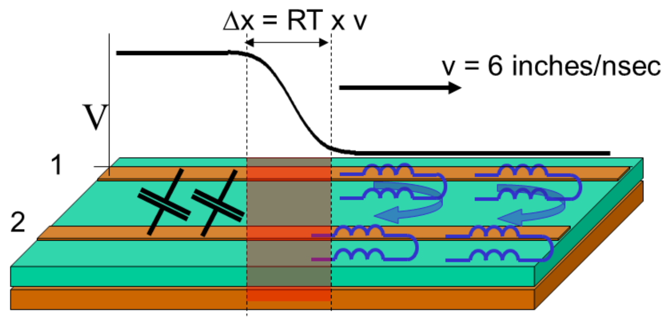
Why Do we Use Planes in Boards?

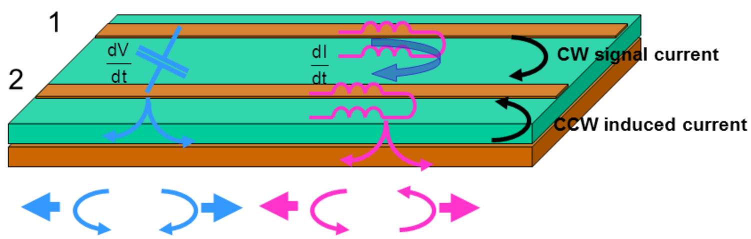
- Forget the word "shielding"!
- To control the impedance
- To keep the signal-return electric, magnetic fringe fields from spreading to other signals.
- Cross talk *DRAMTICALLY* increases without an adjacent plane!



Two Most Important Principles of Cross Talk in Busses

1. The only way noise is induced on quiet line is:
   - ✓ Electric field coupling = capacitive → changing voltage, dV/dt
   - ✓ Magnetic field coupling = inductive → changing current, dI/dt
2. Signals propagates and induced noise propagates





@ Near end: $I_C + I_L$ @ Far end: $I_C - I_L$

Lesson EPSI-07-40 Detailed analysis for NEXT and FEXT

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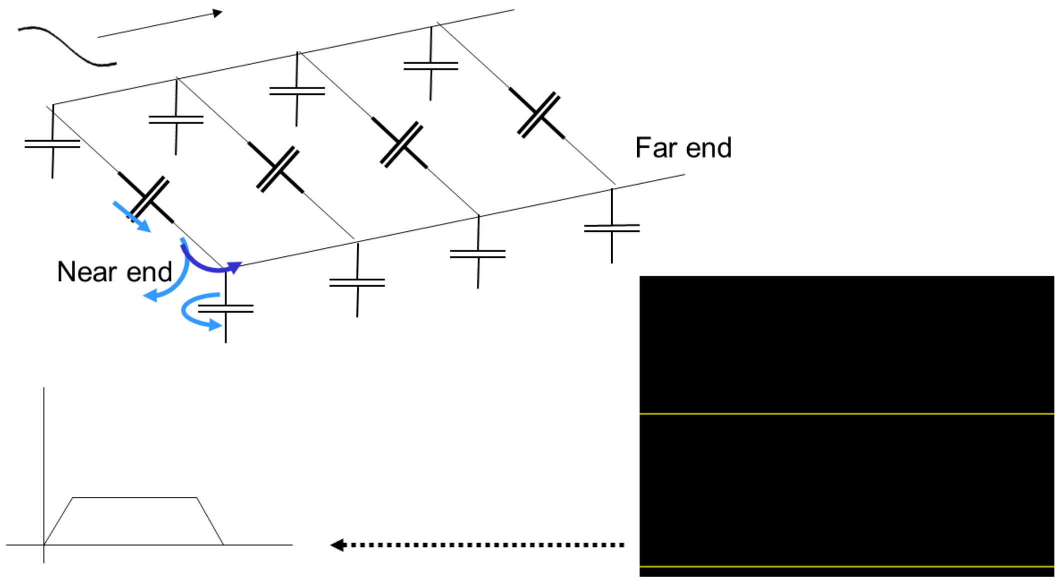
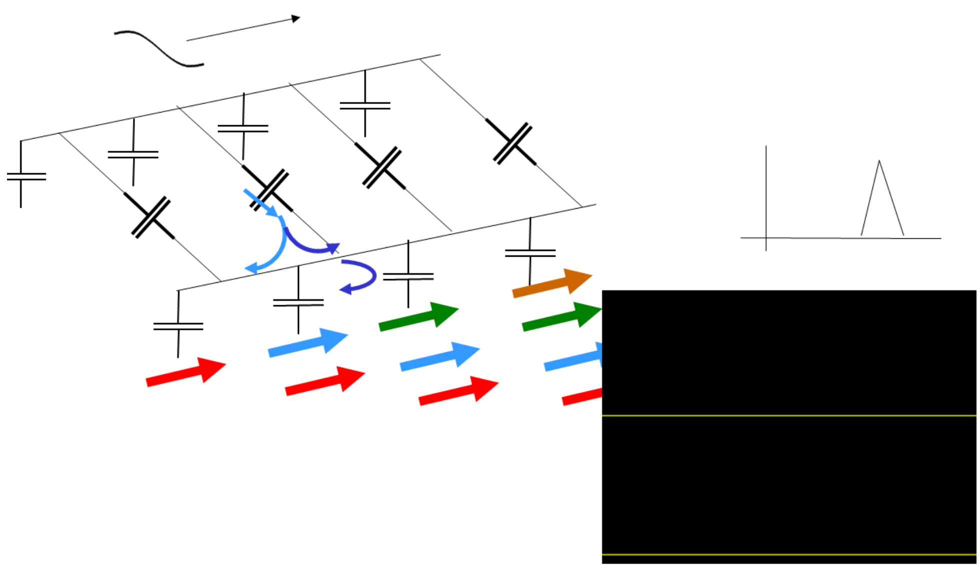
- EPSI-07-40: recorded live, Dec 1, 2013
  - Capacitively coupled currents propagating backward
  - Capacitively coupled currents propagating forward
  - Inductively coupled currents propagating backward
  - Inductively coupled currents propagating forward

