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A Multidisciplinary Electronic Manufacturing Undergraduate Laboratory for the Design and Manufacture of DSP and Computer Based ASIC Systems

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Abstract

In 1995, we received a NSF ILI grant to develop a one-credit laboratory component for our three-credit lecture course on electronic manufacturing aspects of printed circuit boards [1-3]. In this paper, we describe how we have been able to increase the utilization of the equipment from its original intended use. We do this by developing two additional one-credit laboratory courses for two lecture courses using the laboratory that was set up with the grant. The two new laboratory components will give students experience in the electronic manufacturing aspects of application specific integrated circuit (ASIC) design for digital signal processing (DSP) and computer engineering applications. This will require minimal modification to the existing hardware and software.

The manufacturing aspects of DSP applications focus on incorporating the benefits of high speed hardware circuitry to handle real time decoding and post-processing of video signals. The manufacturing aspects of computer engineering focus on the implementation of special purpose hardware for solving a stiff system of coupled non-linear differential equations. Field programmable gate arrays (FPGAs) will be used for technology implementation. The reconfigurable feature of FPGAs will be exploited to overcome parameter sensitivity and provide the performance needed by adequately customizing the hardware to the solution algorithm.

In addition to describing the details of the two new laboratory courses, the paper will present the results of our continuing efforts to assess student satisfaction of the PCB/ASIC design laboratory as well as our progress in the two laboratory components.

I. Introduction

With the continued and rapid increase of computer and electronic equipment usage, electronic manufacturing has become a significant sector in the manufacturing industry. Electronic production worldwide is undergoing a revolutionary change in both component manufacturing and manufacturing techniques used in chip and board technologies. These new technologies have reduced component size and costs, and have improved the reliability of electronic products. Advancing the state-of-the-art in electronic manufacturing technology presents a challenge to U.S. electronics manufacturers in the highly competitive world of the 90s.

The field of electronic manufacturing is a multi-disciplinary area that encompasses several technologies from electrical, materials, industrial, chemical, and computer engineering. For example, circuit analysis, electronics, automation, thermal sciences, physics, chemistry, material properties, CAD/CAM, software engineering, and production planning are necessary for students to learn the latest techniques in computer and DSP technologies. It is our belief that the growing electronic manufacturing industry will demand increasingly large numbers of engineers who have a better understanding of this multidisciplinary area.

Microchip components and DSP based system technologies require innovative changes in computer and DSP board design algorithms, testing, and inspection. New computational techniques, design methodologies, and the abundance of new application areas developed in industry are currently being introduced into the university classrooms. The sophisticated automation systems of the present and future will require planners, designers, and operators who possess a higher degree of knowledge and technical skills. This makes it mandatory that institutions in this country develop state-of-the-art programs to equip their graduates with the latest information for a rapidly changing domestic industry.

In this work, we describe a state-of-the-art, multidisciplinary undergraduate laboratory components for existing three 3-credit hour courses namely Electronic Manufacturing, Computer Organization, Digital Signal and Image Processing, that are intended for seniors in electrical engineering. The courses with their new laboratory components are scheduled for the Fall 1999 semester. The addition of the laboratory components to the existing courses brings the theoretical study, laboratory design, and actual manufacturing of application specific integrated circuit as applied to computer design and digital signal processing (DSP). It will also emphasize interdisciplinary group work of students from different disciplines including computer engineering and electrical engineering.

II. Description of Courses

2.1 PCB/ASIC Design

The electronic manufacturing course consists of lecture material that includes ASIC design and PCB layout design emphasizing surface mount assemblies. The course taught by two instructors exposes students to electronic manufacturing aspects of the design of integrated circuits and printed circuit boards. Students in the class learn how to design and actually manufacture boards and microchips. The details of the course is as follows:

Part I: ASIC Design

In this part of the course, students are introduced to the device aspects from the layout point of view. The MOS device is modeled to include the secondary effects of short channels. Simulation results utilizing the model are generally in agreement with those of actual digital systems that are built in students' projects. The prerequisite of this course is an introductory digital electronics class in which they learn digital design and synthesis. In five weeks, students are required to design and generate the artwork file for manufacture. The material covered in this period is:

- Historical background on IC design that started with the invention of the point contact transistor, until the most recent technology in 90s.
- The market share for digital and analog: CMOS and BJT technologies. Differences between technologies in all aspects: integration, power, N.I., etc.

