

Industrial Design Projects in a Junior-Level Digital Systems Design Course

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Abstract

We present a junior-level one-semester course in digital systems design, taken by all Electrical and Computer Engineering students, in which we have integrated a significant design project. Many of the design projects have been mentored by local companies. The industry mentor, together with the instructor, is responsible for defining the problem, reviewing designs, providing project guidance, and funding the project. In this paper we focus on the projects mentored by Smiths Aerospace. We present the project goals, deliverables, and the long-term benefit of the project to the company. We also present the perspective of the company on their involvement with the design projects.

Introduction

The senior capstone project course in our undergraduate engineering program primarily comprises industry-mentored and sponsored projects. We consistently receive positive evaluations of this course from both students and industry mentors, many of whom return year after year to sponsor new projects. The success of the capstone project course has encouraged us to attempt industry-mentored projects at the junior level as well. Our goals in doing so are to improve student motivation, improve student understanding, and to better prepare students for the capstone project.

The junior-level course described in this paper is EGR326, Advanced Digital Systems. This is a course taken by all Electrical and Computer Engineering emphasis students in the first semester of their junior year. Our engineering school has a secondary admission program and a two-year engineering fundamentals course sequence that is nearly the same for all engineering emphases (computer, electrical, mechanical, and product design/manufacturing). This program structure means that the first semester of the junior year is the first time that the ECE students are together as a cohort for the first time. At this point, the ECE students will have had, among other fundamental courses, introductory courses in C programming, basic circuit analysis, and digital systems. Concurrent with EGR326, most students will take a second course in circuit analysis and a first course in electronic circuits and devices. This semester, then, is when ECE students are exposed to emphasis-specific advanced concepts in ECE, and as a result, it is traditionally a difficult semester for students.

The junior year is also a time for personal growth. We expect that students have had fairly well-defined projects and laboratory experiences up to this point. In their senior year, they will be required to work on a challenging, open-ended capstone project, reporting directly to an industrial sponsor, and with no final grade assigned until the project is complete and successful. In the junior year, then, we must effect a transition in academic maturity and self-confidence (in addition to technical instruction) that prepares students for the capstone project.

Smiths Aerospace designs and produces electronic systems for a variety of platforms. From its inception in 1943 as Lear Avia, Inc., later known as Lear Siegler and currently Smiths Aerospace, Smiths has been a leading supplier of state-of-the-art avionics products. Smiths navigation, flight management and data acquisition systems are standard on such diverse vehicles as the M1A2 main battle tank, F-15, F-16 and F-18 fighter aircraft, F-117, F-22 and B-2 stealth aircraft as well as the Boeing 737.

Smiths Aerospace has been a consistent supporter of both the junior-level and senior capstone project courses. In this paper we focus on the junior-level projects mentored by Smiths Aerospace. We present the project goals, deliverables, and the long-term benefit of the project to the company. We also present the perspective of the company on their involvement with the design projects.

Course Structure

EGR326 comprises both traditional lectures and laboratory/homework assignments in addition to the course project. The homework assignments are concentrated near the beginning of the course to allow students to focus on their projects near the end. The project occupies the entire semester. It is divided into several sub-tasks, as diagrammed in Figure 1.

