Worcester Polytechnic Institute
Department of Electrical and Computer Engineering
EE529 --- Analog Circuits and Intuitive Design Methods
Spring, 2009
COURSE GUIDELINES AND SYLLABUS

Lecturer:	Prof. Marc T. Thompson, AK316
Email:	marctt@thompsonrd.com, marctt@aol.com
Level:	Graduate level
Lecture:	Thursday evenings, 6:00-8:50 on Worcester campus, AK233
Course Secretary:	(508) 831-5231
Marc Thompson WPI website:	http://www.ece.wpi.edu/People/mtt.html
Marc Thompson business website:	http://www.thompsonrd.com

Philosophy

The application of some simple rules-of-thumb and design techniques is a possible first step to developing intuition into the behavior of complex electrical systems. This course outlines some ways of thinking about analog circuits and systems that hopefully will help to develop intuition.

The course is run as a graduate seminar, and discussion and debate is highly encouraged. The lectures are a mixture of instructional sessions covering new background material, and design case studies. Topics covered include: analog signal processing, transistor amplifier bandwidth analysis, switching transistor transient analysis, analog filter design, and feedback system design. Student assignments are a mixture of problem sets, and longer design problems.

Prerequisites

Permission of instructor is required. Prerequisites are basic background in device physics, transistor amplifier and operational amplifier design. Control systems. Electromagnetism. Access to web searching and PSPICE simulation tools. It is assumed that the student also has the prerequisite background in Laplace domain analysis, Bode plots, pole-zero analysis, and the like.

Course load

Lectures

Attendance in lecture and class participation is required. It is expected that the lecture will be very interactive with a lively "give-and-take." The classes will be a mixture of standard lecture format and Socratic question and answer sections.

Reading assignments

Reading will be a mixture of the course textbook chapters, Powerpoint slide presentations, technical papers and manufacturers' application notes.

Problem sets

Homework assignments will be given and due the following week. Material covered will be derived from lecture topics and reading assignments. Some homework assignments may contain a lab or simulation (SPICE or MATLAB component). **Late problem sets will not be accepted.**

Exams

There will be 2 exams.

Design problems

Several design problems will be given. The design problem assignments will be narrower in scope than the homework assignments and will require significant design effort, simulations and/or lab work, and a written report. More information will be given later on in the term. **Late design problems will not be accepted.**

Grading
Grading will be done with the *approximate* percentage distribution:
- Homework: 20%
- Design problems: 50%
- Classroom participation: 10%
- Exams: 20%

Comments on grading
- ***The grader will not search for your answers.***
- ***Answer questions in a clear, concise manner.***
- ***If graphs are required, make sure that you label all axes.***
- ***If we can't find your answers easily, you don't get the credit!***

Required text
- Marc T. Thompson, *Intuitive Analog Circuit Design*, Newnes, 2006. Errata sheet will be emailed out separately.
- Course Powerpoint presentations are available on MyWPI.
- Other industry application notes are available on the MyWPI course website.

Other recommended texts
Floyd M. Gardner, *Phaselock Techniques*, 2d edition, John Wiley, 1979
Paul R. Gray and Robert G. Meyer, *Analysis and Design of Analog Integrated Circuits*, 2d edition, John Wiley, 1984. *Contains other information on method of open circuit time constants.*
Richard S. Muller and Theodore I. Kamins, *Device Electronics for Integrated Circuits*, 2d edition, John Wiley, 1986
S. M. Sze, *Physics of Semiconductor Devices*, John Wiley, 1981
D'Arcy W. Thompson, *On Growth and Form*, Cambridge University Press, 1961

Other references
MicroSim website, *http://www.microsim.com*
MicroSim Demo Version of PSPICE, version 8
Marc Thompson links website, http://www.thompsonrd.com/links.htm
PSIM evaluation software

Late policy
Late work will not be accepted, unless there is a family emergency.

