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An Innovative Model for Senior Level Undergraduate Engineering Education in Electronic Manufacturing*

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In this paper we describe a new course development model that brings together in partnership the educational institution and manufacturing industry. We will demonstrate how this linkage can deliver state-of-the-art technical education to senior electrical engineering students by bringing together theoretical study, laboratory design, actual product manufacturing, and testing of integrated circuits (ICs) and printed circuit boards (PCBs). In this partnership, lectures, laboratory design and product testing are conducted on the campus of Indiana University—Purdue University Indianapolis, while the IC fabrication is produced using MOSIS Service at the University of Southern California. Learning about the manufacturing of the PCBs is done through course work and tours of the Electronic Manufacturing Productivity Facility (EMPF), a local industry near the school. The impact of the course on student learning, satisfaction and career planning is discussed.

INTRODUCTION

IN RECENT years, with the rapid growth in the production of commercial and industrial electronics, electronic manufacturing has become a significant sector in the manufacturing industry. This rapid growth has been assisted by the development of new technologies and new design tools which make possible the design of complex electronic systems, including both the design of integrated circuits (ICs) and printed circuit boards (PCBs) using either surface mount or through-hole technology.

Until recently, designers who wished to take advantage of new electronic technologies in the design of custom systems faced hurdles that have now been removed. These hurdles, particularly the lack of access to IC and PCB fabrication facilities and the lack of design expertise, have been eradicated by the availability of software packages that convert system specifications at the functional level to the mask specification needed by fabrication services.

There is a current trend in engineering education for universities to link with companies to form working partnerships to deliver educational experiences. In some cases, the company and the university conduct a faculty/staff exchange. In other cases, the company allows the university to use its facilities for hands-on experiences. To determine industrial reaction to forming linkages, we conducted a survey of several companies across the United States concerning their interest in this area. The results of the survey were positive and are reported later in this paper.

In this paper, we will describe a course that was recently developed at Indiana University–Purdue University Indianapolis in which a university–industry linkage was formed to enable students to design practical, large-scale, electronic systems. This course, Electronic Manufacturing, provides senior level students with a learning environment where they are afforded opportunities to design modern, industrial-quality, electronic systems in reasonable time and with reasonable effort. This experience is carried out in our departmental laboratories using moderately priced equipment that is well within the economic reach of schools and small businesses. The material taught is fundamental, and while immediately useful, will not become dated in the foreseeable future. Instead, the course provides a fundamental basis that will continue to serve the needs of designers as their experience and knowledge increase. Thus this course brings designers quickly to the level where useful electronic systems can be designed, and it is able to provide the initial base upon which further study and experience can lead to highly optimized, state-of-the-art designs.

Our Electronic Manufacturing course has been offered twice so far, and the feedback from students has been very satisfying. The course was designed

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so that it can be replicated at any institution that can find a local industrial partner.

BACKGROUND ON THE DEVELOPMENT OF THE COURSE

The idea for this course originated from discussions with representatives from several local industries that are involved in electronic manufacturing. These discussions focused on topics such as solder flow, CAM, micro-electronics manufacturing, design of surface mount PCBs, ASIC design, and related thermal considerations. A survey of engineering programs in the United States uncovered very few courses in this area that could serve as models. Thus the decision was made to develop our own course.

The faculty team began planning the course 3 years ago when the Electronic Manufacturing Productivity Facility (EMPF) relocated its physical plant a mile from our campus. This provided a natural university/industry linkage, and the EMPF facility has opened its facilities to student use.

The faculty team established several principles that would be followed in the development of the course. For the CAD/CAM aspects of the course, the software packages must be state-of-the-art and widely adopted in industry and must be user-friendly, and the hardware platform must be affordable. In addition to hardware and software considerations, the course would have to include interdisciplinary topics including electrical and electronic circuits, and material and thermal sciences.

DESCRIPTION OF THE COURSE

The overall goal of the course is to prepare students for careers in electronic manufacturing. This is accomplished by including topics ranging from the placement of the surface mount components (SMCs) and through-hole components (THCs) to learning how to use professional software packages which generate the artwork for manufacturing PCBs. To achieve the stated goal, the course contents would be delivered in the following progression: CAD design, manufacturing and testing.

