EE504: Power Management for VLSI Systems  
Fall 2013

**Catalog Description:**
Theory, design and applications of power management/regulation circuits (Linear/switching regulators, battery chargers, and reference circuits) including: System and circuit architectures, Performance metrics and characterization, Practical implementations, design considerations in advanced nanometer CMOS technologies, design considerations for large portable, wireless, and RF SoCs.

**Course Outcomes/Objective:**
By completing this course, students will be able to a) Understand power regulation system and circuit specifications, performance parameters, and data sheets, b) Understand fundamental design techniques and performance tradeoffs of linear and switching regulators, c) Understand power regulation schemes in large mixed-signal SoCs and the latest industrial trends and challenges pertaining to integration and silicon technologies, d) Perform a complete design of a switching regulator including system level and transistor level design, e) Fully characterize the performance of any power regulation circuit both in simulations and lab measurements.

This class has a substantial hands-on laboratory section. Students will be using expensive, sensitive, and potentially hazardous test equipment. Safety in the lab is a number one priority for students and instructors and to ensure a safe laboratory experience, a brief safety presentation will be given the first day of lab. It is mandatory that all students attend this presentation. Moreover, it is expected that students follow any and all posted safety guidelines. For reference, a copy of the University Laboratory Safety Manual can be found at:

**Syllabus:**

**Week 1:**
Introduction: Definition of power management and regulation, main tasks of power management systems, typical load types, Power regulation and distribution schemes in large mixed-signal SoCs, noise coupling through power regulation circuits and coexistence of mixed-signal modules in large SoCs, Configurability and programmability of power regulation circuits.

**Week 2:**
Specifications of power regulation circuits: Quiescent current, Load current, Efficiency, Accuracy, DC/Transient load and line regulation, Settling time, Power Supply Rejection, Load isolation, Output impedance, Output noise, Output programmability, Over-voltage and Over-current protection, Startup/shutdown time.

**Week 3:**
Linear and Low-Drop-Out regulators: Definition, Efficiency, basic topologies, stability and compensation, role of control loop bandwidth, role of the load capacitance, PMOS versus NMOS Power transistors, Sources of errors.

**Week 4:**
Introduction to switching regulators: Evolution of step-down switching regulators out of linear regulators, Efficiency versus noise, Basic topologies, Basic operation of buck and boost regulators.

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Week 5:
Control of switching regulators: Basic low-gain voltage-mode control, Control loop modeling, Transfer functions in the ideal case, stability, voltage ripple calculations, relation between component values and performance parameters.

Week 6:
Control of switching regulators: Drawbacks of the basic low-gain voltage-mode control, Stabilization using ESR and its impact on voltage ripple, Line and Load regulation, stabilization using passive compensation networks

Week 7:
Control of switching regulators: High-gain voltage-mode control, Advantages, stability issues, Active compensation.

Week 8:
Control of switching regulators: Current-mode control, Advantages, stability issues, Active compensation.

Week 9:
Control of switching regulators: Hysteretic control, Gated oscillator control, Line-Voltage Feed-Forward control, pulse width modulation and pulse frequency modulation, duty cycle limiting, current limiting, soft starting, PWM latching, Under-voltage lockout.

Week 10:
Efficiency of switching regulators: Power loss mechanisms, Conduction losses, switching losses, quiescent current, Efficiency considerations and calculations, synchronous rectification.

Week 11 and 12:
Circuits for switching regulators: Power transistor design, Power transistor gate drivers, Comparators, Ramp generators, Current sensing.

Week 13:
Output voltage ripple: Impact on sensitive analog circuits, studying the frequency spectrum of ripples, impact of circuit nonidealities on voltage ripple spectrum, switching noise mitigation techniques. Passive Components for power regulation circuits and the impact of chip/package parasitic.

Week 14:
Full integration of power regulation circuits: Industry trends, cost and performance tradeoffs, LDOs with on-chip capacitors, High frequency switching regulators, low-voltage digital CMOS technologies’ promise and challenges: reliability, and interfacing with high-voltage batteries.

Week 15:
Battery chargers: Basic operation of linear and switching battery chargers, Li-Ion battery chargers, battery gauging.

Prof. Ayman Fayed