Integrated Circuits & Systems, Electronics

Prof. Mingoo Seok
ELEN 4312: Analog Electronic Circuits

Syllabus:

• CMOS and Bipolar transistor operation (small signal & large signal behavior)
• Analog biasing techniques, digitally assisted biasing techniques
• Single-ended, differential and multistage amplifier design
• Analysis of various op-amp circuits and configurations
• Bandwidth considerations, bode-plots & frequency response
• Negative feedback theory and implementation
• Stability criteria, compensation techniques, avoiding undesired oscillations
• Design project: Varies with year (high-frequency amplifier, feedback amplifier, etc.)

Instructor:

Prof. Tod Dickson

Summary:

Introductory-yet-detailed analog circuits course that prepares the student for an advanced analog IC class. Fundamental course for any electrical engineer!
ELEN 4321: Digital VLSI

**Syllabus:**
- Design and analysis of high speed logic and memory.
- Digital CMOS and BiCMOS device modeling.
- Integrated circuit fabrication, layout & CAD tools.
- Interconnect and parasitic elements.
- Static and dynamic techniques.
- Worst-case design; heat removal and I/O; yield and circuit reliability.
- Logic gates, pass logic, latches, PLAs, ROMs, RAMs, receivers, drivers, repeaters, sense amplifiers.
- *Design project:* full-custom microprocessor design

**Instructor:**
Prof. Ken Shepard

**Summary:**
Introductory-yet-detailed digital VLSI course that introduces the student to transistor-level (custom) digital design and CAD tools for digital IC design.
ELEN 6314: Advanced Comm. Circuits

**Syllabus:**

- **Focus on Radio-Frequency Integrated Circuit Design**
- Overview of communication systems
- Receiver and transmitter architectures
- Noise, sensitivity, and dynamic range
- Nonlinearity and distortion
- Low-noise RF amplifiers, mixers, and oscillators
- Phase-locked loops and frequency synthesizers
- Typical applications discussed include wireless RF transceivers.
- Computer-aided analysis techniques are used in homework(s) and a design project.

**Design Project:** teams of 2 students design RF receiver front end in CMOS

**Instructor:**

Prof. Peter Kinget.

**Summary:**

Advanced class that trains students to design ICs for RF and wireless communications applications.
ELEN 6320: Millimeter-Wave ICs.

Syllabus:

• Introduction to millimeter-wave (30GHz and above!) systems and applications.
• Si-based devices for mmWave (Modern SiGe and CMOS technologies, $f_T$, $f_{max}$, large-signal models).
• Si-based passive devices (Inductors, capacitors, resonators, transformers, transmission lines).
• mmWave amplifier design (Max. available gain, max. unilateral gain, cascade vs. cascode)
• mmWave and microwave low-noise amplifier design (CS, CB, $NF_{min}$, $Y_{opt}$, noise circles).
• mmWave power-amplifier design (Class A-F, load-pull, efficiency/output power circles, impedance transformation and power combining).
• mmWave mixers for frequency translation.
• mmWave VCOs (LC oscillators, standing-wave oscillators, push-push and distributed oscillators).
• Oscillator phase-noise theory and its impact on mmWave VCO design.
• Injection locking, injection pulling and coupled oscillators.
• mmWave frequency synthesis (Regenerative dividers, injection-locked dividers, mmWave PLLs).
• Phased arrays and multiple-antenna systems (Architectures, phase-shifter circuits).
• Design project: design of a 60GHz wireless receiver front-end in a 90nm CMOS process.

Instructor:

Prof. Harish Krishnaswamy.

Summary:

Cutting-edge class that trains students to design ICs for emerging mm-Wave applications.
ELEN 6901: Advances in PLLs

Syllabus:

• PLL Concepts: basic PLL operation, type I and type II PLLs, Analog PLLs, Digital PLLs

• PLL Architectures: Analog PLLs, Integer-N PLLs, Fractional-N PLLs, Impact of circuit non-idealities, Digital PLLs

• PLL Performance: jitter and phase noise modeling, simulation and measurement

• Building Block Design: oscillators, dividers, phase-frequency detectors and charge pumps, filters, delta-sigma modulators, time-to-digital converters

• PLL Applications: frequency synthesis, clock synthesis, generation of phase or frequency modulated signals, clock and data recovery (if time permits)

Instructor:

Prof. Peter Kinget.
ELEN 6903: Principles of RF and Microwave Measurements

This hands-on lab-based course covers the principles behind RF and microwave simulation and metrology, key skills in scientific research and industrial development.

