University-Industry Partnership in Semiconductor Engineering

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Donald Y.C. Lie received his B.S.E.E. degree from the National Taiwan University in 1987, and the M.S. and Ph.D. degrees in electrical engineering (minor in applied physics) from the California Institute of Technology (Caltech), Pasadena, in 1990 and 1995, respectively. He has held technical and managerial positions at companies such as Rockwell International, Silicon-Wave (now Qualcomm), IBM, Microtune Inc., SYS Technologies, and Dynamic Research Corporation (DRC). He is currently the Keh-Shew Lu Regents Chair Professor in the Department of Electrical and Computer Engineering, Texas Tech University, Lubbock, Texas, and also an Adjunct Professor in the Department of Surgery, Texas Tech University Health Sciences Center (TTUHSC). He is instrumental in bringing in multi-million dollars research funding and also designed real-world commercial communication products sold internationally. He has been a Visiting Lecturer to the ECE Department, University of California, San Diego (UCSD) since 2002 where he taught upper-division and graduate-level classes and affiliated with UCSD's Center of Wireless Communications (CWC) and co-supervised Ph.D. students. Dr. Lie has been serving on the Executive Committee of the IEEE Bipolar/BiCMOS Circuits and Technology Meeting (BCTM), IEEE SiRF, IEEE MWSCAS, IEEE TSWMCS, and also serving on various Technical Program Committees (TPCs) for IEEE RFIC Symp., IEEE VLSI-DAT, IEEE ISCAS, IEEE PAWR, IEEE-NIH LiSSA, IEEE BIOCAS, etc. Dr. Lie has been awarded with the US NAVY SPAWAR SSC San Diego "Center Team Achievement Award", Spring 2007; won 3 DRC Silver Awards of Excellence, 2005-2007; received IBM "FIRST" chairman patent award, 2001-2002 and Rockwell International's "FIRST" engineering awards, 1996-1998. He has delivered plenary talks, short courses, invited talks, workshops at various conferences, universities and companies. He and his students have won several Best Graduate Student Paper Awards and Best Paper Awards in international conferences in 1994, 1995, 2006, 2008 (twice), 2010 (twice), 2011, 2012, and 2013. Dr. Lie is serving as an Associate Editor of IEEE Microwave and Wireless Components Letters (MWCL), and also on the Associate Editor-in-Chief (EiC) for the Open Journal of Applied Biosensor (OJAB) and and the Editorial Board of i-manager's Journal on Electrical Engineering. He was a Guest Editor of IEEE Journal of Solid-State Circuits (JSSC) in 2009, the Special Topic Editor for IEEE MWCL in 2012, and also has served as a reviewer for many journals and funding agencies. He has consulted for several IC design companies and an international research institute, also for one of the best business trial law firms in the world. Dr. Lie has co-founded the NoiseFigure Research Inc. with his student Dr. Lopez since 2009, focusing on state-of-the-art RF-SoC technologies and the company has won several Phase I

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and Phase II STTR/SBIR awards and other contracts. Dr. Lie has authored/coauthored over 150 peer-reviewed technical papers and book chapters and holds six U.S. patents. Dr. Lie's group has published three most downloaded TOP 100 papers on the IEEE Xplore™ among millions of publications in Sept, 2012, June 2012, and Sept. 2009 (ranked #80, #88, and #21, respectively). His research interests are: (1) power-efficient RF/Analog IC and System-on-a-Chip (SoC) design and test; and (2) interdisciplinary and clinical research on medical electronics, biosensors, and biosignal processing.

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Abstract

We describe a long-standing and successful university-industry partnership in semiconductor device engineering with a primary focus on product and test engineering. The partnership, now (2013) in its 15th year, relies on a symbiotic relationship that has evolved over the years to reflect semiconductor industry trends and advancing university capabilities. The success of the partnership is due to a multifaceted approach with an emphasis on frequent interactions between company personnel and university faculty and students. These interactions feed the core component of the program, student internships. These internships, for which students can obtain course credit, are done at both the undergraduate and graduate level and provide a nearly seamless pathway from school to full-time employment.

Introduction

A critical component of the US industrial base is the development, production, deployment, and utilization of semiconductor devices. This industry relies on a high number of specially trained engineers to accomplish these missions. As semiconductor technologies have continued to advance, severe demands have been placed on educational institutions to properly prepare students for the technical rigors of employment. To maintain exceptional student development, strong partnerships between industry and academia are a necessity.

