AC 2009-151: INTEGRATING SYSTEMS-ON-CHIP IN AN UNDERGRADUATE ECE CURRICULUM

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Integrating System-on-Chip in an Undergraduate ECE Curriculum

ABSTRACT

System-on-Chip (SoC) is the major revolution taking place in the design of Integrated Circuits (IC). However, progress in this rapidly evolving area hinges critically on the availability of well-educated engineers able to bridge the architectural and physical gaps in SoC design. This work is an ambitious collaborative effort by the faculty of the Electrical and Computer Engineering (ECE) department at Rowan University and the Engineering Science (ES) department at Camden County College (CCC) to integrate System-on-Chip (SoC) concepts across the curricula. More specifically, a curricular prototype is under development that cuts across the artificial course boundaries and introduces SoC knowledge through vertically-integrated and problem-oriented laboratory experiments. Beginning with basic concepts, this approach immerses students in actual system-design projects through three specific engineering design flows (digital, analog, and signal processing) where experiences are formalized and encapsulated into reusable methods, libraries and tools. This paper focuses on the systematic and coherent experimental contents being conducted by students, their contributions to various SoC product designs, and how they fit seamlessly within the Rowan ECE and CCC ES curricula.

INTRODUCTION

With the rapid progress of deep submicron technology, efforts in SoC have recently grown from the combination of digital core functions alone to the full integration of all digital and analog functions of a system. This paradigm shift has a significant impact on the skills needed by SoC architects. However, SoC education has not kept pace with this evolution, especially at the undergraduate level [2]. In fact, today's electrical and computer engineering and computer science departments deliver either classical VLSI designers or computer specialists [1]. Therefore, there is a critical shortage of a new breed of SoC engineers that is capable of bridging the architectural and physical gaps in SoC design to meet the industry's workforce demands in the years ahead [1]. As also indicated in [1], the best training for SoC architects must be oriented to problem solving through vertically integrated and multidisciplinary project components, evolving from analysis to open-ended product design at both the undergraduate and the graduate levels. As pointed out by the National Academy of Engineering report [3], "systems" have become the organizing principle for the way that engineering is viewed and engineering design is accomplished. SoC is much more "system" than "chip", and involves aspects of the engineering curricula from basic circuit analysis to digital and analog hardware/software co-design to specialized signal processing procedures. If students understand that their courses are part of a flow that contributes to the design of a system rather than separate bodies of knowledge, they will be in a better position to appreciate the multidisciplinary nature of ECE and ES.

Motivated by these remarks, this project, as part of an NSF-CCLI grant, proposes an innovative approach comprising three fundamental strands of the curricula and vertically integrates SoC concepts with a focus on their contribution to SoC product design. As described below and shown schematically in Figure 1, this vertical integration of curricula: (1) Provides an *Introductory Module* during the Freshman year that presents an early overview of electrical and electronic systems; (2) Reinforces the system concept in laboratory experiments in *Digital, Analog, and Signal Processing* tracks through the sophomore and junior courses; and (3) Emphasizes *System Design* in a series of senior core and elective courses that call directly on project-oriented assignments that prioritize increasing complexity.

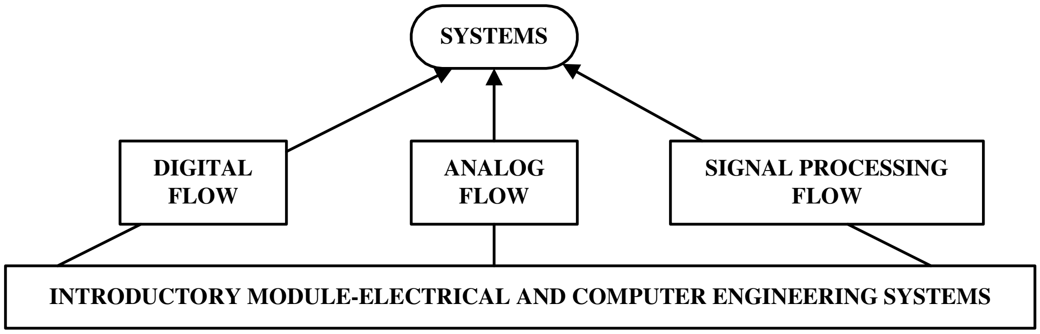

Figure 1: Vertical Integration of SoC into the ECE and ES curricula

The specific goals of the project are to:

