Lesson AGCD-02-01 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-02-01: recorded live, Dec 1, 2013
  - Download a pdf copy of the slides by clicking on the link on this page

Lesson AGCD-02-10 Re-thinking Differential and Common

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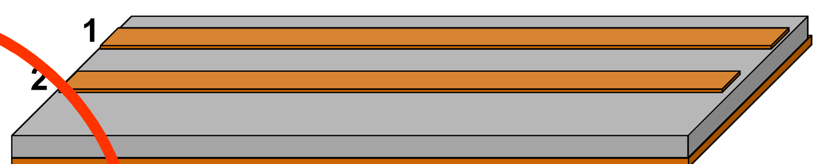
- AGCD-02-10: recorded live, Dec 1, 2013
  - How not to be confused by differential pairs
  - Signals do not have modes, interconnects have modes
  - Differential and common signals
  - Mode conversion that turns a differential signal into a common signal

AGCD: A 2-Day Workshop

- **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

A Secret to Minimize Confusion About Differential Impedance



Differential mode

Common mode

Think:

Differential signals

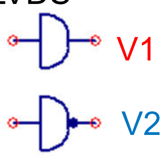
Common signals

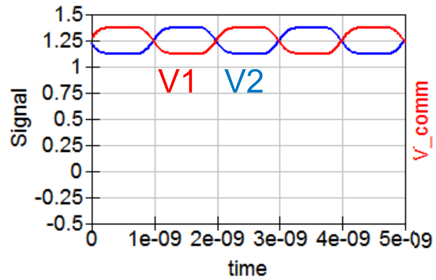
Odd mode

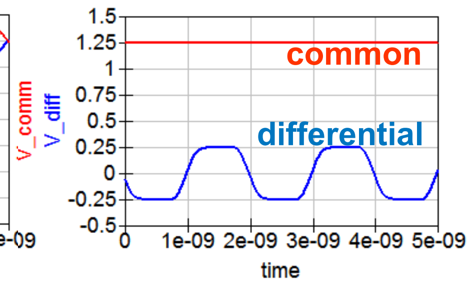
Even mode

Differential and Common Refer to SIGNALS

LVDS



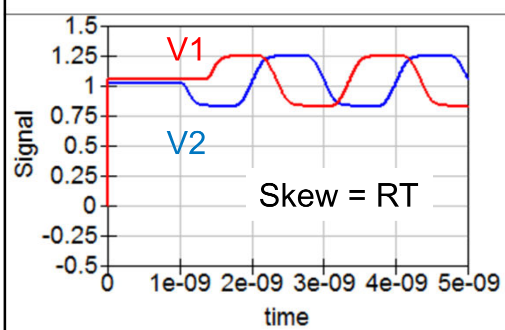


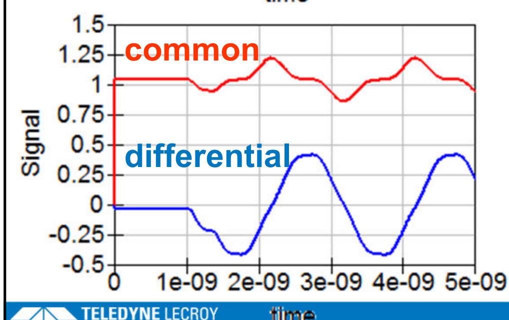


- Definitions:
  - $V_{diff} = V1 - V2$
  - $V_{comm} = \frac{1}{2}(V1 + V2)$

Differential and common signals propagate independently on differential pairs

Every Pair of Signals Has a Differential and Common Component





- Differential and common signals propagate independently and DO NOT Interact on the board
- But: Any line to line asymmetry, anywhere, will convert some differential signal into a common signal: ***mode conversion***
  - Driver skew, amplitude
  - Rise/fall time difference
  - Output impedance
  - Trace impedance
  - Line length
  - Local Dk variation

Definitions:

$V_{diff} = V1 - V2$

$V_{comm} = \frac{1}{2}(V1 + V2)$

Lesson AGCD-02-20 Differential signals and interconnects

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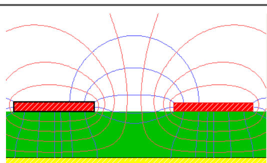
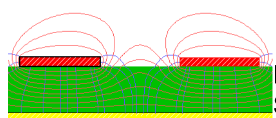
- AGCD-02-20: recorded live, Dec 1, 2013
  - Differential and common signals propagate independently
  - Speed of a differential and common signal
  - Modeling interconnects: S-parameter behavioral models
  - Modeling interconnects: circuit topology transmission line elements

Differential and Common Signals Propagate Independently on a Differential Pair



Effective Dk of odd mode?
Speed of differential signal?

