Integration of a Circuit Board Milling Machine into an ECE Curriculum

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Abstract

Three years ago, the Department of Electrical and Computer Engineering at Lafayette College purchased a printed circuit board milling machine system and began integrating its use into the ECE curriculum. The system has been enthusiastically accepted by our students and the faculty. This paper will describe our experience with this printed circuit board milling machine. Specifically, the paper will describe how the machine is being used in a number of courses ranging from our first-year Introduction to Engineering course, through sophomore and junior year laboratory projects, to our capstone senior design course. The integrated design process used by our students to design printed circuit boards will be described and several representative designs will be discussed to demonstrate the level of design complexity that can be achieved using this technology. Finally, some initial assessment data regarding student reaction to the PCB milling machine is provided.

I. Introduction

Virtually all fundamental phenomena associated with the Electrical and Computer Engineering (ECE) discipline occur at the microscopic level, and therefore cannot be observed by the naked eye. This makes it difficult for students to establish an intuitive sense of the discipline. Furthermore, many students who have good "hands-on" engineering skills are turned off by the abstract nature of our discipline. Therefore, it is important to introduce students to key ECE concepts in the laboratory to ensure that students gain a practical appreciation of the theoretical concepts presented in lecture. In addition, it is important to provide the junior and senior year students with realistic, requirements-through-test and verification, design experiences in their independent projects. In these projects, the students design, construct, and test a fairly complex circuit or system; the project experience is broader in scope or greater in depth than a weekly laboratory experience. The difficulty, we have found, is that with the proliferation of advanced CAE/CAD tools, the level of project complexity proposed by both the faculty and the students has increased dramatically over the past ten years. Students desire to attempt projects that employ high frequency analog and digital circuitry, power electronics, embedded processors, or other complex components that lead to implementation difficulties. While the design tools are in place to support this type of project, the traditional breadboard construction of the designs often produces less than desirable results. In addition, this has happened most often with the more ambitious students who have tackled sophisticated projects, and it often leads to frustration during test, demonstration, or worst of all, the final presentation.

Student laboratory projects are typically implemented using circuit breadboard construction. Unfortunately, breadboard circuit implementations have several drawbacks. In addition to being difficult to neatly construct (and therefore easily troubleshoot), high frequency and high power electronics circuits are often impossible to breadboard due to the inherent limitations of this technology. Furthermore, breadboards are rarely used in industry for prototyping purposes. Alternatively, printed circuit board (PCB) techniques are much more attractive for circuit prototyping work in many instances. Unfortunately, manufacturing printed circuit boards typically requires a chemical etching process, making them inappropriate for student projects. However, at least two commercial companies now offer desktop milling machine systems that can manufacture prototype printed circuit boards quickly, safely, and at low cost, without a chemical process.

Three years ago, in an effort to find an alternative to either breadboard or traditional PCB technology, the Department of Electrical and Computer Engineering at Lafayette College purchased a printed circuit board milling machine system and began integrating its use into the ECE curriculum. Initially, the faculty envisioned that the PCB milling machine would be used primarily for senior honors projects and to support our senior-year design project sequence. However, as the seniors and the faculty advising them related successful outcomes using the PCB milling machine, more students and faculty began to investigate applications for the machine. Its use expanded to the junior project, sophomore laboratories, and our introductory freshman engineering course. We now see that the PCBMM has potential for use across the curriculum and even outside of the ECE Department. One of the engineering shop technicians has recently been assigned the task of learning the operational aspects of the circuit board milling machine, so that it can be used across department boundaries.

II. Integration into the Curriculum

To what extent has the PCB milling machine has been integrated into the ECE curriculum at Lafayette College? As previously mentioned, it was initially envisioned that the PCB milling machine would be used exclusively for senior projects. A primary goal of this two-semester senior design sequence is to provide the students with a significant and non-trivial research and/or design experience. Students may propose their own project or select a project from a list provided by the ECE faculty. In general, these projects are in depth, multi-faceted, realistic examples of engineering research and design. A later section of this paper presents several examples designs that illustrate the complexity and sophistication of projects undertaken which have relied on the milling machine.

