EMC/ESD COURSE OUTLINE

---------- DAY ONE ----------

Session 1.1 - Introduction to EMC

- **Experiment**: Introductory Experiment - ESD immunity and emission
- Blocked and Lumped Equivalent Model, Simplified, Descriptions
- Coupling Interrelationships to Chassis Structure
- Interface Connections as Antenna Equivalents
- **Experiment:** Extended Center Conductor
- Overview of Conductive-Case Shielding Containment
- Initial Susceptibility "Intrusions" Presented by ESD
- Interface Role as “Exit and Entry Currents” in Susceptibility - Immunity Performance
- Overview of EMC Architectural Considerations.
- Short discussion on Kirchoff and Faraday voltage issues and EMC.

Session 1.2 - Logic Devices and Circuit Boards

- Logic Drivers and Cross-Conduction Currents
- Spectral EMI Characteristics of Various Waveforms
- Spread Spectrum Approaches
- Common-mode Structures Within Circuit Boards
- Significance of Propagation Through an Imperfect Plane
- Peak Currents and Repetitive Impulses
- Coupling of Common-mode Potentials to Heat Sinks and Heat Sink Arrays
- Storage Capacitors: Locations and Resonances
- "Array" Effect of Multiple Circuit Devices
- Interface Wires and Cables as Antenna Structures
- **Experiment:** Device Noise Coupling to Cables.
    - Inductive Coupling
    - Capacitive Coupling
    - How to Spot a Problem

Session 1.3 - Field Transfers To Structures from Circuit Boards

- **Experiment:** Circuit Board Coupling to a Metal Plane - CW Signals.
- Concept of Distributed Common-mode Transmission Lines
- Relationship and Modes of Field Transfers to Chassis Planes
- Chassis Planes as Common-mode Image Returns in Distributed Line and Surface Patch Modes
- Spectral Profile Alterations Derived from Imposition of Chassis Planes
- Common-mode Field Potential Displacements and Transfer Impedances to Chassis Structures
- Multi-Mode Propagation Arrays
- Equivalent “Antenna Radial Propagation” of Common-mode Currents in Interface Wires and Cables
- Beneficial Use of "Ground Nulls" to Establish Controlled Reflections Within Distributed Common-mode Field Displacements
- Susceptibility Effects with “Ground Null” Implementations

- Intervals of "Ground Nulls
- Concepts of Partitioning Through "Moats"

Session 1.4 - Circuit Board Layout Considerations

- **Experiment:** Effects of Breaks in Ground Planes - CW Signals.
- **Experiment:** Effects of Paths Changing Layers in PWBs - CW Signals.
- Detailed Review of Transmission Lines in Signal and Power Distributions
- Flux Linkage and Inductance Cancellation
- Dichotomous "Breaks" in Transmission Lines, and Occurrences of "Break-equivalents" in Circuit Boards
- Descriptions of Return Images in Relationship to Flux Linkage
- Reviews of Transmission Lines:
  - Micro-Stripline
  - Stripline
  - Embedded Micro-Stripline
  - Asymmetrical Stripline
  - Edge-Coupled Differential Line
  - Broadside Coupled Differential Line
- Transmission Line Impedance Characteristics of Line Configurations Noted Above
- Flux Linkage Patterns
- Power Plane Configurations and Impedances
- Circuit Board "Stack-up" Considerations for Power and Signal Distributions
- Power Planes and Edge Impedance Terminations
- Undercut Power Planes
- Multiple Dielectric Separations
- Skin Effect and Skin Depths
- Skin Effect Discussion and Examples.
  - Rule of Thumb for Metals.
- "3-W" and "10-W" Trace Width Rules for Flux Boundaries of Traces
- Signal and Power Imaging for Various Board Stack-ups
- Transmission Line Image Return Skew with Layer-Jumping Through Vias
- Skew Route Patch for above
- Factors for Consideration of Imaging on Voltage Planes
- Signal Impedance Matching
- Series and Parallel Terminations
- Circuit Board Functional (EMC Architectural) "Partitioning"
- Blind and Buried Via Effects
- Faraday "Fences" for Partitioning
- "Picket Fences" Within Circuit Boards for Isolation Partitions
- 3-Dimensional Partitions
- Analogue-Digital Partitioning
- Common-mode Inductor Techniques and Valuations
- Susceptibility / Immunity Partitioning in Circuit Boards
- Derivative of Circuit Board Topologies and EMC Architecture from Systems Electrical Architecture.
- Board Examples.