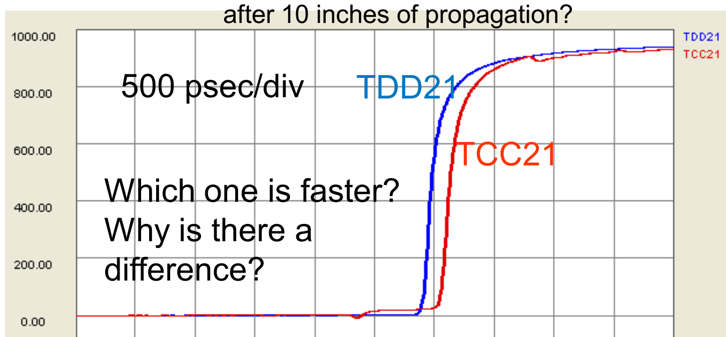
Differential signal



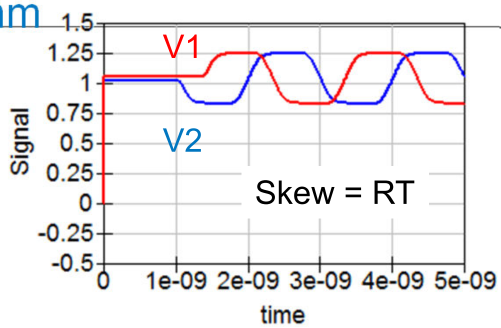
Effective Dk of even mode?
Speed of common signal?

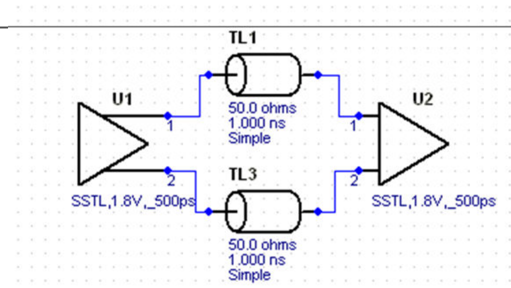
Common signal

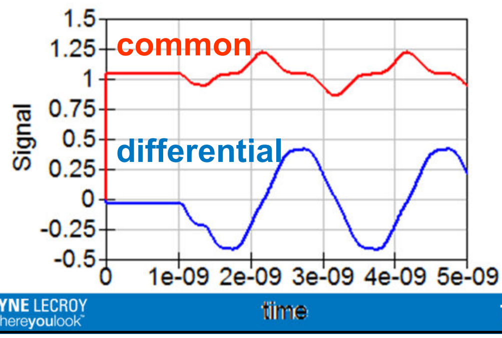
If a diff and comm signal start at the same time, what happens after 10 inches of propagation?



Important Guideline: Do Not Think Vp and Vn, Think Vdiff and Vcomm





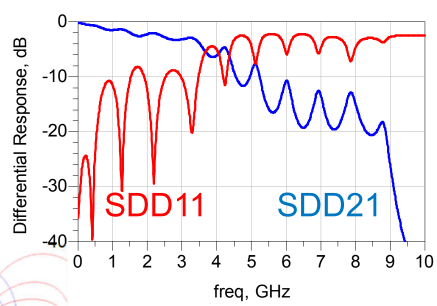


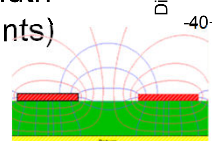
Think:
Differential signal
Differential impedance
Differential time delay

