Presented at COMSOL CONFERENCE Bangalore , 2013

Studying Crosstalk Trends for Signal Integrity on Interconnects using Finite Element Modeling

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COMSOL CONFERENCE BANGALORE2013

Outline

Signal Integrity

- **Parameters for determining the quality of a signal.**
- **Low bit rates and short distances - Signals easily transmitted with sufficient fidelity**
- **High bit rates/Long distances- More chances of signal getting distorted.**
- **Signal Integrity-Aims to mitigate these effects**
- **Covers internal connections in IC through the package, to PCB till intersystem connections.**

Signal Integrity

Key Parameters for evaluating Signal Integrity :

1. **Crosstalk**
2. **Propagation delay and Skew**
3. **Return Loss**
4. **Rise Time Degradation**
5. **Power Supply Noise**

Crosstalk

What?

- **Phenomenon which causes undesired effect on another circuit placed close to one carrying some signal (transmission system).**

Why?

- **Undesired Capacitive, Inductive or Conductive coupling from one circuit to another**

Types

- **Near End Crosstalk (NEXT)**
- **Far End Crosstalk (FEXT)**

Crosstalk

Familiar examples :

1. **Telephony – speech tones leaking from other people's connections**
2. **IC Design – Substrate Coupling and Capacitive Coupling**
3. **Stereo – Signal Leaking from one channel to another**

Associated Problems :

1) **Can cause corruption of nearby signals**
2) **Lead to false trigger induction**

Crosstalk

Understand the trends of crosstalk to ensure signal integrity

Make a model with minimum crosstalk

First-Order Analysis – Simple two interconnect structure-Extract impedance matrices.

$$A_{near\_end} = \frac{V_{input}}{4}\left[\frac{L_M}{L} + \frac{C_M}{C}\right]$$

$$B_{far\_end} = -\frac{V_{input}\, X\sqrt{LC}}{2T_r}\left[\frac{L_M}{L} - \frac{C_M}{C}\right]$$

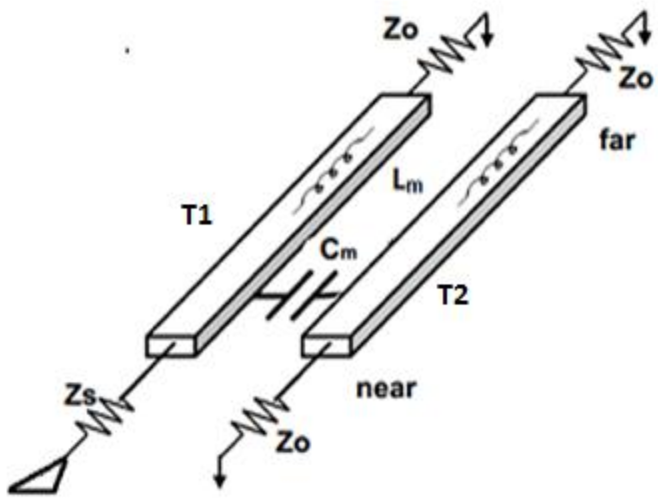
Modeling in COMSOL.

Why COMSOL ?

- **Field simulator for modeling electromagnetic interaction between transmission lines.**
- **Used 2D Electrostatic Mode : Gives inductance and capacitance matrix as a function of conductor length.**
- **Little time for matrix computations.**

Modeling in COMSOL.

Schematic of Transmission Lines :



Zo represents the terminal impedance of the line. To minimize reflection Zo is equal to the characteristic impedance.

Cm = Mutual Capacitance due to electrostatic coupling

Lm = Mutual Inductance due to Magnetic Coupling

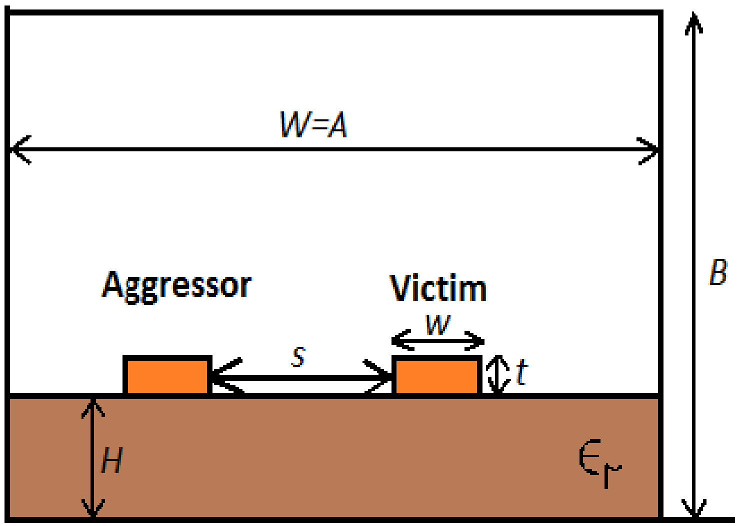
Zs = Source impedance matched with characteristic impedance of line.