In the first year of use, the PCB milling machine was used by two students in this senior design sequence. These projects were a microwave power divider and a microprocessor controlled pulse code modulation (PCM) motor controller. Almost immediately after the installation of the PCB milling machine in our Electronics laboratory, some of our junior electronics students expressed an interest in using the machine for their second semester electronics laboratory design project. This project may be proposed by the student or selected from a list provided by the faculty member supervising the laboratory. The only restriction is that the project must incorporate the analog design techniques presented in the Electronics II course. The department agreed to allow junior students to use the PCB milling machine for their projects provided they were willing to learn to use the system on their own time since no laboratory time was scheduled for this. Two students, comprising one of the eleven junior project teams, chose to use the PCB milling machine under these restrictions.

In the second year of use, the machine was again used for our senior design sequence. At the end of the second year of using the PCB milling machine, we had five of nineteen senior design projects and two of eleven junior electronics projects implemented using the milling machine. Again, no laboratory time was schedule for learning the PCB milling machine. We were pleasantly surprised that the student design groups found the independent learning to be an acceptable arrangement, as they invested a significant amount of their own time mastering the skills necessary to operate the machine.

In the third year, two additional courses leveraged the PCM milling machine capability. First, the instructor for the sophomore-level Digital Electronics I course redesigned the laboratory associated with this course to make use of the PCB milling machine. In this course, students have typically completed a multi-week laboratory to design a state machine to play a simple game called NIM. The implementation of this project employs PLAs and TTL logic, and had previously been done via a wirewrapped circuit board designed and wired by the students. Last year Digital I embraced the introduction of FPGAs into this first digital circuits course using the XILINX Foundation design tools. While the FPGA was suitable for implementing the state machine, the FPGA evaluation board used lacked the circuitry necessary for the user interface (pushbuttons and LED displays). Therefore, the instructor for this course worked with our electronics technician to design a daughter board to hold the necessary display LEDS. This board was fabricated on the PCB milling machine and was mounted to the FPGA evaluation board. It is envisioned that as new projects involving the FPGAs are designed, new daughter boards can be constructed to provide the custom I/O necessary to implement the designs. In the future, the design of the daughter boards also may become part of the students' responsibility.

Also in the third year, use of the PCB milling machine expanded beyond the ECE Department and is now being used to support our freshman Introduction to Engineering course. This course is taught to all of our engineering majors (160 students divided into

32 teams) and has a significant design component that involves principles from the four engineering disciplines offered at Lafayette College: Electrical and Computer, Civil and Environmental, Chemical, and Mechanical Engineering. This year the students participated in the design of a weather station which includes both an anemometer and temperature sensor. The PCB milling machine was used to fabricate the faculty-designed circuit board containing the electronic elements. Students were shown the design process used to manufacture the printed circuit board. This experience was well received by many freshman, some of which had no previous knowledge of electric circuits.

A summary of all the required laboratory courses in our ECE program is shown in Table 1. The table indicates which laboratories are currently making use of the PCB milling machine as well as the laboratories for which we see application of the PCB milling machine in the future.

LABORATORY	Typically Taken	Use PCB MM
Introduction to Engineering	Year 1, Semester 1	YES (Fall 1999)
Digital Circuits I	Year 2, Semester 1	YES (Fall 1999)
Digital Circuits II	Year 2, Semester 2	FUTURE
Analog Circuits	Year 2, Semester 1	NO
Electronics I	Year 3, Semester 1	NO
Electronics II	Year 3, Semester 2	YES (Spring 1998)
Computer Architecture	Year 3, Semester 2	FUTURE
Control Systems	Year 4, Semester 1	NO
Sr. Design I	Year 4, Semester 1	YES (Fall 1997)
Sr. Design II	Year 4, Semester 2	YES (Spring 1998)

Table 1. Required Laboratories and PCB Milling Machine Implementation

III. Design Flow

The Lafayette College ECE department purchased the Quick Circuit 5000 (QC5000) produced by T-Tech, Inc. of Atlanta, Georgia. This machine supports a broad range of file formats and works with a wide variety of CAD systems. To the best of our knowledge, no other undergraduate program uses this type of system in undergraduate coursework. The QC5000 accepts circuit boards as large as 10" by 11" and has a trace resolution of 4 mils. The system supports Gerber, Excellon/NC Drill, and HPGL file formats and is compatible with a variety of CAD systems including Protel, PADS, P-CAD, AutoCAD, OrCAD, and Tango. Analog, digital, RF, and microwave design prototypes are supported. The CAD tools currently used by Lafayette's ECE department include: ORCAD (PSpice), Xilinx Foundation, and HP Advanced Design System. The QC5000 system as installed in our Electronics Laboratory is shown in Figure 1. The generalized design flow starting with design calculations, through the use of CAD tools and PCB fabrication is shown in Figure 2.

