

The Fu Foundation School of Engineering and Applied Science

Department of Electrical Engineering



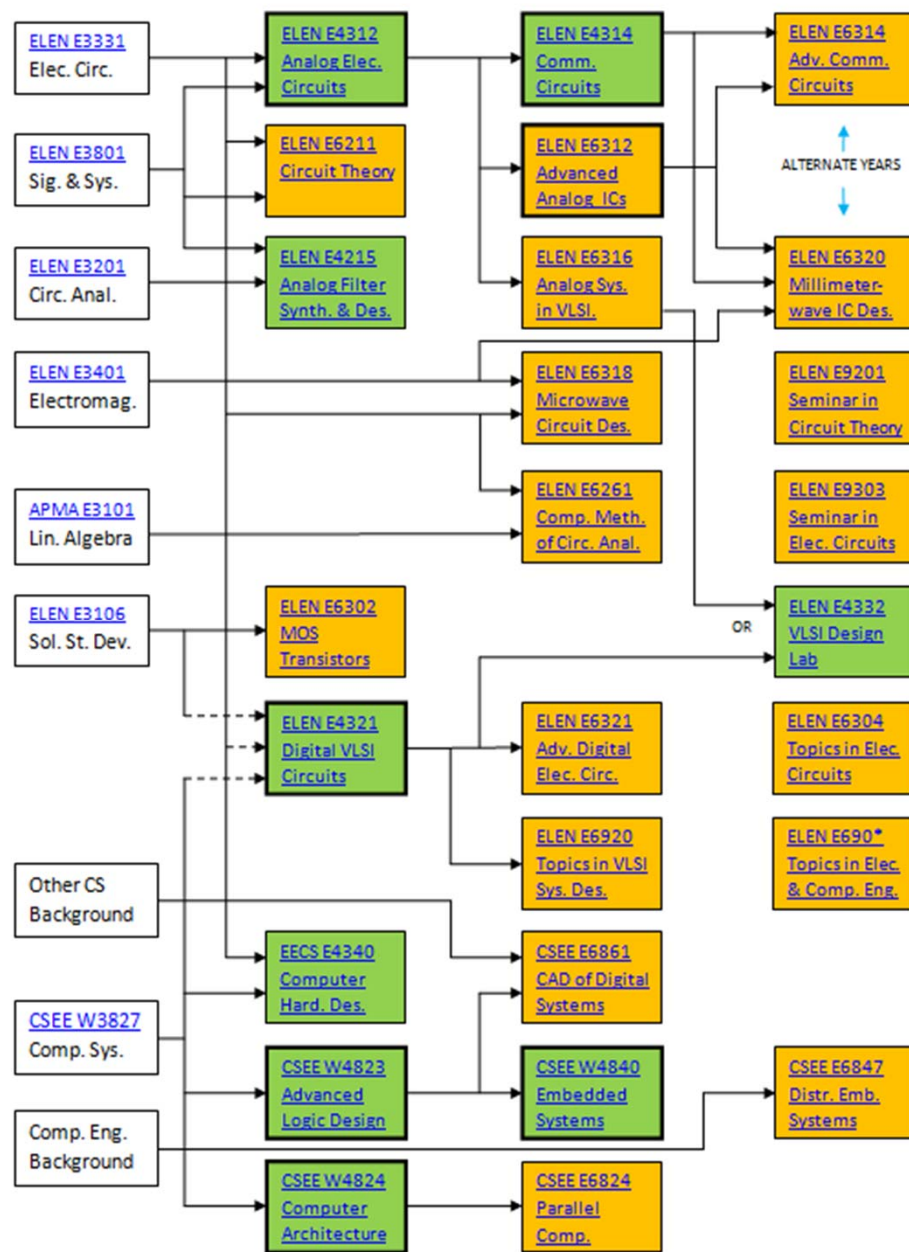
COLUMBIA UNIVERSITY

IN THE CITY OF NEW YORK

# Integrated Circuits & Systems, Electronics

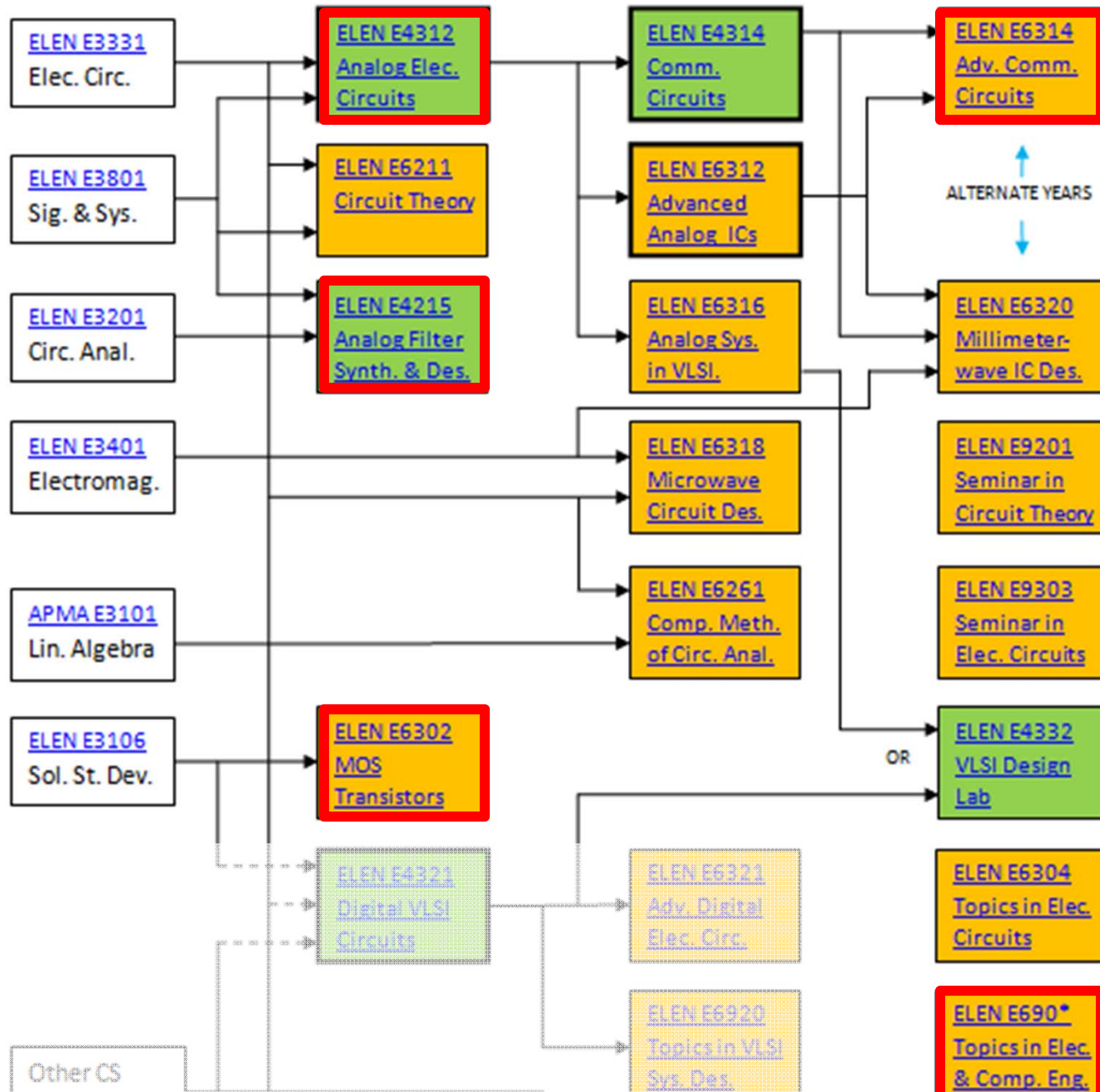
Prof. Peter Kinget

CIRCUITS, ELECTRONICS, & COMPUTER ENGINEERING  
Senior/graduate & Advanced graduate courses in EE



Green = Senior/graduate; Orange = Advanced graduate; Bold border = offered regularly; June 2010