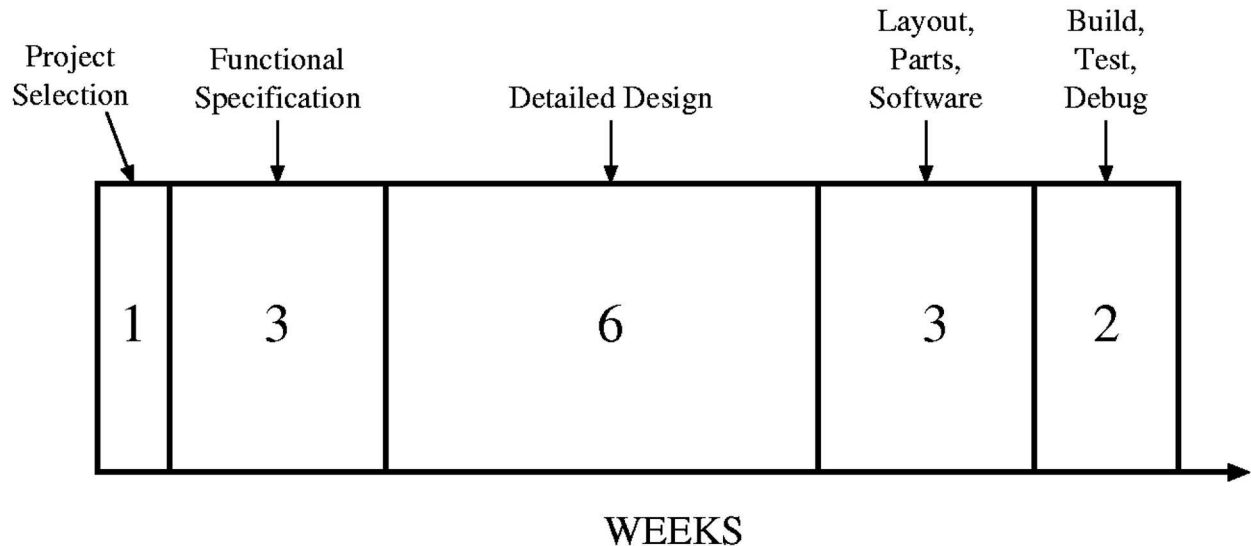


Figure 1. Timeline of the course project's activities in a 15-week semester

Team Selection

The first activity in the course is team selection. On the first day of class, students are required to complete a brief survey on their skills, interests, and work habits. This information, together with each student's academic history, is used by the instructor to assign teams. In the past, student-selected teams were allowed, but this did not lead to good results. Team assignments are announced on the second day of class. Teams are chosen to match academic profiles and diversity in emphasis areas (electrical and computer) as well as skills and interests. Most teams comprise three students, although teams with 2 or 4 students are possible.

Project Selection

The next activity in the course is project selection. A project must be selected within 1 week of the start of the semester. We have experimented with both student-selected and assigned projects. Both approaches work well, although the instructor must be very careful to select the right level of difficulty. In the most recent course offering, students were given a list of possible projects and told to rank-order their preferences. The projects sponsored by Smiths Aerospace were highly ranked by most teams, as expected. Students always seem to be most motivated by and interested in "real" projects.

Functional Specification

By the end of the first month, each team is required to submit a functional specification for their project. This task develops skills in report writing, determining customer requirements, translating requirements to specific deliverables, and describing the functionality of a system without knowing exactly how that functionality will be implemented. After an initial meeting with the sponsor to determine project requirements, the student team may

consult with the sponsor to clarify the requirements and negotiate deliverables.

Students find this part of the project experience to be quite difficult. They generally have had no experience designing an entire system, thus often present either too much or too little detail. They will often want to describe implementations rather than black-box functionality. We find that the process of constructing a functional specification is invaluable, however, as it sets their goals for the remainder of the semester, and prepares them for a similar task in the capstone course.

Design Review

After the functional specification is approved, a detailed design of the project begins. One of the main challenges in this process is that students are learning about the technologies behind their project in class at the same time as they are trying to use those technologies in designing their projects. Close guidance from the course instructor is crucial at this stage to ensure that not too many dead ends are encountered. In theory, there should not be much contact with the industrial sponsor at this stage. However in practice, some project specifications may need to be adjusted based upon students' findings regarding component availability, cost, etc. These changes need to be negotiated with the sponsor.

The design process culminates in an oral presentation from each project team to the rest of the class, the instructor, the industrial sponsor, and other invited guests (including faculty and former students from the class). Each team has approximately 15 minutes to present their project design, including a complete schematic, bill-of-materials, and any necessary background material or calculations to support their design. A question-and-answer period allows the sponsor to raise questions or concerns about the design.

Final Presentation

The final part of the course involves ordering components, completing a circuit board layout, sending the board out for manufacture, soldering the components, and writing firmware. This is an intensive part of the course that, for most teams, culminates in a few long nights as the project deadline draws near. On the last day of class, each team must present their finished project to the public, including the industry sponsor.