Concise Syllabus:

- RF and Microwave Basics
- Theory of S Parameters
- RF Passive Components
- Principles of Network Analysis Measurements
- Principles of Large-Signal Simulations and Measurements
- Principles Behind Spectrum Measurements
- Principles Behind Noise Measurements
- Principles of Time Domain Measurements
- Frequency-Conversion Measurements

Instructor: Prof. Harish Krishnaswamy

Evaluation: midterm exam (20%), final exam (30%), lab modules (50%).

Enrollment: Capped at 27 students. Please send Prof. Krishnaswamy an email by September 5th if you are interested. Qualified students will be admitted on a first-come-first-serve basis.
ELEN 6920: Hardware Architecture for DSP and ML

Syllabus:

• Fundamental & systematic design technique: DFG, IB, pipelining, retiming, unfolding, folding, systolic array, bit-level arithmetic, numerical strength reduction, algorithmic strength reduction, CORDIC, distributed arithmetic

• ASIC architecture: FFT, neural signal processing, neural networks

• Programmable parallel hardware architecture: vector processor, subword parallelism, GPU architecture

Design project:

• Building DSP chips (FFT or neural network) via verilog-HDL to logic synthesis to timing/power analysis

• Can be a good bridge between 4321 and 6321 in terms of CAD tool flow

Pre-requisites:

• 4823 or equivalent: preferred, not mandatory

Instructor:

Prof. Mingoo Seok
Typical Spring Courses

(subject to change)
ELEN 4314: Communication Circuits

**Concise Syllabus:**

- Nonlinearity, distortion, IMD, intercept points, dynamic range.
- Introduction to noise, PSD, BJT/MOS noise models, noise bandwidth, NF.
- Transformers, resonant circuits, quality factor (Q), impedance matching.
- Bandpass amplifier design.
- Power amplifiers (Class A-D).
- Oscillators (startup, describing function analysis, negative-resistance, feedback osc., LC, Colpitts ..).
- Multipliers and mixers.
- Amplitude, phase and frequency modulators and demodulators.
- Introduction to PLLs.
- *Design project:* Varies by year (AM transmitter, FM transmitter, metal locator, Theremin, etc.)

**Instructor:**

Prof. Yannis Tsividis

**Summary:**

Introductory-yet-detailed communication circuits course that prepares the student for an advanced communication IC class.
ELEN 6312: Advanced Analog ICs

**Concise Syllabus:**

- Overview of basic MOS device physics.
- Passive and Active Current Mirrors.
- Single-stage MOS amplifiers - basics.
- Frequency-response of single-stage MOS amplifiers.
- Feedback.
- Noise.
- Operational Amplifiers.
- Stability and Frequency Compensation.
- Bandgap References.
- Switched Capacitor Circuits.
- Nonlinearity and Mismatch.
- *Design project:* design of a single-stage of a pipelined ADC in 0.18\(\mu\)m CMOS.

**Instructor:**

Prof. Harish Krishnaswamy or Prof. Peter Kinget

**Summary:**

Detailed analog circuits course that focuses on integrated CMOS implementations.
ELEN 6316: Analog Systems in VLSI.

**Concise Syllabus:**

- Dynamic range: noise, linearity, distortion, IP3, SNDR, SFDR.
- Sample-and-hold circuits, settling error, charge injection, comparators, offset compensation techniques.
- Discrete-time filters: z-domain analysis, switched capacitor filters and bi-quads.
- Fundamentals of data converters: resolution, conversion rate, INL, DNL, quantization error, sampling jitter, performance limitations/tradeoffs, ADC figures of merit.
- Nyquist rate DACs: Kelvin dividers, binary weighted, R2R, charge redistribution, current-based, hybrid topologies.
- Nyquist-rate ADCs: integrating, flash, folding and interpolative techniques, pipeline architectures, successive approximation, time-interleaving, digital calibration of non-idealities.
- Oversampled data converters: delta modulators, noise shaping, first- and second-order delta sigma (DS) modulators, stability considerations, higher-order DS modulator architectures, MASH architectures, decimation filters, continuous-time DS modulators, band-pass DS modulators.
- **Design project:** Two (one covering filters and one covering data converters).

**Instructor:**

Prof. Todd Dickson.

**Summary:**

Detailed course on filters and data converters. Emphasis is placed on system-level analysis, although transistor-level implementations are discussed when necessary.
**ELEN 6318: Microwave Circuit Design**

**Concise Syllabus:**
- Basic Microwave Design Principles:
  - Transmission lines & Smith-chart, coupled transmission lines
  - S-parameters, Microwave networks
  - Impedance matching and tuning
- Practical Microwave Components:
  - Various transmission lines, power dividers & couplers
  - Active and passive microwave devices
- Design of active microwave circuits
  - Amplifiers: narrow-band, low-noise, broad-band, power amplifiers
  - Non-linear circuits: oscillators, multipliers, mixers
- Simulation and measurement tools for microwave circuits
- A microwave circuit *design project* (using microwave CAD) is an integral part of the course.

