Seminar 33

SIGNAL INTEGRITY

ECHO AND CROSSTALK IN PRINTED CIRCUIT ASSEMBLIES AND MULTI-CHIP MODULES

Seminar contents: This course introduces expert-level approaches for signal integrity in printed circuit assemblies and multi-chip modules (MCMs). We present detailed propagation models based on the theory of multiconductor transmission lines (MTLs). This framework is used to describe and analyze most known techniques for reducing crosstalk and echo in multiconductor interconnections.
Who should attend: R&D and signal integrity engineers and researchers concerned by the reduction of echo and crosstalk in dense interconnections for wide-band signals. We assume that the participants are familiar with advanced signal integrity concepts and results.
Observations: The participants need to be familiar with basic matrix algebra. The Mathcad worksheets and the SPICE netlists used for the simulations are provided as input files and as .pdf files. They provide control over every parameters of frequency domain and time domain simulations involving up to 8 transmission conductors. They can be re-programmed to explore other configurations.
Duration: 2 days.

SEMINAR OUTLINE

1. Per-unit-length impedance and admittance matrices
- Inductances and the p.u.l. inductance matrix of a MTL
- Partial inductances
- Influence of the frequency: skin effect and proximity effect
- Capacitances and the p.u.l. capacitance matrix of a MTL
- Computation of the p.u.l. capacitance matrix
- Losses and dispersion in dielectrics
- The p.u.l. admittance matrix of a MTL and a model
- Criticism of the model for the p.u.l. admittance matrix
- Computation of the high-frequency p.u.l. inductance matrix
- The p.u.l. impedance matrix of a MTL and a model
- Criticism of the model for the p.u.l. impedance matrix
- Examples of interconnections with 2 to 8 transmission conductors
- Direct measurement of the p.u.l. impedance and admittance matrices

2. Theory of uniform multiconductor transmission lines I
- The telegrapher's equations and the chain matrix for two conductors
- The 2-conductor transmission line in the frequency domain
- Propagation problems involving linear terminations
- Time domain analysis of lossless and lossy 2-conductor transmission lines
- The telegrapher's equations and chain matrix of a uniform MTL
- Modal decomposition
- The modal characteristic impedance matrix
- The characteristic impedance matrix
- Bi-orthogonal eigenvectors
- Associated eigenvectors
- The choice of transition matrices and total decoupling

3. Crosstalk and standard crosstalk mitigation techniques
- Internal crosstalk, NEXT and FEXT
- Effects of external fields, emission and external crosstalk
- Single-ended links
- Internal crosstalk in electrically short interconnections
- Internal crosstalk in weakly coupled interconnections
- A model for external crosstalk
- Common-mode coupling and external crosstalk
- Twisted pairs and balanced interconnections
- The **Z** and **Y** matrices of balanced interconnections
- Differential links and pseudo-differential links
- Shielded interconnections and guard traces
- The **Z** and **Y** matrices of shielded interconnections
- Shielded links
- Discontinuity of the screens

4. Theory of uniform multiconductor transmission lines II
- The matrix of the voltage reflection coefficients
- Optimal terminations for single-ended transmission
- Completely degenerate interconnections
- More on the chain matrix of a MTL
- Propagation problems involving linear terminations
- Note concerning long lossy MTLs
- Time domain analysis of lossless and lossy MTLs
- Implementation of a lossless MTL model in SPICE
- Implementation of lossless and lossy MTL models in Mathcad
- Examples of interconnections with 2 to 8 transmission conductors
- Indirect measurement of the p.u.l. impedance and admittance matrices

5. Differential transmission
- Interconnection-ground structures for balanced pairs
- Characteristic impedance matrix of a balanced pair
- Discussion of terminations for differential links
- On the uniformity of the balanced pair
- Internal crosstalk in a multichannel differential link
- Examples of Mathcad and SPICE simulations
- Applicability to non-uniform interconnections

6. The general ZXtalk method
- Definition of the general ZXtalk method
- On the properties of the interconnection
- Design equations for modal voltages
- Design equations for modal currents
- Propagation of signals
- Relation with associated eigenvectors
- Design equations in the time domain
- Examples of Mathcad and SPICE simulations
- Applicability to non-uniform interconnections
- Comparison with other modal transmission schemes
- Implementation and discussion of the ZXtalk method

7. The special ZXtalk method for CDI
- The special ZXtalk method for completely degenerate interconnections
- On the properties of the interconnection
- Design equations and the 8 possible designs
- Design equations in the time domain
- Types of interface circuits
- Use of a MIMO series-series feedback amplifier (MIMO-SSFA)
- Design equations for a MIMO-SSFA
- Examples of Mathcad and SPICE simulations
- Applicability to non-uniform interconnections
- Implementation and discussion of the special ZXtalk method for CDI

8. Pseudo-differential transmission
- The four possible pseudo-differential link architectures
- Termination circuits and damping circuits
- Interconnection-ground structures for PDLs
- Conventional pseudo-differential links
- Definition of the ZXnoise method
- Design equations for the ZXnoise method
- Constant common-mode current drivers
- Comparison of two constant common-mode current drivers
- The 12 pseudo-differential transmission schemes

9. Analysis of the ZXnoise method
- Matrices defining the (n+1)-conductor MTL model
- Shielding action of the return conductor
- Matrices defining the (n+2)-conductor MTL model
- Ideal magnetic screen and ideal electric screen
- Modes and characteristic impedance matrix for an ideal screen
- Design equations
- Examples of Mathcad and SPICE simulations
- Applicability to non-uniform interconnections
- Exact telegrapher's equations
- Assessment of the residual external crosstalk
- Implementation and discussion of the ZXnoise method