- The MOS transistor with considerations for short channel devices, secondary effects such as mobility saturation with the electric field and degradation with the temperatures, hot electrons, electromigration, and aluminum spikes.
- Simple logic circuits with CMOS technology with the use of Pspice simulation to study the circuit performance.
- Introduction to IC fabrication, layout and design rules.
- Use of L-Edit on PCs, and Mentor Graphics on HP/Sparc workstations
- Project. A typical project is an 8-bit shift register in a 40 pin package.

Part II: Printed Circuit Board Assemblies

The basic challenge in the remaining 10 weeks of the course is to teach students enough about manufacturing technology, circuit board layout design practices, and a design automation tool to provide them with an overview of the electronic manufacturing process. Emphasis is placed on learning surface mount component package styles, and their placement on top and bottom sides of 2 to 6 layer fiberglass-epoxy boards. The common manufacturing processes for these boards are studied, and students will have a first hand opportunity to practice some of these processes, as described below:

Laboratory Components

1. Familiarization with Mentor Graphics Design Architect.
2. Component Placement.
3. Automatic Component Placement.
4. Routing.
5. CAM Files for the Routed Boards.
6. Design Project. Typical projects are burglar alarms, traffic light controllers, elevator control circuits, or in general sequential circuit design.

Part III: Mobile Electronic Manufacturing Laboratory (MEML)

The MEML is housed in a 36 foot trailer, and has its home base outside the Engineering and Technology building on the IUPUI campus. Until recently, this facility was managed by the Electronic Manufacturing Productivity Facility (EMPF). The MEML was not part of the original electronic manufacturing course structure, but it was always our intention to use EMPF facilities and personnel to demonstrate basic manufacturing, testing, and cleaning operations. These aspects are available from cooperative fabricators in nearly every urban setting. We have generous cooperation from a local high-quality board fabricator that can supplement our efforts to introduce students to industrial techniques. Nevertheless, the MEML represents a nearby resource that is convenient to introduce students to actual hands-on processes. The MEML is a mini-factory capable of manufacturing small volumes of 2 layer fiberglass-epoxy boards with surface mount components placed only on the topside. Its purpose is educational, but its capability is sophisticated enough to make small production runs. There is a solder paste stencil printer, a programmable pick and place component handler, a convection reflow oven, and an aqueous ultrasonic cleaner. There is also a soldering station for special components which cannot be reflowed effectively in the oven. It accommodates 5-6 working adults at a time.

2.2 Digital Signal and Image Processing

The same equipment used for the PCB/ASIC design course will be utilized by students for performing experiments related to digital signal and image processing. Students are introduced to the areas of digital signal processing with a broad range of multimedia topics related to speech, image processing, and video compression. A set of experiments performed with Matlab and /or C, and Motorola micro-controllers will be assigned. These include:

- Introduction to Software
- Continuous-time and discrete time-signals
- Spectral analysis
- Sampling
- Decimation and interpolation
- Quantization
- 2-D signals and systems
- Image coding
- Computed tomography
- Speech models and characteristics
- Differential pulse code modulation
- DSP Applications using Motorola boards
- Video compression algorithms
- Project. Typically, decoding/encoding of a compressed video signals.

2.3 Computer Organization

In this area, Mentor Graphics software is also used to design combinational/sequential circuits and to generate the artwork for field programmable gate array applications. Students are exposed to computer organization and learn how to design a central processing unit (CPU) of a computer. Students are able to implement their design with FPGA or with application specific integrated circuits (ASIC). Top-down design approach is covered in the class utilizing hardware descriptive language (HDL). Students in this course work in groups and use MOSIS service for implementing their design, or use the school facility to implement FPGA circuitries.

Field program gate arrays are a new class of digital components. Each gate array contains a large number of combinational logic blocks. Initially uncommitted, the function and the interconnect of these logic blocks are determined on-line according to the driving application (i.e. in the field). The process of assigning the interconnect and the function of the logic blocks is called configuration.

