Session 1526

The CSM Electronics Prototyping Facility

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Why an Electronics Prototyping Facility is Needed

Most electronic laboratory projects require building simple circuits that are torn apart as soon as the lab is over -- resulting in a limited opportunity for the students to construct anything useful. Students are often frustrated in electronics courses and laboratories as they never quite get to the level where they can design and build anything practical.[1] The CSM Electronics Prototyping Facility (EPF) provides students with the tools to design and build electronics equipment for real engineering applications. It is a powerful tool to reshape the way students learn and think about electronics.

The Electronics Prototyping Facility brings a vertical integration of design software, programmable devices and local (quick) printed circuit board fabrication that gives the users the ability to create prototype electronic circuit boards in a matter of hours instead of days; the use of programmable logic devices (PLDs) permits the modification of existing circuits in minutes. This has brought a capability to our undergraduate laboratories to design and construct circuits that used to be abstract problems because the implementation was too difficult or expensive. For the first time, the process of design and construction of a significant circuit on a high-quality printed circuit board becomes possible, economical and desirable for undergraduate education.[2]

The electronics industry uses concurrent engineering and other methods to improve productivity by breaking down the barriers between design and production.[3] However, concurrent engineering cannot remedy the basic problem -- many working electrical engineers have no training in electronics production methods. With limitations in time and equipment, electrical engineering four year degree programs concentrate on developing the fundamentals and theoretical understanding of their students. It has been my experience that graduating electrical engineers have a good understanding of electronics but lack the ability to take a design from concept to fabrication. When these engineers enter the workforce, they must then learn electronics production skills on the job and industry must cope with the resulting lower productivity. Given the needs of students and industry, it seems only natural that electrical engineering degree programs ought to give their students a basic preparation in production skills to enable their graduates to function better as working engineers. [4-7]

Educational objectives

To get the real benefit from this facility, we feel it is necessary to rethink the way we teach undergraduate electronics laboratories to emphasize the ties between design and fabrication and to develop modular electronic projects that build on each other in an appropriate manner. A previous paper discusses how our Junior level electronics classes make use of this EPF as part of our standard electronics laboratory instruction.[8,9]

Our specific educational objectives include the following:

(1) To familiarize the students with the manufacturing process for printed circuit boards and have them learn industry-standard software design tools used in the design and production of electronic systems
(2) To revitalize our electronics laboratories by providing a new means to “build up” from smaller modules to a significant system that re-enforces learning and design
(3) To enable the students the means and the practice of implementing their design and breakdown the barriers between theoretical understanding and practical implementation.

These are far reaching objectives and cannot be the result of one project. Rather, they are the cumulative result of sequence of projects throughout our electronics curriculum.

About the Electronics Prototyping Facility

The CSM Electronics Prototyping Facility brings together an integrated set of tools to give our students the ability to design, simulate, fabricate and test electronics systems. This facility was developed to better prepare our students to enter the workforce by giving them the basic hands on skills they need in electronics system fabrication.

Our facility is currently used in our Junior level electronics laboratories and is available for use in our Senior level classes, each with a class sizes of about 40-50 students. In order to achieve our educational goals, each student team designs and fabricates their own unique circuit board for each project. This results in a high mix, low volume prototyping environment, quite different from typical manufacturing needs. Over the past several years, our students have completed over 300 different PCB layouts and fabricated a total of 500-600 boards.

Figure 1. Shown is a outside view of the CSM Electronics Prototyping Facility.

The development of this vertical integration of hardware and software tools has required a substantial effort over several years. There are many methods to accomplish each of the tasks for electronics system fabrication. For each method there are a number of competing considerations including cost, safety, space requirements and feasibility in a university setting.

Electronic System Production Steps

Step 1 Identify the problem

Extract design specifications
Total time: Typical for laboratory projects is a few minutes

Step 2 Analysis and initial design

Consider details of implementation and tradeoff considerations
Simulate to verify performance
Total time: Typical for laboratory projects is about an hour

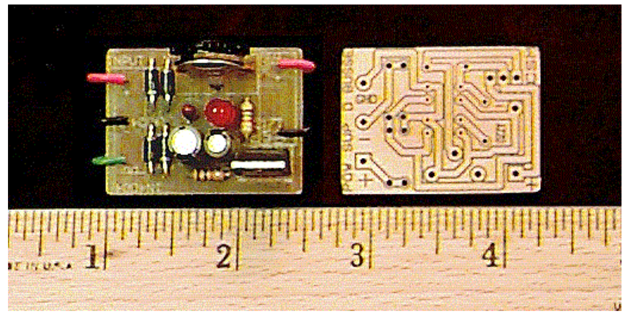

Figure 2. Photographs of the first project students complete - a linear power supply.

