

Legend
 RL = registered lesson; LL = I3.1.12e lesson; LE = I3.1.12e exercise; LC = I3.1.12e CAD class; LS = I3.1.12e seminar; SC = self CAD

	day	weekday	time	room	type	topic	notes and details
2	13/09/2023	Wed	14:30-16:00	IV	LL	L01 Introduction to the course	Course organization, classes, exams, material, program. Status of the MEMS and CMOS market. Key applications and course overview.
4	14/09/2023	Thu	14:30-16:00	virtual	RL	L02 Technologies for MEMS sensors	Overview of a sample MEMS process. Main steps: epitaxial growth, DRIE, bonding, packaging.
6	15/09/2023	Fri	08:30:10:00	virtual	RL	L03 The spring-mass-damper system	Inertial and non-inertial references. Spring-mass-damper system in the time and frequency domains. Quality factor (underdamped and overdamped systems). Role of electrostatic forces in the system.
8	18/09/2023	Mon	08:30:10:00	virtual	RL	L04 MEMS accelerometers: part 1	General architecture: capacitance variation vs displacement. Charge amplifier differential readout. Pull-in effects. Electrostatic softening and overall sensitivity. Linearity of a parallel-plate configuration.
10	20/09/2023	Wed	14:30-16:00	virtual	RL	L05 MEMS accelerometers: part 2	Accelerometer bandwidth and choice of the quality factor. Thermomechanical noise in MEMS. Trade-offs vs applications. Comb finger readout.
12	21/09/2023	Thu	14:30-16:00	25.5.2	LE	E01 MEMS accelerometer design	Design of an in-plane MEMS accelerometer to satisfy a specific application with a specific process.
14	22/09/2023	Fri	08:30:10:00	virtual	RL	L06 MEMS accelerometers: part 3	Sample configurations of springs: in-plane translation, out-of-plane translation and rotation. Series and parallel of springs. Sample accelerometers architectures. Effects of process nonuniformities on springs. Folded springs.
16	25/09/2023	Mon	08:30:10:00	virtual	RL	L07 MEMS accelerometers: part 4	The problems of scaling and pull-in. Charge control vs voltage control: effects of parasitics. Switched capacitor circuits. Force feedback.
18	27/09/2023	Wed				B.S. Graduation day	No classes
20	28/09/2023	Thu	14:30-16:00	25.5.2	LE	E02 MEMS accelerometers electronic readout	Circuits for MEMS accelerometers: description and exercise, noise limitations (MEMS and electronics), dynamics considerations.
22	29/09/2023	Fri	08:30:10:00	9.0.3	LS	L28 UN-related goals	Autonomous driving and its impact on the society for cities of the future. Associated sensor needs. Sensors in biomedical applications. Sensors for sustainable infrastructures
24	02/10/2023	Mon	08:30:10:00	virtual	RL	L08 MEMS resonators: part 1	Comb-finger actuation and sensing. Transduction coefficient and calculation of the admittance. Equivalent electrical model in the frequency domain.
26	04/10/2023	Wed	14:30-16:00	3.1.12	LE	E04 Torsional MEMS accelerometer design	Torsional springs. Calculation of the stiffness and of the moment of inertia for simple configurations. Numerical exercise.
28	05/10/2023	Thu				M.S. Graduation day	No classes
	06/10/2023	Fri	08:30:10:00	virtual	RL	L09 MEMS resonators: part 2	Oscillator circuits: Barkhausen criteria. Sample TIA plus nonlinearity example. Issues of linearity. Example of resonant accelerometer.
30	09/10/2023	Mon	08:30:10:00	virtual	RL	L10 MEMS resonators: part 3	Effects of the feedthrough capacitance on the electrical model of the resonator, and on the Qloop of the oscillator. Common resonator configurations.
32	11/10/2023	Wed	14:30-16:00	3.1.12	LC	E03 CAD simulation of MEMS capacitances	Review of capacitive sensing configurations in MEMS. Ideal laws and deviations due to fringe effects. Case study for vertical parallel plates.
