TO: The Faculty of the College of Engineering

FROM: The Faculty of the Weldon School of Biomedical Engineering

RE: BME 55500 Magnetic Resonance Imaging Theory - New Graduate Course

The Faculty of the Weldon School of Biomedical Engineering has approved the following experimental course for a permanent course number. This action is now submitted to the Engineering Faculty with a recommendation for approval.

BME 55500 Magnetic Resonance Imaging Theory
Term Offered: Spring, Lecture 3, Cr. 3
Prerequisite: ECE 30100 or graduate standing, or consent of instructor

Description: This course covers fundamental aspects of magnetic resonance imaging systems with an emphasis on theory, methodology, and instrumentation. Key principles are derived from the Bloch equations and Maxwell's equations. Topics include pulse sequences, signal acquisition, spatial encoding in k-space, image reconstruction, and tissue contrast. Major components of an MRI scanner are examined, including the static magnet, gradient and shim coils, transmit and receive chains, and radiofrequency coils and arrays. Learning outcomes are assessed by solving problem sets integrating theory with practical applications. As a final research project, students survey recent literature to identify a specialized topic of interest and deliver a peer-evaluated presentation to the class.

Reason: This course provides a thorough study of magnetic resonance imaging, a clinical and research imaging modality of growing importance at Purdue. The College of Engineering and the College of Health and Human Sciences recently invested in two 3-tesla human scanners that, together with the 7-tesla small animal scanner located in Bindley, comprise the Purdue MRI Facility. This course imparts knowledge applicable to all of Purdue's MRI scanners, and provides a solid foundation for graduate students to utilize these scanners to their fullest potential.

This course was developed by Dr. Rispoli and has been offered annually since 2017 under a temporary course number (BME 59500). As the only comprehensive MRI offering at Purdue, this course has facilitated greater interaction across departments and colleges, drawing students primarily from biomedical engineering (BME), electrical engineering (ECE), and health sciences (HSCI). Enrollment has been between 11-19 for the previous three years. For Spring 2020 this course is cross-listed as ECE 59500, and 15 students are enrolled as of 11/19/2019.

George R. Wodicka

George R. Wodicka
Dane A. Miller Head and Professor
Weldon School of Biomedical Engineering

Course Information

Course number and title	BME 55500: Magnetic Resonance Imaging Theory
CRN	
Meeting time & location	
Course credit hours	3
Course web page	Link https://mycourses.purdue.edu/
Pre-requisites	***Required:*** ECE 301, graduate standing, or permission of the instructor ***Recommended:*** Electromagnetics, e.g., ECE 304, PHYS 241/272/330, or equivalent

Information About the Instructor

Name of the instructor	Joseph Rispoli
Office Location	MJIS 3035
Phone number	765.494.6178
Email Address	jrispoli@purdue.edu
Office hours	By appointment: Link https://calendly.com/jrispoli

Course Description

This course covers fundamental aspects of magnetic resonance imaging systems with an emphasis on theory, methodology, and instrumentation. Key principles are derived from the Bloch equations and Maxwell's equations. Topics include pulse sequences, signal acquisition, spatial encoding in *k*-space, image reconstruction, and tissue contrast. Major components of an MRI scanner are examined, including the static magnet, gradient and shim coils, transmit and receive chains, and radiofrequency coils and arrays. Learning outcomes are assessed by solving problem sets integrating theory with practical applications. As a final research project, students survey recent literature to identify a specialized topic of interest and deliver a peer-evaluated presentation to the class.

Learning Outcomes

Students will acquire a broad knowledge base covering the fundamentals of MRI. This includes an understanding of nuclear magnetization, pulse sequences, 2D Fourier imaging, image contrast mechanisms, and instrumentation. Specifically, students will gain an ability to:

- formulate and solve MRI spin and relaxation problems using the Bloch Equations.
- formulate and solve MRI magnetic field problems using Maxwell's Equations.
- analyze radiofrequency coils with sources and passive elements.
- synthesize research knowledge from recent MRI literature.
- communicate a specialized topic related to MRI to an audience.