Step 3 Schematic Capture / Documentation

Part selection and set external interfaces
Total time: Typical for laboratory projects is less than one hour

Step 4 PCB Layout

Considering physical positioning, noise issues, connectors, access, etc.
Total time: Typical for laboratory projects is 2-3 hours

Step 5 PCB Production:

Mill/drill production of PCBs:

PCB board preparation (isolation of traces, positioning, text, etc.)
Run CAM program to control drilling/milling
Drill, mill (one or two sides), route out PCB board
Total time: 1-3 hours for 1 to a few PCBs

Step 6 PCB Assembly

Test PCBs (if necessary)
Manually populate with parts
Manual soldering, clean PCB
Total time: Typical for laboratory projects is 1-2 hours

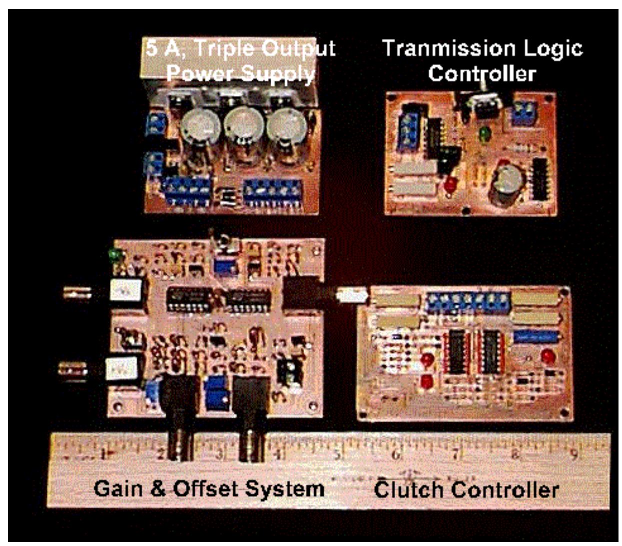

Figure 3. More advanced student projects fabricated the prototyping facility.

Step 7 Electronic system integration

Test sub-systems for functionality
Connect sub-systems into a system and add user interface as necessary
Test system
Total time: Typical for laboratory projects is less than an hour

Total time for entire project: Typical for laboratory projects is about 9-12 hours using the Electronic Prototyping Facility

Function	***CSM Electronics Prototyping Facility Tool***	***Pros***	***Cons***
Simulation	Microsim Pspice (student version)	Free	Some limits, generally good for student projects
Schematic capture	Protel Schematic Capture®	• Educational Discount • Full feature • Coupled to PCB Layout	No connections to circuit simulation, not industry standard
PCB Layout	Protel PCB Layout®	• Educational Discount • Full feature • Coupled to Sch. Cap.	Not industry standard
Programmable Logic Devices	Altera MaxPlus2® and Logical Devices CUPL®	• Educational grant • HDLs Industry accepted • Simplifies prototyping by allowing fewer ICs	• Time to teach • Cost and maintenance • Fine pitch ICs are hard to manual solder
Printed Circuit Board (PCB) Manufacture	T-Tech QC-7000® Mill/drill machine	• Local/quick PCB fab. • Good for single/double sided PCBs • Low cost per PCB • Traces/holes aligned	• High initial cost ($10-15k) • Space, dust issues • Additional software and board preparation tasks
Part Insertion	Manual	• Cheap/easy/quick	• Time, reliability issues
Soldering	Manual soldering Metcal SMT Stations	• Industry standard • High quality soldering experience	• High cost limits wide use • Lower cost stations are adequate for most projects
Inspection	Vision System Mantis® optical inspection (stereo, wide view)	• Easy to use • Needed to see details (esp. surface mount)	• High cost • Not required for simple PCBs
Operational Testing	Standard laboratory bench test equipment (scopes, DVMs, etc.)	• Easy to use • Uses available equipment	Limited ability to test

Table 1. A detailed description of our implementation of the main functions for the CSM Electronics Prototyping Facility.

Greater detail into the particular methods we use here at CSM to accomplish the various design/production functions previously mentioned is provided on Table 1. For each function there are many possible methods/tools available on the market. A number of our choices were driven by cost -- some tools are used because we were able to receive substantial educational discounts and grants. Another issue is that all of our computers available for general use are personal computers, not workstations. Thus, the CAD/CAM tools we selected were constrained to run on personal computers.

The key step in the Electronics Prototyping Facility is the production of PCBs. There are a number of issues to consider in this selection process. First, a school/university environment is much different than a production facility. To get the benefit of hands-on instruction, each student must take their PCB through the production process. As a result, each student then must be trained to complete the production steps in a safe and timely manner. Additionally, the student projects tend to be very sporadic with a high demand for PCBs when projects are due. There are a number of methods to produce a printed circuit boards including using commercial board shops, various chemical means, hobbyist kits, and mill/drill.