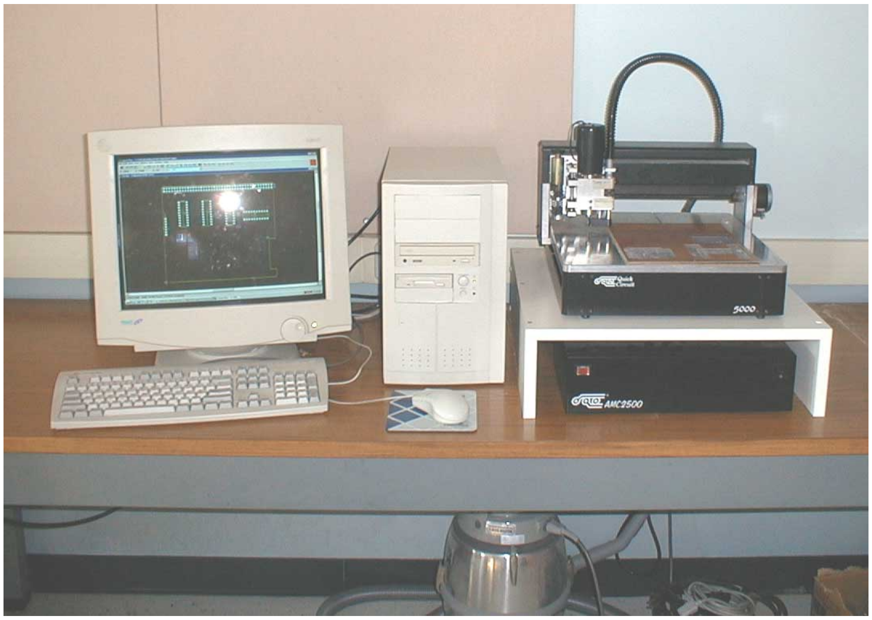

Figure1 QC5000 PCB Milling Machine System

Two primary CAE circuit simulation and design tools are integrated into the ECE curriculum, ORCAD/PSPICE for analog circuit simulation and XILINX FOUNDATION for FPGA design. Students are introduced to both software packages in their sophomore year. PSPICE is introduced in a first semester sophomore laboratory for the introductory course in Electrical Circuits, and is used primarily as a simulation (as opposed to design) tool.   XILINX is introduced in the two-semester sophomore year Digital I and II laboratory sequence and is used primarily as a design tool. The emphasis in the sophomore year is for the students to gain a reasonable mastery of designing successively more complex digital circuits using these tools. PSPICE also is used extensively in the two-semester junior year linear Electronics sequence. The first semester Electronics laboratories are fairly traditional and therefore PSPICE is used primarily as a simulation tool. However, in the second semester of Electronics, the students must complete a design project of their own choosing. PSPICE is used extensively to simulate and optimize these designs. In the past, the students would realize their designs using breadboards; the students are now given the option to implement their designs using the PCB milling machine.   It should also be noted that several students have used the Hewlett Packard Advanced Design System (HPADS) to design RF and microwave circuit boards for their senior design projects.

IV. Examples

The use of the PCB milling machine has expanded from its starting point as a tool for the senior design sequence and honors projects, across the ECE curriculum, and into the freshman introductory engineering course. The following examples illustrate the use of the PCB milling machine as an integral part of the coursework associated with Lafayette College's ECE program. These examples also will serve to show the level of design complexity possible with this machine.

Use in Introduction to Engineering

Figure 3 shows a weather station that contains and anemometer and a temperature sensor. The PCB for the electronics is also shown in the figure. This PCB was designed by the course instructor, however, students witness the PCB manufacturing process and learn to test the PCB board.