The interconnects sit on the top of the dielectric. Length of each interconnect is 1cm. T1 represents the Aggressor with is given 1V ramp input with a rise time of 100ps. T1 is the victim.

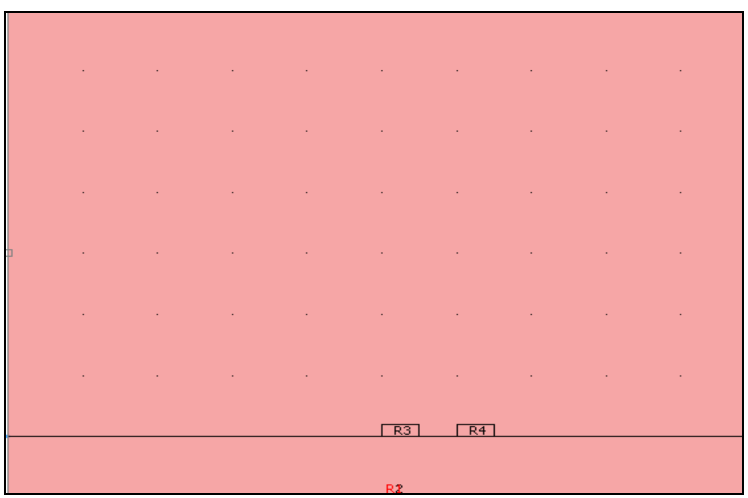
Introduction To Signal Integrity
Crosstalk
COMSOL for Modeling interconnect
Analyzing Trends
Comparative Study
Conclusion
References

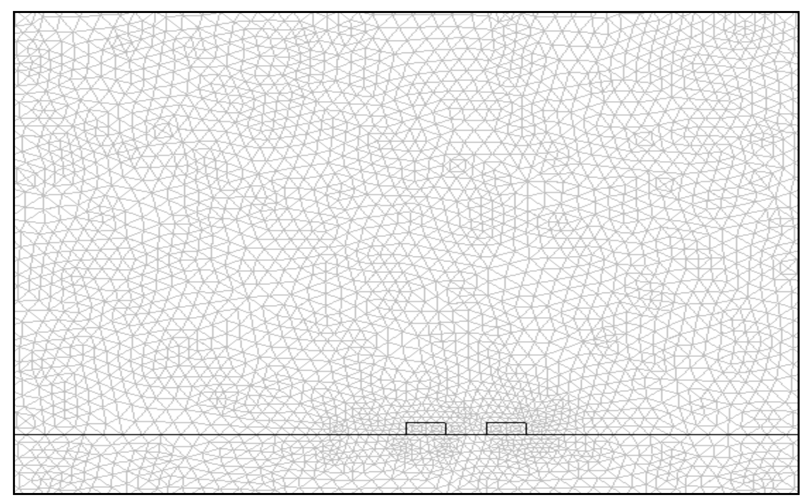
Modeling in COMSOL.

GUI in COMSOL :



