The Fu Foundation School of Engineering and Applied Science

Department of Electrical Engineering

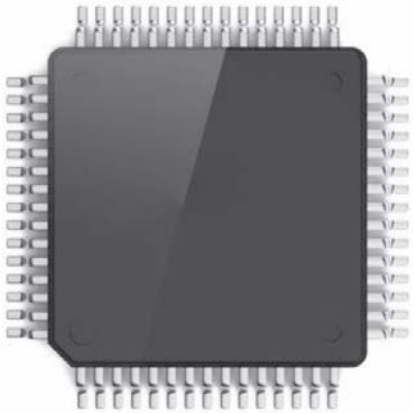
COLUMBIA UNIVERSITY

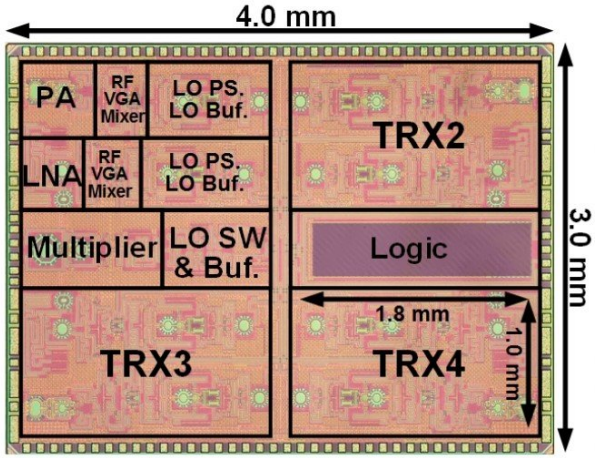
IN THE CITY OF NEW YORK

Integrated Circuits & Systems, Electronics

Prof. Charles Zukowski

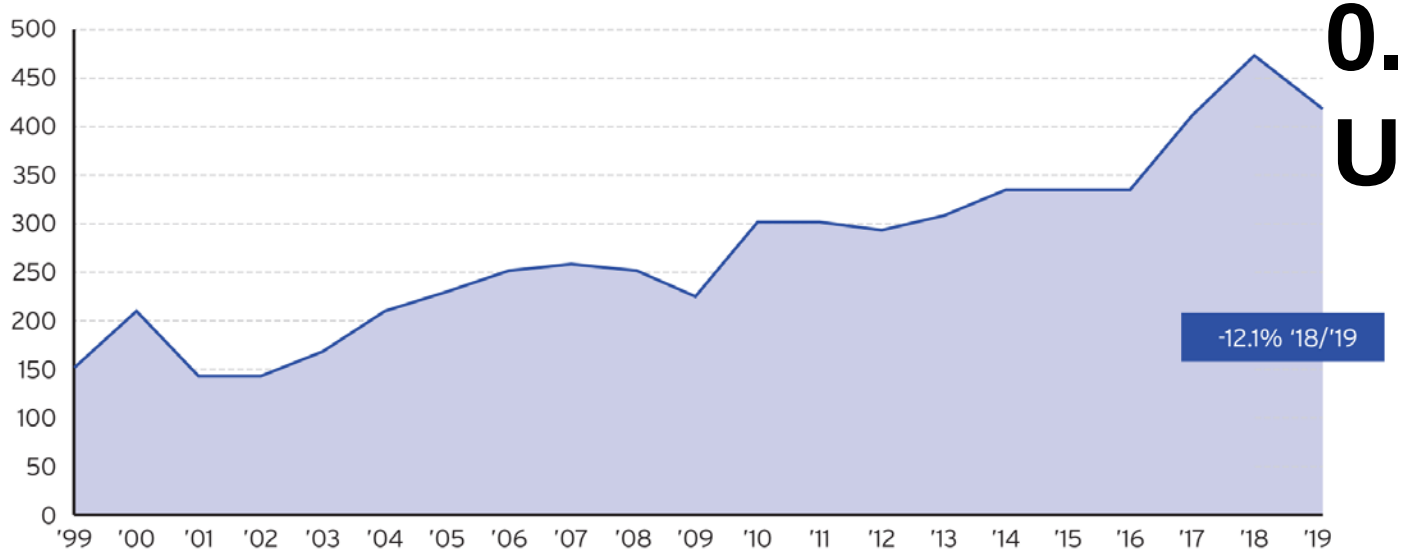
(and thanks to Prof. Mingoo Seok for most of the slides)