Most PCB fabrication methods use a significant amount of chemicals which leads to very real safety concerns given students are directly involved and issues in handling dangerous chemicals (acids with heavy metals, photoresist, etc.). With appropriate instruction, production of PCBs can be safely accomplished using this standard chemical method in a university setting as demonstrated by CalPoly[10] and others.[11] Here at CSM, there is a high direct cost for chemical disposal and this was a major factor in the decision to acquire a mill/drill machine for PCB fabrication.

Electronic Prototyping Facility Components

The list below itemizes the major components in the CSM prototyping facility. A number of the vendors for these items offer educational support programs to help sponsor schools to acquire their products.

Space: One enclosed room of size 18 m^2 (200 ft^2) with outside venting (Figure 1).

Computers:

- One computer dedicated to mill/drill machine control
- Two dedicated workstations for simulation, PCB layout, etc.
- Sixteen shared "CAD Lab" computers for circuit simulation, PLDs, PCB layout, etc.

Figure 4. The dedicated computer and controller with the QC-7000 Mill/drill machine in the back.

Special Software

- Microsim's Pspice® (free student version) for circuit simulation
- Protel's Schematic Capture® and PCB Layout®
- Altera's MaxPlus2® PLD Toolset used for complex PLDs
- Logical Devices CUPL® PLD Tools used with simple PLDs (GALs).
- Gcode's Isolator® for PCB preparation for CAM (sold through T-Tech, Inc.)
- T-Tech's CAM program for control of mill/drill machine (free with machine)

Hardware

- One T-Tech, Inc. QC-7000® Mill/drill machine (Figure 4) with vacuum to remove dust
- Three Metcal surface mount solder stations (Figure 5) plus various standard low cost soldering stations
- A Vision System Mantis® optical inspection station for PCBs, soldering, etc. (Figure 5)

Miscellaneous

- Workbenches and various handtools, drill bits, PCB material (Figure 5)
- Electronic parts
- Tables, cabinets, chairs

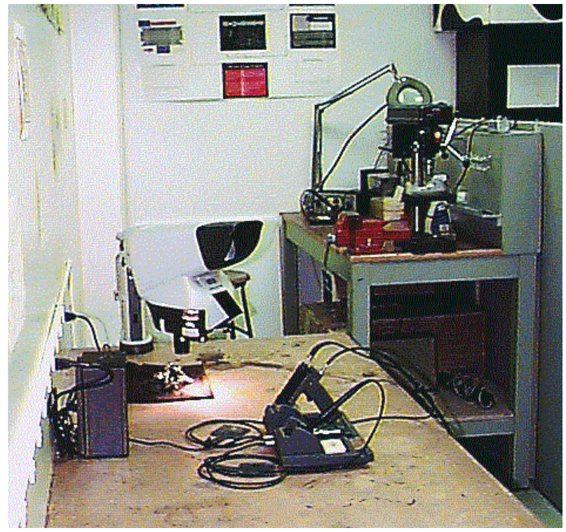

Figure 5. Workbenches with assembly tools.

Conclusions and Impact

We have developed a new type of electronics prototyping facility to provide our students the tools they need to fabricate electronic systems. This facility is a vertical integration of software design/simulation tools with the means to produce printed circuit boards and then assemble/test the system. This facility is used as a standard part of our electronics laboratories and student projects. Using this facility, students have constructed projects ranging from simple power supplies to RF communication systems to complex data acquisition systems. The students not only learn key skills in electronics production, but also benefit from the satisfaction of designing, building and using working electronic systems. The enthusiastic response from both the students and industry employers indicates this approach may be of interest to other sites.

The impact of this facility has been several fold. First, all of our electronics specialty students are exposed to production processes as a natural part of their Junior year electronics laboratory projects. They enter the job market with skills and experience that is important to many employers. Second, as students progress to their Senior year, they then use their production skills to implement many of their laboratory and Capstone Design projects. This enables them to attempt projects that could not be done otherwise due to complexity and/or cost. As a result, *they end up with a higher level of design skills because they can implement their higher level electronics designs.* Lastly, the setup, use and curriculum for this facility has been disseminated among a wide group of educators. With a new educational emphasis towards concurrent engineering that combines an understanding of design and production, other institutions will be able to use this prototyping facility as a model in developing their own approach.

Based on my discussions with industry employers and my own experience, I believe it is important for students to graduate with the knowledge on how to make their designs become a reality. Without sacrificing other aspects of their education, we are able to improve our students learning experience and make it more relevant to their future needs as working engineers through the use of our prototyping facility.

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[10] CalPoly's Industrial Engineering Program facilities include a chemical PCB facility, sheet metal shop and NC mills for prototyping of electrical/mechanical systems
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Biographical Information

Dr. Christopher G. Braun received his S.B. from MIT in 1982 and M.S. and Ph.D. from USC in 1984 and 1987, respectively. Since 1992 he has been a professor at the Division of Engineering at the Colorado School of Mines. Dr. Braun is very active in developing new approaches in teaching electronics. He can be reached at cbraun@mines.edu.