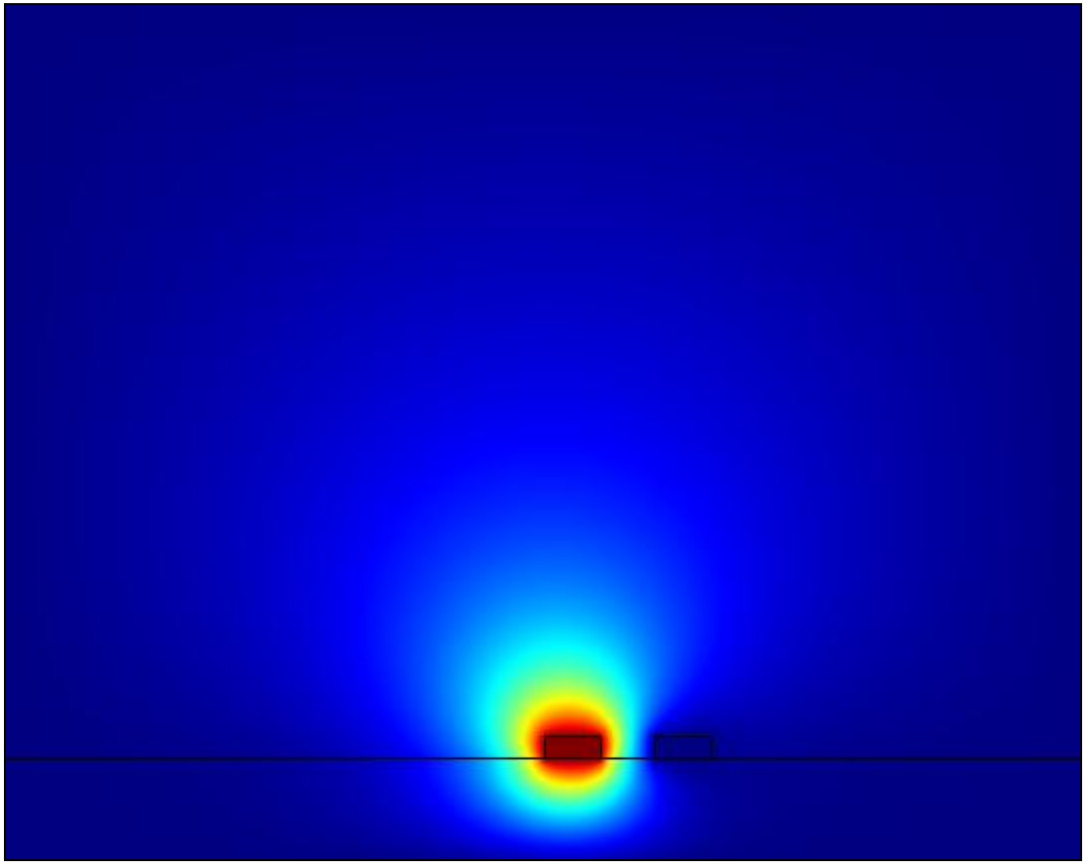
Label	Value
1) A (Fixed)	200 µm
2) B (Fixed)	80 µm
3) W (Fixed)	80 µm
4) H (Variable)	10 µm
5) w (Variable)	5 µm
6) s (Variable)	5 µm





Modeling in COMSOL.

GUI in COMSOL :



Electrostatic Potential Map after solving

Analyzing Trends

For analyzing the behavior of crosstalk induced noise, the following parameters were considered and varied using COMSOL Script :

1. **Dielectric Constant of Substrate**
2. **Thickness of Substrate**
3. **Pitch Ratio**
4. **Insertion and Arrangement of Ground Conductors**

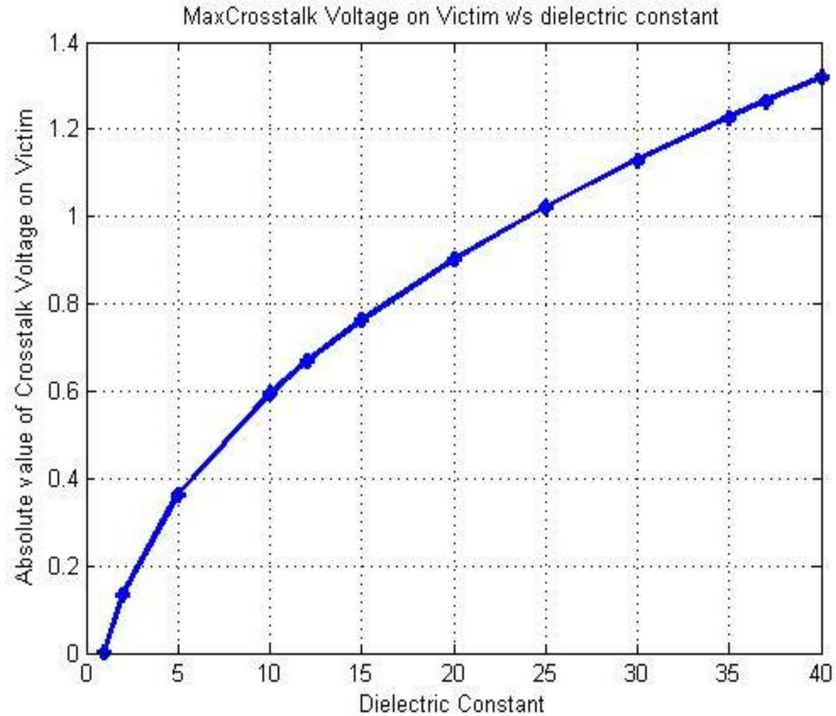
Analyzing Trends

Dielectric Constant of Substrate:

Observation:

The absolute value of the maximum crosstalk voltage increases with increasing dielectric constant.