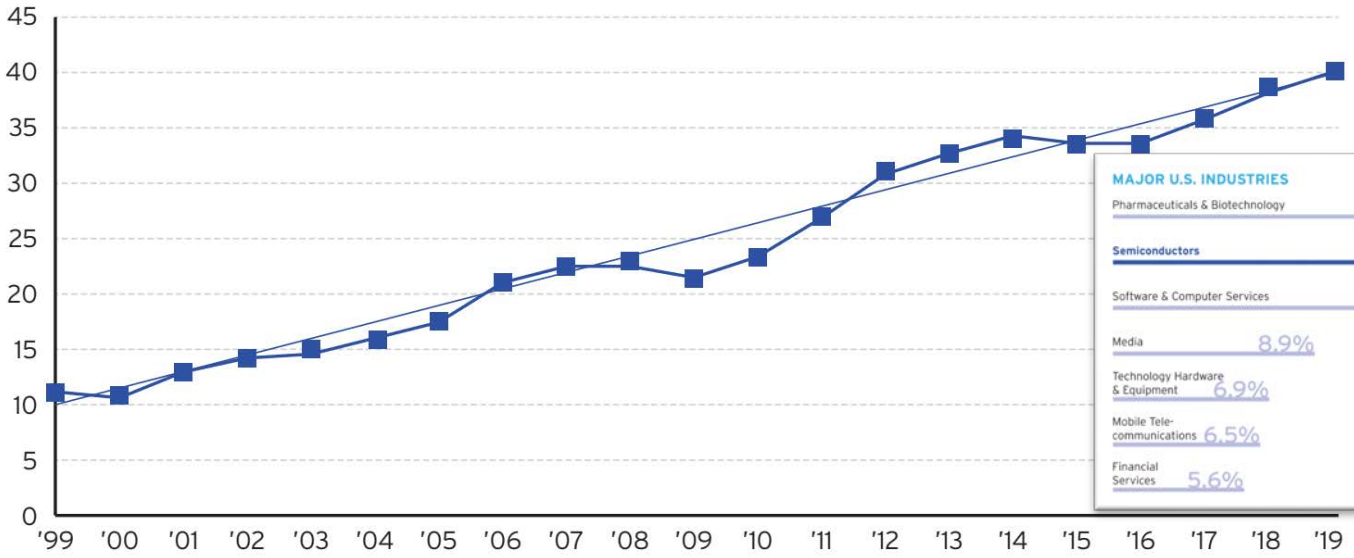
End-Use Category	Communication	Computer	Consumer	Automotive	Industrial	Government
Total Value ($B)	136.0	117.3	54.7	50.2	48.9	5.2

GLOBAL SEMICONDUCTOR SALES ($B)