- Impart fundamental and contemporary SoC knowledge for *all* ECE and ES students, and provide broader SoC background for those who wish to pursue career or graduate education opportunities in SoC related fields
- Improve students' learning and comprehension of engineering concepts by motivating students through continuous exposure to multidisciplinary/interdisciplinary real world problems in SoC design. Such exposure accompanied by appropriate team-based laboratory experience will help students better adapt to industry, make better connections between theory and practical design, enhance an entrepreneurial way of thinking, and improve communication skills
- Increase recruitment and retention of engineering students by promoting diverse learning styles.

EXPERIMENT DEVELOPMENT

Electrical and Computer Engineering is a multidisciplinary endeavor and students trained in this discipline are required to become the architects of complex systems [4]. It is crucial that these students view their discipline globally from concept to implementation. The rapid evolution of SoC further challenges academic curricula to keep pace in instilling multidisciplinary system thinking. The proposed approach addresses this challenge by exposing students to global system engineering as exemplified in SoC. The design sequence is initiated with a system view of complete silicon boards encompassing highly specialized system knowledge in a customized computing platform. Beginning with basic concepts, this approach immerses students in actual system-design projects through three specific engineering design flows (digital, analog, and signal processing) where experiences are formalized and encapsulated into reusable methods, libraries, and tools. By demonstration, explanation, and practice in these three aspects of SoC, we will motivate students to see the interconnection of their courses as a progression of increasing design complexity. This provides an opportunity to accumulate both knowledge and IP that will result in a final product. Table 1 shows an overview of the vertical integration of SoC into the ECE and ES curricula at Rowan and CCC, respectively, through the three comprehensive projects.

Introductory System Module: This module, which will be used in the Freshman Engineering Clinic at Rowan and Introduction to Engineering at CCC, consists of two parts: 1) a description of the system design activities that are typical of an Engineer working in an industrial setting and 2) experiments that demonstrate engineering system components and their interactions. Since the two courses are multidisciplinary (all engineering students are represented) the module will present the system approach as an ECE viewpoint with emphasis on electrical components embedded in a full product design. The main goal is to introduce ECE to an audience that does not yet have extensive background in the detailed workings of electrical systems. The module will begin with a video overview of modern engineering technology, move to a high-level component description of several representative engineering systems using a demonstration/lecture format, then provide the interactive experiments of disassembly, description and analysis of a representative electronic product.

Table 1: Project flows

	Project I	Project II	Project III
FRESHMAN	Freshman Clinic/Introduction to Engineering at CCC(Spring & Fall)		
SOPHOMORE	Digital I (Spring)	Electronics I (Spring)	Network II (Fall)
POST-SOPHOMORE	Introduction to ECE Principles at CCC (Summer)		
JUNIOR	Computer Architecture (Fall)		DSP (Spring)
	Digital II (Spring)		
SENIOR	Electives in Microelectronic System Design*	CpE Core Elective – Electronics II (Fall)	Electives in VLSI Digital Signal Processing Design*
		Electives in Mixed-signal Circuit Design*	

*Elective courses are offered at various times;
The courses listed in the Table are offered at Rowan unless explicitly stated otherwise

Currently, a compelling video to excite students about engineering and engineering system design is being developed. The video chooses a 'real' engineering system - Wind Turbines- as the main theme to showcase how engineers as innovative and creative problem solvers to help improve peoples' lives. It features not only the real wind farm in Atlantic City of New Jersey, but also the team plays at Rowan Engineering to build wind turbines as their sophomore engineering clinic project.

