Learning Guide
High-Frequency Circuits

Credits: 8 (4 *BCD* + 4 *TIE*)

January-May 2020
18-20 hours, Tuesdays and Thursdays
Classroom A-308

Professor Information

José Ernesto Rayas Sánchez, Ph.D.
Office: T-369
Office hours: 10-14, 17:00-21:00 hours
Tel: 3669-3598, Ext. 3096
Email: erayas@iteso.mx
Website: https://desi.iteso.mx/erayas/

Course Presentation

The exponential growth of the telecommunications and computers industries has continuously demanded of ever faster electronic circuits. A great amount of technological breakthroughs confirm this trend: the development of nanometric active devices, which have reached operating frequencies in the THz range; the design of nanometric integrated circuits and systems operating at GHz; the growing access to very broadband internet; the ever higher frequencies in digital circuits; the ever larger storing capacity and data transfer rates for memory chips; the arrival of new interconnect standards, based on serial and differential buses for ultra-high speed data rates; the increasing use of wireless communication media, etc.

With the continuous increment of the operating frequency of electronic circuits (or the continuous reduction in the transition time in digital signals), many physical phenomena cannot be predicted with acceptable accuracy by using conventional analysis methods based on lumped equivalent circuits. This is aggravated by physical size: the larger the circuits with respect to the transmitted wavelength, the less useful are conventional analysis methods. It is in this scenario when specialized high-frequency analysis techniques are required.

This course will give you the opportunity to learn the most fundamental methods to analyze and design high-frequency electronic circuits. You will appreciate the importance of RF and wireless systems. You will analyze the general characteristics of transmission lines, both in the frequency and transient domains. You will design basic high-frequency electronic circuits, such as distributed matching networks and filters. You will also be able to describe some basic signal integrity phenomena in high-speed interconnects, as well as the main performance parameters of an antenna, and the main effects associated to wave propagation. Throughout the course, you will develop skills to simulate these circuits using commercially available CAD tools, including high-frequency circuit simulators as well as full-wave electromagnetic simulators.

Prerequisites

Electricity and Magnetism (compulsory) and Analog Electronic Circuits (recommended).

General Objective

In this undergraduate course you will be introduced to the analysis and design of high-frequency electronic circuits. You will learn the most fundamental techniques to analyze high-frequency circuits using basic transmission line theory, both in the steady state frequency domain as well as in the time domain transient regime. You will learn how to design basic circuits for high-frequency applications, such as matching networks, filters, and high-speed interconnects. You will be able to explain some of the basic signal integrity concepts that characterize a high-speed link, as well as the main performance parameters of an antenna. You will develop skills for high-frequency distributed-circuit simulation and for electromagnetics-based simulation, using state-of-the-art CAD tools.

Specific Learning Objectives

By the end of the course you will be able to:

A. Identify the technological and economical relevance of the RF and wireless systems (COMPREHENSION).

B. Describe the main high-frequency effects on typical transmission media (APPLICATION).

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

D. Efficiently interpret the Smith Chart, and use it for basic transmission line calculations (APPLICATION).

E. Analyze linear circuits in the frequency domain using scattering parameters and chain parameters (ANALYSIS).

F. Analyze linear and nonlinear transmission line problems in the time domain using lattice and Bergeron diagrams (ANALYSIS).

G. Model basic passive components (lumped elements and interconnects) for high-frequency applications (SYNTHESIS)

H. Design impedance matching networks using quarter-wave transformers, stub tuning and other similar techniques (SYNTHESIS).

I. Utilize at a basic level commercially available CAD tools for simulating high-frequency circuits, including distributed circuit simulators and full-wave electromagnetic simulators (APPLICATION).