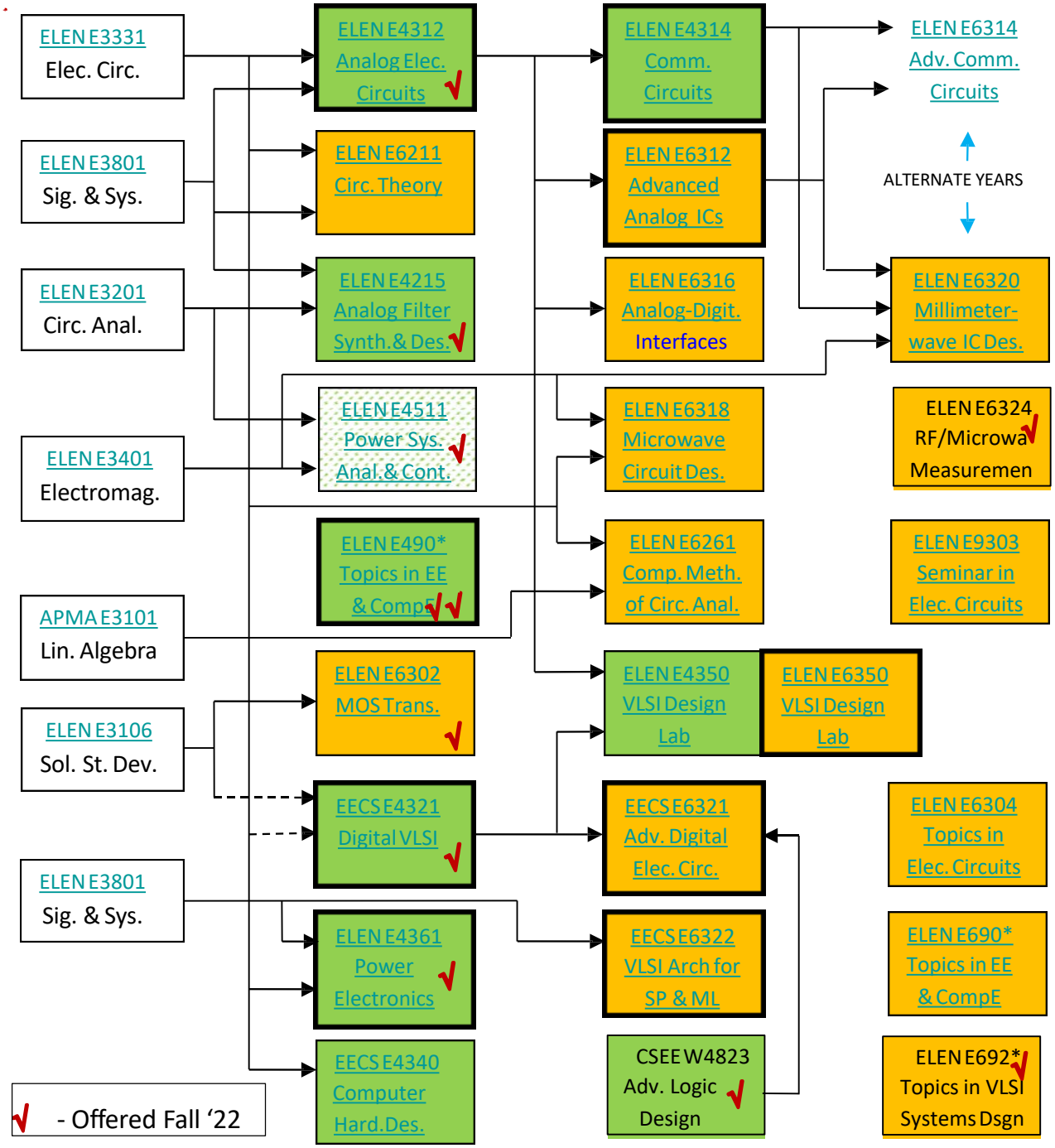
0.5 T USD

R&D EXPENDITURE ($B)



Rank	Company	Sales (USD billions)
1	Samsung	208.5 billion
2	Intel	71.9 billion
3	SK Hynix	35.27 billion
4	TSMC	35 billion
5	Micron Technology	30.9 billion
6	Qualcomm	24.3 billion
7	Broadcomm	20.85 billion
8	Texas Instruments	14.38 billion
9	Toshiba	12.3 billion
10	Nvidia	11.72 billion

- Vertical integration trends: System companies (e.g., Apple, Huawei), and traditional SW companies (e.g., Google, Amazon, Alibaba, MS), are now building their own chips