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# ELEN 4312: Analog Electronic Circuits

## **Concise 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. Shahriar Shahramian

## **Summary:**

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

# ELEN 4215: Analog Filter Synthesis and Design

## Concise Syllabus:

- Introduction: Motivation... Why should I know this stuff?
- Approximation theory
- First-order, second-order filters: passive and active
- Frequency transformation
- Delay filters
- Higher order filters
- Integrated continuous-time filters (basics only)
- Switched-capacitor filters (no transistor level design)
- High-frequency filters (basic only)
- Introduction to “Real” engineering problems: noise, nonlinearity, PVT (process, voltage, temperature) variations, etc.

## Instructor:

Prof. Ken Suyama

**Summary:** Introductory course on analog filters. This course prepares students for more advanced integrated filters.

# ELEN 4321: Digital VLSI

## **Concise 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. .
- The course typically includes an extensive *design project*.

## **Instructor:**

Prof. Ken Sheppard

## **Summary:**

Introductory-yet-detailed digital VLSI course that introduces the student to transistor-level digital design and CAD tools for IC design.

# ELEN 6302: MOS Transistors

## Concise Syllabus:

- Operation and modelling of MOS transistors.
- MOS two- and three-terminal structures.
- The MOS transistor as a four-terminal device;
  - general charge-sheet modelling;
  - strong, moderate, and weak inversion models;
  - short-and-narrow-channel effects;
  - ion-implanted devices;
  - scaling considerations in VLSI;
  - charge modelling;
  - large-signal transient and small-signal modelling for quasistatic and nonquasistatic operation.

## Instructor:

Prof. Yannis Tsividis

**Summary:** A detailed course on MOS transistors, with a review of basic background, that allows chip designers to really understand and make better use of their basic building blocks.

# ELEN 6314: Adv. Communications Circuits.

## Concise Syllabus:

- Focus on the design of RF Integrated Circuits.
- Brief overview of wireless 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 or data links.
- Computer-aided analysis techniques are used in *homework(s) or a design project*.

## Pre-requisites:

- *4314 & 6312 or equivalent experience*

## Instructor:

Prof. Peter Kinget.

**Summary:** Advanced class that trains students to design ICs for RF and wireless communications applications.

# ELEN 6903: Topics in EE & CE: Power Amplifier & Wireless Transmitter Circuits

## **Concise Syllabus:**

- o Introduction to PAs and Transmitters - challenges and opportunities.
- o PA/Transmitter metrics: Output power, Efficiency (drain efficiency, PAE, efficiency under backoff, average efficiency under modulation), Linearity (AM-AM, AM-PM, EVM, ACPR).
- o Class A, AB, B, C, and F PAs. Switching PAs (Classes D and E).
- o Advanced switching PA classes (finite-choke Class E, Harmonic-tuning in Class E, Inverse Class D).
- o Impedance transformation for PAs and power combining (transformer-based combining, Wilkinson-based combining, spatial and quasi-optical combining).
- o Linearizing transmitter architectures (Outphasing/LINC/Chereix, Doherty, Polar/Kahn/Envelope Elimination and Restoration, Envelope Tracking, Digital Polar Transmitters).
- o Supply modulators for PAs.
- o Transmitter Predistortion

**Instructor:** Prof. Harish Krishnaswamy.

## **Summary:**

Cutting-edge class that trains students to design PAs for RF and wireless communications applications.

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# 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 Tsvividis

## **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.
- Continuous-time filters: op-amp RC, Tow-Thomas bi-quad, MOSFET-C, Gm-C, automated filter tuning.
- 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 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 2012: Chip Design + Tape-out & Test Board design
- Summer 2012: Chip Fabrication
- Fall 2012: Chip Test

## Instructor:

Prof. Peter Kinget

Summary: **Get ready to design your own chip!**

# Next Fall Courses

(subject to change)

