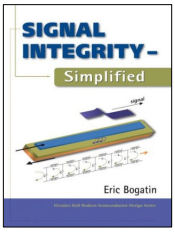
The Three Most Confusing Topics in Signal Integrity

and how not to be confused



with
Dr. Eric Bogatin, Signal Integrity Evangelist,
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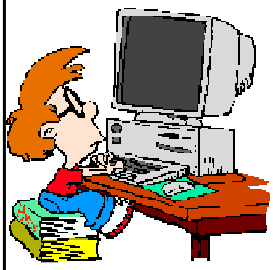
eric@beTheSignal.com

Overview

- Why do we care?
- Specific examples:
  - ✓Characteristic Impedance
  - ✓Differential Impedance
  - ✓Inductance
- Got your own? Send me a note

What are the Designer's Most Important Tools?

From Here → To Here → Or Here



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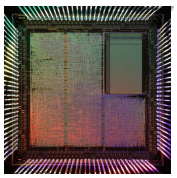
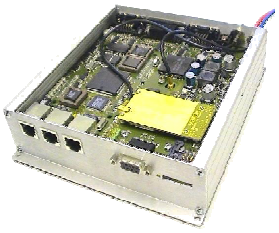
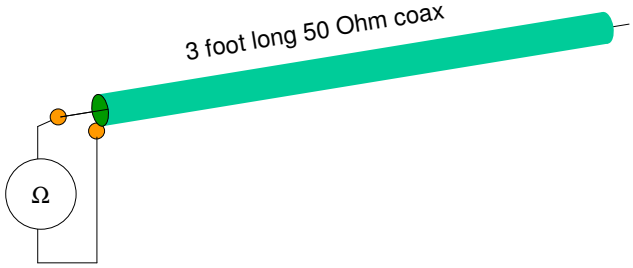




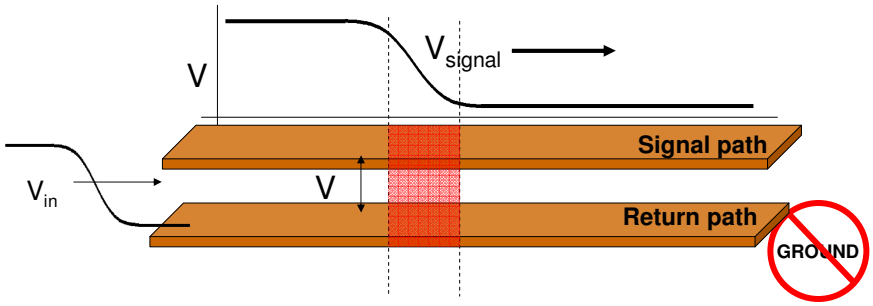
***Creativity** and **intuition** are the key ingredients to the design process*

What Does it Mean to Refer to a Cable as a "50 Ohm Cable"?

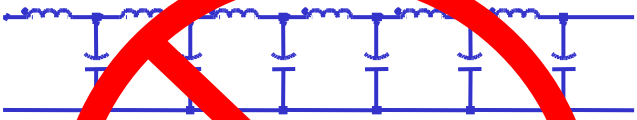


What is the Most Important Electrical Quality the Signal Cares About?

Ans: the instantaneous impedance



Electrical Model of a Lossless Transmission Line

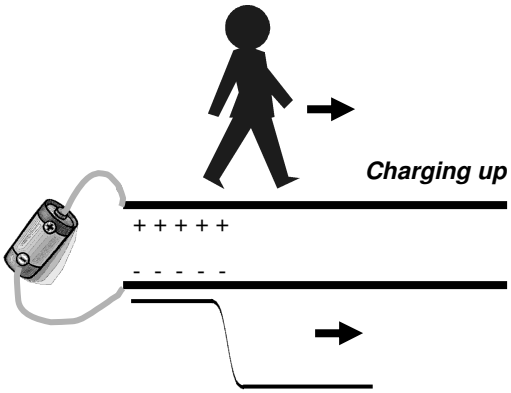


Telegraphers' equation $\frac{\partial}{\partial x}V(x,t) = -L\frac{\partial}{\partial t}I(x,t)$ $\frac{\partial}{\partial x}I(x,t) = -C\frac{\partial}{\partial t}V(x,t)$

Wave equation $\frac{\partial^2}{\partial t^2}V(x,t) = \frac{1}{LC}\frac{\partial^2}{\partial x^2}V(x,t)$ $\frac{\partial^2}{\partial t^2}I(x,t) = \frac{1}{LC}\frac{\partial^2}{\partial x^2}I(x,t)$

derive $Z_0 = \sqrt{\frac{L}{C}}$ TD $\sqrt{LC}$

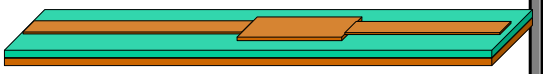
"…be the signal"



