Power Management for VLSI – A short course
Ayman Fayed, Associate Professor
Director, Power Management Research Lab
Dept. of Electrical & Computer Engineering, The Ohio State University

Summary:
Developing power management solutions for VLSI systems and mixed-signal analog/RF System-on-Chip (SoC) requires engineers with solid background in both traditional power electronics design as well as analog/RF mixed-signal VLSI design. Power management circuits with such a VLSI and SoC focus are neither covered in graduate/undergraduate power electronics courses, nor in VLSI courses. With the growing demand in the semiconductor industry for expertise in this area, there is a serious shortage in formally-trained engineers who have the necessary background combination to design efficient and cost-effective solutions for such applications. This course will introduce the fundamental principles of power management circuits such as Linear/switching regulators and battery chargers used in VLSI systems. This includes: Architectures, Performance metrics, characterization, stability and noise analysis, practical implementations, on-chip integration issues, and design considerations (including noise) for portable, wireless, and RF SoCs.

Learning Objectives:
Upon completing the course, students will be able to:
- Understand power management system specifications, performance parameters, and data sheets.
- Understand performance tradeoffs of power regulators and the special requirements for large mixed-signal SoC loads.
- Understand loss mechanisms in switching power converters.
- Understand limitations and requirements of on-chip integration of power converter circuits.
- Understand basic topologies and design procedures of linear regulators and switching converters (buck, boost, and buck-boost).
- Understand basic topologies of linear and switching battery chargers.

Target Audience:
Analog and mixed-signal design and systems engineers who would like to understand the fundamentals of power management design. Product, test, system, and application engineers involved with power management testing and characterization. Design engineers interested in power management in nanometer CMOS technologies, and integration with mixed-signal SoCs. Researchers and graduate/undergraduate students interested in power management design. RFIC design engineers will find this course helpful in understanding issues related to powering RF circuits. Technical managers will also learn current technology limitations and future technology trends.

Outline:
Day One – System level concepts, performance metrics, linear regulators
Basic definitions, Power management tasks, Schemes and challenges in mixed-signal SoCs, Types of loads, Performance metrics of voltage regulators (power management language): DC, small-signal AC, and large-signal transient metrics, Regulation Concepts, Basic linear regulator design, stability analysis and compensation.
Day Two – Linear Regulators and Switching Regulators
Continuation of basic linear regulator design, PMOS versus NMOS power FETs, on-chip versus off-chip output capacitors. Basic switching power concepts, Step-down switching regulator (Buck), basic design equations, continuous and discontinuous conduction modes, loss mechanisms in switching regulators.

Day Three – Switching Regulators
Control Techniques (pulse width and pulse frequency modulation schemes), AC analysis, stability and compensation techniques. Current-mode control, hysteretic and gated-oscillator control, switching noise analysis and mitigation techniques, Step-up switching regulator (Boost), basic design equations, continuous and discontinuous conduction modes, AC analysis, stability and compensation techniques.

Day Four – Switching Regulators and battery chargers
Other switching converter topologies (Buck-Boost, Forward, and Fly-back), Battery Chargers, types of batteries, charging profiles, constant-current constant-voltage charging, pulse charging, charger topologies (linear and switching).

Day Five – Design Projects
Two design projects will be assigned to the students to implement and simulate while being supervised by the instructor. The default projects will be the design of a complete buck regulator and a complete linear regulator in a standard CMOS technology. Other projects are also available for other regulator topologies and battery chargers. This requires the students to have access to Linux workstations, Cadence toolset, and a pdk for a standard CMOS technology; all must be provided by the employer or university.

Ayman Fayed received his B.Sc. degree in Electronics & Communications Engineering from Cairo University in 1998, and his M.Sc. and Ph.D. degrees in Electrical & Computer Engineering from The Ohio State University in 2000 and 2004 respectively. From 2000 to 2009, he held several technical positions in the area of analog and mixed-signal design at Texas Instruments Inc., where he contributed to many product lines for wire-line, wireless, and multi-media devices. From 2000 to 2005, he was with the Connectivity Solutions Dept. at TI, where he worked on the analog frontend design of high-speed wire-line transceivers such as USB, IEEE1394b, and HDMI, and on fully integrated switching/linear regulators and battery chargers for portable media players. From 2005 to 2009, he was a member of the technical staff with the wireless analog technology center at TI, where he worked on delta-sigma data converters for various wireless standards, and on the development of fully-integrated power management solutions for mixed-signal SoCs with multi-RF cores in nanometer CMOS. Dr. Fayed joined the Dept. of Electrical & Computer Engineering at Iowa State University in 2009, where he held the Northrop Grumman Assistant Professorship. He then joined the Dept. of Electrical & Computer Engineering at The Ohio State University in 2015 as an associate professor. He is the founder and director of the Power Management Research Lab (PMRL) and his current research interests include on-chip power grids for dynamic energy distribution in highly-integrated systems, high-frequency switching regulators with on-chip and on-package passives for SoCs, low-noise power supply modulators for RF transmitters, energy-harvesting platforms for power-restricted & remotely-deployed systems, and power conversion in emerging technologies. Dr. Fayed is a senior member of IEEE, an associate editor for IEEE TCAS-I and TCAS-II, and serves in the technical program committee of RFIC, ISCAS, and the steering committee of MWSCAS. He is the author/co-author of many publications in the field and holds 10 US patents. Dr. Fayed is a recipient of NSF CAREER Award in 2013, and the 2015 Darlington Best Transactions Paper Award from the IEEE Circuits and System Society.

Ayman Fayed, Department of Electrical & Computer Engineering, The Ohio State University