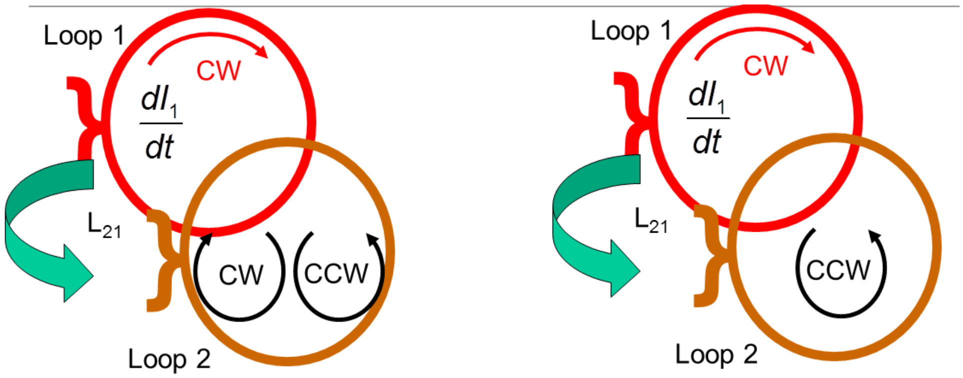
Capacitively Coupled Currents- Backward Direction