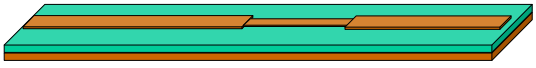
Charging up a transmission line

Instantaneous Impedance, $Z = \frac{V}{I}$

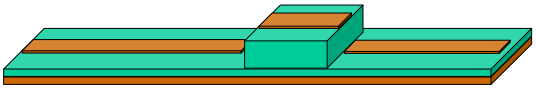
Geometry, Current and Impedance



Line width increases, capacitance **increases**, impedance **decreases**

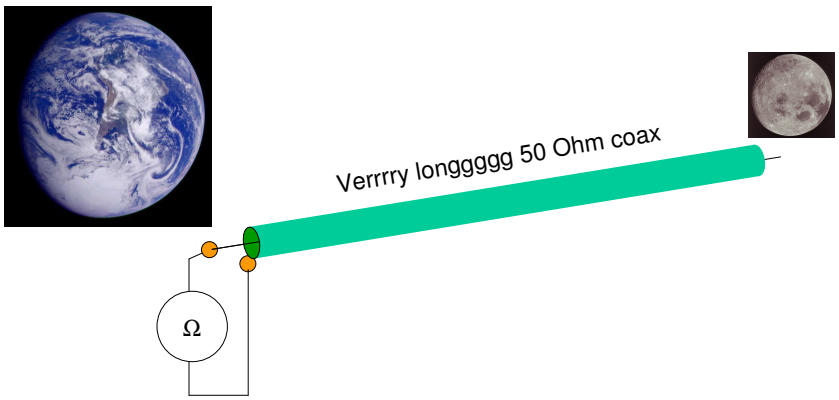


Line width decreases, capacitance **decreases**, impedance **increases**

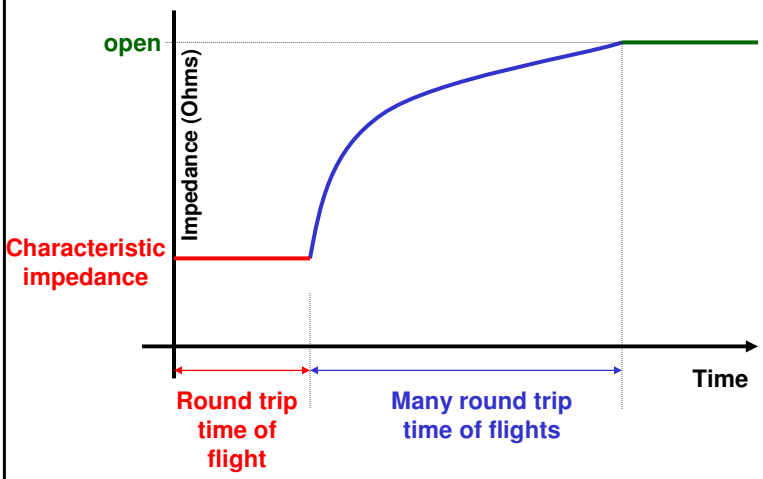


Dielectric thickness increases, capacitance **decreases**, impedance, **increases**

What Does it Mean to Have a 50 Ohm Line?



The Input Impedance of a Transmission Line is Time Dependent

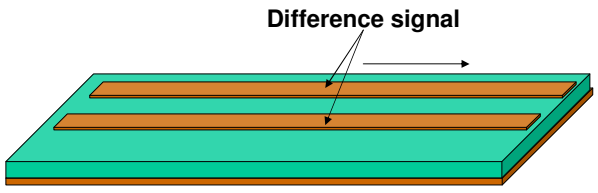


"…the impedance" of a Transmission Line is Ambiguous

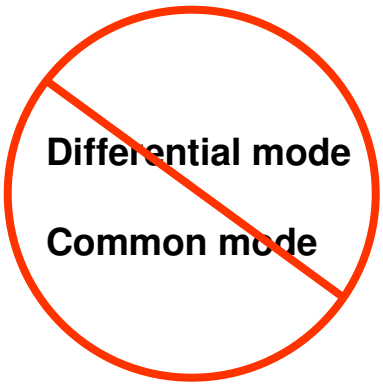
- The input impedance of the transmission line - may be time dependent
- The instantaneous impedance of the transmission line
- The Characteristic impedance of the transmission line

2nd topic: Differential Impedance

- What is differential impedance and how does coupling affect it?



