Worcester Polytechnic Institute
Department of Electrical and Computer Engineering
EE523 --- Power Electronics, Fall 2008
COURSE DESCRIPTION, GUIDELINES, AND SYLLABUS

Lecturer:	Prof. Marc T. Thompson, office Atwater Kent Room 316, (marctt@thompsonrd.com).
	Office hour: Thursdays before class, 5-6 pm
TA:	Ms. Grazia Todeschini (grazia@wpi.edu), AK225, 508-831-6697.
	Office hour: By appointment
Course level:	Graduate level
Course website:	Found on myWPI
Lecture:	Thursdays, 6-8:45 pm
Marc Thompson WPI website:	http://www.ece.wpi.edu/People/mtt.html
Marc Thompson business website:	http://www.thompsonrd.com

PHILOSOPHY

This is a graduate-level power electronics course, covering power electronic systems, device physics, rectifiers, switching power converters (DC/DC and resonant), control issues, practical design issues such as snubbers, gate drives, and thermal design, and magnetic design. The focus is on real-world, approximate design techniques, case studies, and intuitive methods, with special emphasis on switching DC/DC converters. Circuit simulations will be used when necessary.

PREREQUISITES

Basic background in device physics, transistor amplifier and operational amplifier design. Control systems. Electromagnetism. Access to web searching, MATLAB and PSPICE simulation tools. It is also assumed that the students understand the basics of Bode plots, pole-zero analysis, and Laplace transforms.

COURSE LOAD

Lectures and In-class Interaction

Attendance in lecture and class participation is required. It is expected that the lecture will be very interactive with a lively "give-and-take."

Problem Sets

Problem sets will be given most weeks during lecture and will be due the following week. Material covered will be derived from lecture topics and reading assignments. Some homework assignments may contain a lab or simulation (PSIM, SPICE or MATLAB component).

All problem sets must be legible with clearly labeled axes on graphs. Circle your answers. Write the units for each numerical result. Note that the instructor will do a cursory grading of your homework set. It is the student's responsibility to check his results vs. the homework solutions. ***Late problem sets will not be accepted.***

Design Problems

Several 2-week design problems will be given. The design problem assignments will be wider in scope than the homework assignments and will require significant design effort, simulations and/or lab work, and a written report.

Exams

There will be two or more exams covering material in lecture, problem sets, design problems, and reading assignments. During the exams the use of the course notes, textbook and of the calculator is allowed, but any communication device and laptop should be shut off.

GRADING

Grading will be done with the *approximate* percentage distribution (subject to change without notice):

Problem sets	25%
Design problems	45%
Classroom participation	10%
Exams	20%

REQUIRED TEXT AND SOFTWARE

Ned Mohan, Tore M. Undeland and William P. Robbins, *Power Electronics Converters, Applications, and Design*, Third Edition, John Wiley, 2003. The text will be supplemented as needed with instructor's notes and Powerpoint presentations.

PSPICE AND PSIM SIMULATION TOOLS

Student (evaluation) version of PSPICE will be provided. We'll be using the Microsim evaluation version 8.0. A tutorial on how to use this is found here:

http://www.coe.uncc.edu/mosaic/mosaic_help/pc_help/pspice/getting_started1.html

The demo version of PSIM is available here:
http://www.powersimtech.com/download.html

MAGNETIC SIMULATION TOOLS

I'll be intermittently using magnetic finite-element analysis tools to illustrate magnetic fields, etc. The program that I use for 2-dimensional analysis is freeware, provided by Dr. David Meeker of Foster-Miller (Waltham, MA), and the software can be found here:
http://femm.foster-miller.net/wiki/HomePage

OTHER RECOMMENDED TEXTS:

1. Robert Erickson and Dragan Maksimovic, *Fundamentals of Power Electronics*, 2nd Edition, Kluwer Academic Publishers, 2001 ISBN# 0-7923-7270
2. A. E. Fitzgerald, Charles Kingsley, Jr. and Stephen D. Umans, *Electronic Machinery*, 5th edition, McGraw-Hill, 1990 (TK2181.F5). *Useful for transformer design and motor analysis.*
3. General Electric Corporation, *SCR Manual*, 6th edition, Prentice-Hall, 1979. *Useful reference, especially on thermal modeling.*
4. Daniel W. Hart, *Introduction to Power Electronics*, Prentice Hall, 1997 (TK7881.15.H37)
5. International Rectifier Corp., *Hexfet Power MOSFET Designer's Manual*, 1993
6. John G. Kassakian, Martin F. Schlecht, and George C. Verghese, *Principles of Power Electronics*, Addison-Wesley, 1991 (TK7881.15.K37). *Good reference, especially on control systems, state-space averaging, etc.*
7. Philip T. Krein, *Elements of Power Electronics*, Oxford University Press, 1998 (TK7881.15.K74)
8. Eric Lowdon, *Practical Transformer Design Handbook*, Howard W. Sams & Co., Inc., 1980
9. Abraham I. Pressman, *Switching and Linear Power Supply, Power Converter Design*, Hayden Book Company, Inc., 1977. (TK7868.P6P74). *Older reference, but useful step-by-step converter examples are given.*