Capacitively Coupled Currents- Forward Direction



Induced Voltage Between Two Current Loops

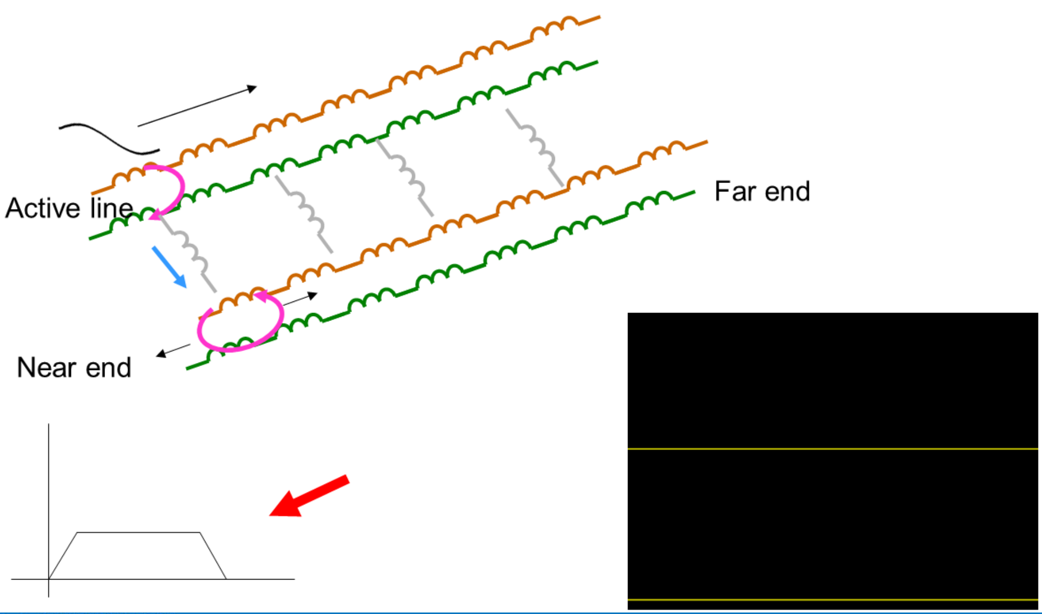


$$V_2 = L_{21}\frac{dI_1}{dt} \longrightarrow I_2 = \frac{V_2}{Z_2} = \frac{L_{21}}{Z_2}\frac{dI_1}{dt}$$

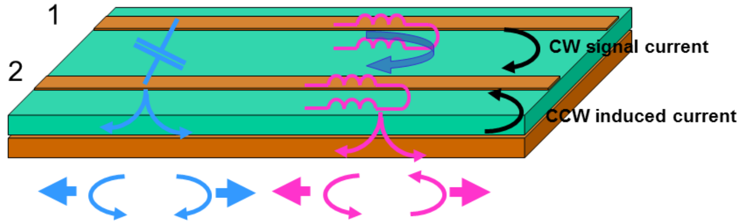
Lentz's: Direction of induced current is opposite direction of inducing current

What direction is the induced current?

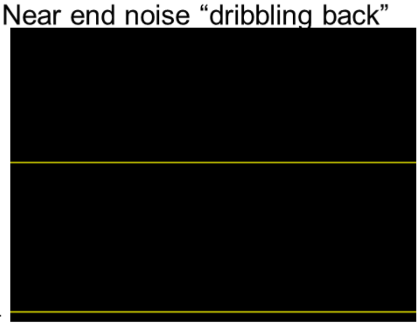
Inductively Coupled Currents- Backward Direction



Different Signatures at Near End and Far End due to Propagation, CCW Induced L Noise Current

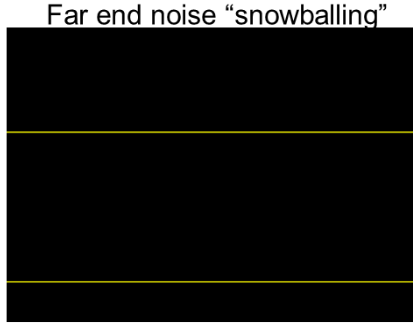


Near end noise “dribbling back”



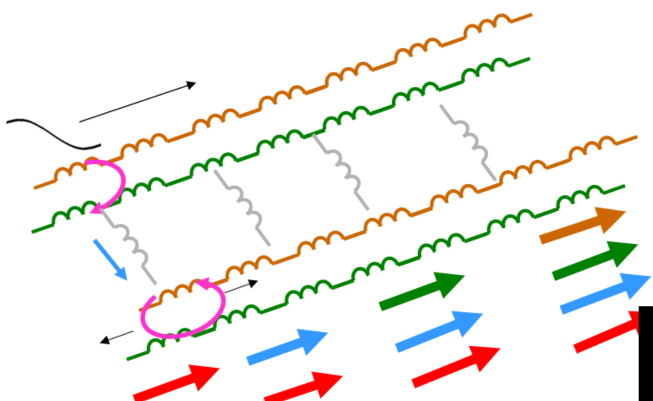
$I_C + I_L$

Far end noise “snowballing”