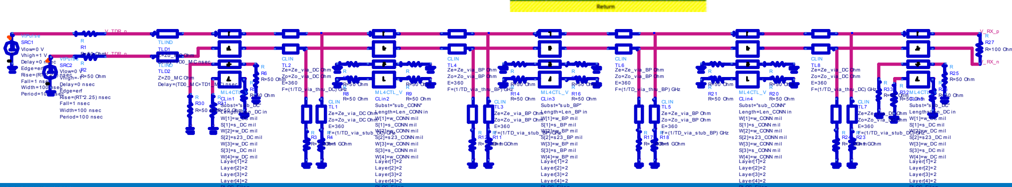
Common signal
Common impedance
Common time delay

ANY Electrical Analysis of an Interconnect Requires an Electrical Model

- Two types of channel electrical models:
- S-parameter files (behavioral model)
- Scalable, circuit topology elements:
  - R, L, or C elements
  - Ideal, lossy, coupled transmission line elements (inherently higher bandwidth possible than lumped circuit elements)







Lesson AGCD-02-30 Differential impedance when uncoupled

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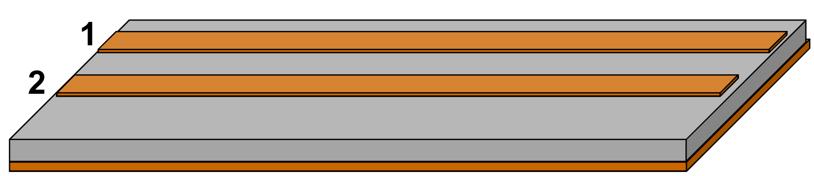
- AGCD-02-30: recorded live, Dec 1, 2013
  - Features of an optimized differential pair
  - Instantaneous differential impedance
  - Differential impedance with no coupling
  - The impedance of one line as the other line is moved closed

The Most Important Building Block Circuit Element: A Differential Pair Transmission Line

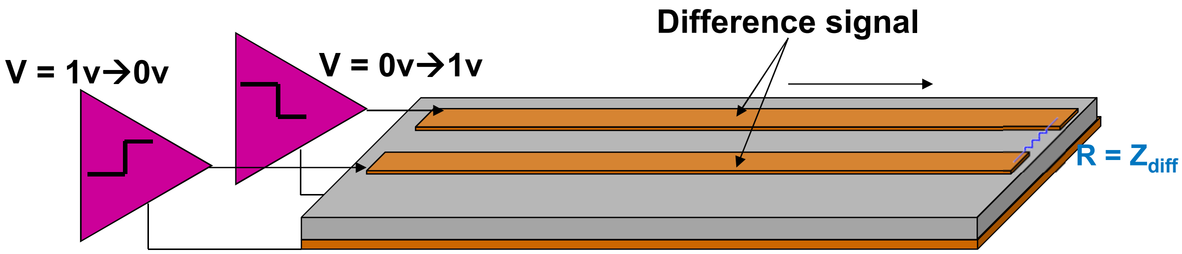
What is a differential pair transmission line?
Ans: ***Any Two Single-ended Transmission Lines***



- Primary features for optimized performance:
  - (L) Wide lines, low Df laminate
  - (R) Uniform differential impedance (controlled impedance)
  - (N) Far from other channels
  - (M) Symmetric lines: matched length, cross section
- What is the optimum coupling? tight or loose?

"it depends!"

Very Important Principle

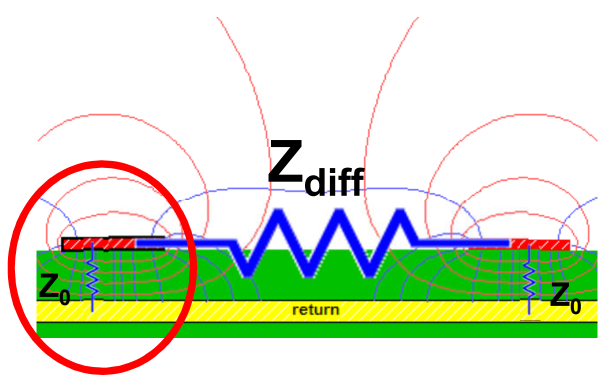


Differential impedance is the instantaneous impedance the differential signal sees

Differential Impedance and Single-ended Impedance

What is the equivalent impedance between the two signal lines?

with no coupling:



$$Z_{diff} = Z_0 + Z_0$$

$$Z_{diff} = 2 \times Z_0$$

What happens to Z0 when traces move closer together?