Learning Resources, Technology, & Texts

- Recommended Texts:
    1. Magnetic Resonance Imaging: Physical Principles and Sequence Design, Robert Brown, Yu-Chung Cheng, Mark Haacke, Michael Thompson, Ramesh Venkatesan, ISBN 978-0-47-172085-0, freely available on Purdue network: Link http://onlinelibrary.wiley.com/book/10.1002/9781118633953
    2. Principles of Magnetic Resonance Imaging, Dwight Nishimura, available at Lulu.com. Further information: Link http://www-ee.stanford.edu/~dwight/book.html
- Additional Readings: As we progress through the course, other readings may be added to the course web page

Assignments and Points

Your learning will be assessed through a combination of homework assignments, two examinations, and a project spread throughout the semester. Details on these assignments and exams, including rubrics to guide evaluation, will be posted on the course website.

Assignments	Due	Points
Homework	Throughout the semester	100
Individual Project	November	100
Midterm Exam	October	100
Final Exam	December	100
		Total: 400

- Homework (100 points). Homework will be assigned most weeks, with assignments due one week later at the beginning of the class period.
- Individual Project (100 points). The final two weeks of the course will consist of project presentations. Each student will select or propose a special topic of personal interest within the first half of the semester and be responsible for teaching it to the class during the final two weeks. The project will be graded by student peers using a rubric developed with input from the instructor.
- Midterm Exam (100 points). The midterm exam will be held during a class period and will cover material from the first half of the semester. Will consist of a mix of short answer and problems to be solved.
- Final Exam (100 points). The final exam will principally cover material from the second half of the semester, although the material builds on top of topics assessed on the Midterm Exam. Will consist of a mix of short answer and problems to be solved.

Missed or Late Work

Missed assignments may only be made up when you notify me ahead of time with an explanation and plan for completion. These requests will be accepted at my discretion; asking for an extension does not guarantee it will be granted. Unexcused late assignments will be marked down by 50% and not accepted one week after the due date.

Grading Scale

In this class, grades serve as an overall measure of your achievement and accomplishment throughout the semester. You will accumulate points as described in the assignments portion above, with each assignment graded according to a rubric. At the end of the semester, final grades will be calculated by adding the total points earned and translating the percentage of points (out of 400) into the following letters (there will be no partial points or rounding).

A+ ≥ 100%
100% > **A** ≥ 90%
90% > **B** ≥ 80%
80% > **C** ≥ 70%
70% > **D** ≥ 60%
F < 60

NOTE: The scale can change per instructor discretion so that a given grade may fall into a lower bin range (e.g., 88% could earn an A); under no circumstances will the reverse occur.

Course Schedule

Date	Meeting #	Lecture Topic
14-Jan	1	Intro to spin systems & relaxation
16-Jan	2	Relaxation & the Bloch Equations
21-Jan	3	The rotating frame
23-Jan	4	Fourier transforms, spin echoes, B_0 gradients & the NMR signal
28-Jan	5	*k*-Space
30-Jan	6	Sequences and image equations
4-Feb	7	Radial acquisition schemes, chemical shift, fat/water imaging
6-Feb	8	Fast imaging sequences, EPI
11-Feb	9	Volumetric imaging
13-Feb	10	Intro to MRS
18-Feb	11	Dia-, para-, and ferromagnetism, intro to susceptibility imaging
20-Feb	12	Intro to flow imaging: phase contrast & non-contrast flow imaging
25-Feb	13	Intro to diffusion imaging: DWI & DTI
27-Feb	14	MR scanner components
3-Mar	15	The static magnet, shim coils, gradient system, eddy currents
5-Mar	16	Biot-Savart Law, Intro to RF coils: surface coils
10-Mar	17	**Midterm Exam review**
12-Mar	18	**Midterm Exam (includes topics through 25-Feb)**
17-Mar	-	**No class (Spring Break)**
19-Mar	-	**No class (Spring Break)**
24-Mar	19	Revisiting signal, noise sources, *Q*-factors, CNR, and SNR
26-Mar	20	Volume RF coils
31-Mar	21	Receive array coils, array signal combination
2-Apr	22	Accelerated parallel reception: SMASH, SENSE, GRAPPA
7-Apr	23	Parallel transmission
9-Apr	24	Numerical modeling & FDTD
14-Apr	25	Optimization strategies
16-Apr	26	**In-class Project presentations**
21-Apr	-	**No class (ISMRM Annual Meeting)**; **Project online submission due at 9 AM**
23-Apr	-	**No class (ISMRM Annual Meeting)**
28-Apr	27	**In-class Project presentations**
30-Apr	28	**Final Exam review**
1-May	-	**Project peer grading due at 5 PM**
4-8 May	29	**Final Exam: time TBD @ location TBD**