J. Design basic high-frequency filters and implement them in microstrip technology (SYNTHESIS).

K. Explain the main performance parameters of an antenna (COMPREHENSION).

Contents

1. An introduction to high-frequency circuits and systems
2. High-frequency effects on transmission media
   - 2.1. Common transmission media
   - 2.2. Modeling uniform interconnects
   - 2.3. Interconnect parasitics and their physical significance
   - 2.4. EM-effects: Skin effect, proximity effect, edge and Indy effects
   - 2.5. From lumped circuits to distributed circuits
3. Fundamental transmission line theory

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- 3.1. Telegrapher equations and wave equation
- 3.2. Traveling waves
- 3.3. Characteristic impedance
- 3.4. Reflection coefficient along the line
- 3.5. Input impedance along the line
- 3.6. Lossless transmission lines
- 3.7. Power along the line
- 3.8. Return loss
- 3.9. Standing wave ratio
- 3.10. Transmission coefficient
- 3.11. Insertion loss
- 3.12. Input impedance in lossless transmission lines (TL)
- 3.13. Lossy *vs* lossless transmission lines
- 3.14. The low-loss line
- 3.15. The lossy distortionless line
- 3.16. How to decide if transmission line theory is needed in practical interconnects

4. The Smith Chart
   - 4.1. Smith Chart origin and interpretation
   - 4.2. Basic Smith Chart applications
   - 4.3. Open circuit transformations
   - 4.4. Short circuit transformations
   - 4.5. Impedance-admittance transformations
   - 4.6. The quarter-wave transformer
5. Frequency-domain analysis of transmission line circuits
   - 5.1. Impedance and admittance parameters
   - 5.2. Scattering parameters
   - 5.3. The transmission (ABCD) matrix
   - 5.4. Analyzing interconnects with discontinuities
   - 5.5. Differential mode signaling
   - 5.6. Mode conversion
   - 5.7. Even and odd impedance
   - 5.8. Differential S-parameters and crosstalk
   - 5.9. Termination techniques for differential signaling
   - 5.10. Two-coupled microstrip lines
6. Transient-domain analysis of transmission line circuits
   - 6.1. Quarter-wave transformer – transient response
   - 6.2. Reflection coefficient revised
   - 6.3. Concept of “transient impedance”
   - 6.4. Applying DC to transmission lines
   - 6.5. Lattice (or bouncing or reflection) diagrams
   - 6.6. Building transient signals from bouncing diagrams
   - 6.7. Under-driven and over-driven lines
   - 6.8. Bouncing diagrams for multiple sections of transmission lines
   - 6.9. Bergeron diagrams
7. CAD tools for high-frequency simulation
   - 7.1. SPICE-like simulation
   - 7.2. Tools for distributed-circuit simulation
   - 7.3. Tools for full-wave EM simulation
8. Fundamental passive components at high frequencies

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   8.1. Lumped resistors
   8.2. Lumped capacitors
   8.3. Lumped inductors
   8.4. Strip lines
   8.5. Microstrip lines
   8.6. Coupled microstrip lines
9. Impedance matching circuits
   9.1. Benefits of impedance matching
   9.2. Matching with lumped elements
   9.3. Matching capacitive loads
   9.4. Single-stub tuning
   9.5. Multiple-sections impedance transformers
10. High-frequency filters
   10.1. Filter design at high-frequencies
   10.2. General characteristics of filters
   10.3. The insertion loss method to filter design
   10.4. Low-pass filter prototypes
   10.5. Filter scaling and transformation
   10.6. High-pass, band-pass and band-reject filters
   10.7. Physical design of high-frequency filters
11. An introduction to antennas
   11.1. Antenna definition and parameters
   11.2. Types of antennas
   11.3. Propagation and radiation
   11.4. Radiation patterns
   11.5. The Friis equation
   11.6. Basic equivalent circuits for antennas

Relationship between Contents and Specific Learning Objectives

	A	B	C	D	E	F	G	H	I	J	K
1	√										
2		√									
3			√	√							
4				√							
5					√				√		
6						√			√		
7									√		
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9				√				√	√		
10									√	√	
11											√

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Course Skeleton

Week	Working Focus	Week	Working Focus
1	Contents 1, 2	9	Contents 6, 8
2	Contents 3	10	Exam 3, Summary
3	Contents 3, 4	11	Contents 7.3, 9
4	Exam 1, Contents 5, 7.1, 7.2	12	Contents 9
5	Contents 5	13	Contents 9
6	Contents 5	14	Exam 4, Contents 10
7	Exam 2, Lab Report 1, Cont. 6	15	Contents 10
8	Contents 6	16	Lab Report 2, Contents 11

Assessment

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

4 Exams	75%
2 Lab reports	20%
Participation	5%

The contents of the exams and lab reports are in most cases cascaded, so that the knowledge and skills developed in a given unit are usually needed in the next units.