ELEN E3331
Elec. Circ.
ELEN E3801
Sig. & Sys.
ELEN E3201
Circ. Anal.
ELEN E3401
Electromag.
APMA E3101
Lin. Algebra
ELEN E3106
Sol. St. Dev.
ELEN E3801
Sig. & Sys.
ELEN E4312
Analog Elec. Circuits
ELEN E6211
Circ. Theory
ELEN E4215
Analog Filter Synth.& Des.
ELEN E4511
Power Sys. Anal.& Cont.
ELEN E490*
Topics in EE & CompE
ELEN E6302
MOS Trans.
EECS E4321
Digital VLSI
ELEN E4361
Power Electronics
EECS E4340
Computer Hard.Des.
ELEN E4314
Comm. Circuits
ELEN E6312
Advanced Analog ICs
ELEN E6316
Analog-Digit. Interfaces
ELEN E6318
Microwave Circuit Des.
ELEN E6261
Comp. Meth. of Circ. Anal.
ELEN E4350
VLSI Design Lab
EECS E6321
Adv. Digital Elec. Circ.
EECS E6322
VLSI Arch for SP & ML
CSEE W4823
Adv. Logic Design
ELEN E6314
Adv. Comm. Circuits
ALTERNATE YEARS
ELEN E6320
Millimeter-wave IC Des.
ELEN E6324
RF/Microwa
Measuremen
ELEN E9303
Seminar in Elec. Circuits
ELEN E6350
VLSI Design Lab
ELEN E6304
Topics in Elec. Circuits
ELEN E690*
Topics in EE & CompE
ELEN E692*
Topics in VLSI Systems Dsgn
- Offered Fall '22

ELEN 4312: Analog Electronic Circuits

Syllabus:

- Analysis techniques for complex analog circuits and blocks
- Negative feedback theory and implementation in analog electronics
- Stability criteria, compensation techniques, avoiding undesired oscillations
- Bandwidth considerations, bode-plots & frequency response
- Biasing techniques, matching and layout considerations
- Board-level system design techniques as well as integrated-circuit design techniques will be introduced
- Transistor-level design techniques: CMOS and Bipolar transistor small signal & large signal behavior; single-ended, differential and multistage amplifier design, common mistakes pitfalls
- *Design project*: Varies with year (high-frequency amplifier, feedback amplifier, instrumentation amplifier, etc.)

Instructor:

Prof. Peter Kinget – http://www.ee.columbia.edu/~kinget/teaching.html

Summary:

Fundamental course for any electrical engineer. An opportunity to learn about feedback, critical circuit analysis techniques, design considerations and to develop an intuition about complex analog circuits. Introductory-yet-detailed analog circuits course that prepares the student for designing analog interfaces for systems or as a preparation for advanced analog IC classes like 6350, 6312, 6316, …

ELEN 4215: Analog Filter Synthesis and Design

Overview:

Course covers the design of analog filters, from designing transfer functions that will achieve a desired filter specification, to transfer functions realization using a variety of passive and active filter topologies.

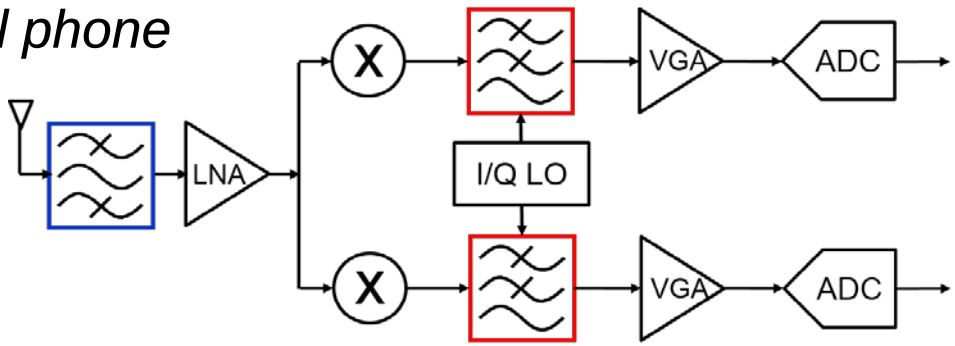
Instructor:

Prof. Tod Dickson

Syllabus:

- Filter specifications, transfer functions
- Filter approximations (Butterworth, Chebyshev, Elliptic, Bessel)
- 1st & 2nd order passive & active (op-amp-RC) filter implementations
- Integrator-based biquads
- MOSFET-C filters
- Gm-C filters
- Filter tuning
- Ladder filters & active realizations
- Discrete-time signaling & switched capacitor filters