A Secret to Minimize Confusion About Differential Impedance



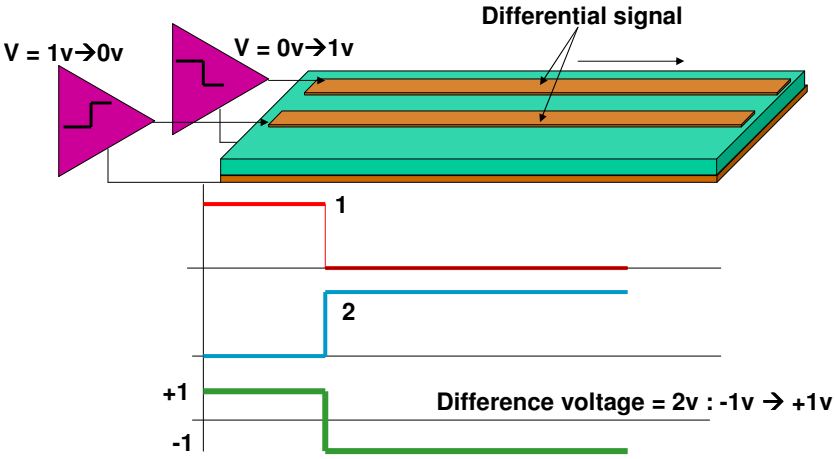
Think:

Differential signals
Common signals
Odd mode
Even mode

Essential Principle

Differential impedance is the instantaneous impedance the differential signal sees

The Differential Signal

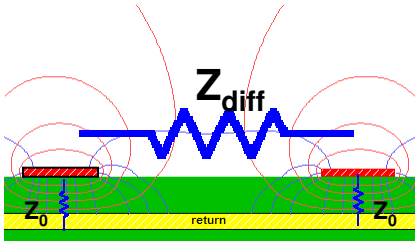


What is the impedance the difference signal sees?

Differential Impedance and Series Impedances

What is the equivalent impedance between the two signal lines?

with no coupling:

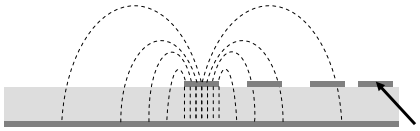


$$Z_{diff} = Z_0 + Z_0$$

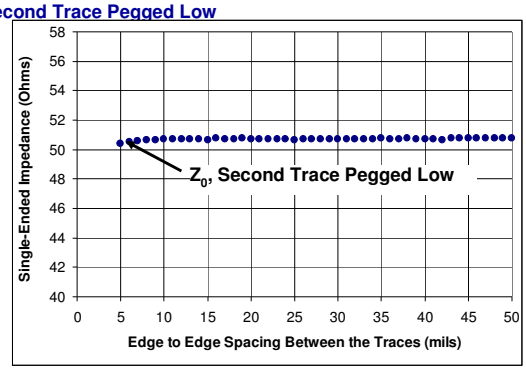
$$Z_{diff} = 2 \times Z_0$$

What happens to the impedance of one line when we turn on coupling?

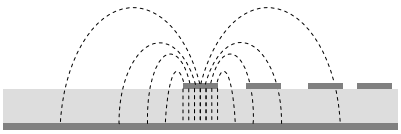
Other Line Is Tied Low

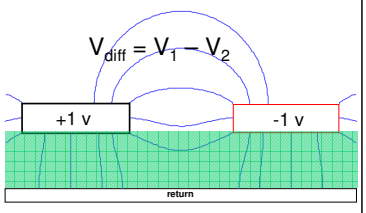


Z_0, Second Trace Pegged Low

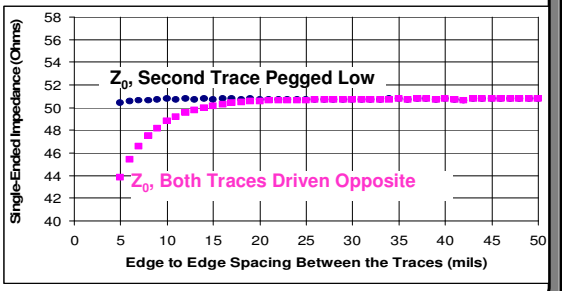


Other Line Driven Opposite





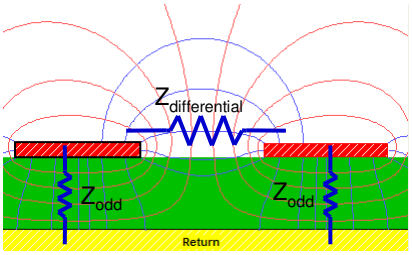
ODD MODE



Relating the Modes' Impedance to the Impedance the Signals See

What is the equivalent impedance between the two signal lines?