10. Muhammad H. Rashid, *Power Electronics Circuits, Devices, and Applications*, 2d edition, Prentice-Hall, 1993 (TK7881.15.R37)
11. SGS-Thomson, Inc., *Designers' Guide to Power Products, Application Manual*, 2nd edition, June 1992.
12. Siliconix, Inc., *Mospower Applications*, 1984 (TK7871.95.M67)
13. E. C. Snelling, *Soft Ferrites*, CRC Press
14. Ralph E. Tarter, *Solid-State Power Conversion Handbook*, John Wiley, 1993
15. Marc Thompson, *Intuitive Analog Circuit Design*, Elsevier, 2006
16. Alex Kusko and Marc Thompson, *Power Quality in Electronic Systems*, McGraw-Hill, 2007
17. Unitrode Corp., *Applications Handbook*, 1997
18. Unitrode Corp., *Power Supply Applications Manual*, 1993
19. Marc Thompson links website: http://www.thompsonrd.com/links.htm

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. In general, collaboration on the homeworks and design problems is discouraged ..... make sure you do your own work.

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

TENTATIVE COURSE SYLLABUS --- (SUBJECT TO CHANGE)

	Date	***Lecture material covered***	***Reading Assignment Due at Next Lecture***
1	9/4/08	**---INTRODUCTION** • Course logistics, overview, requirements, prerequisites • Academic honesty • Introduction to power electronics • Background, motivation, etc. • Introduction to power switches • Circuit concepts • Sinusoidal steady state • Power factor • Harmonics • Root-mean square (RMS)	**Problem Set #1 handed out** Mohan: Chapters 1, 2, 3.1-3.2 Powerpoints: 00, 01, 02, 03A, 03C, 03D MTT notes: ---"Lecture note on switches.doc" ---"Note on RMS value of various waveforms.doc" --- "Energy dissipated charging a capacitor.doc" --- "PSIM Hints 12-24-07.doc"

2	9/11/08	**---INTRODUCTION TO MAGNETIC DESIGN**
		• Basic magnetic concepts
		  • Ampere's Law
		  • Gauss' Law
		  • Faraday's Law
		  • Lorentz force law
		• Magnetic components
		  • Inductors
		  • Transformers
		---ISSUES IN COMPUTER SIMULATION
		---DIODE RECTIFIERS
		  • Single wave rectifier with resistive load
		  • Single wave with LR load
		  • Current commutation
			Problem Set #1 due
			Problem Set #2 handed out
			Powerpoints: 03B, 03C, 04, 05
			MTT note:
			---"Note on power and the Poynting vector.doc"

3	9/18/08	**--- DIODE RECTIFIERS**
		  • Single wave with LR load
		  • Current commutation
		• 3 phase, full bridge
		--- PHASE CONTROLLED RECTIFIERS
		  • 3 phase rectifiers
			Problem Set #2 due
			Problem Set #3 handed out
			Powerpoints: 05, 06
			MTT notes:
			--- "Note on 3 Phase Rectifier Analysis"
			---"Examples of power factor calculations.doc"
			---"Power factor with harmonics.doc"