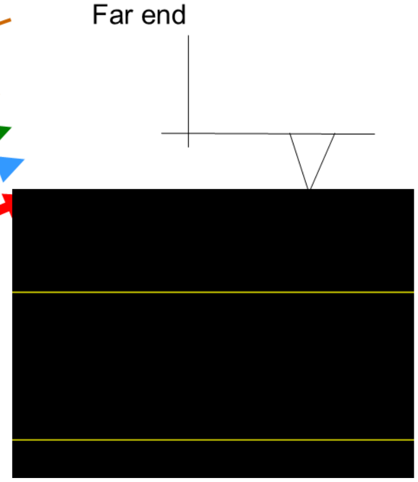


$I_C - I_L$

Inductively Coupled Currents- Forward Direction

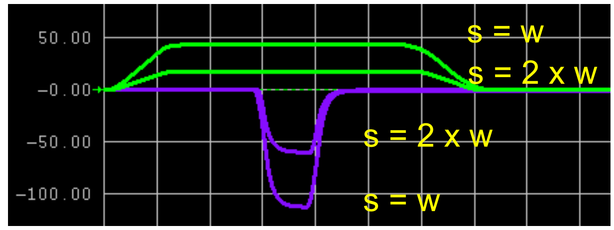


Far end

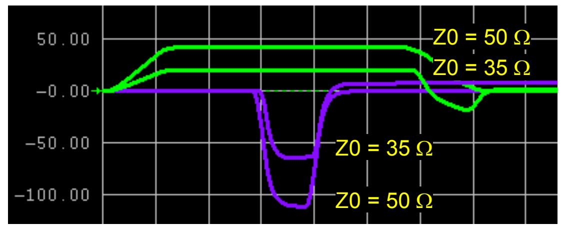


Most important Ways of Reducing NEXT, FEXT: Control the Fringe Fields

- Move traces farther apart (keeping Z0 = 50 Ω)
  - Nominal: s = w
  - Apart: s = 2 x w

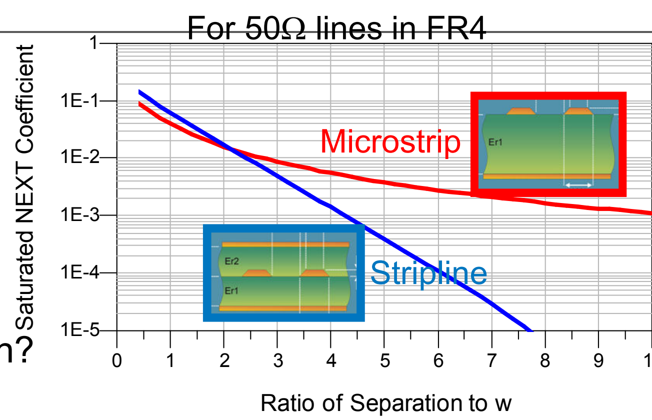


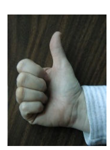
- Bring return plane closer to signal lines (lower impedance)
  - Nominal: Z0 = 50 Ohms
  - Closer plane: Z0 = 35 Ohms



How Else to Reduce NEXT?

- Aren't any!
  - Independent of rise time
  - Independent of coupling length
- Which has lower NEXT?:
  - Microstrip
  - Stripline
- How much cross talk is too much?
  - …it depends!
  - Roughly 5%





For worst case NEXT
in a bus, keep NEXT < 2%
Design separation > 2 x w, MS or SL

Lesson EPSI-07-50 Engineering lower NEXT and FEXT

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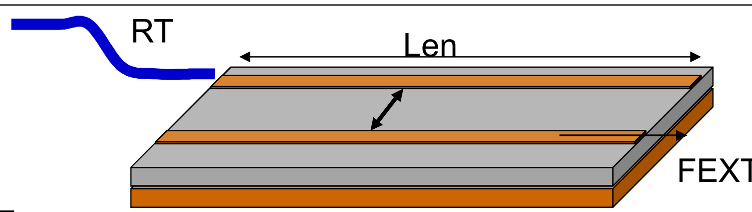
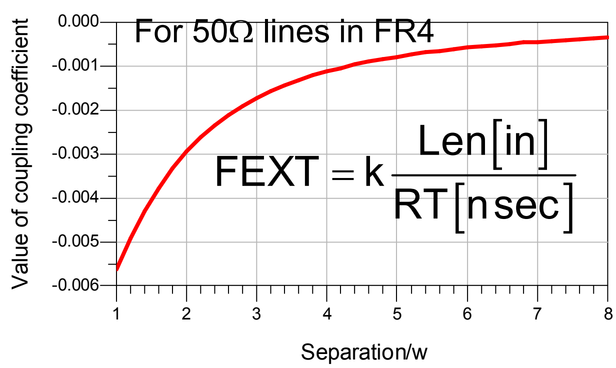
- EPSI-07-50: recorded live, Dec 1, 2013
  - Three design features that will not reduce NEXT
  - Reducing NEXT by separation
  - Three design features that will decrease FEXT
  - Estimating FEXT in microstrip surface traces

Other Ways of Controlling FEXT

- Reduce FEXT:
  - Lower Z0
  - Larger spacing between signal traces
  - Shorter coupling length
  - Longer rise time
- Example 1: Len = 10 inches, RT = 0.3 nsec, separation = w
  - k = -0.005, FEXT = 10 inches / 0.3 nsec x 0.005 = 17% !!!!!!
- Example 2: Len = 2 inches, RT = 0.5 nsec, separation = 2 x w
  - k = -0.003, FEXT = 2 inches / 0.5 nsec x 0.003 = 1%
- Most important way of eliminating FEXT
  - Move to stripline! ($I_C = I_L$)