For Alumina (*k*=10) V(crosstalk_max)=0.6V and for k=40 V(crosstalk_max) =1.3V indicating a square-root dependence.



Pitch Ratio =1

Substrate Thickness = 10 µm

Dielectric Constant = Varied in steps of 3 from 1 to 40

What do we learn :

Prefer low-k dielectrics to reduce interconnect coupling.

Analyzing Trends

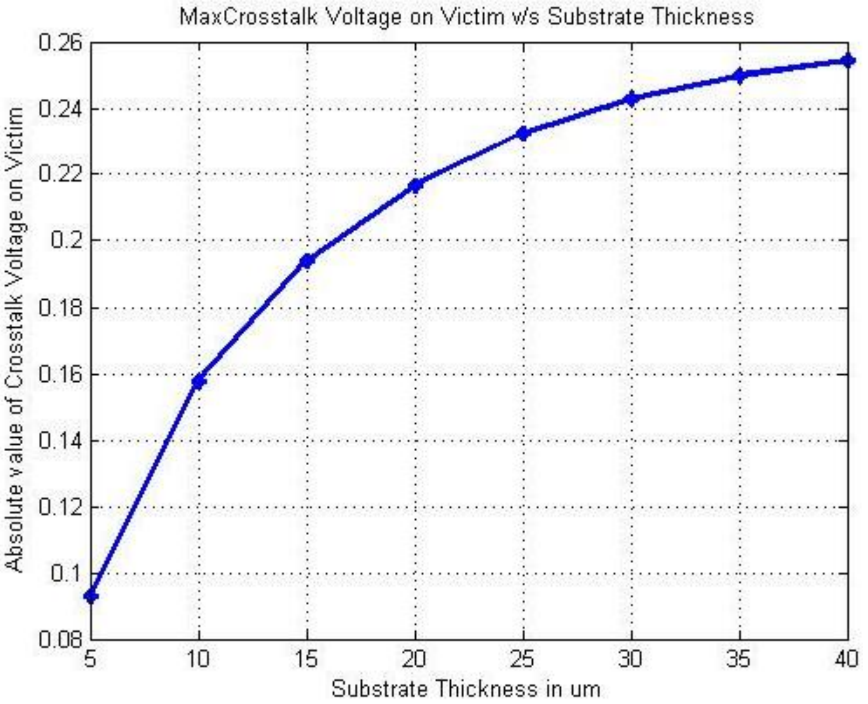
Thickness of the Substrate:

Observation:

The maximum crosstalk increases with increasing substrate thickness. This is due to the reduced effect of shielding from ground with increasing distance from ground plane. This can be seen from the figure.

What do we learn :

Prefer thin substrate to increase ground-interconnect coupling.



Pitch Ratio =1

Dielectric Constant = 10 (Alumina)

Substrate Thickness= Steps of 5µm from 5µm to 40 µm

Introduction To Signal Integrity

Crosstalk

COMSOL for Modeling interconnect

Analyzing Trends

Comparative Study

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Analyzing Trends

Pitch Ratio:

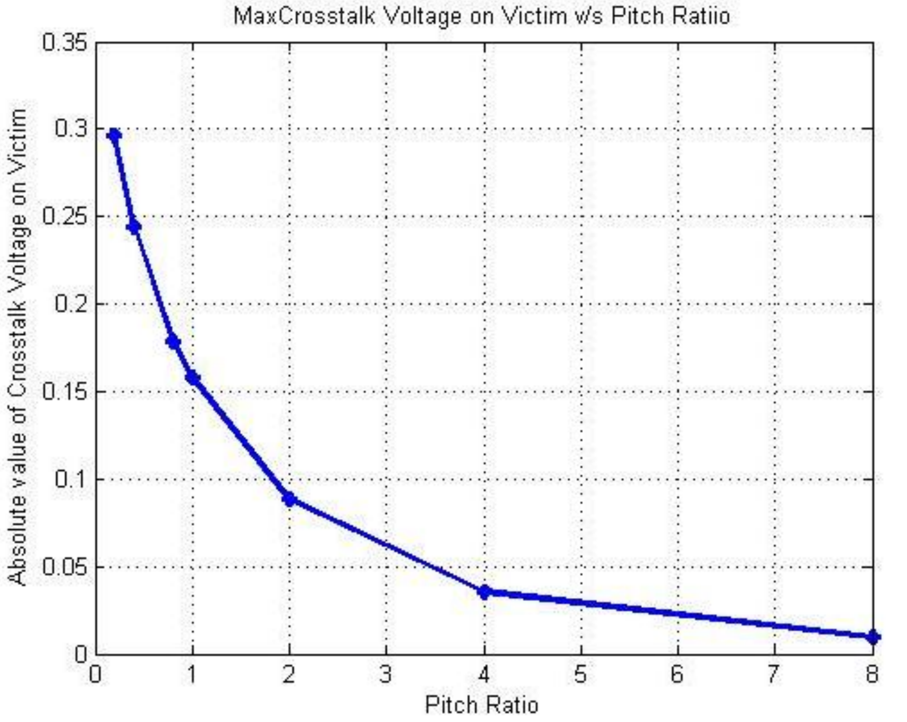
Spacing between interconnects relative to their width i.e. S/W ratio.

