High-Speed Noise and Grounding Seminar

More Black Magic, with Dr. Howard Johnson

About this course | Printable Index

1. Principles of Mixed Signal Isolation

High-Speed Noise and Grounding: Opening Lecture. *HSNG Seminar* (2015): 1.1-1.5.
[EE BASICS, MANAGEMENT] Definition of Noise and Grounding Subject Matter. Purpose of Studying Noise and Grounding. Overview of program.

(pp. 1-5) Notes
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(4 min.) Movie SD
(4 min.) Movie HD

Common-Impedance Coupling. *HSNG Seminar* (2015): 1.11-1.20.
[CROSSTALK, EE BASICS, MIXED SIGNALS] PCB Ground Plane Resistance. Slots in the Ground Plane Control the Flow of Audio-Frequency Current. Can a CPU Draw Audio-Frequency Currents?. Example of Entangled System.

(pp. 11-20) Notes
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(28 min.) Movie SD
(28 min.) Movie HD

Capacitance. *HSNG Seminar* (2015): 1.21-1.30.
[CAPACITANCE, EXAMPLES] Current Flows in Loops. Return Path for an Antenna. Measuring Capacitance. Handheld Capacitance Meter. Example: Capacitance of Scope Chassis to Earth. Approximate Values of Capacitance.

(pp. 21-30) Notes
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(14 min.) Movie SD
(14 min.) Movie HD

Inductance. *HSNG Seminar* (2015): 1.31-1.52.
[EXAMPLES, INDUCTANCE] Current Does Not Flow Instantaneously. Every Loop Has Inductance. Simple Inductance Test Circuit. Inductance of Circular Loop (Empirical). Inductance of Hairpin and Other Structures. Inductance of Wire Above Solid Plane. Why All the Fuss About Inductance?. Mutual Inductance Matters. What About Electromagnetic Radiation?

(pp. 31-52) Notes
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(27 min.) Movie SD
(27 min.) Movie HD

Main Points Not Taught in College. *HSNG Seminar* (2015): 1.53-1.56.
[BACK PLANE, DIFFERENTIAL SIGNALING] Logic Gates Are Differential Amplifiers. Digital Signals Have a Limited Bandwidth. Frequencies That Matter for Digital Signals.

(pp. 53-56) Notes
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(9 min.) Movie SD
(9 min.) Movie HD

Crosstalk. *HSNG Seminar* (2015): 1.57-1.88.
[CROSSTALK] Level of Acceptable Crosstalk. Effect of Limited Package Bandwidth. Five Ways to Reduce Crosstalk:. Shrink the Aggressor. Reduce the Coupling. Change the Timing. Improve the Receiver Margins. Reduce the Number of Simultaneous Aggressors. Crosstalk is Highly Directional.

(pp. 57-88) Notes
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(53 min.) Movie HD

2. Ground Bounce (SSO)

Distributed Nature of Inductance. *HSNG Seminar* (2015): 2.1-2.22.
[GROUND BOUNCE, INDUCTANCE] Difficulties with Observing Ground Noise. Implications for Measuring Voltages. Example Measurement: Inductance of Via.

(pp. 1-22) Notes
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(20 min.) Movie SD
(20 min.) Movie HD

SSO (Ground Bounce). *HSNG Seminar* (2015): 2.23-2.25.
[CHIP PACKAGING, CROSSTALK, GROUND BOUNCE] SSO Test Setup and theory (introduction to movie).

(pp. 23-25) Notes
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(10 min.) Movie SD
(10 min.) Movie HD

BGA Ground Ball Placement. *HSNG Seminar* (2015): 2.26-2.76.
[CHIP PACKAGING, CROSSTALK, GROUND BOUNCE, SILAB HSNG] Measurement of BGA ball inductance. Effect of layout on measured values. Implication for ball pinouts.

(pp. 26-76) Notes
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(35 min.) Movie SD
(35 min.) Movie HD

Driving Heavy Loads. *HSNG Seminar* (2015): 2.78-2.82.
[CAPACITANCE, EE BASICS] VI Diagrams. Short-circuit current. Effect of oversize capacitive load.

(pp. 78-82) Notes
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(8 min.) Movie SD

(8 min.) Movie HD

Debugging SSO. *HSNG Seminar* (2015): 2.83-2.86.
[CROSSTALK, GROUND BOUNCE, TESTING] Disrupting the flow of current with cuts and shorts.