The course assumes a background in elementary digital system theory and design and some elementary background in R-C circuit theory. It also assumes an elementary background in semiconductor devices. However, the course begins with a review of basic, prerequisite information and is essentially self-contained. The course is intended for electrical engineering majors who have selected either computer engineering, electronics and circuits, or robotics and manufacturing as their area of speciality. There is no need for prior knowledge of mask or wafter fabrication. The course sequence that leads to the course is described in Table 1.

Student learning will be accomplished in three basic ways: (i) traditional lectures on circuit layout, components, assembly styles, manufacturing equipment and processes; (ii) use of guest lecturers, plant tours and video tapes to provide a state-of-the-art look at electronic manufacturing; and (iii) use of software packages to teach the fundamentals of microelectronic layout for manufacturing.

The course consists of two main sections: (i) ASIC design, taught during the first 5 weeks of the semester, and (ii) PCB technology, taught during the remaining 10 weeks. Both are multidisciplinary areas which encompass several technologies from electrical and mechanical engineering, supplemented by other elements from industrial engineering, automation, thermal sciences, physics, chemistry, materials, CAD/CAM, software engineering and production planning. The growing electronic manufacturing industry will demand increasingly large numbers of engineers who have a better understanding of these interdisciplinary areas.

The topics covered in the two parts of the course are listed in Table 2. The course uses both instructor written notes and handouts and the textbook, *A Scientific Guide to Surface Mount Technology* by Colin Lea (Electronic Publications, 1988). During the first 5 weeks spent in ASIC design and testing, students learn basic design principles, create designs and generate artwork files for fabrication. The ASIC section is taught at the beginning of the semester so that students will be able to receive

Table 1. Courses sequence leading to the Electronic Manufacturing course

Electrical Engineering Courses	Pre-requisite Courses
EE 201 Linear Circuit Analysis I	Math 261 Multivariate Calculus Phys 251 Heat, Electricity, and Optics
EE 255 Electronic Circuits, Analysis and Design	EE 201 Linear Circuit Analysis I
EE 266 Introduction to Digital Logic Design	EE 201 Linear Circuit Analysis I
EE 305 Semiconductor Devices	Math 261 Multivariate Calculus Phys 251 Heat, Electricity, and Optics EE 255 Electronic Circuits, Analysis and Design

Table 2. Topics covered in the course

ASICS Design (5 weeks)	PCB Design (10 Weeks)
Introduction and overview of integrated circuits	Electronic manufacturing overview
The MOS Transistor	Printed circuit board construction
NMOS and CMOS inverters	Through-hole components--assembly techniques
Cell generation and lithography	Soldering of through-hole components and other assembly steps
Mask patterns and their constraints	Introduction to major types of hybrid circuits
Interconnections	Hybrid circuit manufacturing
Design rule and layouts	Guest lecture on hybrid circuits
Pass transistor networks for gating	Surface mount technology overview
Circuit performance and protections	Surface mount components and construction
GaAs logic gates	Surface mount soldering techniques
Pad frames	Electroless deposition: multiple layer construction
	Guest lecture on surface mount manufacturing, from industry
	Tour: EMPF manufacturing equipment
	Integrated connections, cables
	Guest lecture on testing and viewing tapes from Automated Manufacturing Conference
	Advanced design of PCBSMT

their manufactured ICs from MOSIS with time remaining in the semester for laboratory testing. The remaining 10 weeks of the semester are devoted primarily to the study of surface mount printed circuit assemblies. In this phase of the course, lectures, recitation, laboratory design and testing are integrated with industrial tours in PCB manufacturing. Students use the L-Edit software package [1] from Tanner Research, Inc., for the ASIC design segment of the course and the PADS Work software package [2] from PADS Software, Inc. to design surface mount and through-hole PCBs. The IBM platform is useful for both software packages.

Student assessment over textbook material and the assignment of approximately five articles from appropriate trade journals is accomplished through quizzes and two written examinations. Assessment on the use of course-related software is based on the completion of laboratory assignments and a third examination.