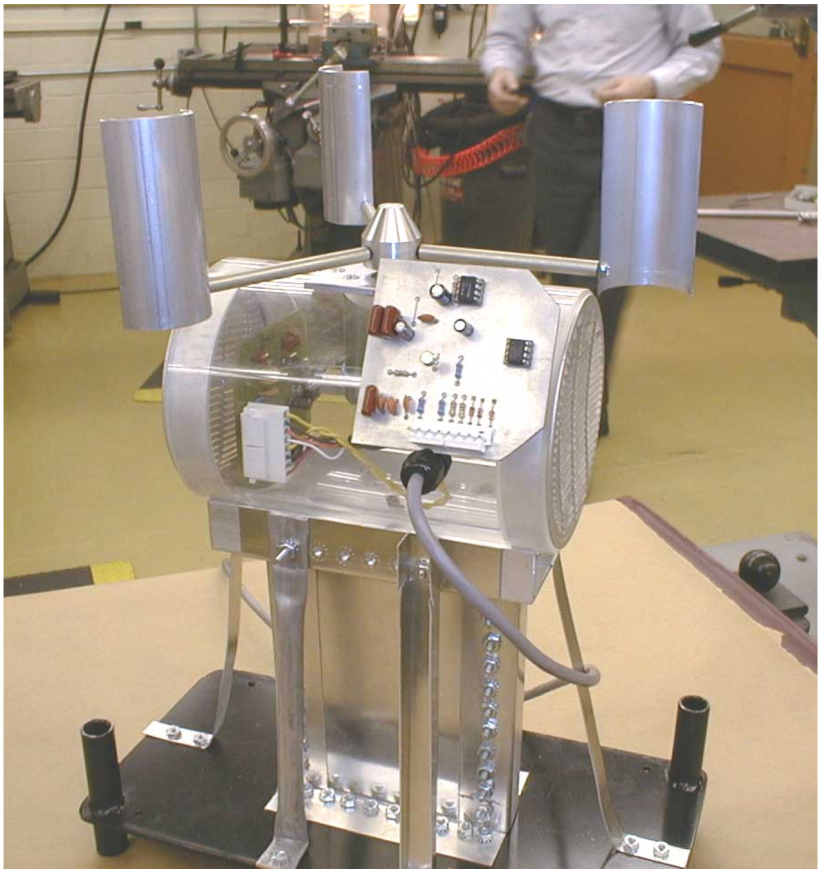

Figure 3. Weather Station

Use in Digital Circuits I

Figure 4. shows a PCB that was designed to provide a user interface for and FPGA application of a simple computer game. The PCB daughter board mates with the FPGA evaluation board. Other daughter boards may be manufactured for other application specific projects.

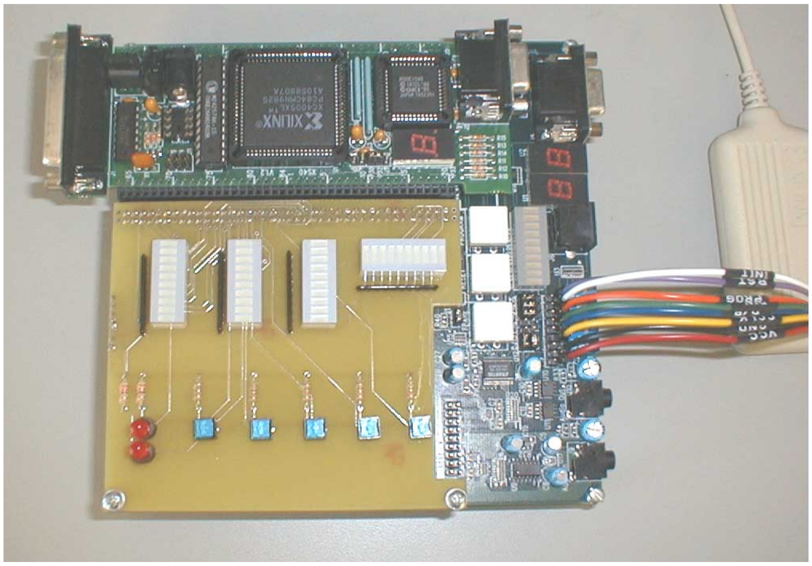

Figure 4. FPGA Daughter Board for User Interface

Use in Electronics Circuits II

Figure 5. shows a student designed circuit that is a wireless 315 MHz transceiver designed to transmit digital data using On-Off Keying (OOK).

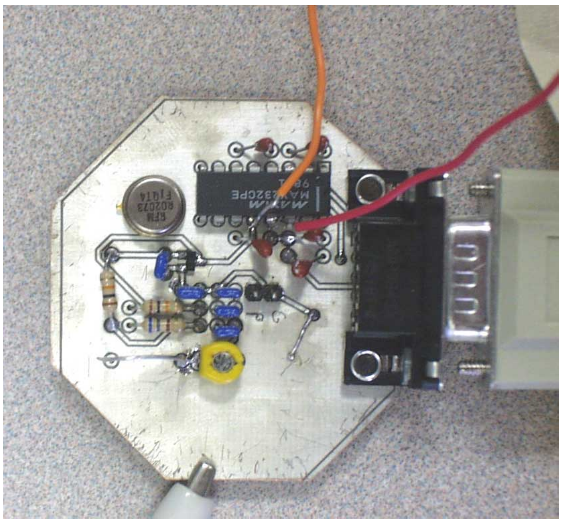

Figure 5. Student Designed Transceiver

Use in Senior Design

Figure 6. shows a student designed circuit that uses a micro-controller and FPGA that serves as the controller for a micromouse robot that navigates a maze. This project is currently in progress.