4	9/25/08	**---INTRODUCTION TO DC/DC CONVERTERS** • Buck converter • Boost converter • Buck-boost converter • Cuk converter • Output voltage ripple • Interleaving	**Problem Set #3 due** **Problem Set #4 out** Powerpoints: 07A MTT notes: ---"Basics of DC_DC converters DRAFT 4.doc" Manufacturers notes: Analogic --- "Output Capacitors" Microchip --- "Synchronous Buck Design" National Semiconductor --- "LM2852 Synchronous Buck Regulator"
5	10/2/08	**---REAL-WORLD DC/DC CONVERTER ISSUES** **---CONVERTERS WITH ELECTRICAL ISOLATION** • Flyback • Forward converters	**Problem Set #4 due** **Design Problem #1 handed out; due in 2 weeks (buck converter)** Powerpoints: 07B, 07C, 10A, 10B MTT note: --- "Buck converter with parasitics" Manufacturers notes: Analogic note --- "Output Capacitors" Microchip --- "Synchronous Buck Design: National Semiconductor --- LM2852
6	10/9/08	**---EFFICIENCY OF CONVERTERS** **---INVERTERS** **---EXAM#1**	Powerpoints: 07B, 08 MTT notes: ---"Switching loss in buck converters" ---"Boost converter with inductor losses.pdf" ---"Boost converter efficiency including inductor losses.doc" Manufacturers notes: Linear Tech note --- "50 A Synchronous Buck" Maxim --- "Buck Converter Noise"
7	10/16/08	**---RESONANT CONVERTERS** • PSIM study: noncontact resonant converter **---INTRO TO MOTOR DRIVES**	• **Design problem #1 due (buck converter)** • **PS5 handed out** • Powerpoints: 09, 12A
8	10/23/08	**---MORE ON MOTOR DRIVES**	**PS5 due** **PS6 handed out** Powerpoints: 13, 14, 15
9	10/30/08	**---POWER QUALITY AND UPS**	**PS6 due** **PS7 handed out** Powerpoints: 11A, 16, 17, 18
10	11/6/08	**---POWER DEVICES** • Basic semiconductor physics (Ch. 19)	**PS7 due** **Design Problem #2 handed out (boost converter with losses)**

		• Power diodes (Ch. 20) • Power BJTs (Ch. 21) • Power MOSFETs (Ch. 22) • Thyristors (Ch. 23) • IGBTs (Ch. 25)	Mohan: Skim chapters 19, 20, 21, 23-26 Powerpoints: 19, 20, 21, 22, 23, 24, 25, 26 MTT notes: ---"Power semiconductor devices.pdf"
11	11/13/08	**---MORE ON POWER DEVICES** • MOSFET switching speed analysis • Use of gate charge data • Gate drive design	Powerpoints: 28A, 28B MTT notes ---"Reading a MOSFET datasheet," ---"Note on Using MOSFET Gate Charge Test Data" ---"Lecture Note on Switches" ---"Mosfet switching speed example" ---"Effect of source inductance on MOSFET switching speed.pdf", ---"MOSFET selection and figures of merit.pdf" Manufacturers notes: ---International Rectifier: AN936, 937, 944, "Power Mosfet Basics" , IRF150 datasheet ---On-Semiconductor: AN1090
12	11/20/08	**---BASIC THERMAL DESIGN** • Conductive, convective and radiative heat transfer • Heat sink selection **---INTRODUCTION TO BASIC MAGNETICS** • Maxwell's equations • Magnetic circuits	**Design problem #2 due** **Design problem #3 handed out (inductor design)** Powerpoints: 29A, 29B, 30A MTT notes: ---"Magnetic brake thermal model.pdf" Paper: Aavid --- "How to select a heat sink" Manufacturers notes: IRF --- "AN-997 Heat Sinking" and "AN-1057 Heatsink characteristics" **(No class next week …Thanksgiving !)**
	11/27/08	**---NO CLASS …THANKSGIVING**	

13	12/4/08	**---INDUCTOR AND TRANSFORMER DESIGN** • Demonstrations: • AC magnetic levitation • Eddy current braking • Magnetic field from power cables • Wire charts • Transformer design • High frequency losses in magnetics • Core losses • Skin and proximity losses • Dowell method • Litz wire	Powerpoints: 30A,B,C,D,E,F,G,H MTT notes: ---"Note on AC winding resistance.doc" ---"Inductance Calculation Techniques --- Part 1.doc" ---"Inductance Calculation Techniques --- Part 2.doc" ---"Note on losses in ferrite cores.doc" ---"Note on wire packing factor kp.doc" Papers: "Thompson --- Electrodynamic Magnetic Suspension.pdf" Witulski --- "Introduction to modeling of transformers and coupled inductors" Beattie --- "Inductance 101.pdf" P. L. Dowell, "Effects of eddy currents in transformer windings.pdf" Dixon--- "Eddy current losses in transformer windings.pdf" Manufacturers notes: Texas Instruments --- "Windings.pdf" Texas Instruments --- "Magnetic core characteristics.pdf" Ferroxcube --- "3f3 ferrite datasheet.pdf" Ferroxcube --- "Ferrite selection guide.pdf"
14	12/11/08	**---EXAM #2** **---PRACTICAL DESIGN ISSUES** • Snubbers • Other	**Design problem #3 due** Mohan: Chapters 27, 29 MTT notes: ---"Snubbers" ---"Snubbers again" ---"Power Factor Corrected Offline Supplies", ---" High Power Laser Driver" Manufacturers notes: Texas Instruments --- Snubber circuits.pdf Fairchild AN-4147 Snubber design for flyback converters
	12/18/08	**---SNOW DATE**