Example Projects

This section describes some of the projects that have been completed for Smiths Aerospace as part of EGR326.

Multi-Purpose Digital Interface

The multi-purpose digital interface (MDI) is an interface adapter between a PC and several sensor and actuator components. The motivation behind the MDI was to allow an engineer to use a uniform hardware and software interface to A/D converters, D/A converters, and other devices rather than have a custom interface to each one. The MDI has 16 I/O signals that are individually controllable with 500ns resolution, as well as a 16-bit bidirectional data bus that is connected to a 32K static memory. A photograph of the MDI is shown in Figure 2.

MDI behavior is programmed using a custom, low-level scripting language. An engineer develops an interface by describing a sequence of events on the I/O lines and the data bus. For example, a sequence of events for capturing an A/D reading would be:

- Set the GO signal (one of the I/O signals) high to the A/D converter
- Wait until the DONE signal is asserted low from the A/D converter
- Capture the contents of the 16-bit data bus to the next memory location
- Negate the GO signal to the A/D converter

These operations can be placed in a loop to perform multiple consecutive acquisitions.

The MDI comprises a single 4-layer circuit board with primarily surface-mount components. The design is centered around an Atmel ATmega128 processor operating at 16 MHz.

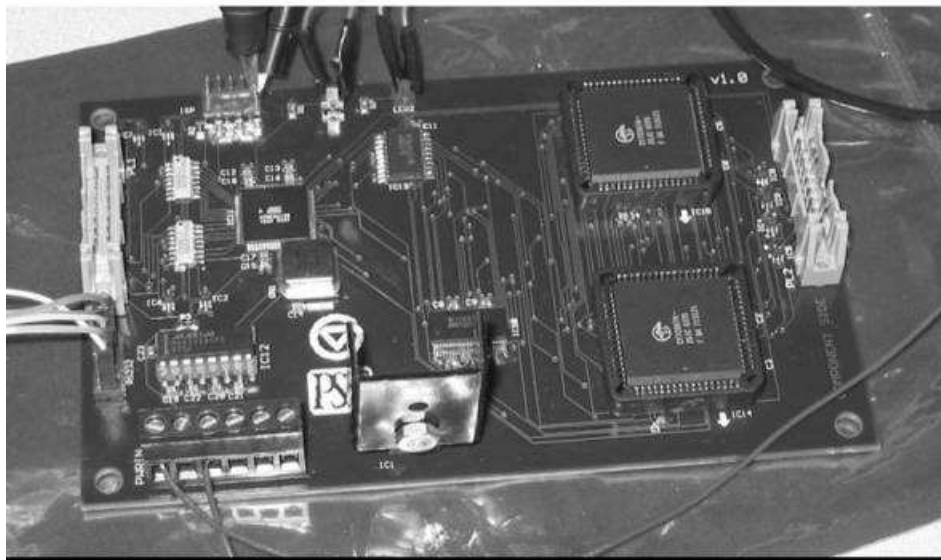


Figure 2: Photograph of the Multi-Purpose Digital Interface

Sinusoidal Waveform Generator

The sinusoidal waveform generator is a test instrument that provides an adjustable frequency/amplitude sine wave along with a white noise source of adjustable power. The specifications for this instrument were too demanding for the students assigned to this project, and while they were able to construct a unit capable of generating sine waves in additive white noise, they were not able to meet the performance requirements set for them. The responsibility for this failure is shared between the students (who did not work on this project at first with the required level of effort) and the instructor, who failed to identify that the demands of this project were beyond the capabilities of first-semester juniors. Since EGR326 is taken before the first course on Signals and Systems, and concurrently with the first course on electronic circuit design, the necessary background concepts, and even basic terminology, for a successful design was not in place.

The completed design comprised two circuit boards, a microcontroller board with an Atmel ATmega162 processor operating at 16 MHz, and a linear power supply board (both designed by the students). A photograph of this project can be seen in Figure 3.

