VUV and X-ray FELs

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Course Description & Class Schedule

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Purpose & Audience:

- This one-week course introduces the physics of coherent radiation generation in a free electron laser (FEL) driven by RF linac and operating in the vacuum ultraviolet (VUV) and x-ray regions. The topics to be discussed include high-brightness electron beam generation and acceleration, bunch compression, incoherent undulator radiation, coherent radiation in an FEL, self-amplified spontaneous emission (SASE), Bragg crystal monochromatization, self-seeding, Regenerative Amplifiers (RAFEL) and XFEL Oscillators (XFELO), as well as various harmonic generation techniques.

Instructional Method:

- The course consists of lectures in both morning (theory and experiments) and afternoon sessions (simulations). Some of the afternoon sessions involve FEL simulation work. Optional evening sessions can be held to explain homework assignments.

Course content:

- Introduction: properties of radiation, special relativity, undulator radiation, harmonics, spectral brightness. transverse motion, transverse and longitudinal velocities, ponderomotive wave, pendulum equation, motion in phase-space, energy and density modulations, coherent radiation from bunched beams, x-ray FEL.
- Components of an XFEL: Electron beam requirements, RF photoinjector, laser heater, RF linac (copper and niobium), chicane bunch compressors, dechirpers, undulators, beam dump and x-ray optics.
- One-dimensional FEL theory: slowly varying envelope approximation, 1-D wave equation, FEL gain (Pierce) parameter, 3rd order differential equation, solutions to cubic equation, growth rate, optical guiding, and tapering.
- Self-amplified spontaneous emission: start-up noise, exponential gain, saturation, spectral and coherence properties, 3-D effects and Ming-Xie parameterization.
- X-ray monochromatization: Bragg diffraction, Bragg crystals, self-seeding, RAFEL, XFELO, optical cavity, cavity alignments, and cavity power outcoupling.
- Harmonic generation techniques: nonlinear harmonics, high-gain harmonic generation, echo-enhanced HGHG, and harmonic seeding.
- FEL simulations: 1-D simulations (using Python) and a 3-D FEL code (Genesis).

Book:

- “Free-Electron Lasers in the Ultraviolet and X-Ray Regime” 2nd edition (Springer 2014) by Peter Schmüser, Martin Dohlus and Jörg Rossbach. Instructors will also provide lecture notes.

Grade:

- Students will be evaluated based on performance as follows: final exam (30% of final grade), homework assignments (30%) and computer class (40%).

Class Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
9:00 – 10:00	Intro to FEL, undulator radiation, and coherence (Dinh)	High-brightness beam techniques (Nicole)	SASE & High gain single-pass FEL (Dinh)	Self-seeding & Seeded FEL (Dinh)	Final exam
10:00 – 10:10					
10:10 – 11:10	Electron motions in an undulator (Dinh)	Injector beam dynamics (Colwyn)	SASE 1D theory (Dinh)	Multi-pass FEL (XFELO, RAFEL) (Dinh)	Lab project presentations
11:10 – 11:20					
11:20 – 12:00	FEL coherent emission process (Dinh)	Bunch compression, Laser heater & CSR (Nicole)	3D & Ming Xie parametrization (Dinh)	Harmonic generation HGHG, EEHG (Dinh)	Lab project presentations
12:00 – 1:30					
1:30 – 3:15	Intro to Sims Lab Computer set-up (Chris & Colwyn)	Electron beam properties & FODO (Chris)	Lab project (Chris & Nicole)	Lab project (Chris & Nicole)	
3:15 – 3:30					
3:30 – 5:30	LUME-Genesis & Jupyter Lab (Chris & Colwyn)	FEL simulations with Genesis v. 4 (Dinh)	Lab project (Chris & Nicole)	Lab project (Chris & Nicole)	
5:30 – 7:00	Dinner	Dinner	Dinner	Dinner	
7:00 – 10:00	Homework 1 (Dinh, Nicole & Colwyn)	Homework 2 (Dinh, Chris & Colwyn)	Homework 3 (Nicole, Chris & Colwyn)	Lab project presentation preparation	