Lesson AGCD-02-40 Differential impedance when tightly coupled

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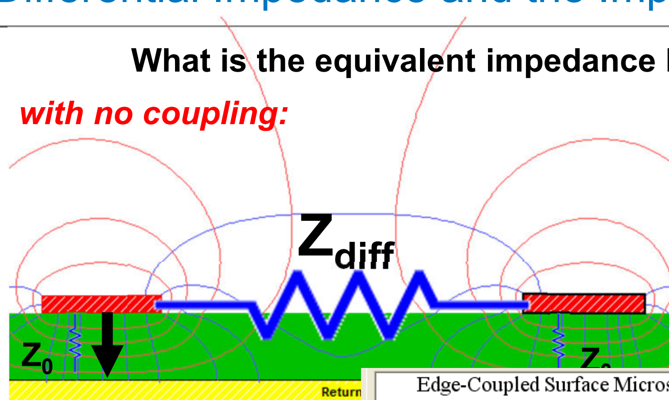
- AGCD-02-40: recorded live, Dec 1, 2013
  - Impedance of one line when the second is brought closer
  - Differential impedance and coupling
  - Tight, loose and uncoupled differential pairs
  - Calculating differential impedance with a field solver

Differential Impedance and the Impedance of Each Line

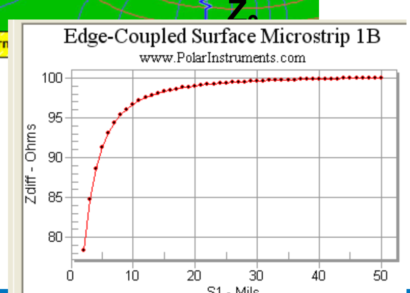
What is the equivalent impedance between the two signal lines?

with no coupling:

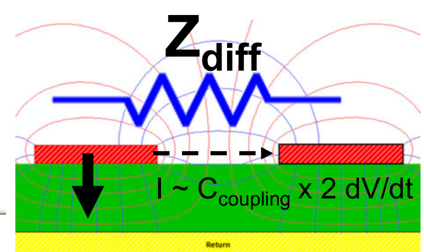


$$Z_{diff} = Z_0 + Z_0$$

$$Z_{diff} = 2 \times Z_0$$



with coupling:



Current increases, impedance decreases

$$Z_{diff} = 2 \times (Z_0 - \Delta Z)$$

The larger the coupling, the lower the differential impedance

Lesson AGCD-02-50 Which is better, tight or loose coupling?

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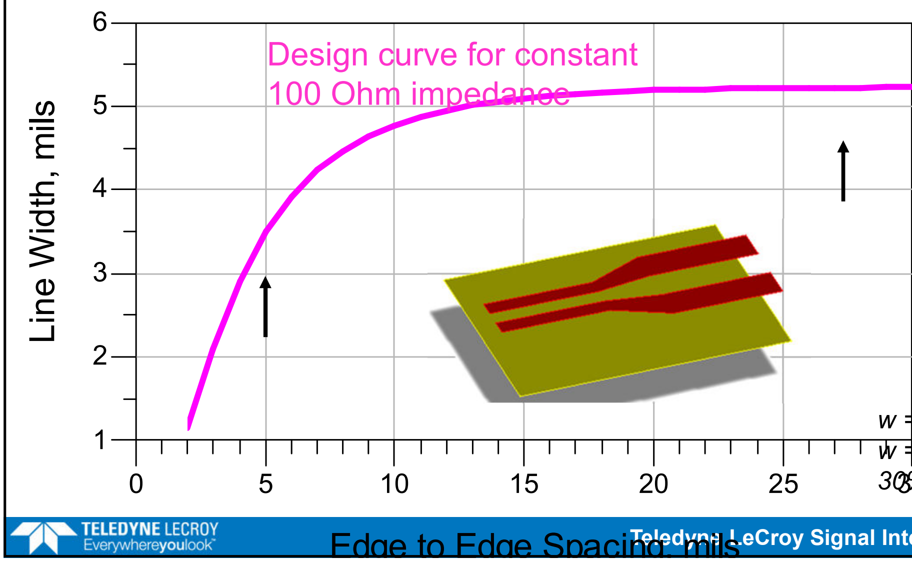
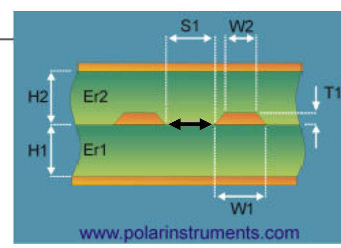
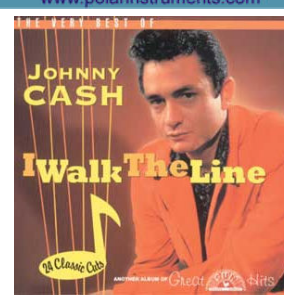
- AGCD-02-50: recorded live, Dec 1, 2013
  - Differential impedance in stripline
  - Keeping differential impedance constant as coupling changes
  - Measured single-ended and differential impedance and coupling
  - Which is better, tight or loose coupling?

