Characterize and Debug Crosstalk, through Simulation and Scope Measurements

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Make important design decisions and recover your crosstalk margins
Agenda

– Crosstalk Overview
– Crosstalk Simulation for Increased Confidence Level in Design
– Challenges with Crosstalk Analysis Using a Scope
– Overcoming Challenges with Scope Crosstalk Analysis Application
– Scope Crosstalk Demo
– Summary
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Two Independent Transmission Lines

Two 50ohm transmission lines with large spacing

- When there is sufficient spacing between the two lines in which one line is driven by PRBS (Pseudo Random Bit Sequence) source, what will be seen on the other trace?

Signals on main line (Aggressor)  
Signals on the other line (Victim)
When the spacing gets narrower, what will be seen on the other trace?

Crosstalk!!!

- Crosstalk is becoming a more important issue, as data speeds increase, and more lanes are packed into small spaces. For example:
  - 100 Gb/s @ 4 parallel 25 Gb/s lines
  - ASICS with 100’s of SerDes
Crosstalk Mechanism

How Does That Happen?

- Mainly caused by capacitive or inductive coupling between multiple signal lines.
- Transmission line crosstalk is the result of electromagnetic interference between electrical components.
- Two prominent types:
  - Next End Crosstalk (NEXT)
  - Far End Crosstalk (FEXT)
Crosstalk vs. Coupling
Two Different Perspectives…

Time Domain

Crosstalk

Waveforms

But same physical phenomena…

Frequency Domain

Coupling

Transfer Function
Crosstalk vs. Coupling
Two Different Perspectives…

- The results are interpreted by two different ways, one from waveform standpoint and the other from transfer function standpoint.
Crosstalk With Step Source Input

Step Response with Matched Termination

- Test signal = 50ps Step
Crosstalk With PRBS Source Input

- Test signal = 1Gbps PRBS pattern
- FEXT has higher noise contribution than NEXT
Crosstalk vs. Spacing and StackUp Height
NEXT and FEXT with Step Response

- NEXT and FEXT vary with spacing and stackup height since they change the crosstalk (coupling) level
- The narrower the spacing is, the higher crosstalk (fixed line width)
- The higher the stackup is, the higher crosstalk (fixed line width)
No Crosstalk
• Data Rate = 1 Gbps
• Other line is terminated

With Crosstalk
• Data Rate = 1 Gbps
• Other line = 300 Mbps
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Simulation Technologies for Crosstalk

ADS (Advanced Design System)

- S-parameter simulation
- Transient Convolution
- Channel Simulation
- DDR Bus Simulation

**ChannelSim**
NumberOfBends = 100000
Enforced Equal Area Mode = On

**SFP Channel**

**DDR4 BUS**
Simulation Models for Crosstalk

ADS, EMPro, SIPro, PIPro

- Multilayer Library
  - Lines, coupled lines and discontinuities with losses for dielectrics and metals
  - Substrate components, MLsubstrate
  - Versatile layer definitions: signal, ground, power, blank
  - RLGc models available

- Pure 3D EM models
  - Accounts for complete electro-magnetic behaviors
  - ADS Momentum
  - EMPro for FEM and FDTD simulation data
  - ADS SIPro/PIPro EM models
New SIPro Crosstalk Model Example
Xilinx KCU105 FPGA Platform Board

SFP: 8 Gbps, 16Gbps w 64b/66n encoding

w/o crosstalk

w/ crosstalk
Electric (E) and Magnetic (B) Field Visualization

EMPro FDTD With Step Response

Electric Field

Magnetic Field

TDR

Step Response
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Legacy Method of Measuring Crosstalk

- The need to troubleshoot and characterize crosstalk is not new, but the legacy methods of measuring crosstalk in digital communications systems has relied on the process of selectively disabling some channels while enabling others.

- This necessarily requires measuring the crosstalk effects in the system while operating in special test modes, which means measuring them under abnormal conditions. Worse yet, some systems cannot even operate the necessary special modes.

Other challenges:
- Huge effort and time to characterize crosstalk from multiple serial aggressors.
- Power supply cannot be turned off.
Crosstalk Simulation, but not Identification or Removal

- VNA can be used to characterize crosstalk between serial data lines. S-parameter models are generated by the VNA.

- Scope and software tools are available today, using the S-parameter models to simulate the waveform distortion, eye closure and jitter performance.