Electrical engineering coursework has many fundamental aspects to it. However, advancing technologies require continuous updating of content in many classes. This is challenging for classes that incorporate hands-on/laboratory based content. The systems that are required can be prohibitively expensive and difficult to maintain. Close partnerships with one or more industrial

partners can allow universities to provide laboratory experiences to closely approximate the real-world work environment.

History

To begin the discussion of an electrical engineering program at Texas Tech University (TTU), a historical overview is provided. In 1996, Texas Instruments' (TI) analog business was growing rapidly and needed to add a number of well-qualified analog electrical engineers. TI was not successful in the initial recruiting effort and determined that a more organized initiative was needed to provide sufficiently trained engineers for the analog business units. A plan was formulated to identify the top analog faculty in North America and to recruit and hire their top graduate students. A list of 50 professors was identified. In 1997, the Analog University Program was established and furnished with a multi-million dollar budget to fund graduate student stipends during their studies. The agreement was that top MS and PhD analog students would be funded at a level consistent with other graduate fellowships and research positions at the respective universities, with the understanding the students would do an internship at TI, write a thesis based on their TI work, and accept a full-time job if offered. By the end of the second year, TI was funding students, both undergraduate and graduate, at 28 universities in North America. By the summer of 1998, more than 300 students were enrolled, either at a university or interning at TI. The mix was 60% undergrads and 40% grad students. The program now supported most of TI's businesses, and had become TI's university recruiting strategy. The university funding came directly from the manager's business profits, so the managers expect a good return on the investment.

In the summer of 1998, essentially in parallel with the Analog University Program, a vice-president of TI and alumnus of TTU determined that there was a lack of engineers with training

in product engineering. To initiate a program at TTU, a $1M donation was made to establish facilities and curriculum to train product engineers.

Product engineers are responsible for interacting with the design, development, testing, production and maintenance teams of new and existing products. Hiring product and test engineers is a particularly strong need for the semiconductor industry. These engineers must be broadly trained, as they must be skilled in testing circuits, and they must interface with circuit designers, wafer fabrication and assembly personnel, and customers. These engineers have to be technically diverse and have good communication skills.

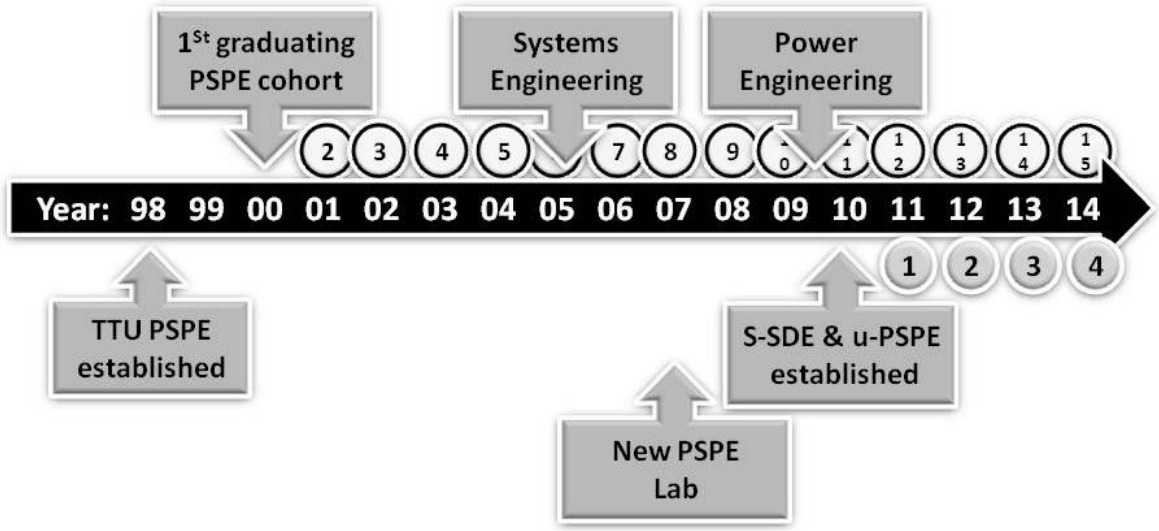

Figure 1. Historical perspective of semiconductor product engineering at Texas Tech from its establishment to current. The numbers above the years refer to the PSPE cohort and the numbers below refer to the uPSPE/S-SDE cohorts.

