Signal Integrity and High-Speed Interconnects
(ME638 / MEI221)

January-May 2006
Thursdays 7-10 pm
Classroom W-201

Instructor Information

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General Description

This course will enable students to efficiently analyze and design basic interconnect circuits for high-speed applications. Students will gain fundamental skills on transmission line theory, high-frequency network analysis, and basic microwave engineering as applied to signal integrity problems. They will demonstrate proficiency in the understanding of signal integrity concepts and terminology. Students will also be enabled to efficiently use, at a basic level, high-frequency distributed-circuit CAD tools as well as full-wave electromagnetic simulators. The use of simulation software and lab measurements for hands-on experience will be emphasized throughout the course.

Prerequisites

No previous graduate course is required. It is expected that students taking this course are skilled on basic electronics and circuit analysis, and are familiar with essential electromagnetism. Experience with SPICE simulation would be very useful. Familiarity with numerical processing software (e.g., Matlab) would also be useful.

Learning Objectives

By the end of this course the student will be able to:

A. Identify the technological and economical relevance of signal integrity and get familiar with the fundamental related terminology (COMPREHENSION)

B. Calculate characteristics impedances, reflection coefficients, standing wave ratios, insertions losses, etc., using fundamental transmission line theory (ANALYSIS)

C. Efficiently interpret the Smith chart, and use it for impedance matching (SYNTHESIS)

D. Design impedance matching networks using quarter-wave transformers and other similar techniques (SYNTHESIS)

E. Analyze linear circuits in the frequency domain using scattering parameters and chain parameters (ANALYSIS)
F. Analyze linear and nonlinear circuits in the time domain using lattice and Bergeron diagrams (ANALYSIS)
G. Efficiently utilize commercially available CAD tools for simulating high-frequency circuits, including distributed circuit simulators and full-wave electromagnetic simulators (APPLICATION)
H. Identify and utilize fundamental models of physical interconnects, ground and power planes, and I/O buffers (APPLICATION)
I. Describe the basic signal integrity phenomena related to high-speed communication links, such as attenuation, jitter, intersymbol interference, crosstalk, etc. (ANALYSIS)
J. Generate eye diagrams of high-speed interconnect circuits using simulation tools, and apply fundamental equalization and pre-emphasis techniques to improve signal integrity (SYNTHESIS)

General Contents

1. An overview on signal integrity
   1.1. Market and technology trends
   1.2. SI terminology
2. Transmission line theory
   2.1. From lumped circuits to distributed circuits
   2.2. Transmission line parameters and physical significance
   2.3. Special cases of lossless terminated transmission lines
   2.4. The Smith chart
   2.5. Basic impedance matching
   2.6. Lossy transmission lines
3. Frequency-domain analysis of transmission line circuits
   3.1. Scattering parameters
   3.2. The transmission (ABCD) matrix
   3.3. Differential S-parameters
4. Transient-domain analysis of transmission line circuits
   4.1. Lattice diagrams
   4.2. Bergeron diagrams
5. CAD tools for high-frequency simulation
   5.1. SPICE-like simulation
   5.2. Tools for distributed-circuit simulation
   5.3. Tools for full-wave EM simulation
6. Modeling physical interconnects
   6.1. Nonideal physical effects: skin effect, edge effect, proximity effect, Indy effect
   6.2. Strip lines
   6.3. Microstrip lines
   6.4. Printed circuit boards (traces, vias and stackups)
   6.5. On-chip interconnects
7. Modeling I/O buffers
   7.1. Behavioral models
   7.2. IBIS models

   - 7.3. Equivalent circuit models
   - 7.4. Physics-based models
   - 7.5. Metastability in buffering circuits
8. Return paths and power supply decoupling
   - 8.1. Lumped models for power-ground planes
   - 8.2. Distributed models for power-ground planes
   - 8.3. Modeling decoupling capacitors
   - 8.4. Simultaneous Switching Noise (SSN)
9. Serial data transmission
   - 9.1. Harmonic contents in data streams
   - 9.2. Line codes, bit rate and data rate
   - 9.3. Block codes for serial transmission
   - 9.4. Intersymbol interference (ISI)
   - 9.5. Eye diagrams
   - 9.6. Equalization and pre-emphasis
   - 9.7. DC-blocking capacitors
10. Single-ended and differential signaling
   - 10.1. Even and odd modes
   - 10.2. Multiconductor transmission lines
   - 10.3. Crosstalk
   - 10.4. Differential signaling: noise rejection, terminations and layout
   - 10.5. Mode conversion
   - 10.6. Crosstalk minimization techniques

