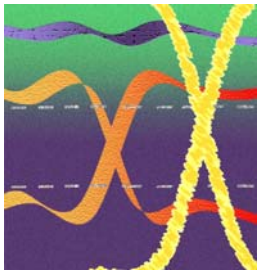

HIGH-SPEED NOISE AND GROUNDING

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Focus of this class:

Interactions between your system and the natural world around it.

- Radiation
- Susceptibility
- Electrostatic discharge

Program

1. Principles Of Mixed Signal Isolation
2. Ground Bounce (SSO)
3. PCB Layer Stack
4. System-level Grounding
5. Clock-related Noise Issues
6. Electromechanical Issues
7. System Test

Chapter 1: Principles of Mixed Signal Isolation

Forms of Coupling

- Common Impedances
- Parasitic Mutual Capacitance
- Parasitic Mutual Inductance
- E&M Field Radiation

Points to Remember

- If my current path overlaps yours, we crosstalk.
- Some systems are orders of magnitude more sensitive to noise than others.
- The limits of acceptable crosstalk depend on your signal level and its required noise-free dynamic range.

Facts Necessary for Understanding High-Speed Noise and Grounding

- Current flows in loops
- Loops may be completed by parasitic capacitance
- All loops have inductance

Mutual Inductance Matters

Among high-speed, low impedance digital circuits, mutual inductance is often a worse problem than mutual capacitance.

Points to Remember

- All circuits suffer from parasitic shunt capacitance and parasitic series inductance.
- Mutual capacitance between devices can cause crosstalk.
- Mutual inductance can cause crosstalk as well.
- Among high-speed, low impedance digital circuits, mutual inductance is often a worse problem than mutual capacitance.

Frequencies That Matter for Digital Signals

The power in a digital signal concentrates in the band from *DC* up to the *Knee Frequency*

Knee frequency is a function of rise/fall time, not repetition rate

Five Ways to Reduce Crosstalk

Shrink the Aggressor
Reduce the Coupling
Change the Timing
Improve Receiver Margins
Reduce the Number of Aggressors

Points to Remember

A solid plane makes a very good defense against crosstalk.
Synchronous signals suffer crosstalk only when sampling.
Asynchronous signals remain sensitive to crosstalk at all times.

Chapter 2: Ground Bounce (SSO)

In the presence of fast-changing magnetic fields,

You can only measure voltages between nearby points.
Use the shortest ground attachment possible on your probe.

Distributed nature of inductance

The energy stored in an inductor is nothing more, and nothing less, than the energy stored in the magnetic field surrounding that inductor.
The magnetic field exists in the spaces between conductors.
Inductance is not a property of the conductors.
Inductance is a property of the spaces between conductors.

Points to Remember

Displacement current (due to parasitic capacitance) flows between otherwise unconnected regions,
Magnetic induction from fast-changing magnetic fields induces voltages in your circuit.
Never measure voltages between widely separated points.

BGA package crosstalk (SSO coupling) varies with:

Separation between signal pathways
Height of *via + ball + package thickness*
Rise or fall time of the aggressive signal (specifically, the di/dt)

Points to Remember

SSO is one of many forms of inductive crosstalk.
SSO is caused by outgoing signal currents, and also by returning signal currents.
SSO varies pin by pin.
It increases as you approach aggressive signals.
It decreases as you approach ground balls (ergo, use a lot of ground balls).

BGA Ground Ball Placement

This 40 min. film presents the theory of SSO crosstalk in BGA packages with examples, giant scale models, and measured lab results.

Outline of Film

What causes crosstalk in BGA packages?
What can be done to improve it?
Demonstrate crosstalk in a scale-model package.
Compare alternative ground-ball layouts.

Chapter 3: PCB Layer Stack

The Path of Return Signal Current

Capacitance between boards conveys current from one board to another.
Shunt that current to the reference plane using broad, flat straps or short, thick standoffs.

Interconnections Between Boxes

Coaxial
Twisted-pair
Fiber-optic

Points to Remember

The interconnection topology determines the magnitude of currents flowing on a coaxial shield
The shield transfer impedance determines the noise pickup internal to a coaxial cable
A twinax cable further attenuates the received noise
Always test for crosstalk!