(pp. 83-86) Notes
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(7 min.) Movie SD
(7 min.) Movie HD

3. PCB Reference Planes

Returning Signal Current at AF versus RF. *HSNG Seminar* (2015): 3.1-3.4.
[REFERENCE PLANES, RETURNING SIGNAL CURRENT] Distribution of High-Frequency Current Underneath a Signal Trace.

(pp. 1-4) Notes
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(9 min.) Movie SD
(9 min.) Movie HD

Crosstalk Experiments. *HSNG Seminar* (2015): 3.29.
[CROSSTALK, TESTING] Crosstalk Over a Solid Plane. Measuring Tiny Amounts of Crosstalk. Three Ways to Control Unwanted Current. Example: Common-Mode Choke. Example: Current Shunt. Example: Change the Circuit Topology.

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(34 min.) Movie SD
(34 min.) Movie HD

A Solid Plane Is Your Best Defense. *HSNG Seminar* (2015): 3.30-3.36.
[CROSSTALK, REFERENCE PLANES] Your Reference Plane Is Not Perfect. Fast-Changing Magnetic Flux Passes Underneath Every PCB.

(pp. 30-36) Notes
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(9 min.) Movie SD
(9 min.) Movie HD

Perspective and Vertical Height. *HSNG Seminar* (2015): 3.37-3.46.
[CONNECTORS, EMC, LAYOUT] Enchanted Rock (story). Example: Marshall LCD-15 Video Monitor. Consequences of stacking connector.

(pp. 37-46) Notes
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(13 min.) Movie SD
(13 min.) Movie HD

Power Plane Segments. *HSNG Seminar* (2015): 3.48-3.51.
[FERRITE BEADS, LAYOUT, POWER SYSTEMS] When to Segment the VCC Plane. Power Region Placement. About Ferrite Beads. Information Required to "Design" Power Filter Network.

(pp. 48-51) Notes
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(22 min.) Movie SD
(22 min.) Movie HD

Moat and Drawbridge Construction. *HSNG Seminar* (2015): 3.52-3.55.
[CROSSTALK, MIXED SIGNALS, RETURNING SIGNAL CURRENT, SPLIT PLANES] Efficacy of Ground Cuts at RF. The Cut Does NOT Eliminate RF Crosstalk.

(pp. 52-55) Notes
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(14 min.) Movie HD

4. System-Level Grounding

Understanding Grounding. *HSNG Seminar* (2015): 4.1-4.13.
[CROSSTALK, GROUNDING, RETURNING SIGNAL CURRENT] Immutable Law of Development. Difficulties Understanding Orders of Magnitude. Difficulties Imagining Behavior of Solid Sheets of Copper. Picture Frame Analysis: a New Way of Thinking. Principle of Single-Point Grounding. A Common Grounding Mistake. Principle of Moat and Drawbridge Construction. Single-Point Connection to Chassis. Double-Connected Analog Region. But, I Did the Bad Thing and It Worked!.

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Three Ideas for Audio-Frequency Isolation. *HSNG Seminar* (2015): 4.14-4.22.
[CROSSTALK, GROUNDING, MIXED SIGNALS, SPLIT PLANES] High Impedance Blocks Unwanted Current. Low Impedance Shunts Current Away. Change the Topology. Example: ADC Grounding. Moats for Multiple ADCs. Align Each Moat with Its Special Power Region. Moats and Floats: Your Chance to Experiment.

(pp. 14-22) Notes
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(27 min.) Movie SD
(27 min.) Movie HD

Audio-Frequency Isolation. *HSNG Seminar* (2015): 4.23.
[CROSSTALK, EXAMPLES, MIXED SIGNALS, SILAB HSNG] Mixed-Signal Isolation, Part I, "Audio Examples". Crosstalk at audio frequencies. Mitigation strategies.

(page 23) Notes
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What's Different at RF. *HSNG Seminar* (2015): 4.24-4.46.
[LAYOUT, MIXED SIGNALS] Overview of RF issues. Capacitance of planes. Inductance of wires. Structural resonance. Adequate grounding.

(pp. 24-46) Notes
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(41 min.) Movie HD

Interconnections Between Boxes. *HSNG Seminar* (2015): 4.47-4.57.
[CROSSTALK, EXAMPLES, MIXED SIGNALS, SILAB HSNG] Mixed-Signal Isolation, Part II: "RF Crosstalk" (live discussion) Coaxial Cables and Connectors. Test Arrangement for measuring crosstalk (slide 60). Extending the Dynamic Range of Your Scope. Increase Level of Aggressor. Example Measurement: Coaxial Shield Effectiveness.