# ELEN 6320: Millimeter-wave ICs.

## Concise 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.

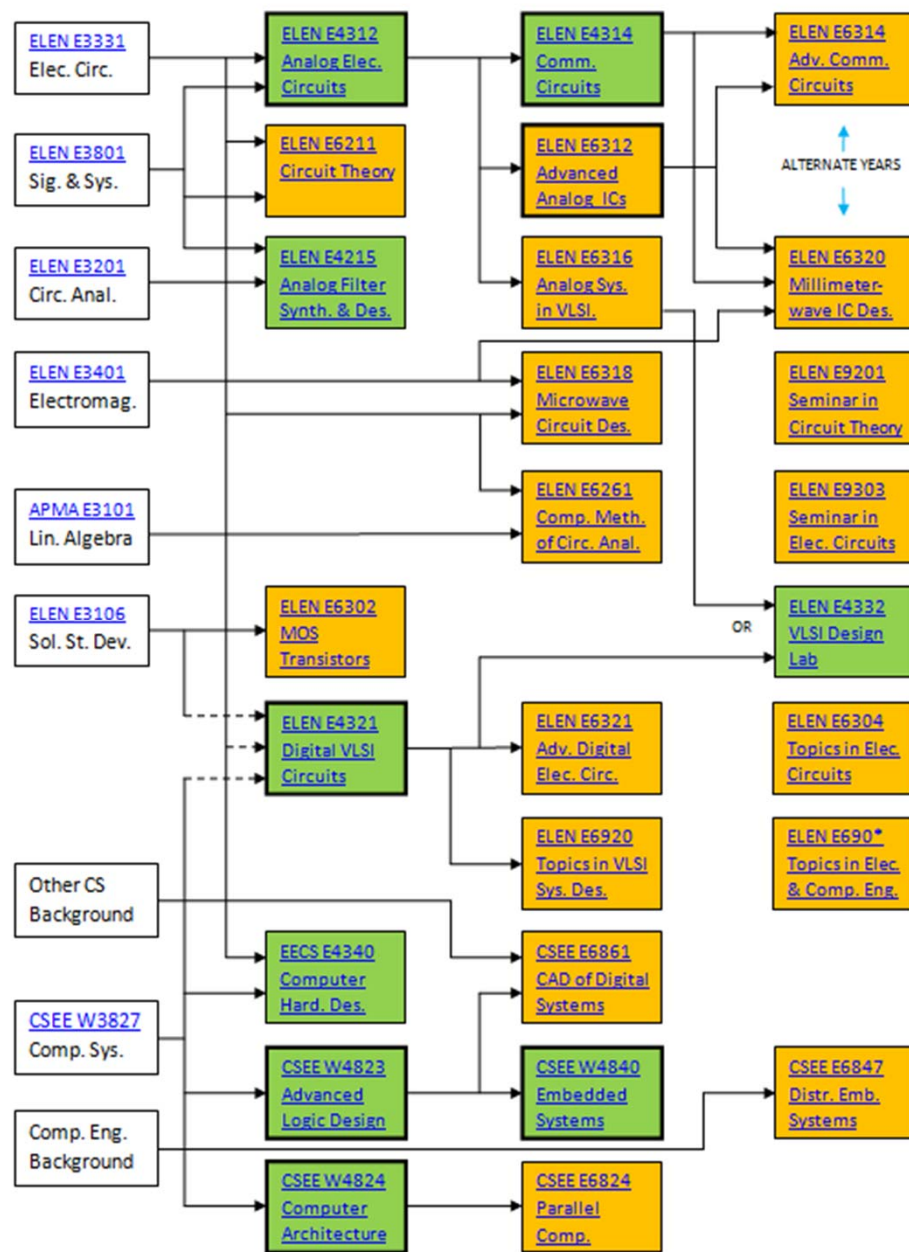
## Instructor:

Prof. Harish Krishnaswamy.

## Summary:

Cutting-edge class that trains students to design ICs for emerging mm-Wave applications.

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# Other courses relevant to Circuits

- See [http://www.ee.columbia.edu/misc-pages/advice\\_circuits.html](http://www.ee.columbia.edu/misc-pages/advice_circuits.html)
  - 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.edu/optional-ms-concentrations>
  - Advisors: Kinget, Krishnaswamy, Shepard, Tsvividis, 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>
  - Visit the open labs!