Programmable Transient Generator

The programmable transient generator is a test instrument intended to simulate power supply transients. It is capable of generating millisecond-resolution transients that switch between two voltage levels (up to 100V) and source up to 15A. The duration and repetition rate of the transients is programmable through a keypad/LCD interface.

The design comprises four circuit boards (all designed by the students) including a microcontroller board based on the PIC16F877, a linear power supply, a switching board, and an overcurrent sensing and management board. A photograph of the programmable transient generator is shown in Figure 4.

Industrial Perspective

Design and subsequent production support of Smiths' products requires complex and specialized test equipment. In the past Smiths has had to resort to purchasing custom designed equipment or developing in-house designs. Commercial vendors are often reluctant to provide custom test equipment. If they are willing to develop it the cost is usually prohibitive.



Figure 3: Photograph of the Sinusoidal Waveform Generator driving a sine wave into an oscilloscope



Figure 4: Photograph of the Programmable Transient Generator

While Smiths has had success in the past with designing and building specialized test equipment, it places a burden on the company's internal resources. Normally this activity can only be supported during slow work times. This development, then, is often not concurrent with the actual need.

It has been only in recent years that Smiths has explored the idea of using college class projects as a means of acquiring some of this specialized test equipment.

The Programmable Transient Generator was originally conceived as an update to a piece of test equipment designed at Smiths several years ago. The original equipment was analog in nature, relying on analog timers to set the timing. The precision requirements of the timing, demanded by customers, were achieved by turning knobs and monitoring the resulting waveform with an oscilloscope. The project designed by Grand Valley State University students was

digitally programmable. This greatly simplified the interface for the design engineer and reduced test time accordingly.

The Programmable Transient Generator was the first collaboration between Smiths and Grand Valley State University on this type of endeavor. As such there was much that Smiths engineers did not understand about the ability of the students at this level. Consequently, the scope of this project exceeded the ability of the students involved. Most of the required analog design was beyond the understanding of the students and considerable support was required by Smiths. Some of the more subtle features desired of the project remained inoperative at the completion of the project.

Nevertheless, the Programmable Transient Generator finds itself in constant demand in Smiths laboratories for the checkout and verification of power supply designs. An improved design has been commissioned in support of the capstone project which will not only solve the inoperative features issue but will significantly extend the capability of the original design. In fact the project was so successful that Smiths has participated in additional projects.

The Multi-Purpose Digital Interface is used regularly in testing and development of another Smiths product, the Analog Processor Unit. During the analog development phase of this unit the design of the complex digital control is usually not sufficiently mature to use in control of the analog acquisition circuitry. The MDI allows the designer to interact with the analog circuitry, accumulate data and process it on a standard PC.

Participation in the junior-level project course has provided Smiths with the opportunity to develop moderately complex test equipment while avoiding most of the pitfalls noted above.

Smiths has been able to interface with many potential employees through this process and has subsequently hired several of the project participants. In working with Smiths on their project the students begin to get an idea of the process structure and the people at Smiths. This exposure reduces the indoctrination phase when/if these students are ultimately hired.

Most of the students that Smiths has encountered have been knowledgeable and enthusiastic. Smiths engineers have tried to provide mentoring by pointing students in the correct direction without necessarily providing an answer which might be evident to a seasoned designer. Even if they are not ultimately hired at Smiths the insight into the working environment and the hands-on mentoring that Smiths employees provide can only serve to enhance their eventual career.

Summary

A junior-level design course in digital systems has been presented. In partnership with Smiths Aerospace, several design projects were completed by teams of electrical and computer engineering students. The mentorship provided by Smiths has allowed several students to experience the standards, practices, and culture of the engineering workplace, while engaging in significant and meaningful design work. In return, Smiths has acquired customized test equipment that would normally be difficult to obtain due to design costs or lack of internal resources. Smiths has also been able to evaluate potential future employees through their involvement with this course. The level of difficulty of the course projects is necessarily below that of the senior capstone experience, and not all projects are successful (unlike the capstone project, in which an Incomplete grade is assigned until the project is complete). Over time, both Smiths and the course instructor are improving their understanding of the scope and nature of projects that are likely to be successful.

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Biography

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