(pp. 47-57) Notes
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(17 min.) Movie HD

RF Cables. *HSNG Seminar* (2015): 4.58.
[CROSSTALK, EXAMPLES, MIXED SIGNALS, SILAB HSNG] Mixed-Signal Isolation: Part II (continued): Measured crosstalk between two coaxial cables.

(page 58) Notes
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Imperfections in Shield Coverage. *HSNG Seminar* (2015): 4.59-4.62.
[COAXIAL, GROUNDING, SHIELDING] Shielding Effectiveness (Shield-Current Transfer Impedance). Direct Attachment of Coax to Chassis. Coaxial Shield Circuit Theory.

(pp. 59-62) Notes
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(17 min.) Movie SD
(17 min.) Movie HD

System-Level Grounding. *HSNG Seminar* (2015): 4.64-4.72.
[CROSSTALK, GROUNDING] Earth Potential. Building Wiring. Rules for System-Level Grounding.

(pp. 64-72) Notes
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(17 min.) Movie HD

Flex Cables. *HSNG Seminar* (2015): 4.73-4.78.
[EXAMPLES, LAYOUT, REFERENCE PLANES] Crosshatched Ground. Crosshatch Impedance. Crosshatch Crosstalk vs. Spacing (graph).

(pp. 73-78) Notes
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(11 min.) Movie SD
(11 min.) Movie HD

Lightning Example. *HSNG Seminar* (2015): 4.79-4.83.
[EM FIELDS, EXAMPLES] Lightning EMF Equivalent Circuit. Lightning Balls.

(pp. 79-83) Notes
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5. Clock-Related Noise Issues

Unexpected Synchronization Difficulties. *HSNG Seminar* (2015): 5.1-5.9.
[DATA CODING, DIFFERENTIAL SIGNALING] What Happens When You Unplug a Link?. How To Detect Unplugged or Inoperative Links. Well-Balanced Plug-able Differential Interface. Killer Packets. Difficulties with Multi-synchronous Systems.

(pp. 1-9) Notes
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(31 min.) Movie SD
(31 min.) Movie HD

Do Terminations Reduce Emissions?. *HSNG Seminar* (2015): 5.10-5.15.
[EMC, TERMINATION] Live Discussion of Signal Spectra.

(pp. 10-15) Notes
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(2 min.) Movie SD
(2 min.) Movie HD

Common and Differential Modes. *HSNG Seminar* (2015): 5.16-5.23.
[DIFFERENTIAL SIGNALING, EXAMPLES] Differential Example. Every Signal Comprises Two Parts. Why We Care About Modes. UTP Applications Require Extreme Common-mode Attenuation.

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Imbalanced Output Circuit. Example: Fast/Gigabit Ethernet Launch.

(9 min.) Movie HD

What is Jitter. *HSNG Seminar* (2015): 5.26-5.40.
[JITTER] Racing Game Analogy. Tracking Bandwidth. Definitions of Jitter. Jitter: a New Dimension. Why Jitter Matters. Causes of Jitter. Additive Noise. Vertical Shift vs. Timing Offset. Three Ways to Reduce Additive Jitter. Sources of Additive Noise.

(pp. 26-40) Notes
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Example Jitter Measurements. *HSNG Seminar* (2015): 5.41-5.68.
[EXAMPLES, JITTER] Duty-cycle distortion. Effect of ringing. Effect of pair skew. Example of skew from DLL. Making a good low-jitter clock source. Jitter propagation.

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Periodic Jitter. *HSNG Seminar* (2015): 5.69-5.89.
[EXAMPLES, JITTER] National Semiconductor EVK board. Main Types of Jitter. Jitter Test Setup. Jitter Track. Jitter Histogram. Synchronizing the scope with power supply ripple. Sync with AUX (waveform). Sync with VCC01 (waveform). Sync with FM mod (waveform).

(pp. 69-89) Notes
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Clock Modulation. *HSNG Seminar* (2015): 5.90-5.94.
[CLOCKS, EMC, JITTER] Modulation vs. Scrambling.

(pp. 90-94) Notes
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6. Connectors

Connectors. *HSNG Seminar* (2015): 6.1-6.12.
[COAXIAL, CONNECTORS, CROSSTALK, SHIELDING] ERmetZD. Ground Transfer Impedance. Mutual Inductive Noise Coupling. Coaxial Shield Grounding. Ground Transfer Impedance. Examples. Ground Transfer Impedance Calculation.

