The Three Most Confusing Topics in Signal Integrity

and how not to be confused

with
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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

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”? 

3 foot long 50 Ohm coax
What is the Most Important Electrical Quality the Signal Cares About?

Ans: the instantaneous impedance

Electrical Model of a Lossless Transmission Line

Telegraphers’ equation
\[ \frac{d}{dx} V(x,t) = -L \frac{d}{dt} I(x,t) \]
\[ \frac{d}{dt} I(x,t) = -C \frac{d}{dx} V(x,t) \]

Wave equation
\[ \frac{d^2}{dt^2} V(x,t) = \frac{1}{LC} \frac{d^2}{dx^2} V(x,t) \]
\[ \frac{d^2}{dt^2} I(x,t) = \frac{1}{LC} \frac{d^2}{dx^2} I(x,t) \]

derive
\[ Z_0 = \sqrt{\frac{L}{C}} \]

TD = \sqrt{\frac{LC}{C}}
"…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

Characteristic impedance

Round trip time of flight

Many round trip time of flights
“...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
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:

\[ Z_{\text{diff}} = Z_0 + Z_0 \]
\[ Z_{\text{diff}} = 2 \times Z_0 \]

What happens to the impedance of one line when we turn on coupling?
Other Line Is Tied Low

Single-Ended Impedance (Ohms) vs. Edge to Edge Spacing Between the Traces (mils)

Z₀, Second Trace Pegged Low

Other Line Driven Opposite

Single-Ended Impedance (Ohms) vs. Edge to Edge Spacing Between the Traces (mils)

Z₀, Second Trace Pegged Low

V_{diff} = V_1 - V_2

ODD MODE

Z₀, Both Traces Driven Opposite
Relating the Modes’ Impedance to the Impedance the Signals See

What is the equivalent impedance between the two signal lines?

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

Right hand rule

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 \leftrightarrow mutual
loop \leftrightarrow 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 \rightarrow physical design
  - Partial self and partial mutual inductance
Most Important Principle (#3) of Inductance

\[ V \Rightarrow I \Rightarrow B \quad \Rightarrow B \Rightarrow V \]

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

Michael Faraday’s discovery: **Induction**: \( \frac{dB}{dt} \Rightarrow V \Rightarrow I \)

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

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Summary

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- Specific examples:
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  - Differential Impedance
  - Inductance
- Got your own? Send me a note
Thanks for listening!