with coupling:



$$Z_{differential} = 2 \times Z_{odd}$$

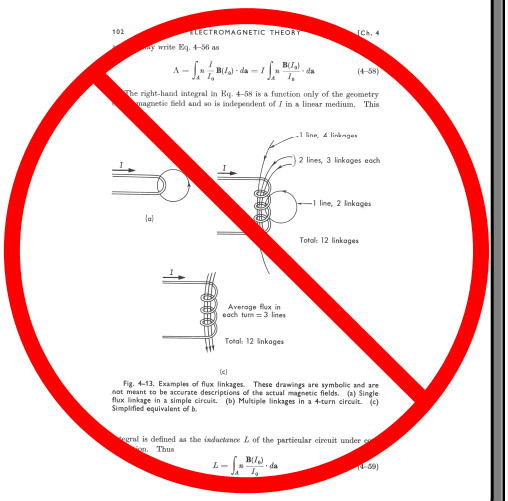
As coupling increases, differential impedance will: ___*decrease*___

What's Inductance?

- ✓
- ✓
- ✓
- ✓

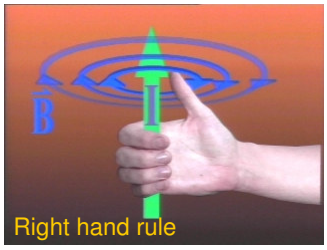
Deficiencies with Text Book Definitions

- Too mathematical to provide insight
- Deals with coils, not traces on a board



Inductance Principles -1

Rings of magnetic field lines are around all current carrying conductors



wire carrying a current

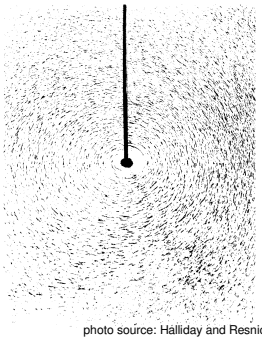


photo source: Halliday and Resnick, Physics, 1962

What influences the total number of rings of field lines?

Inductance Principles -2

2. Inductance is the number of rings of magnetic field lines around a conductor, per amp of current through it

Units: Webers/amp = Henry
nH more common

Inductance is a measure of the efficiency of a conductor to create rings of magnetic field lines at the cost of current
- high inductance, lots of field lines

Many flavors of inductance:

self ←→ mutual

loop ←→ partial

total, net or effective

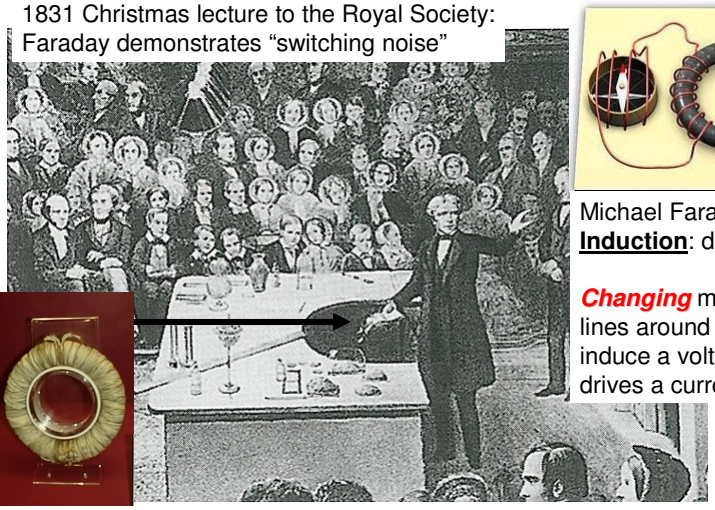
Inductance Plays a Pivotal Role in Signal Integrity

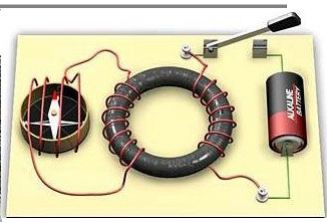
- Signal propagation:
  - ✓ loop self inductance
- Discontinuities:
  - ✓ loop self inductance
- Cross talk:
  - ✓ loop mutual inductance
- PDN and rail collapse:
  - ✓ loop self inductance
- Ground bounce:
  - ✓ total inductance of the return path
- Hacking interconnects: performance → physical design
  - ✓ Partial self and partial mutual inductance

Most Important Principle (#3) of Inductance

V → I → B ***?B → V***

1831 Christmas lecture to the Royal Society:
Faraday demonstrates "switching noise"



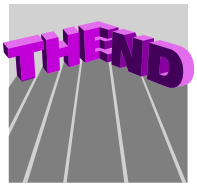


Michael Faraday's discovery:
Induction: dB/dt → V → I

Changing magnetic field lines around a conductor induce a voltage, which drives a current.

Summary

- Why do we care?
- Specific examples:
  - ✓Characteristic Impedance
  - ✓Differential Impedance
  - ✓Inductance
- Got your own? Send me a note



Thanks for listening!