Lesson EPSI-07-60 Cross talk as affected by terminations

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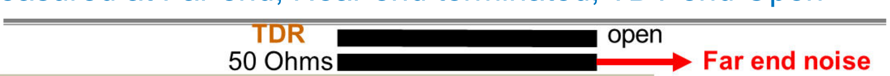
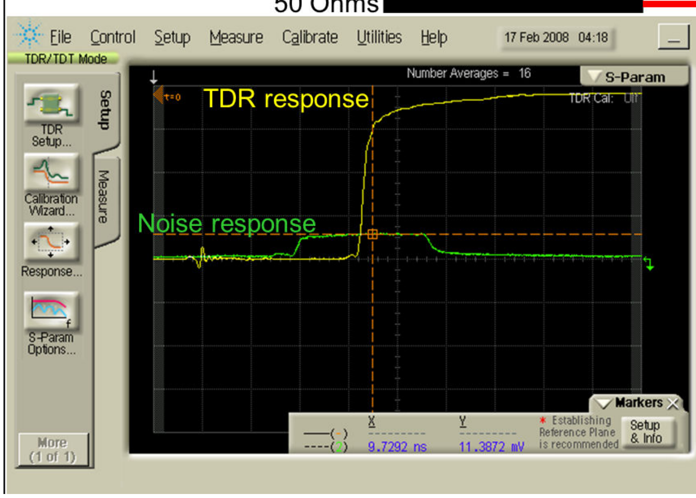
- EPSI-07-60: recorded live, Dec 1, 2013
  - TDR set up to measure FEXT
  - Measured FEXT in MS and SL
  - Simulating NEXT and FEXT in coupled MS
  - Role of terminations affecting FEXT and NEXT

Eliminate FEXT with Stripline

Measured at Far end, Near end terminated, TDT end Open



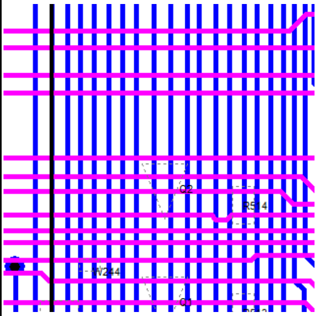


Differences:

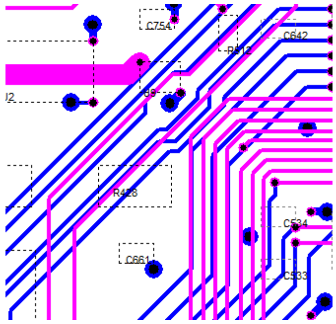
Far end cross talk in microstrip: $I_L > I_C$

No far end cross talk in stripline: $I_L = I_C$

A Common Problem with Dual Stripline: Two Routing Layers Between Return Planes

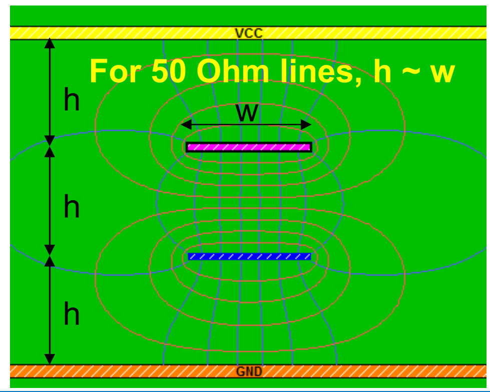


Normally, route the layers orthogonal as x-y



But what if there is inadvertent overlap?

Broad side coupled stripline



Broadside Coupling Can be Huge!

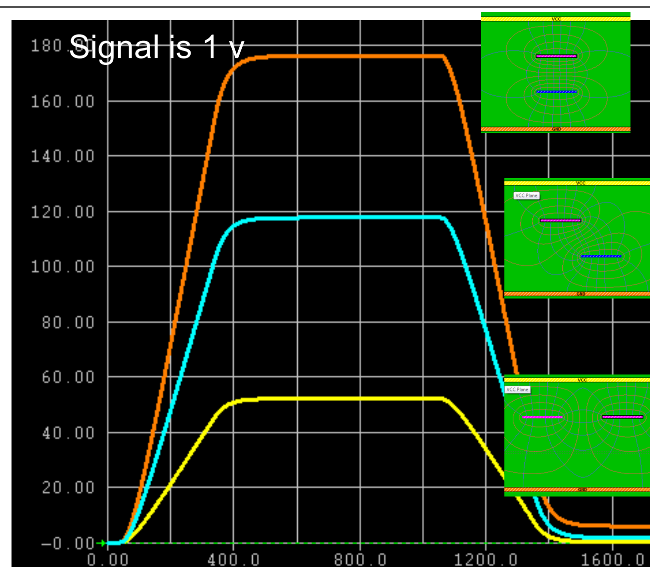
When there is perfect overlap, broad side coupling, NEXT ~ 18%