- However, the tools are limited only to simulation, but unable to identify source of crosstalk on the real system or remove crosstalk from the measured waveforms for analysis to see how much margin can be recovered.
– For serial data lines, VNA can be used to characterize the crosstalk because they are linear network models.

– However, the influence of power supply noise to serial data jitter and amplitude distortion is non-linear and no easy way to characterize the noise transfer.

Power supply noise creates a non-linear transfer on the serial data timing error. The transfer model is difficult to solve and correlate.
Types of Power Supply Noise Affecting Designs

– Power Supply Aggressor

• Power Supply Induced Jitter (PSIJ) – Adds jitter through PLL power supply
• Voltage-Dependent Amplitude Noise – Adds noise to logic level 0 & 1 via voltage references

– Power Supply Victim

• Simultaneous Switching Network – Causes “Ground Bounce” or “Vcc Sag” on power supply
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Crosstalk Analysis Challenges Solved by Application

– Crosstalk Identification
  • Which signals are coupling onto your victim?

– Crosstalk Quantification
  • How much error does each aggressor add to your victim?

– Crosstalk Removal for Analysis
  • What would your signal look without crosstalk?
  • How much margin can be recovered on your signal without crosstalk?
  • If the signal was failing spec, can it pass without crosstalk?

Assist in making important design decisions:
• Is it worth reducing crosstalk impact in design?
• Where to improve?
Features of the Crosstalk Analysis Application

1. Analyze up to four signals (aggressors or victims) at once
2. No crosstalk model or simulation files required
3. Identify aggressors by probing around
4. Report the amount of crosstalk present on victims
5. Work for both NEXT and FEXT, automatically determined by the app
6. Work for power supply analysis
7. Plot waveform without crosstalk on the scope which can be:
   • Used by SDA, EZJIT Complete, InfiniiSim, Equalization and Mask test
   • Saved as a waveform file
Crosstalk Analysis Setup

1. Probe up to 4 signals (Aggressors or victims). No simulation models or inputs are required.

2. Setup the victim signal.

3. Set the number of aggressors and configure the aggressor type.

4. The app reports the amount of crosstalk from each aggressor and returns a waveform without crosstalk for analysis.
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Scope Crosstalk Demo Setup

Near-end serial aggressor  
**Channel 2**

Serial data victim  
**Channel 1**

Power supply aggressor (PSIJ)  
**Channel 3**
Visit Keysight Booth #725 to learn more!
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Crosstalk Analysis, From Simulation to Measurements

- Effect of crosstalk is becoming more prominent in high speed designs
- Crosstalk simulation can increase confidence level in designs
- Characterize and debug crosstalk with the scope analysis app
- Get your product to market faster with Keysight solutions
Inaccessible Aggressor Signals

– Crosstalk could happen inside a package with accessibility only to the serial data output. It is not possible to probe at any aggressors.

– Is there a way to characterize or debug such scenario?

– Could the serial data signal be eliminated to obtain the residual waveform, which can then be analyzed using FFT or markers so the sources of aggressor can be narrowed down?

Many crosstalk issues happen inside the package. How to troubleshoot crosstalk when the aggressors are inaccessible?
Overcome Inaccessible Aggressor Signals

- The crosstalk application can remove the ideal, ISI and return a waveform with “Unknown XT + Noise” (residual).

- Perform further analysis on this residual waveform with measurements such as FFT, markers, etc. to root cause the source of aggressor.

Crosstalk app builds a network model.

\[ M = I + ISI + XT + UXT + N \]

Measured waveform = Ideal + ISI + (Known XT) + (Unknown XT + Noise)

Removing I, ISI and XT will return “UXT + N”, which is the residual waveform.

Use FFT to measure residual waveform to pinpoint the source of crosstalk.
Power Supply Aggressor Crosstalk Results

- Power supply aggressor
- Original serial victim with crosstalk
- Serial victim with crosstalk removed
- Original eye diagram with crosstalk
- Crosstalk removed eye-diagram

Victim : Aggr
C1 C1 = ISI
C1 C3 = XT

ISI distortion
Aggr crosstalk on high level
Aggr crosstalk on low level
Crosstalk jitter time skew
Jitter-XSI = (RMS TIE attributed to ISI or XT) / (TIE of victim)

Amplitude External Signal Interference (Amp-XSI) = (RMS of ISI or XT) / (RMS of victim)

Most jitter distortion comes from power supply (91%). Little distortion on level 0 & 1.