Relationship between Contents and Objectives

	1	2	3	4	5	6	7	8	9	10
A	✓								✓	✓
B		✓								
C		✓								
D		✓								
E			✓							
F				✓						
G			✓	✓	✓	✓	✓	✓	✓	✓
H						✓	✓	✓		
I									✓	✓
J									✓	✓

Course Skeleton

For the proposed skeleton it is assumed: a group of 6 to 18 students; 1 lecture per week (3-hour long each) during 16 weeks (48 hours in total); laboratory available 8 hours a day, from Monday to Friday; simulation software available at ITESO and/or at home (for SPICE simulation: WinSpice, OrCad PSpice, Electronic Workbench or any other similar circuit simulator; for EM simulation: Sonnet and CST Microwave Studio; for high-frequency circuit simulation: Aplac; for general computing: Matlab).

It is also expected that the student will be able to dedicate an average of 8 hours of work per week to this course, including attending classes.

Week	Unit	Unit Description	Subtopics
1	1 2	An overview on signal integrity Transmission line theory	1.1-1.3 2.1-2.2
2	2	Transmission line theory	2.2-2.5
3	2	Transmission line theory	2.5-2.6
4	3	Frequency-domain analysis of transmission lines	3.1-3.2
5	3 4	Frequency-domain analysis of transmission lines Transient-domain analysis of transmission lines	3.3 4.1
6	4	Transient-domain analysis of transmission lines	4.1-4.2
7	5	CAD tools for high-frequency simulation	5.1-5.3
8	5	CAD tools for high-frequency simulation	5.2-5.3
9	6	Modeling physical interconnects	6.1-6.3
10	6	Modeling physical interconnects	6.4-6.5
11	7	Modeling I/O buffers	7.1-7.5
12	8	Return paths and power supply decoupling	8.1-8.5
13	9	Serial data transmission	9.1-9.5
14	9	Serial data transmission	9.6-9.7
15	10	Single-ended and differential signaling	10.1-10.2
16	10	Single-ended and differential signaling	10.3-10.6

Assessment

The overall grade in this course will be built from the following elements:

Assignments and labs	70%
Final Project	30%

Each student will realize a final project during the course on a topic directly related to the contents. The topic chosen must be approved by the instructor. The final project must be submitted following a template that will be indicated later in the course. Students will make a technical presentation on their final project selected. Depending on the selected topic and class size, the project and the corresponding presentation can be realized individually or in teams of up to 2 students. The report must be hand in on the day of the presentation, with copies for the rest of the students. The presentation and the report will be evaluated not only by the instructor but also by the classmates. Further instructions about the technical presentations will be explained later on.

Ideally, final projects of this course could be presented in the Second ITESO-Intel International Workshop on Signal Integrity (I^3WSI-2006), to be held at ITESO during October 5-6, 2006. More information regarding this workshop will be presented later in the course.

The quality of the participation of the students during the lectures will be graded. This participation will be evaluated based on student's attitude and performance during class: punctuality, willingness to ask relevant questions, respect to others, attention during class, ability to answer questions, etc.

Teaching Methods

This course will use a variety of teaching methods including: lecturing, seminars, computer simulations, assignments, lab experiments, readings, project report writing and self-conducted research work.

Important information related to the course will be posted in the instructor's web site throughout the course. Open and frequent communication with the instructor is encouraged. Collaboration between the students is also encouraged.

The course will be conducted mainly in Spanish, but some of the lectures and discussions might be held in English. Most of the written material for the course will be available in English.

References

Instructor's web site
http://iteso.mx/~erayas

Books on signal integrity and high-speed interconnects:

High-Speed Digital System Design
Stephen H. Hall, Garret W. Hall and James A. McCall
Wiley-Interscience, 2000

High-Speed Circuit Board Signal Integrity
Stephen C. Thierauf
Artech House, 2004

Interconnect Analysis and Synthesis
C-K Cheng, J. Lillis, S. Lin and N. Chang
Wiley-Interscience, 2000

High Speed Signal Propagation: Advanced Black Magic
Howard W. Johnson and Martin Graham
Prentice Hall, 2003

High Speed Digital Design – a Handbook of Black Magic
Howard W. Johnson and Martin Graham
Prentice Hall, Inc., 1993

Signal Integrity – Simplified
Eric Bogatin
2003 (Amazon)

Digital Signal Integrity
B. Young
Prentice-Hall, 2001

Signal and Power Integrity in Digital Systems: TTL, CMOS, & BiCMOS
J. Buchanan

McGraw Hill, 1996

Introduction to PCI Express: A Hardware and Software Developer's Guide
Adam Wilen, Justin P. Schade, Ron Thornburg
Intel Press, 2003