FPGAs have traditionally been used for rapid prototyping. However, with technological improvement, FPGAs are becoming more and more suitable as an end-target hardware implementation media. In particular, FPGAs are ideal for applications that are time critical and that require different hardware implementations that are tailored to different set of input parameters. As the reconfiguration latency of FPGAs is improved, it becomes possible to reconfigure for a new hardware implementation on-line.

The use of FPGAs to overcome the parameter sensitivity and the time constraints of certain applications will introduce students to current research in special purpose CPU design and ASIC design. Furthermore, in building the subcomponents of the system, students will explore design issues in data path design, ALU design, memory interfacing and digital/analog interfacing. As all of these areas are integrated in order to provide a high performance solution to the target application.

Currently, a prototype project has been defined and is in the final stages of development. Based on this prototype, a term project will be incorporated in the computer organization course. The above mentioned prototype will be used to demonstrate the feasibility of the project. Students will then be asked to create their own design solution.

As this project becomes fully developed, small and contained tasks within the project will be identified. These tasks will be used as laboratory experiments in an introductory digital design course. The migration of parts of this project to an introductory course will allows us to introduce students early on to ASIC design. Furthermore, it provides continuity from one course to another in our curriculum

III. Classroom Support

Because of the exceptional laboratory experiences, much of the formal course lecture materials are chosen specifically to support the laboratory. That is, to support the intelligent use of the Mentor Graphics software, students must be instructed in component package types, board substrate materials, layout design rules, common electronic manufacturing processes, and testing procedures. In the manufacturing course, because of the pervasive use of tin-lead solder, some attention is given to its metallurgy and so its effect on reliable board manufacturing. A guest lecturer normally gives a comprehensive overview of solder paste technology along with a brief discussion of the developing solder-alternative technology. Although the time limit restricts us to use one style of board, namely the glass-epoxy FR-4 substrate, other board styles are introduced to place this substrate in context. The Mentor Graphics training circuit uses multiple layers to demonstrate the major features of the software, and classroom material presents the use of ground and power planes, signal planes, and design rules for standard blind and buried vias in multi-layer boards. These features are handled differently in double-sided boards, with varying trace widths and restricted power and ground trace placement.

IV. Student Satisfaction

The following items were assessed for the electronic manufacturing course after adding the laboratory component that is partially supported by NSF ILI grant. Based on a 5.0 scale, the following data were received:

1. I intend to pursue a career in electronic manufacturing or a closely related area.	4.0
2. This course has helped me in job interviews.	4.33
3. This course has given me confidence to pursue an engineering job.	4.20
4. This course has given me a better understanding of what engineers do in industry	4.50
5. Courses like this one motivate me to put effort into my studies.	4.0
6. I enjoyed working with L-Edit.	4.5
7. I enjoyed working with mentor Graphics.	4.25
8. Topics covered in this course met my expectations.	4.25
9. If I were to take technical electives, I would like to take another course in this area.	4.67
10. The hands-on aspects of the course made it interesting.	4.5
11. The computer facilities added to the quality of my experiences in this course.	4.0
12. I enjoyed the interdisciplinary nature of this course.	4.33
13. Overall, taking this course was enjoyable experience.	4.75

IV. Discussion

The three-year project started August 1st, 1995 and ended July 31st, 1998. The electronic manufacturing course which received the NSF ILI grant was successfully developed and taught several times on campus. The other two courses in image and signal processing, and computer engineering that utilize the same laboratory equipment are designed and will be offered for the first time with their laboratory components in Spring and Fall 1999. Smaller versions of these new courses are offered under experimental design capstone courses and have received great interests from electrical engineering students. The students' feedback in the electronic manufacturing course indicated that the laboratory component of the course has made it very enjoyable and met students' expectations. In general, students enjoyed the hands-on aspects and decided to pursue careers in related areas. The course motivated students academically and met the objectives. Likewise, we are expecting that the other two courses using the same equipment will meet student expectation in computer engineering and signal processing areas.

References

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