When signals are offset by w, NEXT ~ 12%

When signals are edge coupled, NEXT ~ 5%

If dielectric thickness between signal layers is thinner, NEXT is larger

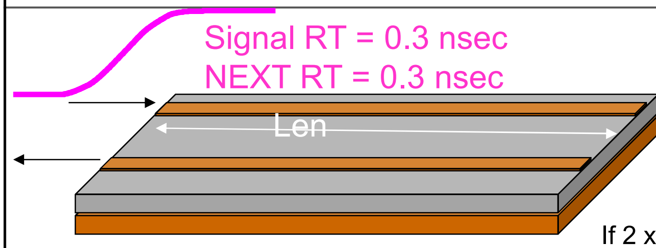
Always try to add dielectric fill layers between signal layers



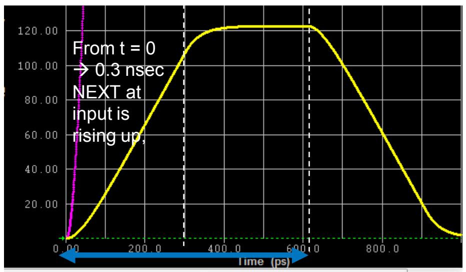
Broadside coupling can be ***HUGE***!

Saturation of Near End Cross Talk

Signal RT = 0.3 nsec
NEXT RT = 0.3 nsec



Len = 1.8 inches,
@ 6 inch/nsec, TD = 0.3 nsec



2 x TD

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] or Len_{sat}[cm] = 7.5 x RT[nsec]

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

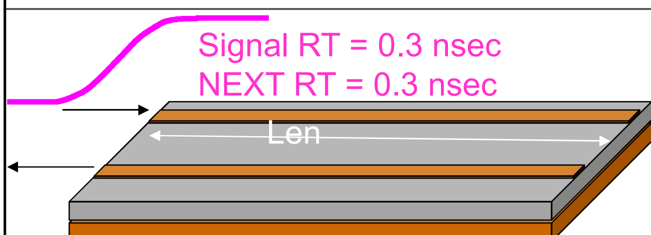
$$NEXT = \frac{Len}{Len_{sat}} NEXT_{sat}$$

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

Len_{sat}[cm] = 7.5 x RT[nsec]

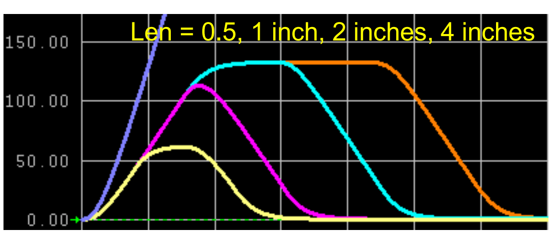
Another Way to Reduce Near End Cross Talk

Signal RT = 0.3 nsec
NEXT RT = 0.3 nsec



Len_{sat}[inches] = 3 x 0.3 nsec = 0.9 inches

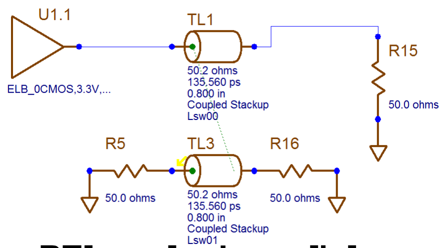
Len_{sat}[cm] = 2.25 cm

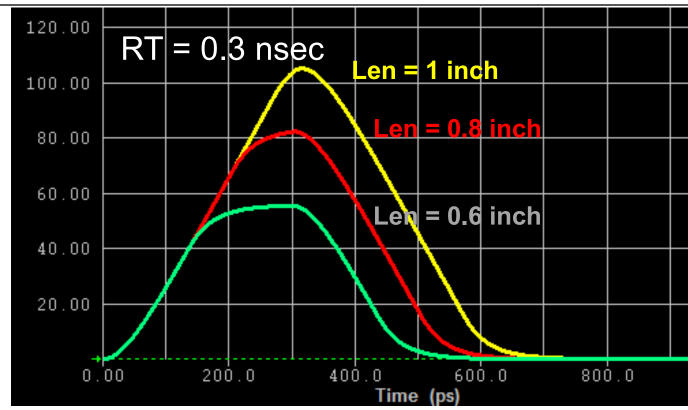


If Len can be reduced below Len_{sat},
NEXT can be reduced

For RT = 1 nsec, Len_{sat} = 3 inches = 7.5 cm
For RT = 0.3 nsec, Len_{sat} = 1 inch = 2.5 cm