Collaboration and academic honesty[1]
All the rules of WPI's Academic Honesty Policy will be in effect (http://www.wpi.edu/Pubs/Policies/Judicial/sect5.html). You must review them and be familiar with them. They describe procedures that will be taken if dishonesty is suspected. You may not copy from any source (person, book, old homework, web etc.). If you are not sure whether your or a classmate's behavior follows the Honesty Policies, be sure to ask. **The use of old homework sets, course "bibles", etc. is explicitly not allowed.**

[1] Excerpted from Prof. Fred Looft's Academic Honesty webpage, http://ece.wpi.edu/~fjlooft/honesty.htm

Syllabus (subject to change)

#	DATE	LECTURE MATERIAL COVERED	ASSIGNMENTS
1	1/22/09	**---INTRODUCTION** • Course overview and philosophy, syllabus • Academic honesty • Scaling laws • Energy methods applied to electrical and mechanical circuits • Oscillation modes of mechanical and LC circuits • Review of signal processing basics	• **PROBLEM SET #1** • **Book, Chapters 1, 2 and 16** • **Powerpoint notes 00, 01, 02 and parts of 16** • Jezierski --- "On Electrical Analogues of Mechatronic Systems"
2	1/29/09	**---REVIEW OF SEMICONDUCTOR PHYSICS** • The ideal diode • Non-ideal diode • Load lines • Reading a diode datasheet---1N914, 1N4001, Schottky • Bipolar transistor (BJT) basics • Transistor large signal models • Transistor small-signal models • Low frequency • High frequency • Reading transistor datasheets---2N3904, 2N3906, 2N2222, MPSH81	• **PROBLEM SET #1 due** • **PROBLEM SET #2** • **Book, Chapters 3 and 4, selected datasheets** • **Powerpoints 03, 04** • W. Shockley --- "Transistor technology evokes new physics," (Nobel prize lecture, 1956) • Brinkman --- "A history of the invention of the transistor and where it will lead us"

3	2/5/09	**---BIASING AND TRANSISTOR BUILDING BLOCKS**
		• Basics of biasing
		• Common-emitter amplifier gain and bandwidth calculations
		• Closed-form
		• Miller approximation
		• Emitter follower
		• Differential amplifier
		• Peaking amplifier
		• Video amplifier design example
		• Differential amplifiers
		    • Half circuits for common-mode and differential mode
		    • CMRR
			• **PROBLEM SET #2 due**
			• **PROBLEM SET #3**
			• **Book, Chapter 5**
			• **Powerpoints 05A – 05E**
			• Phang: "Measurement of hybrid pi parameters"
			• Thornton: "Limitations of transistor DC amplifiers"
			• Lundberg ---"Origin of the Miller effect (with original paper)"

4	2/12/09	**---AMPLIFIER BANDWIDTH ESTIMATION TECHNIQUES** • Open-circuit time constants • R/C network bandwidth estimation • Common-emitter amplifier revisited • Emitter follower bandwidth estimate • BJT amplifier design using OCTCs as a design aid • Iterative design case study: Gain of 100 amplifier	• **PROBLEM SET #3 due** • **DESIGN PROBLEM #1 (2 weeks, high frequency amplifier design)** • **Book, Chapter 6** • **Powerpoint 06** • Mazhari --- "On the Estimation of Frequency Response in Amplifiers Using Miller's Theorem"
5	2/19/09	**---ADVANCED AMPLIFIER TECHNIQUES** • Worst case OCTCs • Common-emitter amplifier with emitter degeneration • Differential amplifier with emitter degeneration • Emitter follower terminal impedances; effects of capacitive loading • Bootstrapping • Another OCTC example with bootstrap bandwidth enhancement • Peaking amplifier revisited --- with finite base spreading resistance r_x • Common-base amplifier • Current-switching amplifier • Pole-splitting • Short-circuit time constants • Theoretical background	• **Book, Chapter 7** • **Powepoint 07A, 07B** • "Kozikowski --- Analysis and design of emitter followers at high frequencies"