(pp. 1-12) Notes
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(12 min.) Movie SD
(12 min.) Movie HD

Connector Examples. *HSNG Seminar* (2015): 6.12.
[CROSSTALK, EXAMPLES, MIXED SIGNALS, SILAB HSNG] Mixed-Signal Isolation: Parts II-III, "RF Connectors" and "Achieving 120 dB Isolation": Showing the importance of a good ground attachment between the connector and your PCB.

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PCB Traces at RF. *HSNG Seminar* (2015): 6.12.
[CROSSTALK, EXAMPLES, MIXED SIGNALS, SILAB HSNG] Mixed-Signal

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Isolation: Part III "PCB Traces": Showing two traces on the same side of the same board, and what it takes to attain 120 dB isolation between the two traces. Effects of grounding, good connector layout, and shielding.

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Connector Mechanical Considerations. *HSNG Seminar* (2015): 6.13-6.25.
[CONNECTORS] Vibration, shock, salt fog, dust and sand. Trends in interconnect design..

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7. System Test

System Test. *HSNG Seminar* (2015): 7.1-7.13.
[TESTING] Compliance Testing vs. Debugging. An Eye Pattern is a Compliance Test. Example: 2.5 Gb/s Differential Link. Compilation of Eye Diagram. Worst Patterns are Clearly Visible Within the Eye. A Step Response is a Debugging Test. Compliance Testing: Interview with J. P. Miller. Debugging Procedures. Working with Very Pure Signals: SINAD. Working with Very Large Signals: ESD.

(pp. 1-13) Notes
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(28 min.) Movie SD
(28 min.) Movie HD

Working with People. *HSNG Seminar* (2015): 7.22-7.37.
[MANAGEMENT] Consultants. Special Assignments. Other Practical Advice. Thank You For Attending.

(pp. 22-37) Notes
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(17 min.) Movie SD
(17 min.) Movie HD

HSNG Seminar—Extra Material

RoHS with Joe Fjelstad. *HSNG Seminar* (2015).
[RELIABILITY, SILAB HSNG, SOLDERING] Lead-free solder is not a "green" solution. Lead-free solder actually damages the environment more than 60/40 solder. System-reliability impact of lead-free solder.

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About This Course

High-Speed Noise and Grounding focuses on mixed-signal applications involving high-speed digital electronics used in conjunction with sensitive analog circuits such as radio receivers, GPS devices and cell phones. This course addresses the critical issues of noise and grounding that are seen in

many advanced signal processing applications today, including avionics, telemetry and guidance systems.

Main topics

mixed signals	grounding	ground bounce	ferrite beads
clocks	jitter	synchronization	electromagnetic compatibility
split planes	coaxial shielding	testing	

Who should watch this course?

- Digital logic designers
- System architects
- EMC specialists
- Military, medical, or high-reliability specialists
- Analog engineers working on mixed-signal applications
- Applications engineers
- Anyone who works with mixtures of digital and analog technology

This is a practical course. It is filled with examples, explanations, and classroom demonstrations. Anyone who works with high-speed digital signals will understand and benefit from the material presented.

Go to the course

How to view this course

The author recommends that you view no more than one hour at a time. It may help for you to print out the notes pages for each lecture and take written notes. The sections in the notes marked *Points to Remember* are not often highlighted in the lecture, but offer good opportunities for personal thought and reflection.

The three courses provide a certain degree of redundancy. Each begins with a section designed to make each attendee aware of certain basic concepts and vocabulary peculiar to that course. Where there is overlap, the author emphasizes different aspects of the core material, uses different examples, and approaches the subjects from varying angles. He recommends that you watch all three courses, all the way through, including all the extra movies.

The course materials cover much more material than could possibly be presented in the six days of lecture that we were able to film. Dr. Johnson arranged the slides with extra material to give himself the flexibility to focus on specific issues of interest to each particular class and to respond to questions. We include the full set of student materials here for your reference, even though some of those slides were not filmed. To help you keep on track, slide numbers appear on the right side of the course contents listing.

In addition to the student course materials, the collection includes a full set of instructor materials in Powerpoint format. The instructor materials include original source artwork that may be of

interest to those attempting to teach these courses. The necessary animation files, should you wish to use them independant of the lectures, are also available.

Go to the course | Get the animations