Crosshatched Ground: To what degree does patterning affect…

Trace impedance
Crosstalk

Chapter 5: Clock-Related Noise Issues

Unexpected Synchronization Difficulties: Points to Remember

Test your system with links unplugged
Test your system with killer packets
Test your system with input clocks adjusted to slightly *different* frequencies

Do Terminations Reduce Emissions: Points to Remember

An long unterminated transmission line harbors resonances that exacerbate radiation at certain frequencies.
Terminations can help.

In a differential link: Points to Remember

Skew creates a common-mode signal
DCD (individually on each output) creates a common-mode signal
Common-mode signals radiate far more than differential signals

Jitter Effects in Modern System Design II

The following slides are adapted from a Tech On-Line presentation I made for Xilinx on December 6, 2005. Thanks to LeCroy and Xilinx for their help making these measurements possible.

Outline of Presentation

Tracking down jitter, like medicine, is a diagnostic science.
You must make independent tests to see what actually causes your jitter.
Planning for these tests is the most important thing you can do to address jitter in your high-speed system architecture.

Chapter 6: Electromechanical Issues

Board-to-board Connector Electrical Noise Performance: Points to Remember

The measure of connector noise-generating capability in a mixed-signal system is *ground-transfer impedance*.
The ground-transfer impedance is a function of connector design and board layout.

Shielded Cabling Connectors: Points to Remember

The ground-transfer impedance of a shielded connector determines the amount of stray current emanating from that location.
Conversely, the ground-transfer impedance also determines the susceptibility of the interface.

Mechanical Issues: Key environmental parameters

Shock and vibration
Temperature
Humidity
Sand and dust
Durability
Electrostatic discharge (ESD)

Points to Remember

Everything shakes
Everything corrodes
Every good ground contact eventually works free
Everything intentionally not grounded eventually becomes so

Trends in Interconnect Design

Smaller (better for RF); show examples
Multiple contacts; show examples of advanced contact design

Standards-Based Design

Why compete? Pick one of the standards and use most (if not all) of its standard parts.

Example of standards-based system: Firewire (IEEE 1394)

Points to Remember

Easy: Figure out how to pass your data through a standard LAN architecture
Hard: Design a new LAN

Tin Whisker Alert

What is a tin whisker, and why does it matter to my design?

Points to Remember

Keep abreast of the fast-changing "tin whisker" subject.
In situations that require long-term reliability, do not use pure tin.

Chapter 7: System Test

Eye Don't Like It

An eye diagram makes a terrible diagnostic tool.

Compliance Testing: An Interview with JP Miller, distinguished technologist at Hewlett Packard.

Testing a data link in isolation is never sufficient; links must be tested in combination with other noise sources.
Isolate Effects to pinpoint sources of error
Quantify Your Results with stress testing

Debugging Hardware

Chop the System into small pieces for initial tests
Remain Ever Vigilant for even the smallest clue about system behavior.
Keep Meticulous Records
Use your simulator to maximum effect

Measurement Problems

Measuring tiny voltages
ESD Induces Large Voltages
ESD Induces Large Currents

Personnel issues

Working with Consultants
Assigning your best engineers to critical design tasks

Practical System-Design Advice (Wrap-up)

1. With the development of any new product, limit your use of new and untried technical innovations to five.
2. Never fully utilize any ASIC or custom IC. As you approach 100% utilization, the difficulty of routing and placement approaches infinity.
3. Ignore the maximum toggle frequency for a flip-flop.
4. Once you obtain a decent probe, immediately pin a big REWORK tag on it. The tag may discourage others from taking it.
5. Stress Test Everything
6. Build plenty of test outputs into every ASIC.
7. With passive components, never specify the most extreme value listed in a catalog.
8. Always include a few spare traces on a backplane. You never know what additional features you may need later.
9. Your first version of a product need not adhere to the final form factor. If it does, you have wasted a lot of valuable engineering time by mechanically squeezing everything into the final packaging.
10. Hire Only First-Rate People