Typical experiments and projects in the course

The course begins with the student considering the design of a complex electronic system. As the first step of the educational process, students provide the system into subsystems, which in turn can be designed using a combination of CMOS technology and through-hole or surface mount technology. Choices are based on the nature of the electronic specifications and power dissipation of the subsystems, their complexity, and the inclusion of passive and active components. Students usually start with L-Edit [1]. They start with the block diagram of an IC and convert it to a logic diagram. After simulating it with SPICE, students lay out the circuit library components. In some cases, students specify their own custom design components to achieve better system performance. After the layout design has been checked with the design rule checker (DRC), the students send their Caltech Intermediate File (CIF file) via e-mail to MOSIS for fabrication. Typical projects conducted during this phase of the course include the design of sequential circuits such as burglar alarms and traffic controllers, binary adders/multipliers, MUXs, memory design, ADCs and DACs.

In the second part of the course, students complete software assignments on the following: schematic capture, PCB layout, advanced board layout techniques for high-speed circuits, solder reflow and component handlers. Students use the PADS Work [2] software to design PCB layouts and to gain familiarization with library components. In these assignments, students are given design projects, and they may utilize both the library and custom design components of the software package. Figure 1 shows in block diagram for the various phases of the manufacturing process that students study in the course [3].

OUTCOMES FROM THE CURRENT COURSE

From assessment of student satisfaction with the course and from job placement feedback, we have found that the course has satisfied both faculty goals and student expectations. Two significant benefits of the course lie in its impact on the student's curriculum and career. The impact of the course on placing graduating seniors has been positive, particularly when students subsequently do a senior project in electronic manufacturing.

Several students have completed their senior projects in areas related to the course content. They work closely with teaching faculty, the professional staff at EMPF, and engineers and CAD operators at a local PCB board fabricator. In these projects, students begin with a circuit design which needs little or no modification before it can be breadboarded and tested. Examples of recent designs are a multiplier/divider circuit, a heart rate monitor and a demonstration timer. Students research the availability of parts for the given design, then use PADS Work to lay out the PCB and generate all the artwork files required by the board fabricator. They also select a package and complete the design of the finished product. While the bare boards are being produced by the board fabricator, the students attend training sessions at the EMPF where they receive instruction in automated component placement, wave, reflow and hand soldering techniques, cleaning and inspection operations. When the bare boards arrive, the students apply all they have learned by performing component placement on the boards, soldering [4, 5], cleaning [6], inspecting and testing, all under the supervision of EMPF technical staff.

Of the first 23 students who took the course, 15 sought engineering positions. Eight of the remaining students are still in school as undergraduate or graduate students, and four continued on in positions they held during their pursuit of the degree. Of the 15 students who found new positions, eight found positions in electronic manufacturing, attesting to the positive experiences they received in the course. The ASIC part of the course helped prepare