Reducing NEXT by Shorter Coupling Length or Longer RT





RT[nsec]	**Len_{sat}[in]**
1 nsec	3 inches
0.3 nsec	0.9 inches
0.1 nsec	0.3 inches
0.05 nsec	0.15 inches

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

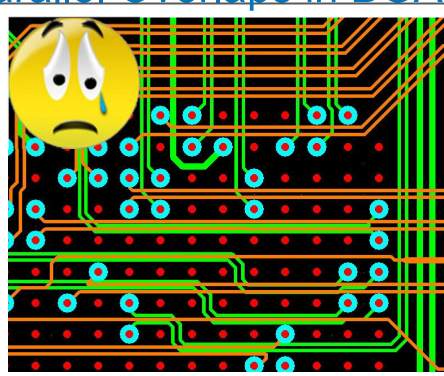
To keep NEXT < 5% when saturated broad side coupling = 15%: for special case of RT = 0.3 nsec

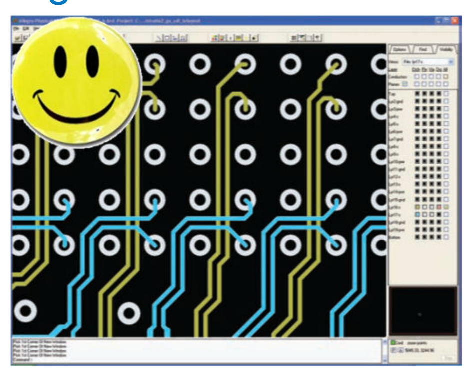
$$5\% = \frac{Len}{0.9\text{inches}} 15\%$$

Len < 1/3 Len_{sat} = 0.3 inches

What is the design constraint for even shorter rise times?

Inadvertent Broad Side Coupled Stripline: Unintentional Co-parallel Overlaps in BGA Breakout Region





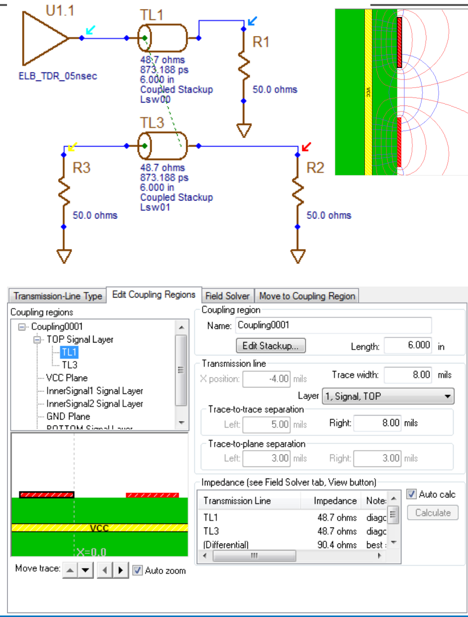
Courtesy of Altera

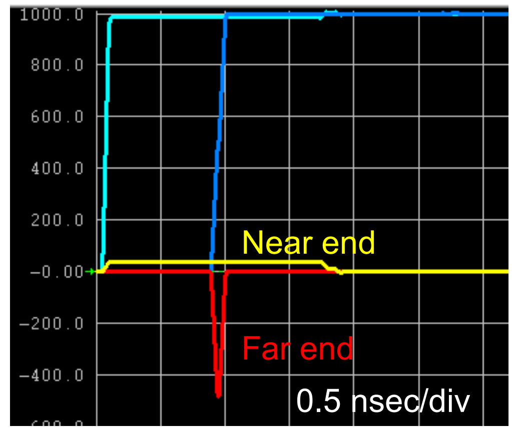
Inadvertent broadside near end cross talk in BGA break region can be > 15%!

