

## **Resonant MEMS**

EEL 5934 Section 1705 / EEL 4930 Section 022B

**Class Periods:** T-TR, Periods 4-5 (10:40 am – 12: 35 pm)

**Location:** BEN 0328

**Academic Term:** Spring 2017

### **Instructor:**

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- Office Phone Number: 352-846-3017
- Office Hours: Wednesday, 4:00 pm – 5:00 pm, LAR 217

### **Course Description**

Fundamentals of resonant micro-electro-mechanical systems (Resonant MEMS) and their applications. Credits: 3.

### **Course Pre-Requisites / Co-Requisites**

Introduction to Signals and Systems (EEL 3135); Circuits 2 (EEL 3112); Elementary Ordinary Differential Equations (MAP 2302); or per instructor's permission.

### **Course Objectives**

Learn the basics of MEMS resonant devices: their principles of operation, theoretical limits of performance and applications. Introduce resonator-based frequency references, physical sensors and signal processors. Design micro-resonators to meet desired needs and specifications.

These objectives will be accomplished through:

1. Introductory analysis of Resonant MEMS through basic analytical models.
2. Discussion on the sensitivity of Resonant MEMS to physical perturbations.
3. Review of Resonant MEMS applications in consumer electronic systems.
4. Introduction to a finite element simulation software for mixed-domain modeling of Resonant MEMS.

### **Required Textbooks and Software**

The course notes are developed by the instructor.

- Title: **Resonant MEMS: Fundamentals, Implementation and Application**
- Author: Oliver Brand, et. al.
- Publication date, edition, and publisher: 1<sup>st</sup> Ed., Wiley-VCH, 2015
- ISBN number: 978-3-527-33545-9

Software: COMSOL Multiphysics (Note: The instructor provides access of students, in few groups, to the licenses purchased by IMG.)

### **Recommended Materials**

Books:

- V. Kaajakari, *Practical MEMS*, Small Gear Publishing, 2009
- J. Rosenbaum, *Bulk acoustic wave theory and devices*, Artech House, 1988.

Primary Journals:

- Applied Physics Letters* (AIP)
- Trans. On Ultrasonics, Ferroelectrics and Frequency Control* (IEEE/UFFC)
- J. Microelectromechanical Systems* (IEEE/ASME)
- Trans. On Electron Devices* (IEEE/EDS)
- Sensors and Actuators* (Elsevier)

Major Conferences:

- Transducers 'XX, Int. Conf. on Solid-State Sensors and Actuators, odd-numbered years since 1983, proceedings available from IEEE (US meetings), Elsevier (European meetings), IEE Japan (Japanese meetings).

IEEE MEMS 'XX, annual since 1989, proceedings available from IEEE.  
 IEEE IFCS 'XX, annual since 1946, proceedings available from IEEE.  
 IEEE Sensors 'XX, annual since 2002, proceedings available from IEEE.  
 Hilton Head 'XX, Solid-State Sensors and Actuators Workshop, Hilton Head, SC, even-numbered years since 1984, proceedings available from Transducer Research Foundation.  
 Eurosensors 'XX, annual since 1987, proceedings published in special issues of Sensors and Actuators.

Informative Websites:

[www.kaajakari.net/~ville/research/tutorials/tutorials.shtml](http://www.kaajakari.net/~ville/research/tutorials/tutorials.shtml) (MEMS tutorials)

[www.memsjournal.com](http://www.memsjournal.com) Premiere online journal of MEMS-related news

[www.memsnets.org](http://www.memsnets.org) General MEMS and Nanotechnology Information

### Course Schedule

Week	Topic	Due Dates (estimated)
1	Course overview, Intro to resonant MEMS devices, Damped oscillation of microstructures	
2	Integrated transducers and electromechanical coupling efficiency, Lumped element modeling	HW1
3	Performance sensitivity of MEMS resonators to ambient variables: Temperature, Pressure, Viscosity	
4	Compensation and tuning of MEMS resonators	HW2
5	Dissipation mechanisms and quality factor	
6	Finite element modeling of MEMS resonators	HW3
7	Resonant MEMS in timing & frequency references	
8	Resonant MEMS for physical sensing: Environmental sensors, Gravimetric sensors	HW4
9	Resonant MEMS for signal processing: Electrically and mechanically coupled VHF filters	
10	Resonant MEMS for signal processing: Acoustically coupled UHF filters, Resonant RF switches	HW5
11	Power handling and non-linearity in MEMS resonators	
12	Acoustic phonons and dispersion curves	HW5
13	Phonon traps and evanescent waves	HW7
14	Multi-mode phonon traps	
15	Combinatorial phononic sensors	HW8