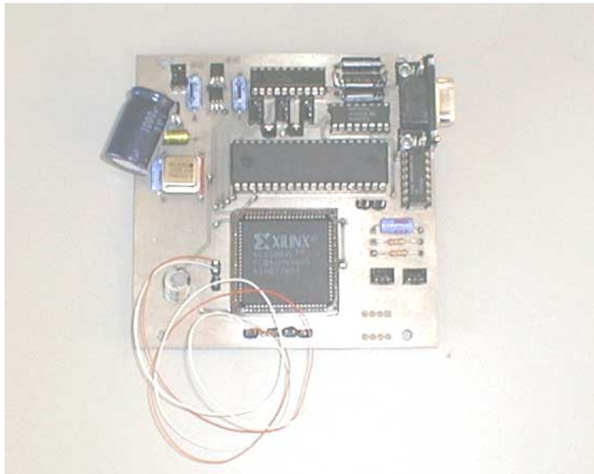

Figure 6. Student Designed Controller Board

V. Assessment Data

This was the first year the ECE department at Lafayette College conducted a formal survey regarding the use of the milling machine. Ten students from the current senior class participated in the survey. Seven of our ten senior students have used the PCB milling machine in either their junior electronics project or senior project. Seven of them used the PCB milling machine as juniors for their junior electronics project and four of them are using the PCB milling machine for their senior project work. The reason for the reduction in the number of students using the machine in the senior year is that five of the students are doing research oriented project work that does not require the construction of a prototype or the use of the machine. All seven students who have used the machine indicated that it took them from five to ten hours to learn how to use the machine. The students were also asked why they chose to use the PCB milling machine. The results are tabulated in Table 2.

Why did you choose to use the PCB milling machine for your project work?	Number of Responses
Project required PCB construction (e.g. high frequency or power circuits)	4 of 7
Packaging requirements necessitated PCB compactness	4 of 7
Circuit wiring complexity was reduced using PCB construction.	4 of 7
PCB layout is a good skill to learn.	6 of 7

Table 2. Reasons for Using PCB Milling Machine

The students were also asked a number of questions regarding their experience using the PCB milling machine using a scale from 1 to 5.

Rating: 1= (difficult) 5=(very easy)	1	2	3	4	5
Did you find the integrated suite of design tools easy to use?		4	2	1	
Did you find the PCB milling machine easy to use?		3	3	1	

Table 3. Ease of Use (7 respondents)

Drill bits breaking was the most common difficulty the students experienced. This occurs because there is a skill that must be developed to properly set the cutting depth for the drill bit. The electronics technician also initially experienced a high rate of bit breakage. This problem was eliminated as the operator gained additional experience with the machine. Finally, the students were asked to rate the overall value of their experience using the milling machine.

Rating 1 = (not valuable) 5 = (very valuable)	1	2	3	4	5
How valuable to you consider your experience with the PCB milling machine?		1	2	3	1

Table 4. Value of PCB Milling Machine Use (7 respondents)

VI. Conclusions

This paper described the use of a printed circuit milling machine in an undergraduate ECE curriculum at Lafayette College. Board level and chip level layout are important aspects of current ECE design that are often not adequately addressed in an undergraduate curriculum. The PCB milling machine forces students to worry about not only the function, but also the form and fit of their circuit design. While chip level design is difficult to effectively implement in an undergraduate curriculum, board level design can be addressed through the use of PCB design implementation. The PCB milling machine was initially acquired to circumvent the problems associated with chemically-based etching of PCB boards, and to provide a reliable circuit breadboarding strategy for senior-level ECE projects. Its applicability was quickly recognized for courses across the ECE curriculum. The Department is presently considering the installation of a second milling machine because of the increased utilization and because down time for a single unit could prove to be a critical problem for student designers under deadlines.