Example Application:
Filters in a cell phone receiver



EECS 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

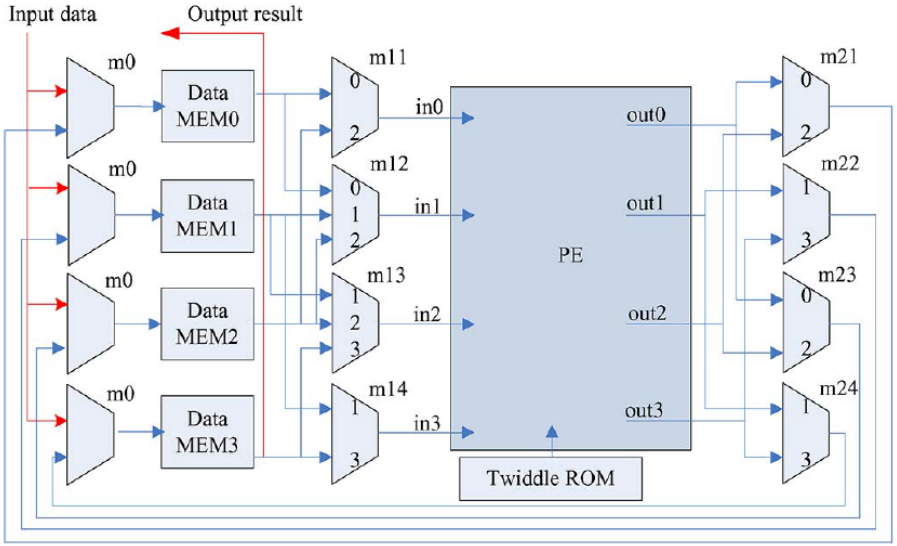
Instructor:

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.

CSEE 4823: Advanced Logic Design



Syllabus:

- Combinational, sequential gates
- Arithmetic circuits
- Logic circuit synthesis
- Logic circuit analysis
- Advanced logic: asynchronous, testing

Project:

- Group project to build a medium-size logic circuit such as FFT, FIR, neural network inference engine, etc.
- Verilog-RTL coding, gate-level logic synthesis, verification, post-synthesis static timing analysis and power characterization
- Use industrial CAD tools and the modern CMOS process to do above

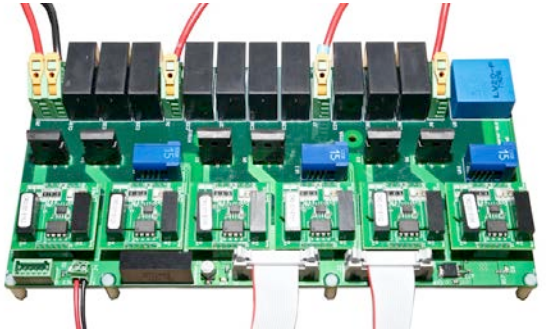
Instructor:

Prof. Matthew Ziegler

EECS 4361: Power Electronics

Syllabus:

- Non-sinusoidal power computations, modeling, and simulations
- Introduction and discussion of the main power electronic switching devices: power diodes, IGBTs, MOSFETs, etc.
- Analysis and design of power converters:
  - Single and three-phase rectifiers
  - DC/DC converters,
  - Isolated DC power supplies
  - Single and thee-phase inverters
- Discussion of power electronic applications:
  Plug-in vehicles, renewable energy, high-voltage DC transmission
- Students develop an open-ended experimental project and write a research-paper styled report
- Best paper is considered for publication!



Instructor:

Prof. Matthias Preindl

Summary:

Introduction to solid-state electric power conversion. By the end of the class, students are able to design, analyse, and simulate converter circuits.

ELEN 4511: Power Systems Analysis

Objectives:

- Understand how electric power is generated, transmitted, delivered and used
- Develop the tools you will need to analyze Power Systems
- Be able to analzye an electric system under various conditions
- Perform a load flow analysis including modeling
- Explore future technologies and their impact on the network

Instructor:

Prof. D. Sciano

Summary:

Modeling of power networks, steady-state and transient behaviors, control and optimization, electricity market, and smart grid.

