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 basic signal integrity concepts and results.
Observations: The course uses basic matrix algebra. Many examples involving up to 8 transmission conductors are treated. This course is an advanced sequel to our Seminar 32.
Duration: 3 days.

SEMINAR OUTLINE

1. General considerations on interconnection models
- About interconnection models.
- Assumptions and definitions used throughout this course.
- Some notations and units.
- Introduction to the MTL model.
- Uniform ideal conductors in vacuum.
- Equations of the lossless uniform MTL model.
- Signal in the time domain and causal system.
- Signal in the frequency domain and causality.
- Passivity.
- Good and bad interconnection models.

2. Per-unit-length impedance and admittance matrices
- Inductances and the p.u.l. inductance matrix of a MTL.
- Low-frequency inductance and partial inductance.
- Influence of the frequency: skin effect and proximity effect.
- Capacitance 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.
- The high-frequency p.u.l. internal impedance matrix.
- The p.u.l. impedance matrix of a MTL and a model.
- Some interconnections with 1 to 8 TCs and rules of scaling.
- Criticism of the models.
- Direct measurement of the p.u.l. impedance and admittance matrices.

3. Two-conductor and multiconductor transmission lines
- 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 or lossy transmission lines.
- Computation of the eye diagram.
- The telegrapher's equations and chain matrix of a uniform MTL.
- Modal decomposition.
- The modal characteristic impedance matrix.
- The characteristic impedance matrix.
- The special case of the lossless MTL.
- Biorthonormal eigenvectors.
- Associated eigenvectors.
- Total decoupling.
- Performance regions of an interconnection.

4. Crosstalk and standard crosstalk mitigation techniques
- Echo, internal crosstalk, NEXT and FEXT.
- Electromagnetic immunity, electromagnetic emission and external crosstalk.
- Internal crosstalk in electrically short single-ended links.
- Internal crosstalk in weakly coupled interconnections.
- Models for the external crosstalk.
- Balanced pairs and balanced interconnections.
- The $\mathbf{Z}'$ and $\mathbf{Y}'$ matrices of a balanced interconnection.
- Shielded interconnections and guard traces.
- The $\mathbf{Z}'$ and $\mathbf{Y}'$ matrices of a shielded interconnection.

5. Properties of uniform multiconductor transmission lines
- The choice of transition matrices.
- Completely degenerate interconnections.
- Computation of the chain matrix of a MTL.
- Use of matrix functions.
- Modal electrical variables in the frequency domain.
- Natural electrical variables in the frequency domain.
- Matched termination circuit and pseudo-matched terminations.
- Propagation problems involving linear terminations circuits.
- Time domain analysis of lossless and lossy MTLs.
- Approximate solutions for low losses.
- Approximate solutions for weak coupling.
- Indirect measurement of the p.u.l. impedance and admittance matrices.

6. Single-ended parallel links
- Single-ended transmission and the underlying model.
- Interconnection structures and design formulas.
- Optimal termination for single-ended transmission.
- Effect of the dielectric on propagation and crosstalk.
- Crosstalk mitigation using an increased TC-to-TC spacing.
- Crosstalk mitigation using guard traces.
- Compensation.
- Crosstalk mitigation using signal processing.
- Differential and pseudo-differential receiving circuit.
- Reducing common-mode coupling at the sending end.

7. Differential transmission
- Differential transmission and the underlying model.
- Modal analysis of a pair.
- Interconnection structures and design formulas.
- Discussion of terminations for differential links.
- On the uniformity of the balanced pair.
- Modal analysis of a multipair interconnection.
- Internal crosstalk in a multichannel differential link.
- Applicability to non-uniform interconnections.
- Current-mode receiving circuit.

8. Modal transmission
- Principle of modal signaling.
- On the properties of the interconnection.
- The general ZXtalk method.
- Terminations for the ZXtalk method.

The 8 possible designs and the propagation of signals.
Relation with associated eigenvectors.
Design equations for voltage-mode modal signaling.
Design equations for current-mode modal signaling.
Applicability to non-uniform interconnections.
Comparison with other crosstalk cancellation schemes.
Implementation of the ZXtalk method.

9. Crosstalk reduction in a degenerate interconnection

The special ZXtalk method for completely degenerate interconnections.
On the properties of the interconnection.
The 8 possible designs and the propagation of signals.
Design equations for voltage-mode.
Design equations for current-mode.
Applicability to non-uniform interconnections.
Using a MIMO series-series feedback amplifier.
Implementation of the special ZXtalk method for CDI.

10. Pseudo-differential transmission

Pseudo-differential transmission.
The four possible pseudo-differential link architectures.
Termination circuits and damping circuits.
Interconnection-ground structures for PDLs.
The telegrapher's equations for pseudo-differential transmission.
Conventional pseudo-differential links.
The ZXnoise method.
Design equations for the ZXnoise method.
Applicability to non-uniform interconnections.
The 12 pseudo-differential transmission schemes.
Comparison with other innovative transmission schemes.

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