**Instructor:**
Prof. Yves Baeyens

**Summary:**
Advanced class that teaches the design with non-lumped circuit elements for microwave applications.
ELEN 6321: Advanced Digital Electronics Design

**Concise Syllabus:**

- Advanced topics in VLSI designs (typically after 4321)
- Modern and emerging IC technologies; static and dynamic logic families
- Noise analysis and avoidance
- Process variations and design for manufacturing (DFM)
- Low power and ultra low power design;
- Leakage characteristics and low leakage design
- Design adaptive to PVT variations and device aging effects
- On-chip interconnect and signaling; clock networks
- Embedded low-power memory design

*Design project:* Teams of ~4 students design a digital processor/system/IP using full-/semi-automated flow. Expect to use ~5 to 10 CAD tools encompassing rtl coding to physical design

**Instructor:**

Prof. Mingoo Seok

**Summary:**

The advanced (after 4321) graduate-level VLSI course in MS/PhD program that covers advanced topics in digital/VLSI circuits and system design with a large group project
ELEN 6350: VLSI Design Lab.

Concise Syllabus:

• Design & test of a large-scale deep submicron CMOS integrated circuit.
• The class will divide up into teams.
• Lectures introduce circuit design issues related to the projects, CAD tools, chip integration issues, packaging, ESD, and design for test., may divide up into teams to work on different aspects of a single mixed-signal circuit.
• Instructor provided projects or student proposed project. Project emphasis is on (small) system-on-chip designs

Pre-requisites:

• 4312: Analog Electronic Circuits
• 4321: Digital VLSI Circuits

Timeline:

• Spring 2016: Chip Design + Tape-out
• Summer 2016: Chip Fabrication
• Fall 2016: Test Board design + Chip Test

Instructor:

Prof. Peter Kinget or Prof. Harish Krishnaswamy

Summary: Get ready to design your own chip!
ELEN 4332: VLSI Design Lab.

Concise Syllabus:
• Design & test of a large-scale deep submicron CMOS integrated circuit.
• The class will divide up into teams.
• Lectures introduce circuit design issues related to the projects, CAD tools, chip integration issues, packaging, ESD, and design for test., may divide up into teams to work on different aspects of a single mixed-signal circuit.
• Instructor provided projects or student proposed project. Project emphasis is on (small) system-on-chip designs.

Pre-requisites:
• 4312: Analog Electronic Circuits
• 4321: Digital VLSI Circuits

Timeline:
• Spring 2014: Chip Design + Tape-out & Test Board design
• Summer 2014: Chip Fabrication
• Fall 2014: Chip Test

Instructor:
Prof. Peter Kinget or Prof. Harish Krishnaswamy

Summary: Get ready to design your own chip!
Other courses relevant to Circuits

  - ELEN E4810x Digital Signal Processing
  - ELEN E4815y Random Signals and Noise
  - ELEN E4998 Intermediate Projects in Electrical Engineering
  - ELEN E4824x Computer Architecture
  - CSEE W4825y Digital Systems Design
  - CSEE E4861y Computer-Aided Design for Digital Systems
  - EEME E4601y Digital Control Systems
  - ELEN E4702y Communication Theory
  - ELEN E4703y Wireless Communications
  - ELEN E4301y Introduction to Semiconductor Devices
  - ELEN E4401x Wave Transmission and Fiber Optics
  - ELEN E4411x Fundamentals of Photonics
  - ELEN E4501x Electromagnetic Devices and Energy Conversion
  - ELEN E4503x Sensors, Actuators, and Electromechanical Systems
  - ELEN E4944 Introduction to Semiconductor Processing
  - ELEN E4896y Music Signal Processing
General Tips

• **Ask advice!**
  – Academic advisors, instructors, fellow (senior) graduate students, …

• Think about your **overall program**

• M.S. students, consider one of the **concentrations**: e.g., “Microelectronic Circuits”,
  – see [http://bulletin.engineering.columbia.eduoptional-ms-concentrations](http://bulletin.engineering.columbia.edu/optional-ms-concentrations)
  – Advisors: Kinget, Krishnaswamy, Seok, Shepard, Tsividis, Zukowski

• M.S. students, consider getting involved with **research**
  – ELEN 6001 Advanced Project Courses
  – First, need to find a research project advisor
  – See [http://www.cisl.columbia.edu](http://www.cisl.columbia.edu)
  – Visit the open labs!
Questions?