ELEN 4901: Topics in Electrical and Computer Engineering.

TPC: Photovoltaic Systems Engineering and Sustainability

Instructor:

* Prof. Vasilis Fthenakis

ELEN 4904: Topics in Electrical and Computer Engineering.

TPC: Battery Management Systems

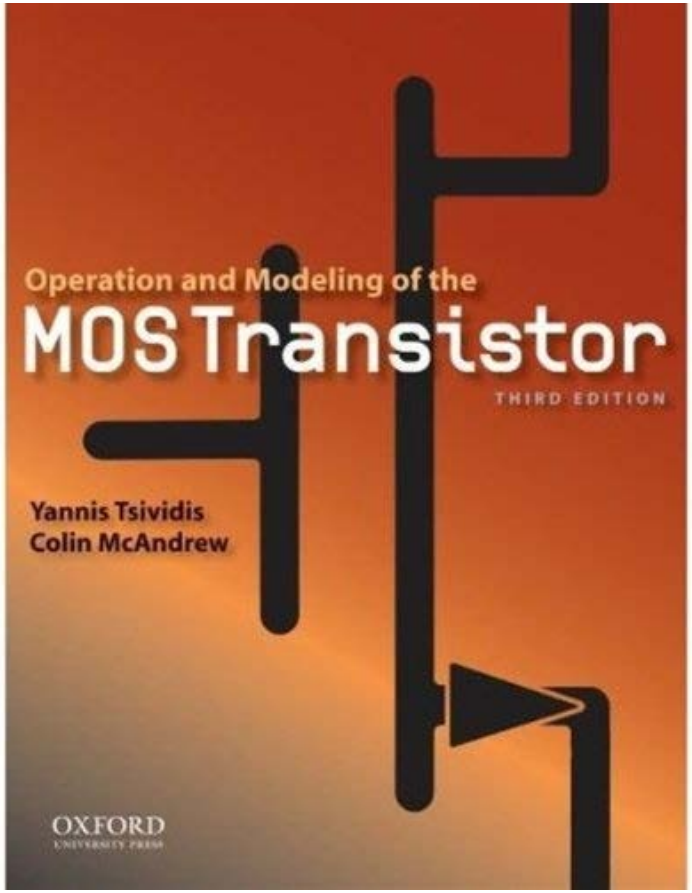
Instructor:

* Prof. Weizhong Wang

ELEN 6302: MOS Transistors

Syllabus:

- Introduction and background review
- MOS two- and three-terminal structures
- The MOS transistor as a four-terminal device
- Strong, moderate, and weak inversion models
- Short- and narrow-channel effects
- Scaling considerations in VLSI
- Quasistatic and nonquasistatic operation
- Charge modeling and large-signal transient response
- Small-signal modeling and noise.
- Project.



Instructor:

Prof. Yannis Tsividis

Targeted audience:

The understanding provided in this graduate course is essential not only for device modelers, **but also for designers of high-performance circuits.**

ELEN 6320: Millimeter-Wave ICs.

Syllabus:

- What's next in wireless communication and radar? Millimeter waves!
- Introduction to millimeter-wave (30GHz and above!) systems and applications.
- Phased arrays – the most exciting technology in 5G cellular
- Designing millimeter-wave wireless circuits using silicon (CMOS and SiGe)
- mmWave amplifier design
- mmWave mixers for frequency translation.
- mmWave oscillators
- mmWave frequency synthesis
- *Design project*: design of a mmWave source using VCO and frequency multiplier

Instructor:

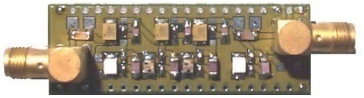
TBA

Summary:

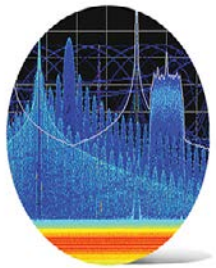
Cutting-edge class that trains students to design ICs for emerging mm-Wave applications.