The exams will be applied during class and will take 1 hour and 50 minutes each. Each exam typically consists of three sections: selected response assessment (multiple choice, true/false, etc.), brief analysis problems, and a more complex analysis problem or a design problem. *Missed exams and lab reports deadlines cannot be made up.*

The lab reports might consist of simulations in the computer, implementations in the laboratory, or a combination of both. Lab projects and reports can be realized individually or in teams of several students.

Quality of students' participation 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.

It is expected that the student will be able to dedicate to this course an average of 8 hours of work per week throughout the semester, including attending classes (4 hours of extra-class work).

Teaching Methods

This course will use a variety of teaching methods including: lecturing, problem solving sessions, self-conducted laboratory work, computer simulations, lab report writing, assignments, and readings.

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

Out of class student's work is fundamental in the learning process. It is extremely important to read the corresponding materials before each lecture. It is also very important to solve the suggested assignments, either alone or in collaboration with other classmates.

Students will be asked to solve problems in some lectures. These problems are intended to re-inforce the learning process as well as to evaluate students' participation. Students should bring at least a scientific calculator to each class.

The course will be conducted mainly in Spanish, but some of the lectures and discussions might be in English. Most of the written material for the course will be available in English. The lab reports can be submitted in either English or Spanish.

Bibliographic References

Microwave Engineering
David M. Pozar
Wiley, 2011

RF Circuit Design: Theory and Applications
Reinhold Ludwig and Pavel Bretchko
Prentice Hall, 2008

Advanced Signal Integrity for High-Speed Digital Designs
Stephen H. Hall and Howard Heck
Wiley-IEEE, 2009

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

Microwave and RF Design of Wireless Systems
David M. Pozar
Wiley, 2000

Small Signal Microwave Amplifier Design
Theodore Grosh
Noble Publishing, 1999

Electromagnetics for High-Speed Analog and Digital Communication Circuits
Ali M. Niknejad
Cambridge University Press, 2007

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

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

Computer-Aided Design of Microwave Circuits
K. C. Gupta, R. Garg, and R. Chadha

Artech, 1981

Microwave Circuit Modeling Using Electromagnetic Field Simulation
Daniel G. Swanson and Wolfgang J. R. Hoefer
Artech Publishers, 2003

Introduction to RF Design Using EM Simulators
Hiroaki Kogure, Yoshie Kogure, and James Rautio
Artech House, 2010

Other Resources

Course website:
https://desi.iteso.mx/erayas/rf_circuits.htm

Microwaves101.com
https://www.microwaves101.com/

MIT Open Courseware
https://ocw.mit.edu/index.htm

Software Tools

Keysight ADS and EM-Pro
https://www.keysight.com/en/pc-1297113/advanced-design-system-ads?nid=-34346.0&cc=MX&lc=eng

Qucs, high frequency circuit simulator
http://qucs.sourceforge.net/

Sonnet, EM simulator
http://www.sonnetsoftware.com/

COMSOL Multiphysics
https://www.comsol.com/

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

Cadence (PSpice OrCAD)
https://www.orcad.com/resources/orcad-downloads

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Learning Situations

Opening Introductions				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
Main characteristics of this course, and its most important resources.	1	• Get familiar with professor's background and profile. • Express your expectations related to the course, and contrast them with the course design. • Get to know the expectations of other classmates.	• Visit course website and get familiar with its contents. • Visit some of the suggested websites for "Other Resources". • Go to the library and browse suggested textbooks. • Acquire at least one of the suggested textbooks.	• Individual expectations of each student. • Global expectations of the group.