34	12/10/2023	Thu	14:30-16:00	25.5.2	LE	E05 Resonator design	Dimensioning of a Tang resonator to be used in a 32 kHz clock, with process spread and tunability.
36	13/10/2023	Fri	08:30:10:00	virtual	RL	L11 MEMS gyroscopes: part 1	Generalities and the Coriolis force. Sample architecture. Resonant operation. Drive displacement. Sensitivity.
38	16/10/2023	Mon	08:30:10:00	virtual	RL	L12 MEMS gyroscopes: part 2	Issues from accelerations and advanced architectures. Single and double decoupling. In-plane and out-of-plane architectures. Tuning fork. Capacitive PP sense detection. Overall sensitivity.
40	18/10/2023	Wed	14:30-16:00	3.1.12	LE	E06 Oscillator circuit	Dimensioning of an oscillator based on a CA configuration. Comparative discussion with respect to the TIA case.
42	19/10/2023	Thu	14:30-16:00	25.5.2	LE	E07 Gyroscopes electromechanical design	Push pull actuation and sizing of relevant electromechanical parameters.
44	20/10/2023	Fri	08:30:11:00	virtual	RL	L13 MEMS gyroscopes: part 3 + QA1	Gyroscope bandwidth. Sensitivity and gain-bandwidth trade-off. Electronics and thermomechanical noise.
46	23/10/2023	Mon	08:30:10:00	virtual	RL	L14 MEMS gyroscopes: part 4	Issues in resonance operation (temperature dependence). Off-resonance operation. Gyroscope bandwidth. Sensitivity and gain-bandwidth trade-off.
48	25/10/2023	Wed	14:30-16:00	3.1.12	LC	E08 CAD simulation of MEMS accelerometers	Introduction to CAD FEM simulations for MEMS. Examples on an accelerometer.
50	26/10/2023	Thu	14:30-16:00	25.5.2	LE	E09 Drive circuits for gyroscopes	Oscillators for gyroscopes. Relevance of AGC circuits and solutions. AGC stability.
52	27/10/2023	Fri	08:30:10:00	9.0.3	SC	E10 CAD simulation of torsional accelerometers	Autonomous design of an out-of-plane MEMS accelerometer with capacitive readout for consumer applications.
54	30/10/2023	Mon	08:30:10:00	virtual	RL	L15 MEMS gyroscopes: part 5	Thermomechanical noise in mode-split operation. Electronic noise in mode-split operation. Examples of real measurements.
	01/11/2023	Wed				All saints holidays	No classes
56	02/11/2023	Thu	14:30-16:00	25.5.2	LC	E11 CAD simulation of MEMS yaw gyroscopes	Design of a MEMS gyroscope. Parametric approach and finalisation of the geometry.
58	03/11/2023	Fri	08:30:10:00	self-activity	SC	E12 CAD simulation of pitch MEMS gyroscopes	Autonomous design of a MEMS gyroscope.
60	06/11/2023	Mon				Suspension of classes	No classes
	08/11/2023	Wed	14:30-16:00	3.1.12	LL	L16 MEMS gyroscopes: part 6	Quadrature error. Origin. Modelling. Coupling with phase noise. Quadrature error compensation. Tatar scheme.
62	09/11/2023	Thu	14:30-16:00	25.5.2	LE	E13 Sense circuits for gyroscopes	Sensing and demodulation electronics for capacitive gyroscopes. Noise considerations.
64	10/11/2023	Fri	08:30:11:00	facultative	RL	L17 MEMS magnetometers: part 1 + Q&A n.2	Lorentz force and resonant working principle. Simplified architecture. Sensitivity. Comparison with Coriolis and inertial forces. Noise, offset.
66	13/11/2023	Mon	08:30:10:00	facultative	RL	L18 MEMS magnetometers: part 2	Off-resonance operation and solutions of the trade offs. Design criteria. Integrated electronics. Comparison with other technologies (AMR, Hall).