ELEN 6324: 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 industria



Concise Syllabus:



- Do You Know Your Lab? From DC to Light!
- 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

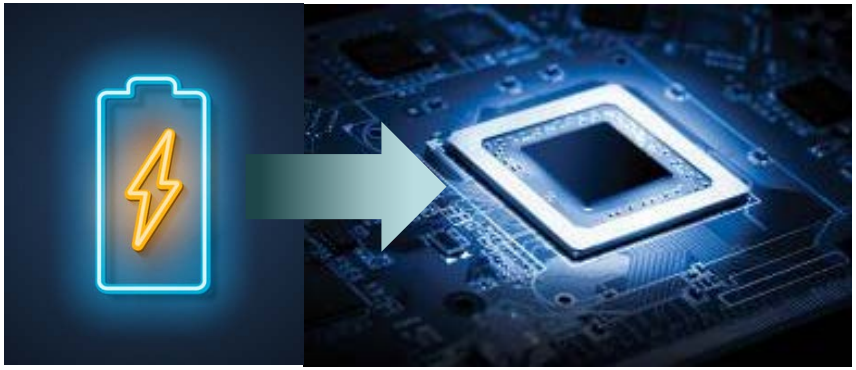
Instructor: Dr. Shahriar Shahramian (Shahriar.Shahramian@Nokia-Bell-Labs.com)
Evaluation: Midterm Exam (20%), Lab Project & Final Report (50%), Final Exam (30%)
Enrollment: Please send Dr. Shahramian an email if you are interested. Qualified students will be admitted on a first-come-first-serve basis.

ELEN 6920: Modern Power Management Integrated Circuits

Overview:

Power Management is one of the most critical infrastructural function for an integrated circuit.

This course presents basics and advanced topics in modern power management ***integrated*** circuits (PMIC) design with a focus on modern system-on-chip (SoC). Course will cover architectural-level design, control methods, design tradeoffs and performance metrics.



Syllabus:

- Linear regulators;
- Digital LDO;
- Switch-mode power converter;
- Control methodologies for switch-mode power converters;
- Switched capacitor converters;
- Hybrid converters;
- Voltage references;
- Energy harvesting;
- Advanced topics in power management

Instructor:

Prof. Xin Zhang

Typical Course Offerings in Spring

(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:

TBA

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 0.18μm CMOS.

Instructor:

TBA

Summary:

Detailed analog circuits course that focuses on integrated CMOS implementations.

ELEN 6316: Analog-Digital Interfaces in VLSI

Overview:

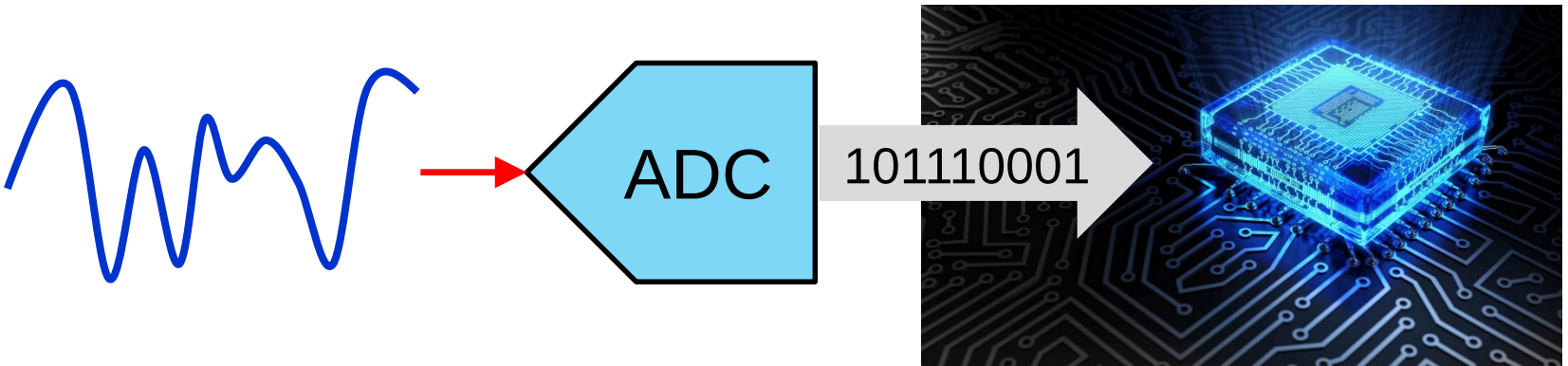
Detailed study of data converter architectures and circuits found at the boundary between analog and digital circuit domains. Course will cover data converter metrics, architecture tradeoffs, and implementation details for Nyquist-rate and oversampled ADCs and DACs.