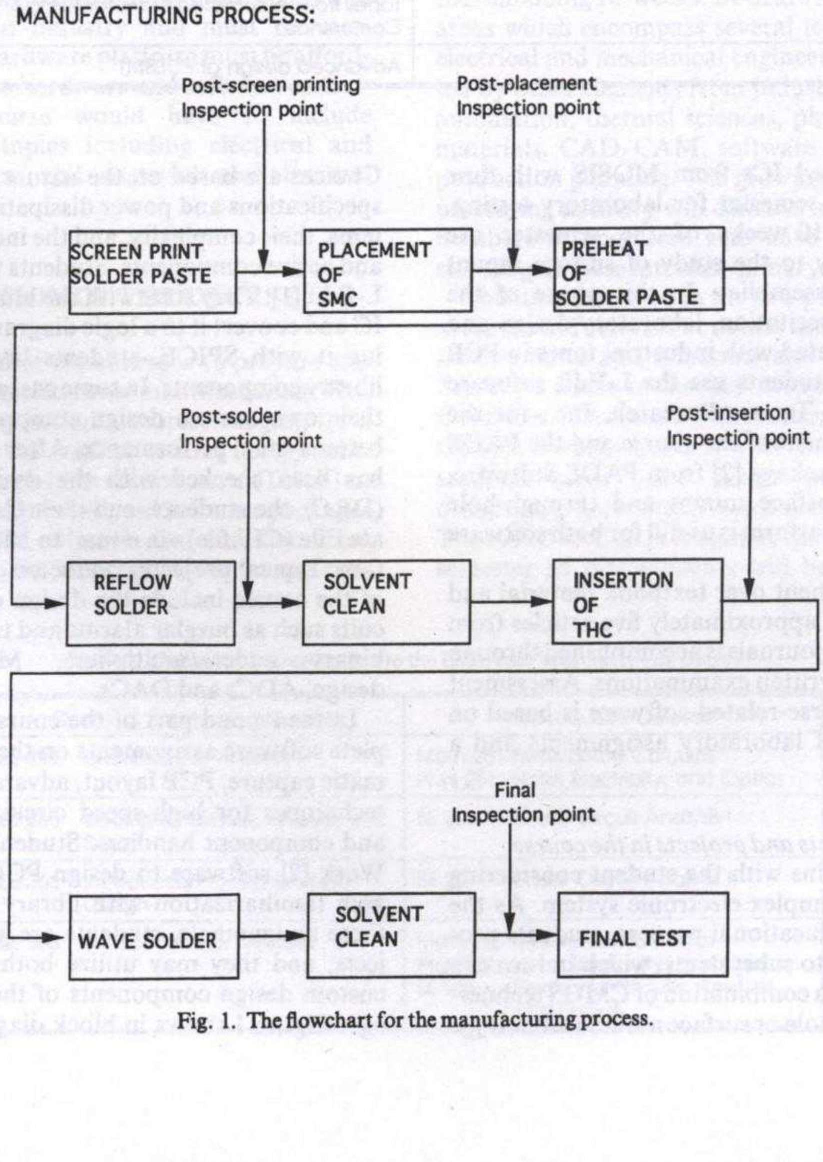

Fig. 1. The flowchart for the manufacturing process.

students who pursued graduate education in computer engineering and solid state electronics.

PORTABILITY OF THE COURSE

The faculty team felt that it was important to determine if this type of co-operative course development between university and industry can be adopted practically by other schools. To do so, we conducted a survey of 15 companies across the United States on their attitudes toward linking with universities, with 10 reporting back. The survey sheet described the current trend in engineering education of forming a working partnership in the delivery of educational experiences. We also indicated that in some cases, the company allows the university to use their facilities for hands-on experiences. We asked particularly about their interest and attitude toward this linkage. The responses of these 10 companies are summarized below:

- Three companies are currently involved in such partnerships, four companies have not been involved and would be willing to consider forming the partnership, and three companies have been involved in the past and would be willing to consider new partnerships.
- Nine companies indicated that they would allow students to perform laboratory work in their facility at no cost to the university.
- Two companies indicated that they would be willing to provide technical staff to team-teach the course, and seven could not comment at this time.

The results of the survey indicate industrial support for educational partnerships with universities, and that companies are willing to support and sponsor design projects. They may also be willing to provide technical staff to participate in team teaching and project design. The course, therefore, can be duplicated in many universities that have faculty expertise in this area.

THE INTERDISCIPLINARY FACULTY TEAM

For this course, our school co-operates with EMPF, one of four Navy Centers of Excellence. EMPF, whose mission is to provide a link between developers and users of technology by providing management support, workforce training and technology education, is equipped with the latest in advanced electronic manufacturing capabilities. Students are taught the design, simulation, and testing of IC circuitries and surface mount assemblies in the classroom and laboratories on the campus, and they are taught the manufacturing process in the EMPF facility. This arrangement enables students to benefit from motivational, hands-on experiences by engaging in the actual manufacturing process. Such an arrangement requires that students take only half-day trips to the manufacturing plant. Thus the plan can be implemented by universities even though participating industries are some distance from the school.

CONCLUDING REMARKS

From the faculty point of view, hands-on experience in the real world of a manufacturing facility has been successfully integrated into the course with successful motivational influences. Real-world electronic manufacturing serves as an ideal environment to introduce state-of-the-art software and state-of-the-art manufacturing processes that have been integrated into the course. From the point of view of the students, they report that the 'real' engineering experiences gained in this course have given them a better idea of life after college, showing students that engineering is not just textbook learning. In the future, this course will be expanded to include instruction in team-building and group skills. Since many of the students enrolled in this course expect to work in the electronic manufacturing sector, where they usually end up working on project teams, students will benefit from this instruction. This will be added in response to the feedback from local industries that suggested that we incorporate team-building skills into the course.

The team of faculty that developed this innovative course has found this to be a rewarding experience.

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