68	15/11/2023	Wed	14:30-16:00	3.1.12	LS	Seminar from industry n. 1	Job profiles in the MEMS industry: the system architect and case studies on digital processing for MEMS
70	16/11/2023	Thu	14:30-16:00	25.5.2	LE	E14 MEMS microphone	Exercise on a sensor not treated in the course, to stimulate the students approach towards other sensors developed in the same technology.
72	17/11/2023	Fri	08:30:10:00	virtual	RL	L20 MEMS characterization and the Allan Variance	The next killer application: the IMUs. Stability issues. Offset drift and the Allan variance. Definition, relation with white noise, and use.
74	20/11/2023	Mon	08:30:10:00	virtual	RL	L21 Light sensors basics: part 1	Human vision. Description of the eye, photoreceptors, concept of a color space, stimuli to the brain. Basics of light sources.
76	22/11/2023	Wed	14:30-16:00	3.1.12	LS	Seminar from industry n. 2	Job profiles in the MEMS industry: the MEMS designer and case studies on gyroscope and process design
78	23/11/2023	Thu	14:30-16:00	virtual	RL	L22 Light sensors basics: part 2	CMOS image sensors. System architecture. Basics of optics and diffraction. Number of photons on a pixel.
80	24/11/2023	Fri	08:30:11:00	virtual	RL	L23 CMOS 3T APS: part 1 + Q&A n.3	Interaction of light in semiconductors. Absorption law. Simple photodiode and typical dimensions. Signal generation and noise overview.
82	27/11/2023	Mon	08:30:10:00	virtual	RL	L24 CMOS APS: part 2	3-transistor APS topology. Transistor-level architecture. Operation. Phases. Linearity. Signal to Noise ratio.
84	29/11/2023	Wed	14:30-16:00	3.1.12	LC	E15 CAD light absorption in Silicon	Preliminary CAD to imaging sensors
86	30/11/2023	Thu	14:30-16:00	25.5.2	LE	E16 photons on a pixel	Calculation of the number of photons generated per second on a pixel of a mobile phone camera from a generic scene.
88	01/12/2023	Fri	08:30:10:00	2.1.3	LS	Seminar from industry n. 3	Job profiles in the MEMS industry: the test and qualification engineer and case studies on MEMS testing
90	04/12/2023	Mon	08:30:10:00	virtual	RL	L25 CMOS APS: part 3	Dynamic range of a 3T image sensor. Other limitations: fixed pattern noise. Photon transfer curve.
92	06/12/2023	Wed	14:30-16:00	3.1.12	LE	E17 SNR in a 3T topology	Calculating the Signal to Noise Ratio for a 3T CMOS pixel topology. Numerical examples.
94	11/12/2023	Mon	08:30:10:00	virtual	RL	L26 CMOS APS: part 4	Limits of a 3T topology and introduction of 4T topologies. Correlated Double Sampling. Backside illumination and advantages.
96	13/12/2023	Wed	14:30-16:00	3.1.12	LE	E18 DR and maximum SNR in 3T APS	Maximum SNR and dynamic range of a 3T CMOS pixel. Choice of the ADC number of bit.
98	14/12/2023	Thu	14:30-16:00	25.5.2	LE	E19 photon transfer curve	Example of a circuit for correlated double sampling in CMOS APS 4T topologies with calculation of DR, PTC and its analysis.
100	15/12/2023	Fri	08:30:11:00	virtual	RL	L27 CMOS APS: part 5 + Q&A n. 4	CFA for CMOS image sensors. Demosaicking. Layered junction sensors (working principle). General pros and cons of the two approaches. Color conversion and color spaces. White balance.
	18/12/2023	Mon	08:30:10:00			Backup slot	No classes
102	20/12/2023	Wed	14:30-16:00	self-activity	SC	E20 CAD simulations of advanced imaging pixels	Autonomous design of a Pinned photodiode
	21/12/2023	Thu	14:30-16:00			Backup slot	No classes
	22/12/2023	Fri	08:15:11:15	25.5.3	XM	Anticipated exam session	