Observation:

The maximum crosstalk decreases with increasing pitch-ratio. This is obvious due to the reduced interconnect coupling because of increasing separation.

What do we learn :

As much as is possible (considering other restrictions as total chip area), try to keep interconnect separation large.



Dielectric Constant = 10 (Alumina)

Substrate Thickness= 10µm

Pitch Ratio = Varied in steps of 0.25 to 8 in powers of 2

Analyzing Trends

Inserting Ground Conductors:

It is known from references that inserting ground planes helps reducing coupling between interconnects and can help reduce crosstalk induced noise.

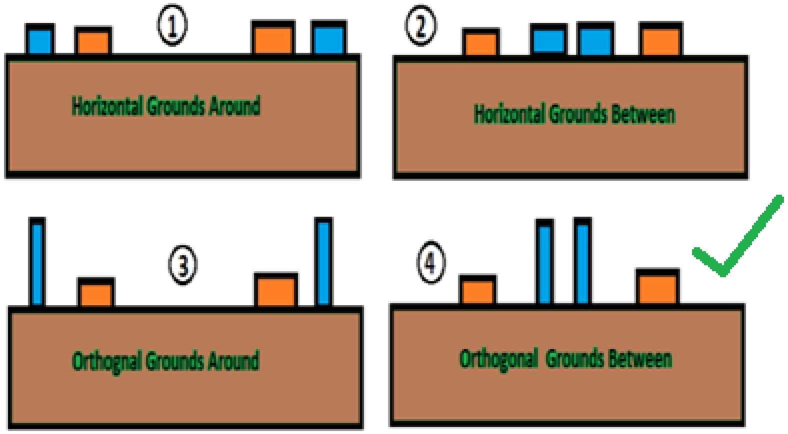
Consider the following arrangements :

1) Horizontal Grounds Around the lines.

2) Horizontal Grounds Between the lines.

3) Orthogonal Grounds Around the lines.

4) Orthogonal Grounds Between the lines.



Observation:

It is found from simulations that corresponds to vertical grounds between the lines has lowest maximum crosstalk.

Comparative Study

For comparison purposes, we consider two cases Case A and Case B which have properties as listed in Table.

Case A has high-dielectric constant, thick substrate and small pitch ratio.

The opposite is true for case B.

Property	Case A	Case B
Dielectric Constant	30	15
Substrate Thickness	30 µm	15 µm
Pitch Ratio	3	6
Crosstalk Victim	-0.377 V	-0.306 V

Observation:

The maximum crosstalk voltages on the Victim and Aggressor for both cases illustrates that 50% change in each value leads to 20% decrease on victim.

Conclusion

SUMMARY

- **Considered 2 transmission lines on a dielectric.**
- **Used FEM based COMSOL for modeling and impedance extraction.**
- **Analyzed the crosstalk voltage behavior with respect to variation in Dielectric Constant of Substrate, Thickness and Pitch Ratio.**

TO MINIMIZE CROSSTALK

- **Prefer low-k and thin substrate.**
- **Keep pitch ratio high.**
- **Insert Orthogonal grounds between two interconnects.**

THE WAY AHEAD

- **Consider multilevel interconnects with complex geometries.**
- **Full Wave 3D Modeling for complicated arrangements and frequency dependent parameter analysis.**
- **Barbed Wire.**

References

1. SM Musa, NMO Sadiku, Analysis of Multiconductor Quasi-TEM Transmission Lines and Multimode waveguides", Excerpt from the Proceedings of the COMSOL Conference 2010, Boston

2. Ashok Goel, "High Speed VLSI Interconnection: Modeling, Analysis and Simulation", Wiley series in Microwave and Optical Engineering.

3. Stephen Hall, Garrett Hall, James McCall "High Speed Digital System Design: A handbook of interconnect theory and Design Practices", A Wiley Interscience Publication.

Thank You