Learning Objective A: Identify the technological and economical relevance of the RF and wireless systems (COMPREHENSION)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• The electromagnetic spectrum. • Market and technology trends in the following industries: Semiconductors, Computers, and Communications.	1	• Attend professor's presentation entitled "An Introduction to High-Frequency Circuits and Systems". • Ask relevant questions about discussed topics.	• Download from the course website materials for Section 1 (An Introduction to High-Frequency Circuits and Systems). • Study previous materials and write down comments or questions if necessary.	• No concrete outcomes for this learning objective.

Learning Objective B: Describe the main high-frequency effects on typical transmission media (APPLICATION)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• Common transmission media • Modeling uniform interconnects • Interconnect parasitics and their physical significance • EM-effects: Skin effect, proximity effect, edge and Indy effects • From lumped circuits to distributed circuits	2	• Attend professor's presentation entitled "High-Frequency Effects on Transmission Media". • Ask relevant questions about discussed topics. • Solve a problem on how to model a lossy dielectric by a distributed negative and imaginary capacitor. • Explain the transversal current distribution in two wires with opposing currents. • Explain how the parasitic distributed capacitance varies when the dielectric height is increased in a microstrip line. • Explain how the parasitic distributed inductance can be reduced in a PCB trace.	• Download from the course website materials for Section 2 (High-frequency effects on transmission media). • Study previous materials and write down comments or questions if necessary. • Solve problems of assignments and exercises labeled "Probs 1".	• Problems labeled "Probs 1" solved.

Learning Objective C: Calculate characteristics impedances, reflection coefficients, standing wave ratios, insertions losses, etc., using fundamental transmission line theory (ANALYSIS)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• Telegrapher equations and wave equation • Traveling waves • Characteristic impedance • Reflection coefficient along the line • Input impedance along the line	3	• Attend professor's presentation entitled "Fundamental Transmission Line Theory (Part 1)". • Attend derivation of the wave equation. • Ask relevant questions about discussed topics. • Explain the general form to convert a time harmonic voltage to the frequency domain, and vice versa. • Explain the general condition for a non-dispersive transmission line. • Calculate the input impedance of a given lossy transmission line.	• Download from the course website materials for Section 3 (Fundamental transmission line theory). • Study previous materials and write down comments or questions if necessary. • Solve problems 1-3 of assignments and exercises labeled "Probs 2".	• Problems labeled "Probs 2" solved.
• Lossless transmission lines • Power along the line • Return loss • Standing wave ratio	4 - 5	• Attend professor's presentation entitled "Fundamental Transmission Line Theory (Part 2)". • Ask relevant questions about discussed topics. • Calculate the reflection coefficient and the SWR of a terminated transmission line. • Calculate the return loss at a transition between two transmission lines.	• Study previous materials and write down comments or questions if necessary. • Solve problems 4-7 of assignments and exercises labeled "Probs 2". • Study handwriten notes on "Power delivered to a load through a lossless transmission line using a matched source".	

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• Transmission coefficient • Insertion loss • Input impedance in lossless transmission lines	5 - 6	• Attend professor’s presentation entitled “Fundamental Transmission Line Theory (Part 3)”. • Ask relevant questions about discussed topics. • Calculate the transmission coefficient at a transition between two transmission lines. • Calculate the input impedance of a given lossless transmission line. • Convert a capacitor into an inductor by using a segment of transmission line.	• Study previous materials and write down comments or questions if necessary. • Start Lab Report 1.	
• Lossy vs lossless transmission lines • The low-loss line • The lossy distortionless line • How to decide if transmission line theory is needed in practical interconnects	6	• Attend professor’s presentation entitled “Fundamental Transmission Line Theory (Part 4)”. • Ask relevant questions about discussed topics. • Read first two sections of the paper entitled “Distortion Minimization for Packaging Level Interconnects”, and make connection with the Heaviside condition. • Apply empirical criteria to decide if TL theory is needed in a given case.	• Study previous materials and write down comments or questions if necessary. • Study the following paper: H. Zhu, R. Shi1, H. Chen, C-K Cheng, A. Deutsch, and G. Katopis, “Distortion minimization for packaging level interconnects,” in IEEE Conf. Electrical Performance of Electronic Packaging (EPEP 2006), Scottsdale, AZ, Oct. 2006, pp. 175-178.	