Project 1: Prototype an FPGA-based Transmission Control Protocol (TCP) Stack: High-speed networks impose heavy processing demands on servers and storage devices, sharply limiting host CPU performance, system bandwidth, and scalability [5]. Offloading TCP/IP processing into an embedded device is emerging as a solution to this dilemma. This project, as an initial stage of an on-chip TCP/IP offload engine, will not only expose students to object-oriented Hardware Definition Language (HDL) design techniques but also enhance student understanding and learning in computer networks. Hierarchical design is very important for development of moderate and high complexity. According to the primary features of TCP communications, the project starts with defining the system architecture (see Figure 1) into data path and control unit via algorithmic state machine (ASM). With input and output signals identified, the data path is further decomposed to smaller function blocks called modules. Students in the junior-level course (i.e., *Computer Architecture*) analyze the system and design the data path and control unit for the architecture. Experiments on recurring combinational/sequential logic components (e.g., counter, comparator, and timer etc.) and modules are carried out in the sophomore-level course (i.e., *Digital I*). The integration and verification of the design will be performed by students in the senior-level courses (i.e., *SoC Verification* and *Senior Engineering Clinic* (similar to a capstone design course)). Xilinx tools, including Xilinx Spartan III development board [6], Xilinx Virtex II-Pro development board [7], ISE Foundation, and Embedded Development Kit, are applied in the labs of this design flow, accordingly.

Project 2: Operational Amplifier for Communications Applications: The operational amplifier (OpAmp) is one of the fundamental components in analog and mixed-signal circuit design. The OpAmp is a multistage amplifier with extremely high gain characteristics. These gain characteristics are so high that when negative feedback is applied, the closed loop transfer function is nearly independent of the gain. It is often used in circuit design as a "black box" three-terminal device but a solid understanding of its design and implementation serves pedagogical goals both in applications and fundamental knowledge. The advantage of using the OpAmp as the basis for a set of experiments that span the curriculum is not only that it is a pervasive component in systems from communications to medical electronics but it requires an understanding of aspects of electronics from the physical operation of simple components such as the MOSFET to the understanding of the subtle interactions among components that control characteristics such as feedback, frequency response and noise performance. Currently, three fundamental experiments (the CMOS differential input amplifier design, the CMOS two-stage operational amplifier design, and ASIC low noise amplifier design) are developed and being tested by Rowan students in *Electronics I*, a sophomore level introductory analog electronic course, and *Electronics II*, a required senior course at Rowan. Mentor Graphics™ tools are applied in all experiments of this project flow. The schematic design tool, Design Architect, and the analog simulator, Accusim, are employed to investigate each functional component and, eventually, the full differential input amplifier.

Project 3: SoC implementation of a quadrature mirror filter (QMF) bank: The QMF bank is used in speech coding [8] and is a project that spans concepts in filter design and implementation and the implementation of multirate building blocks. Three experiments towards the SoC QMF bank have been developed and tested by Rowan students in *Digital Signal Processing* and *System and Control,* two junior-level courses. The experimental contents include analog butterworth low-pass filters, digital IIR filters, and FIR linear phase filter.

Introduction to ECE Principles Course at CCC A new summer bridge course is under development for Engineering Science (ES) program at CCC as part of this proposal. ES program is a transfer program for students who have a strong interest in engineering and plan for further study of engineering at a 4-year college/university. This course uses the low-level experiments from the projects above and emphasizes coherent ECE content with a focus on digital/analog system analysis, design and integration. Topics includes Boolean Algebra, Combinational and Sequential Circuit analysis, Diodes, Transistors, Operational Amplifier, AC circuit analysis, concepts of frequency response, transfer functions, and analog filter design and realization. The laboratory-oriented course not only teaches students basic ECE principles and facilitates their transition to major in ECE at a 4-year college/university, but also gives students skills and tools necessary to advance their knowledge in SoC.

CONCLUSION

Three series of experiments with the focus on different aspects of SoC products are under development and being implemented in the all-level of the ECE and ES curricula at Rowan and CCC, respectively. In addition, a summer bridge course is being developed at CCC to help ES students develop the knowledge and skills necessary to seamlessly transfer concepts into an ECE curriculum at a 4-year university. The learning materials as well as their organization optimize student learning and help them develop a strong foundation to carry over for subsequent coursework

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