---------- DAY TWO ----------

Session 2.1 - Paralleled EMC Relationships of "Stacked" Circuit Boards

- EMC Essentials of Interconnected Circuit Boards
- EMC Essentials of Interconnected Circuit Boards With Interface Cable Configurations
- EMC Essentials of Paralleled and Interconnected Circuit Boards With Interface Cables
- Electromagnetic Field Transfers and Displacement Interactions Of Paralleled Circuit Boards
- Experiment: Device Noise Measurement and Troubleshooting (2nd)
- Field Interactions Between Paralleled Boards and Chassis Structures
- Ground "Null" Applications to Paralleled Circuit Boards
- Topology and Partitioning of Paralleled Circuit Boards
- Backbone Implementation for Partitioning Between Paralleled Circuit Boards

Session 2.1a - Power Supply Isssues.

- Modes of Noise Generation
  - Input Ripple
  - Output Ripple
  - Magnetic Fields
  - Common Mode "Ground" Noise
- Measurement and Characterization
  - Measurement and Troubleshooting of Magnetic Fields (simple and intuitive with war stories)
  - Measurement and Troubleshooting of Common Mode "Ground" Noise (simple and intuitive with war stories)
    - Limits for Reliable Operation
    - Possible Problems to Watch For
- Examples

Session 2.2 - Perpendicular Bus-Structure Circuit Boards with Motherboard

- EMC Essentials of Perpendicularly - Connected Circuit Boards
- Common-mode Architectural Considerations With Perpendicular Circuit Boards
- Common-mode Field Distributed Transfer Interactions
- Field Displacements to Chassis Planes
- Common-mode Transfers to Interface Cables
- Field Transfer Interactions to Interface Cables With Multiple Cards
- EMC Implications of Ancillary Connections to Perpendicular Circuit Boards
- Ground Null Applications to Motherboards and Perpendicular Interface Circuit Boards
- Topological Layout Implications of Common-mode Fields

Session 2.3 - Backplane and Midplane Products Integrated with Individual and Multiple Card Cages

- Backplanes Viewed Initially With A Single Interconnected Systems Board
- "Lumped" Common-mode Considerations
- Card Cage Impositions With Backplanes With Interconnected Systems Board
- Field and Current Transfers to Card Cages from Backplanes With Interconnected Systems Boards
- Backplane Architecture to Systems Boards
- Differential-Mode Signal Approach
- Common-mode Aspect Ratios of System Boards

- Interface Cable Connections to Backplanes and Systems Boards
- Interconnections of Multiple Systems Boards
- Approximation of Antenna Structures Referenced to Chassis (Card Cage) Planes
- Common-mode References of Backplanes With Systems Boards
- Common-mode Current Circulation Closure
- Special Situation: Chassis Connection References for DC Chassis-Isolated Backplanes
- Reference Technique With Chassis Stripes and Via Patterns
- Establishment of "Null Zones" in Backplanes
- Null Zones and Regional Partitions
- Inter-layer Backplane Referencing Method With Connection Detail
- Backplane Layering Construction, Stack-up Considerations
- Interconnected Systems-Card Edge Reference Application
- Card Guide Connection Null Approach
- Distributed DC Power Subsystem Backplane Partitioning
- Null Partition References of Interconnected Systems Boards
- Derivation of Common-mode EMC Architecture from Systems Electrical Architecture
- Null Partition References - Card Cage and Backplane Integration
- Termination of Null Partitions to Backplane
- Mid-Planes - Partition Integration
- Mid-Plane Partitions and Stack-up Concepts
- Mid-Plane Common-Mode Architectural Derivation

Session 2.4 - EMC Implications of Systems Interconnections

- Simplified Antenna Theory.
- Initial Implications Related to Systems Interconnections
- EMC Issues Affecting Radiated Field Susceptibility and Emissions
- Interrelationships of Currents Between Systems Units
- Spatial EMC Excitations Among Systems Unit Members
- Rack-Mount Integration of Multiple Card Cage Products
- Multiple Card Cage Products - Independently and Remotely Mounted
- Common-mode EMC Excitations Imposed to Mechanical Mounting Structures
- Field Transfers (Interactions) Between Multiple Card Cage System Products
- Lumped Representations of Multiple Card Cage Products
- Rack-mount Integration of Multiple Card Cage Products
- EMC Mitigation Methods for Rack Mount Products
- Distributed Common-mode Attenuation Technique Through Interface Cables
- Implications of Primary (Utility) Power Interconnections
- Interconnections to Facility Power Distributions
- Historical Implications of Facility Common-mode Events
- Voltage and Current Ground Shifts From Facility Power That Impact Systems
- Alternate Architectural Systems Structure to Mitigate Facility Common-mode Events
- Concept of Software Coding and Physical Interface Transport Communication Layers
- Essential EMC Characteristics of Telecommunication Transport Layers
    - Multi-wire Cables
    - Twin-axial Cables
    - Tri-axial Cables
- **Experiment:** Coaxial Cables, Pigtails, and Systems (or how to make a multi-element antenna without really trying).
- **Experiment:** Parallel Wire Coupling.

Session 2.5 - Troubleshooting Techniques - CW Signals.