Learning Objective D: Efficiently interpret the Smith Chart, and use it for basic transmission line calculations (APPLICATION)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• Smith Chart origin and interpretation • Basic Smith Chart applications • Open circuit transformations • Short circuit transformations • Impedance-admittance transformations • The quarter-wave transformer	7	• Attend professor’s presentation entitled “The Smith Chart (Part 1)”. • Calculate Γ, *SWR* and *RL* using the Smith Chart • Attend professor’s presentation entitled “The Smith Chart (Part 2)”. • Calculate Z_{in} and perform impedance inversions using the Smith Chart.	• Download from the course website materials for Section 4 (The Smith Chart). • Study previous materials and write down comments or questions if necessary. • Solve problems 2-5 of assignments and exercises labeled “Probs 2” using the Smith Chart.	• Problems labeled “Probs 2” solved by the Smith Chart (only 2-5).

Exam 1				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• All above	8	• Solve exam.	•	• Exam 1, solved and graded.
	9	• Understand exam’s solution. • Receive feedback on performance.	• Review accumulated material. Study unclear concepts.	

Learning Objective E: Analyze linear circuits in the frequency domain using scattering parameters and chain parameters (ANALYSIS)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• Impedance and admittance parameters • Scattering parameters	9 - 10	• Attend professor's presentation entitled "Frequency-Domain Analysis of Transmission Line Circuits (Part 1)". • Obtain the *Z* matrix of a particular lumped circuit. • Obtain the *Y* matrix of a particular lumped circuit. • Attend the derivation of the *S* matrix of a particular lumped circuit.	• Download from the course website materials for Section 5 (Frequency-domain analysis of transmission line circuits). • Study previous materials and write down comments or questions if necessary. • Study example: "S-parameters of a lumped filter". • Solve problems 1-4 of assignments and exercises labeled "Probs 3".	• Problems labeled "Probs 3" solved.
• The transmission (ABCD) matrix • Analyzing interconnects with discontinuities	11	• Attend professor's presentation entitled "Frequency-Domain Analysis of Transmission Line Circuits (Part 2)". • Obtain the ABCD matrix of a particular lumped circuit. • Attend the solution of a cascaded high-frequency network using ABCD parameters. • Attend derivation of conversion formulas between Z and S parameters.	• Study previous materials and write down comments or questions if necessary. • Solve problems 5-11 of assignments and exercises labeled "Probs 3".	
• Differential mode signaling • Mode conversion • Even and odd impedance • Differential S-parameters and crosstalk • Termination techniques for differential signaling • Two-Coupled microstrip lines	12	• Attend professor's presentation entitled "Frequency-Domain Analysis of Transmission Line Circuits (Part 3)". • Derive matching formulas for differential terminations.	• Study previous materials and write down comments or questions if necessary.	

Learning Objective I (first part): Utilize at a basic level commercially available CAD tools for simulating high-frequency circuits, including distributed circuit simulators and full-wave electromagnetic simulators (APPLICATION)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• SPICE-like simulation • Tools for distributed-circuit simulation	10	• Attend professor's presentation entitled "An Introduction to APLAC". • Simulate a couple of circuits using APLAC.	• Download from the course website materials for Section 7 (CAD tools for high-frequency simulation).	• Simulation cases in APLAC.

		• Simulate in APLAC two coupled microstrip lines as a four-port network and obtain the corresponding near- and far-end crosstalk.	• Install in your laptop the student version of software APLAC. • Study previous materials and write down comments or questions if necessary. • Implement in APLAC the circuit used in example: "S-parameters of a lumped filter". Confirm expected results. • Solve problem 2 of assignments and exercises labeled "Probs 3" using APLAC.	

Exam 2				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• All above	13	• Solve exam.	•	• Exam 2, solved and graded. • Lab Report 1 submitted.
	14	• Understand exam's solution. • Receive feedback on performance.	• Review accumulated material. Study unclear concepts. • Finish laboratory report.	