Keeping The Instantaneous Differential Impedance Constant in Stripline

Nominal 5 mil line width, 100 Ohms, uncoupled
H_total = 13 mils, t = 0.7 mils, Dk = 4



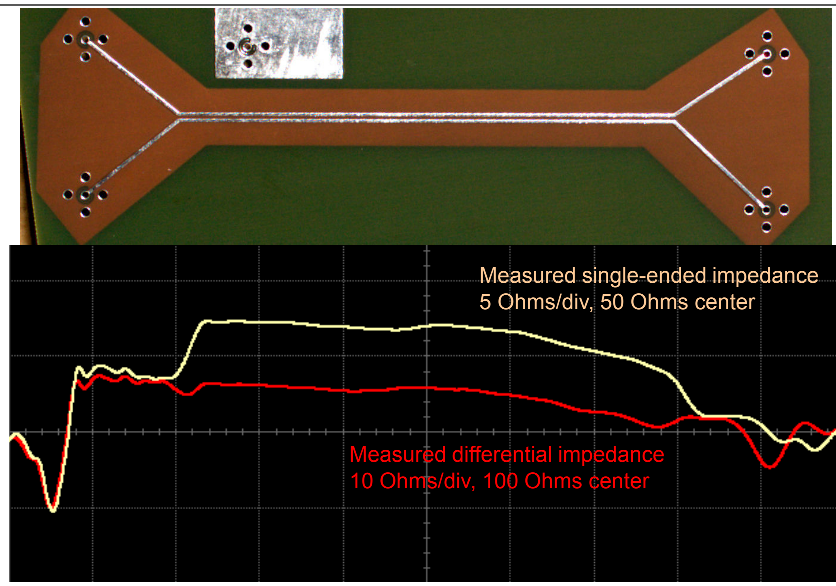




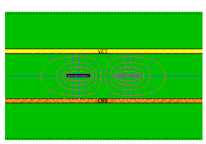
w = 5.2 mils, uncoupled
w = 3.5 mils for tightly coupled
30% narrower line for tightly coupled

MS diff pair Designed for Uniform Diff Impedance

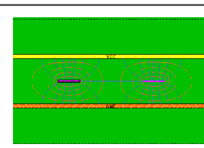
To keep diff impedance constant as coupling changes, requires line width change



Which is Better, Tight or Loose Coupling?



?



- Lowest cost will always be with highest interconnect density:
  - Tight coupling should always be the first choice.
- What is the downside to tight coupling?
  - Narrower line width → more loss
  - If loss is important, > 2-3 Gbps, ***and*** long lines, consider loose coupling
    (Can actually be ***slight increase*** in channel to channel cross talk from tighter coupling!)
  - @ > 10 Gbps, loss is critical: loose coupling should be first choice
- ***Regardless of bit rate, always do your own analysis***


Done!