		• SCTC design example	
6	2/26/09	**---EXAM #1** **---BJT HIGH GAIN STAGES AND CURRENT MIRRORS** • Base-width modulation • Extended hybrid-pi model • High gain stages • Current mirrors	• **DESIGN PROBLEM #1 due** • **PS#4 out** • **Book Chapter 8** • **Powerpoint 08A, 08B** • Widlar --- "Some Circuit Design Techniques for Linear Integrated Circuits" • Thompson --- "High gain amplifiers" • Early --- "Effects of space-charge layer widening in junction transistors"
7	3/5/09	**---CMOS AMPLIFIERS** **---THE CHARGE CONTROL MODEL**	• **Book, Chapter 9** • **Powerpoint 09, 10A** • **PS#4 due** • **PS#5 out** • Mohan --- "Bandwidth enhancement in CMOS with optimized on-chip inductors" • Analog Devices --- ADG601 analog switch datasheet
8	3/12/09	**---THE CHARGE CONTROL MODEL FOR SWITCHING TRANSISTOR DESIGN**	• **Book, Chapter 10** • **Powerpoint 10A, 10B** • **DESIGN PROBLEM #2 (2 weeks, charge control)** • **PS#5 due** • Sparkes --- "A Study of the Charge Control Parameters of Transistors" • Ebers and Moll --- "Large Signal Behavior of Junction Transistors"
9	3/19/09	**---CHARGE CONTROL EXAMPLES** • Laser driver design example **---BEGIN FEEDBACK SYSTEMS**	• **Book, Chapter 10** • **Powerpoint 10B, 10C, 11A** • Thompson --- "High Power Laser Driver"
10	3/26/09	**---FEEDBACK SYSTEMS, STABILITY AND COMPENSATION** • Stability • The phase margin/gain margin test • Examples	• **Book, Chapter 11** • **Powerpoint 11A, 11B** • **DESIGN PROBLEM #2 due** • **PS#6 out** • Texas Instruments --- "Opamp stability and input capacitance"
11	4/2/09	**---OP-AMPS --- IDEAL AND NOT** • Basic op-amp topologies • Non-ideal op-amp • Applications	• **Book, Chapters 12** • **Powerpoint 12A, 12B, 12C** • **PS#6 due** • **DESIGN PROBLEM #3 out (2 weeks, feedback)** • Solomon --- "The monolithic opamp - a tutorial study" • Boyle --- "Macromodeling of opamps" • Widlar --- "Design Techniques for Monolithic Operational Amplifiers" • Widlar --- "A Monolithic Power OpAmp"

			• Texas Instruments --- "Understanding Operational Amplifier Specifications"
12	4/9/09	**---CURRENT FEEDBACK OP-AMPS** • Topology of the CFA • Practical differences between voltage feedback and current feedback amplifiers • real-world issues **---BEGIN ANALOG FILTERS**	• **Book, Chapter 13, 14** • **Powerpoint 13, 14** • Sauerwald --- "Current Feedback and Voltage Feedback Amplifiers" • Lillis Patent --- "Complementary Current Mirror"

13	4/16/09	**---ANALOG FILTERS**
		• Filter types and tradeoffs
		  ◦ Butterworth
		  ◦ Bessel
		  ◦ Chebyshev
		  ◦ Elliptic
		  ◦ Allpass filters
		• Filter response in the time domain
		• Filter response in the frequency domain
		• Group delay
		  ◦ Group delay equalization
			• **Book, Chapter 14**
			• **Powerpoint 14**
			• **DESIGN PROBLEM #3 due**
			• **DESIGN PROBLEM #4 out (2 weeks, analog filters)**
			• MTT papers: "Designing Video Circuits" parts 1, 2, 3
			• Marshak --- "A Bessel Rational Filter"
			• Texas Instruments --- "Active lowpass filter design"

	4/23/09	**NO CLASS THIS WEEK**	
14	4/30/09	**---EXAM #2** **---PASSIVE COMPONENTS** **---ISSUES IN PC BOARD DESIGN** **---OTHER DESIGN TECHNIQUES AND LOOSE-ENDS**	• **Book, Chapters 15, 16** • **Powerpoint 15, 16** • **DESIGN PROBLEM #4 due** • Disanto --- "Proper PC board layout improves dynamic range" • Texas Instruments --- "The PCB is a component of op amp design" • Analog Devices --- "Grounding for low and high frequency circuits" • Analog Devices --- "Avoiding passive component pitfalls" • Analog Devices --- "A Practical Guide to High Speed PCB Layout"

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JAN	11	12	13	14	15	16	17
	18	19	20	21	22	23	24
	25	26	27	28	29	30	31
FEB	1	2	3	4	5	6	7

	S	M	T	W	R	F	S
	8	9	10	11	12	13	14
FEB	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
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MAR	15	16	17	18	19	20	21
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	29	30	31	1	2	3	4
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APR	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
	26	27	28	29	30	1	2
	3	4	5	6	7	8	9
MAY	10	11	12	13	14	15	16