Learning Objective F: Analyze linear and nonlinear transmission line problems in the time domain using lattice and Bergeron diagrams (ANALYSIS)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• Quarter-wave transformer – transient response • Reflection coefficient revised • Concept of "transient impedance" • Applying DC to transmission lines • Lattice (or bouncing or reflection) diagrams • Building transient signals from bouncing diagrams	14 - 15	• Attend professor's presentation entitled "Transient-Domain Analysis of Transmission Line Circuits (Part 1)". • Obtain the transient waveforms of a transmission line circuit when it is turned on. • Simulate in APLAC the previous circuit and confirm results.	• Download from the course website materials for Section 6 (Transient-domain analysis of transmission line circuits). • Study previous materials and write down comments or questions if necessary. • Solve problems 1-2 of assignments and exercises labeled "Probs 4".	• Problems labeled "Probs 4" solved. • Simulation cases in APLAC.
• Under-driven and over-driven lines • Bouncing diagrams for multiple sections of transmission lines	15	• Attend professor's presentation entitled "Transient-Domain Analysis of Transmission Line Circuits (Part 2)". • Obtain the transient waveforms of a circuit with 2 transmission lines. • Simulate in APLAC the previous circuit and confirm results.	• Study previous materials and write down comments or questions if necessary. • Solve problems 3-4 of assignments and exercises labeled "Probs 4".	

• Bergeron diagrams	16	• Attend professor's presentation entitled "Transient-Domain Analysis of Transmission Line Circuits (Part 3)". • Attend derivation of the transient waveforms of a practical buffer driving a nonlinear load through a transmission line.	• Study previous materials and write down comments or questions if necessary. • Solve problems 5 of assignments and exercises labeled "Probs 4".	

Learning Objective G: Model basic passive components (lumped elements and interconnects) for high-frequency applications (SYNTHESIS)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• Lumped resistors • Lumped capacitors • Lumped inductors	17	• Attend professor's presentation entitled "Fundamental Lumped Components at High Frequencies" • Simulate in APLAC the manufacturer's equivalent circuit of a commercial 50-Ω thin-film chip resistor.	• Download from the course website materials for Section 8 (Fundamental lumped components and interconnects). • Study previous materials and write down comments or questions if necessary.	• Simulation cases in APLAC.
• Strip lines • Microstrip lines • Coupled microstrip lines	18	• Attend professor's presentation entitled "Basic Interconnects at High Frequencies (Part 1)" • Simulate in APLAC two coupled microstrip lines as a four-port network, obtain the near and far end crosstalk varying the dielectric constant of the substrate layer. • Attend professor's presentation entitled "Basic Interconnects at High Frequencies (Part 2)".	• Study previous materials and write down comments or questions if necessary.	

Exam 3				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• All above	19	• Solve exam.	•	• Exam 3, solved and graded.
	20	• Understand exam's solution. • Receive feedback on performance. • Attend professor's presentation entitled "Criteria for using Transmission Line Theory: Basic Experiments" (summarizing discussion)	•	

Learning Objective I (second part): Utilize at a basic level commercially available CAD tools for simulating high-frequency circuits, including distributed circuit simulators and full-wave electromagnetic simulators (APPLICATION)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	

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• Tools for full-wave EM simulation	21	• Attend professor’s presentation entitled “An Introduction to Sonnet”. • Simulate a microstrip circuit using Sonnet.	• Download from the course website materials for Section 7 (CAD tools for high-frequency simulation). • Install in your laptop the Lite version of Sonnet. • Study previous materials and write down comments or questions if necessary.	• Simulation cases in Sonnet.