### Attendance Policy, Class Expectations, and Make-Up Policy

Students are expected to attend class lectures and arrive on time. Please turn off cell-phones, pagers, and other electronic devices.

### Evaluation of Grades

Assignment	Per. of Final Grade (5932)	Per. of Final Grade (4930)
Homework Sets (8)	20%	35%
Midterm Exam	20%	20%
Final Exam	25%	25%
Presentation	35%	20%
TOTAL	100%	100%

## **Grading Policy**

<b>Percent</b>	<b>Grade</b>	<b>Grade Points</b>
90 - 100	A	4.00
87 - 89	A-	3.67
83 - 86	B+	3.33
80 - 82	B	3.00
77 - 79	B-	2.67
73 - 76	C+	2.33
70 - 72	C	2.00
67 - 69	C-	1.67
63 - 66	D+	1.33
60 - 62	D	1.00
57 - 59	D-	0.67
0 - 56	E	0.00

In order to graduate, graduate students must have an overall GPA and a major GPA of 3.0 or better (B or better). Note: A “B-” average is equivalent to a GPA of 2.67, and therefore, it does not satisfy this graduation requirement.

More information on UF grading policy may be found at:  
<http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020>

### ***Students Requiring Accommodations***

Students with disabilities requesting accommodations should first register with the Disability Resource Center (352-392-8565, <https://www.dso.ufl.edu/drc>) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodation. Students with disabilities should follow this procedure as early as possible in the semester.

### ***Course Evaluation***

Students are expected to provide feedback on the quality of instruction in this course by completing online evaluations at <https://evaluations.ufl.edu/evals>. Evaluations are typically open during the last two or three weeks of the semester, but students will be given specific times when they are open. Summary results of these assessments are available to students at <https://evaluations.ufl.edu/results/>.

### ***University Honesty Policy***

UF students are bound by The Honor Pledge which states, “We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: “On my honor, I have neither given nor received unauthorized aid in doing this assignment.” The Honor Code (<https://www.dso.ufl.edu/sccr/process/student-conduct-honor-code/>) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

### ***Software Use***

All faculty, staff and student of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

### ***Campus Resources:***

## Health and Wellness

### **U Matter, We Care:**

If you or a friend is in distress, please contact [umatter@ufl.edu](mailto:umatter@ufl.edu) or 352-392-1575 so that a team member can reach out to the student.

**Counseling and Wellness Center:** <http://www.counseling.ufl.edu/cwc>, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

### **Sexual Assault Recovery Services (SARS)**

Student Health Care Center, 392-1161.

**University Police Department** at 392-1111 (or 9-1-1 for emergencies), or <http://www.police.ufl.edu/>.

## Academic Resources

**E-learning technical support**, 352-392-4357 (select option 2) or e-mail to [Learning-support@ufl.edu](mailto:Learning-support@ufl.edu).  
<https://lss.at.ufl.edu/help.shtml>.

**Career Resource Center**, Reitz Union, 392-1601. Career assistance and counseling. <https://www.crc.ufl.edu/>.

**Library Support**, <http://cms.uflib.ufl.edu/ask>. Various ways to receive assistance with respect to using the libraries or finding resources.

**Teaching Center**, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring.  
<https://teachingcenter.ufl.edu/>.

**Writing Studio, 302 Tigert Hall**, 846-1138. Help brainstorming, formatting, and writing papers.  
<https://writing.ufl.edu/writing-studio/>.

**Student Complaints Campus:** [https://www.dso.ufl.edu/documents/UF\\_Complaints\\_policy.pdf](https://www.dso.ufl.edu/documents/UF_Complaints_policy.pdf).

**On-Line Students Complaints:** <http://www.distance.ufl.edu/student-complaint-process>.