* Schedule subject to change. Any changes will be announced in class and posted to the course web site.

Attendance Policy

Absences and late work will only be excused as described in Purdue University's Academic Regulations and Procedures: Link http://www.purdue.edu/studentregulations/regulations_procedures/classes.html

Academic Integrity

Academic integrity is one of the highest values that Purdue University holds. Individuals are encouraged to alert university officials to potential breaches of this value by either emailing integrity@purdue.edu or by calling 765.494.8778. While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern.

The Purdue Honor Pledge Link https://www.purdue.edu/odos/osrr/honor-pledge/about.html "As a boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together - we are Purdue"

Nondiscrimination Statement

Purdue University is committed to maintaining a community which recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. Please refer to Purdue's nondiscrimination policy statement: Link http://www.purdue.edu/purdue/ea_eou_statement.html

Students with Disabilities

Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let me know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at drc@purdue.edu or by phone: 765.494.1247.

Emergency Preparation

In case of fire, evacuate the building via the east doorways (towards S. Russell St.) if they are free of hazards. Do not use the west doorways as a primary exit as those will be the doors accessed by emergency responders and fire personnel. The primary Emergency Assembly Area location (after evacuating the building) is on the west lawn of the Lilly Hall of Life Sciences. The secondary Emergency Assembly Area location, in case of inclement weather, is the interior northwest hallway of Lilly Hall.

If "sheltering" owing to a tornado warning, immediately go to the MJIS basement and position yourself in the safest portion of the area away from glass. Be prepared to kneel facing a wall and cover your head.

If "sheltering" owing to an active shooter, building intruder, or a civil disturbance on campus, follow police instructions. In the absence of instructions, if unable to evacuate the building, close and lock the classroom doors and take refuge in a corner unseen from outside the doors.

Mental Health Statement

- **If you find yourself beginning to feel some stress, anxiety and/or feeling slightly overwhelmed,** try WellTrack Link https://purdue.welltrack.com. Sign in and find information and tools at your fingertips, available to you at any time.
- **If you need support and information about options and resources**, please see the Office of the Dean of Students for drop-in hours (M-F, 8 AM - 5 PM).
- **If you're struggling and need mental health services**: Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of mental health support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at 765.494.6995 during and after hours, on weekends and holidays, or by going to the CAPS office of the second floor of the Purdue University Student Health Center (PUSH) during business hours.

Course Evaluation

During the last two weeks of the course, you will be provided with an opportunity to evaluate this course and your instructor. Purdue uses an online course evaluation system. You will receive an official email from evaluation administrators with a link to the online evaluation site. You will have up to two weeks to complete this evaluation. Your participation is an integral part of this course, and your feedback is vital to improving education at Purdue University. I strongly urge you to participate in the evaluation system.

Disclaimer

This syllabus is subject to change. Changes made to the syllabus will be announced in class, and the syllabus update will be noted on the course web page.