This is a major “sneaky failure mode”

Keep inadvertent broad side coupling < 1/3 Len_{sat} for the given rise time

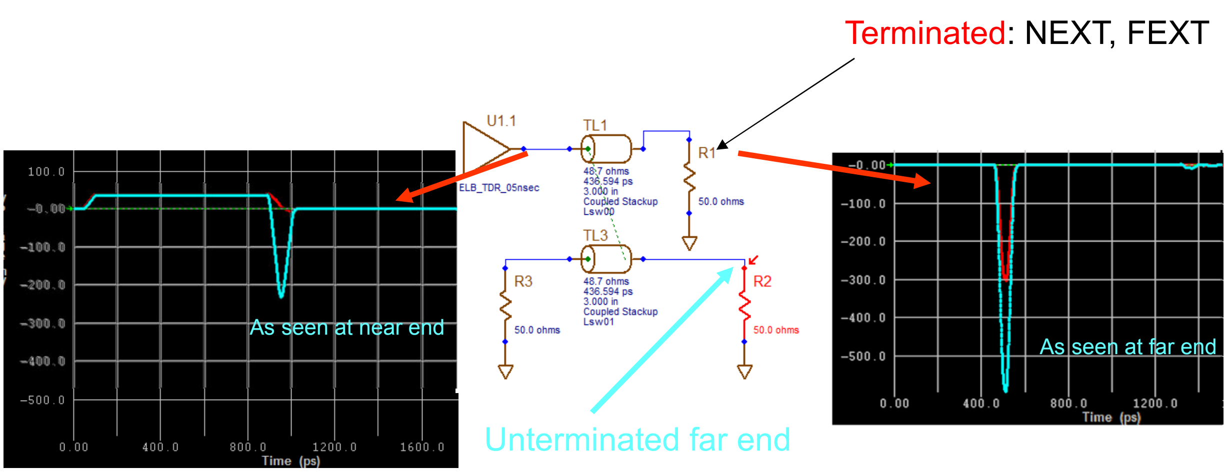
Simulate NEXT and FEXT (Requires 2D Field Solver!)



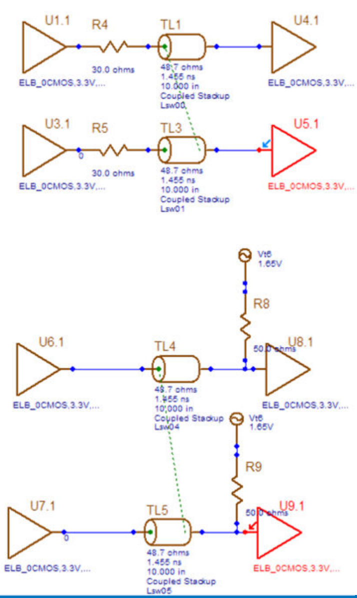


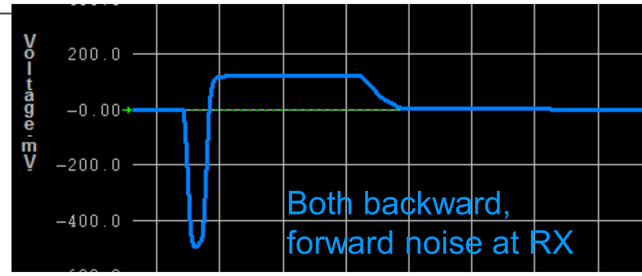
Induced Cross Talk and Terminations

- Amount of coupled noise is INDEPENDENT of the terminations
- Near end and far end noise will reflect just like signals

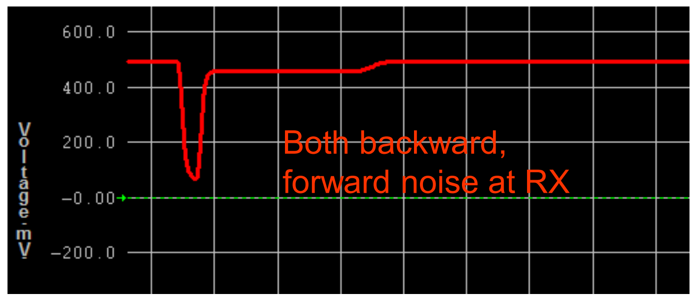


NEXT and FEXT Affected by Termination Topology





Vcc = 3.3 v, RT = 300 psec, Len = 10 inches, R_{source} = 20Ω



If both ends terminated, similar to NEXT and FEXT

Summary

- Cross talk is generated by capacitive and inductive coupling: fringe electric and magnetic fields
- Reduce NEXT, FEXT by:
  - Moving traces farther apart
  - Bringing return plane closer- lower impedance
- Propagation direction creates different noise generated in the forward or backward directions
- For most digital applications, when s ~ w, watch out for NEXT, FEXT. Try to keep s > 2 x w
- Watch out for inadvertent broad side coupling
- FEXT can be much higher than NEXT
- See microstrip → think FEXT
- Far end noise is eliminated in stripline, always estimate FEXT in microstrip


Done!