- Voltage Measurements
  - Active vs. Passive Probes
  - Single Ended vs. Differential Measurements
- Current Measurements
  - Predicting Emissions
  - Use of Matched Probes
  - Easy to Make Relative Phase Measurements on a Spectrum Analyzer (yes, it is possible) to Troubleshoot EMC Problems

Session 2.6 - Product Shielding: Application of Conceptual Theory

- Properties of Electromagnetic Waves
- Concepts of Electromagnetic Wave Impedance Mismatches
- Transmission Line Analogies of Shielding Processes
- Electromagnetic Wave Impedances
  - Near Field
  - Transition Region
  - Far Field
- Electromagnetic Wave Impingement - Shield Performance Mechanisms
- Reflection Losses From Shield Surfaces
- Initial Reflection Shielding Function of a Boundary
- Skin Effect Boundaries
- Inter-boundary Effects
  - Thick Shields
  - Thin Shields
  - Surface Boundary Shields
- Shielding Effectiveness Functions of a Continuous Shield Boundary
  - Reflection Losses
  - Absorption Losses
- Compilations of Shielding Effectiveness Parameters
- **Experiment:** An Alternate Simple Shielding Effectiveness Measurement.

Session 2.7 - Perimeter Case and Chassis Shielding: Gaps, Seams, Slots, Perforations and Waveguides in Cutoff

- Factors Limiting Shield Performance
- Coincidence of Apertures to Circuits and Circuit Boards
- Applications of Seams and Gaps as Shield Apertures
- Induction Flux Equivalence
- Aperture-Arrayed Shield Structures
- Waveguides in Cutoff - Individual Apertures
- Waveguides in Cutoff - Aperture Arrays
- Perforated and Screen Shield Examples
- Honeycomb Shield Arrays
- Rectangular and Circular Waveguides
- Cavity Resonance in Enclosures

Session 2.8 - Shielded Modules Carried on Circuit Board Partitions

- Device-level Heat Sinks Utilized as Shields
- Completing Shields of Device-level Heat Sinks
- Regional Shield Partitions with Lumped Coupling Approximations
- Cavity Resonance Effects and "Q-Factor"

Session 2.9 - Cable Shielding Applications

- Shielded Cable Operation.
- Purpose of Cable Shielding
  - Tri-axial Cable Shields
  - Twin-axial Cable Shields
  - Twisted Pairs
  - Unshielded Twisted Pairs
- Importance of Connector Characteristics
- Shield Categories of Multi-Conductor Shielded Cables
- Twisted and Twisted-Shielded Pairs Within Multi-Conductor Cables
- Significance of Shield Termination Impedance
- **Experiment:** When a Cheap Shielded Cable is Best, by Radiated EMI.

---------- DAY THREE ----------

Session 3.5 - Immunity / Susceptibility Consideration

- Common-mode Entry and Exit Currents (to or from products)
- Null Redistributions of Common-Mode Exit Currents
- Implications of Redistributions to Shielded Cables
- Common-Mode to Differential-Mode Conversions
- Common-Mode Current Circulating in the Shield of the Cable Wire Pairs
- EMC Reference Interactions with Chassis-Case Structures
- Overview of Case-Structure Apertures
- Transfer Mechanisms of Susceptibility Response
- Effects of Product Immersion into Radiated Excitation Field Structures
- Concepts of Bandwidth Limiting (Filtering / Conditioning)
- Common-mode and Differential Mode Approaches
- Concepts of Demodulation and Detection of RF Carrier Processes
- Electrostatic Discharge (ESD) Processes and Impacts
- Fast Transient (EFT) Coupled Impacts
- Radiated Field Influences.

Session 3.6 - Brief History of ESD and Testing

- Early ESD Principles That Still Apply
- Quick Overview of Recent ESD Work.

Session 3.7 - Pulsed EMI Issues and Troubleshooting.

- Relationship of emissions, immunity, and SI (3 ring diagram)
- Unusual forms of ESD (or why your product can meet all requirements and still go wrong)
  - Characteristics and relationship to “normal” ESD

    - Lab and field data
    - Troubleshooting
- Software considerations
- Troubleshooting Techniques - Pulsed Signals
- **Experiments**
    - **Experiment:** Circuit Board Coupling to a Metal Plane - Pulsed Signals
    - **Experiment:** Effects of Breaks in Ground Planes - Pulsed Signals
    - **Experiment:** Effects of Paths Changing Layers in PWBs - Pulsed Signals
    - **Experiment:** Shielded Cable Effects - ESD Currents
    - **Experiment:** Transient Suppression Plane
- Electrical Fast Transients - Tips and Troubleshooting
- Review of the Standard
- Real World EFT
    - Hot Plug PWBs and Modules - EFT Where You Least Expect It!

Session 3.8 - Open Discussions

Questions or suggestions? Contact me at doug@dsmith.org