Learning Objective H: Design impedance matching networks using quarter-wave transformers, stub tuning and other similar techniques (SYNTHESIS)				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• Matching with lumped elements	22 - 23	• Attend professor’s presentation entitled “Impedance Matching Circuits (Part 1)” • Solve a matching problem with an L-section using the Smith Chart. • Attend professor’s presentation entitled “Impedance Matching Circuits (Part 2)”. • Derive equations for matching a capacitive load by conventional techniques.	• Download from the course website materials for Section 8 (Fundamental lumped components and interconnects). • Study previous materials and write down comments or questions if necessary. • Solve problems 1-4 of assignments and exercises labeled “Probs 5”.	• Problems labeled “Probs 5” solved. • Simulation cases in APLAC.
• Single-stub tuning	23 - 24	• Attend professor’s presentation entitled “Basic Interconnects at High Frequencies (Part 3)”. • Solve several matching problems with a single-stub tuning using the Smith Chart.	• Study previous materials and write down comments or questions if necessary. • Solve problems 5-7 of assignments and exercises labeled “Probs 5”.	
• Multiple-sections impedance transformers	25	• Attend professor’s presentation entitled “Basic Interconnects at High Frequencies (Part 4)”. • Design a multi-section Butterworth impedance transformer for a resistive load.	• Study previous materials and write down comments or questions if necessary. • Solve problems 8-10 of assignments and exercises labeled “Probs 5”.	

Exam 4				
Intended knowledge and skills	Session	Learning Activities		Outcomes and assessment
		In class (*BCD*)	Extra class (*TIE*)	
• All above	26	• Solve exam.	•	• Exam 4, solved and graded.
	27	• Understand exam’s solution. • Receive feedback on performance.	•	

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<table>
<tr><th colspan="5">Learning Objective J:
Design basic high-frequency filters and implement them in microstrip technology (SYNTHESIS)</th></tr>
<tr><th rowspan="2">Intended knowledge and skills</th><th rowspan="2">Session</th><th colspan="2">Learning Activities</th><th rowspan="2">Outcomes and assessment</th></tr>
<tr><th>In class (BCD)</th><th>Extra class (TIE)</th></tr>
<tr><td>• The insertion loss method to filter design</td><td>27 - 28</td><td>• Attend professor's presentation entitled "High-Frequency Filters (Part 1)"
• Design a low-pass prototype filter to satisfy a set of specifications.</td><td>• Download from the course website materials for Section 10 (High-frequency filters).
• Study previous materials and write down comments or questions if necessary.
• Solve problem 1 of assignments and exercises labeled "Probs 6".
• Start Lab Report 2.</td><td rowspan="3">• Problems labeled "Probs 6" solved.</td></tr>
<tr><td>• Filter scaling and transformation</td><td>28 - 29</td><td>• Attend professor's presentation entitled "High-Frequency Filters (Part 2)"
• Design a high-pass prototype filter to satisfy a set of specifications.
• Design a band-pass prototype filter to satisfy a set of specifications.</td><td>• Study previous materials and write down comments or questions if necessary.
• Solve problems 2-5 of assignments and exercises labeled "Probs 6".
• Continue Lab Report 2.</td></tr>
<tr><td>• Physical design of high-frequency filters</td><td>30</td><td>• Attend professor's presentation entitled "High-Frequency Filters (Part 3)"
• Design a low-pass filter and implement it in microstrip technology.</td><td>• Study previous materials and write down comments or questions if necessary.
• Solve problem 6 of assignments and exercises labeled "Probs 6".
• Continue Lab Report 2.</td></tr>
</table>

<table>
<tr><th colspan="5">Learning Objective K:
Explain the main performance parameters of an antenna (COMPREHENSION).</th></tr>
<tr><th rowspan="2">Intended knowledge and skills</th><th rowspan="2">Session</th><th colspan="2">Learning Activities</th><th rowspan="2">Outcomes and assessment</th></tr>
<tr><th>In class (BCD)</th><th>Extra class (TIE)</th></tr>
<tr><td>• Antenna system parameters
• The Friis equation
• Basic practical antennas</td><td>31</td><td>• Attend professor's presentation entitled "An Introduction to Antennas"
• Solve a problem on far-field distance.
• Solve a problem on calculating the power received by an antenna under specific conditions.</td><td>• Submit Lab Report 2
• Download from the course website materials for Section 11 (An introduction to antennas).
• Study previous materials and write down comments or questions if necessary.
• Simulate a patch antenna in Sonnet.</td><td>• Sonnet simulation case.
• Lab Report 2.</td></tr>
</table>

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

Periférico Sur 8585
45604 Tlaquepaque, Jal., México

Tel +52 33 3669 3598
www.iteso.mx