Signal Integrity Issues and Printed Circuit Board Design
Douglas Brooks
(Amazon)

Printed Circuits Handbook
Clyde Coombs
McGraw Hill, 2001

Books on microwave engineering as applied to SI

Foundation of Interconnect and Microstrip Design, 3rd Edition.
T. C. Edwards and M. B. Steer
Wiley, 2001

Nonlinear Microwave and RF Circuits
Stephen A. Mass
Artech House, 2003

Microwave Engineering
David M. Pozar
Wiley, 1998

RF Circuit Design: Theory nand Applications
Reinhold Ludwig and Pavel Bretchko
Prentice Hall, 2000

Microstrip Lines and Slotlines
K.C. Gupta, Ramesh Garg, Inder Bahl, Prakash Bhartia
Artech House, 1996

Fields and Waves in Communication Electronics
Ramo, Whinnery and Van Duzer
John Wiley, 1985

Transmission Lines and Wave Propagation
P. Magnusson, G. Alexander, V. Tripathi
CRC Press, 1992

Transmission Lines for Digital and Communication Networks
R. E. Matick
IEEE Press, 1995

Books on CAD techniques for SI and high-speed interconnects:

LINPAR for Windows: Matrix Parameters for Multiconductor Transmission Lines, Software and User's Manual, Version 2.0 (Diskette)
Antonije R. Djordjevic, Miodrag B. Bazdar, Tapan K. Sarkar, Roger F. Harrington
Artech House, 2005

Introduction to High-Speed Circuit and Interconnect Analysis
Michel Nakhla and Ram Achar
Omniz Global Knowledge Corporation, 2002

Digital Signal Integrity: Modeling and Simulation with Interconnects and Packages
Brian Young
Prentice-Hall, 2001

Books on timing and I/O buffers:

Digital Systems Engineering
W. Dailly and J. Poulton
Cambridge University Press, 1998

Computer Circuits Electrical Design
R. Poon
Prentice Hall, 1995

Circuits Interconnections and Packaging for VLSI
H. B. Bakoglu
Addison Wesley, 1990

Basic ESD and I/O Design
S. Dabral and T.J. Maloney
Wiley-Interscience, 1998

High-speed digital circuits
M. Shoji
Addison Wesley, 1996

Books on RF and microwave simulation:

Computer-aided analysis of nonlinear microwave circuits
Paulo J.C. Rodrigues
Artech House, 1998

Introduction to Computer Methods for Microwave Circuit Analysis and Design.
J.A. Dobrowolski.
Artech House 1991

Steady-State Methods for Simulating Analog and Microwave Circuits

Kenneth S. Kundert, Jacob K. White, Alberto L. Sangiovanni-Vincentelli
Kluwer Academic Publishers, 1990

Microwave Circuit Modeling Using Electromagnetic Field Simulation
Daniel Swanson
Artech Publishers

Behavioral Modeling of Nonlinear RF and Microwave Devices
Turlington
Artech Publishers

Books on SPICE simulation:

Semiconductor device modeling with SPICE
Paolo Antognetti, editor, Giuseppe Massobrio, coeditor.
Imprint New York : McGraw-Hill, c1988.

SPICE: A guide to circuit simulation and analysis using Pspice
Paul W. Tuinenga
Prentice Hall, 1992

Edición y Simulación de Circuitos con OrCAD
José Luis Calvo-Rolle
Alfaomega Ra-Ma, 2004

Software Tools

WinSpice circuit simulator
http://www.winspice.com/

Cadence (Pspice Orcad)
http://www.cadencepcb.com/products/pspice/

Multisim circuit simulator from Electronics Workbench
http://www.electronicsworkbench.com

TINA-TI
http://www.ti.com/tina-ti

TopSpice (Penzar Development), Spice simulator
http://www.penzar.com/

Tanner (T-Spice and L-Edit)
http://www.tanner.com/EDA/

Spice Models
http://www.pspice.com/models/default.asp

http://www.intusoft.com/
http://www.penzar.com/links.htm

APLAC, EM and high-frequency circuit simulator
http://www.aplac.hut.fi/aplac/main.html

Sonnet, EM simulator
www.sonnetusa.com

CST Microwave Studio
http://www.sonnetsoftware.com/products/cst/index.asp

Learning English at ITESO
Centro de Lenguas, Office N-15, cenlenguas@iteso.mx

NOTA: En caso de alguna dificultad o confusión respecto de este programa de estudios (por estar en idioma inglés), favor de consultar directamente con el profesor.