Instructor:

Prof. Tod Dickson

Syllabus:

- Dynamic range: noise, distortion, SNDR
- Component matching
- Data converter specifications (resolution, quantization error, INL, DNL)
- Sample-and-hold circuits, comparators, switched-capacitor techniques
- Nyquist rate DACs
- Nyquist-rate ADCs (flash, SAR, pipeline, integrating)
- Time interleaving techniques
- Digital assistance/calibration techniques
- Oversampled (delta-sigma) data converters



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.

EECS E6321: Advanced Digital Circuits

Syllabus:

• Advanced topics in modern VLSI hardware design

• Low-power and ultra-low-power design; low-leakage and ultra-low-leakage design; variation tolerant design; on-chip power supply; design for reliability; embedded memory circuits;

Design project:

• Building a medium/large-size digital chip from verilog-HDL to logic synthesis to automatic placement and routing to static timing and power analysis

Pre-requisites:

• 4321 and 4823

Instructor:
TBA

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:

TBA

Summary:

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

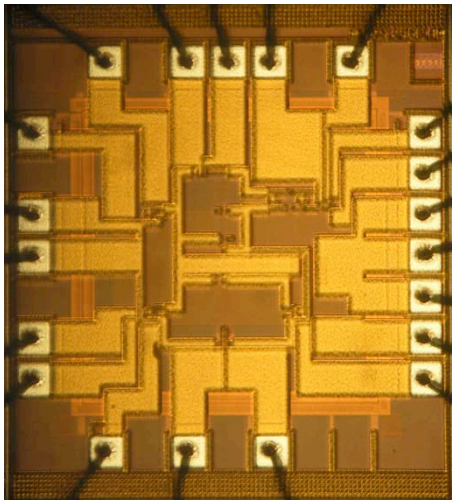
ELEN 6350: VLSI Design Lab.

Concise Syllabus:

- **Design & test of a full-custom deep submicron CMOS integrated circuit demonstrating an application**
- 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.
- Instructor-provided projects or student-proposed project. Project emphasis is on (small) system-on-chip designs; see http://www.ee.Columbia.edu/~kinget/teaching.html

Pre-requisites:

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



Timeline:

- Spring 2023: Chip Design + Tape-out
- Summer 2023: Chip Fabrication
- Fall 2023: Test Board design + Chip Test

Instructor:

Prof. Peter Kinget (kinget@ee.columbia.edu)

Summary: Get ready to design your own chip!

General Tips

- *Ask for 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, Preindl, 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
  - Visit the open labs!

Other courses relevant to Circuits

- See http://www.ee.columbia.edu/misc-pages/advice_circuits.html

Some 4000-level examples:

- **ELEN E4810x Digital Signal Processing**
- **ELEN E4815y Random Signals and Noise**
- **ELEN E4998 Intermediate Projects In Electrical Engineering**
- **ELEN E4824x Computer Architecture**
- **CSEE E4861y Computer-Aided Design for Digital Systems**
- **EEME E4601y Digital Control Systems**
- **ELEN E4702y Communication Theory**
- **EECS E4750x Heterogeneous Computing for Sig. & Data Proc.**
- **EECS E4764x IoT – Intelligent and Connected Systems**
- **ELEN E4106x Advanced Solid State Devices and Materials**
- **ELEN E4411x Fundamentals of Photonics**
- **ELEN E4944 Introduction to Semiconductor Processing**
- **CSEE W4868 System-on-chip Platforms**
- **CSEE W4840 Embedded Systems**