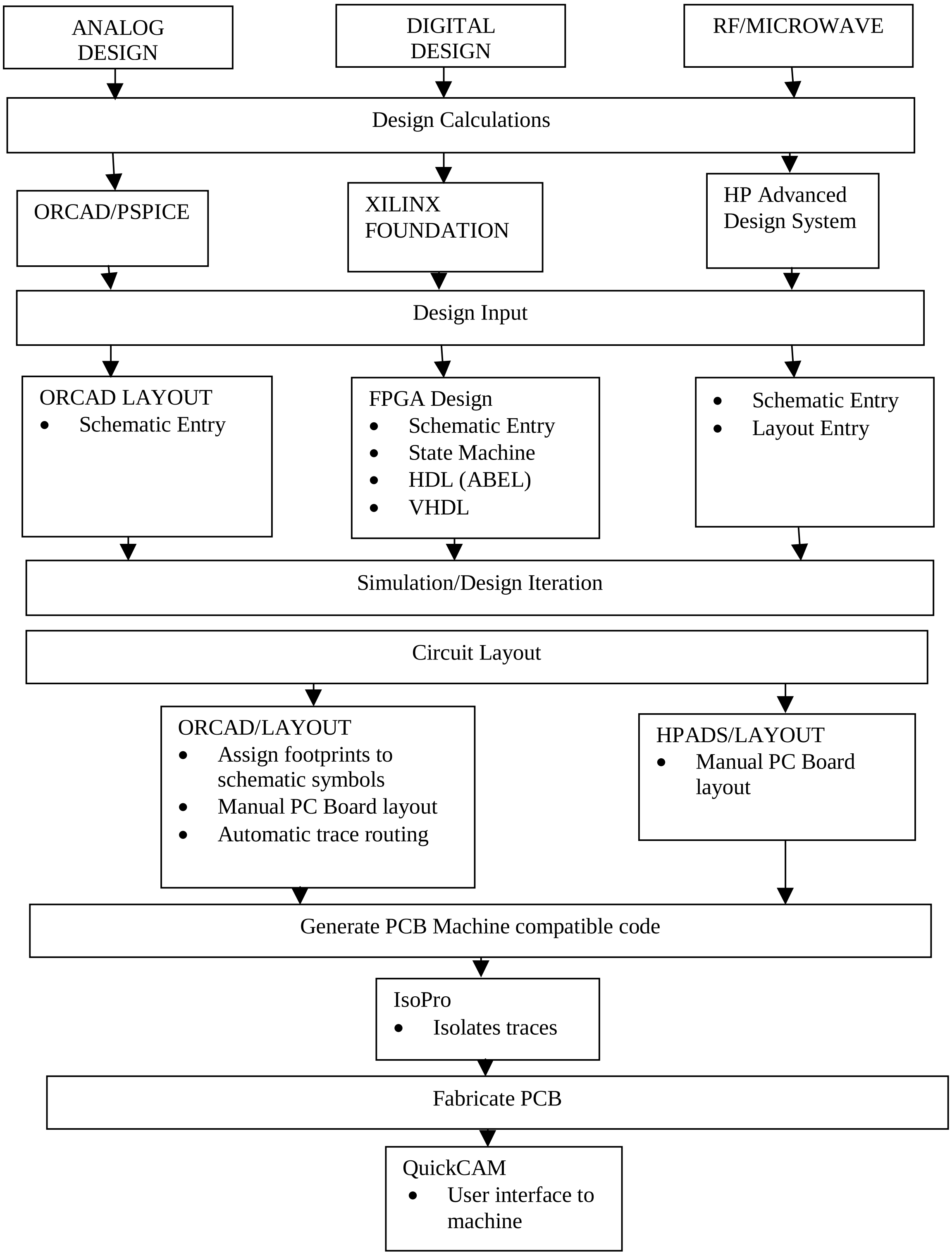

Figure 2. PCB Design Flow

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William D. Jemison received the BSEE degree from Lafayette College in 1985, the MESc degree from Penn State University in 1988, and the Ph.D. degree from Drexel University in 1993. He joined the faculty of Lafayette College in 1996. He teaches courses in applied electromagnetics, analog and digital circuits, and control systems. Prior to 1996 Dr. Jemison served as a senior engineer and project manager at the Naval Air Warfare Center, Lockheed Martin Corporation, and Orbit/FR in the field of microwave system design. Dr. Jemison is a member of Eta Kappa Nu, ASEE, and is a Senior Member of the IEEE.

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