The endeavor at TTU became known as the Program for Semiconductor Product Engineering (PSPE). Shortly thereafter, the TTU program was incorporated into the broader Analog University Program. The TTU program was expanded to support nearly all of TI's business units including: DLP (Digital Light Processing), SPARC (Sun Microsystems design support), HVAL (High Volume Analog), and HPA (High Performance Analog).

PSPE has a few key components, but a primary goal is to prepare students for an internship and full time employment with a semiconductor company. Typically, a student will take two semesters of graduate level work before the internship. Table I provides a typical contingent of courses. In order for a student to have enough time to become immersed in a project and the company, the internships have usually been a summer plus a semester for a total of 6 months. The vast majority of PSPE students have done internships with TI, but some have interned at Applied Materials, X-Fab, National Instruments, Advanced Micro Devices, Freescale, Intel, and Qualcomm. A student's MS thesis is based on a project undertaken during the internship. Data and results collected during the internship are analyzed, written-up, and presented for the thesis. Although this is an ideal arrangement in many respects, when the subject matter is competition-sensitive, it can place obstacles in the path of student publication. We have reached a workable solution by embargoing select thesis publication on a year-by-year basis with company oversight. PSPE students enroll in a seminar that has been designed to better prepare them for corporate culture and expectations. Two of the PSPE related faculty had extensive careers with TI prior to joining the faculty at TTU. Their insights and experiences are conveyed during the seminar. In addition, students who have already interned present their experiences to the new students. Additional content includes financial planning, technical presentation pointers, salary negotiations, and other semiconductor industry relevant topics.

TABLE I. Sample Curriculum

Semester	Fall I	Spring I	Summer	Fall II	Spring II
Course 1	Solid State Devices	Introduction to VLSI Design	Industrial Internship		PSPE elective
Course 2	Testing of Digital Systems	Parametric/Functional Device Testing			Master's Thesis
Course 3	Semiconductor Processing	Statistics			
Course 4	PSPE Seminar	PSPE Seminar			PSPE Seminar

Figure 1 provides an illustration of important events in PSPE from its establishment until 2013. The important developments include periodic upgrades of facilities and equipment as well as new programs, initiatives, and courses. It is important to note that not all the components have enjoyed long-term success. In some cases, changes in TI business focus have led to contractions and eliminations of programs.

TI initially provided support for nine TTU MSEE students who began their studies in the fall semester of 1998. This cohort all interned with TI for six months, they all graduated, and they all joined TI in the summer of 2000. On average, 10 students are admitted to PSPE each year. Figure 2 shows the cumulative totals for enrollees, interns, and hires. The conversion rate is a significant figure of merit to TI and is a prime driving force for continued support. In order to show TI's assessment of program outcomes and return on investment, we provide a statement from Mr. Mark Gary who is the Business Unit Manager for Linear Power.

> *There are several advantages TI gains from the program. In general, TI recruits from a wide range of domestic and international universities. What stands out is an overall lack of knowledge of what product engineering is and what the job role entails. A large majority of EE graduates all believe they want to be IC designers due the curriculum presented to them. However, through the PSPE program, TTU has been able to provide awareness and excitement to this valuable function at TI and the industry. Product Engineers are in the center of product development cycle, bringing together Design, Manufacturing, Quality, Test, and Characterization to successfully launch new products into production. Second, TI works with TTU by creating internships for PSPE students. This allows students to get an industry view of various Product Engineering Roles in TI. Many students intern with multiple businesses working with different types of products over a period of one to three years. Over the course of one or multiple internships both the candidate and TI get a better feel for each other. This helps make sure TI and a candidate are the right fit for each other which intern boosts long-term retention. Last, there is definitely a financial return on TI's investment. Through the program, internships, and conversion to full-time hire, we see great acceleration of new hires into their roles. The PSPE conversions are able to hit the ground running without having to go through more rigorous training during their initial transition to the workplace. This helps TI two-fold. One, TI can avoid additional ramp up training that might average $10-$20K during the first year of employment. Second, the new hire can make a more immediate impact to a project. On average I see that PSPE student can ramp almost twice as fast as a non-PSPE student in a Product Engineering role. If one takes into*

account an average starting salary for a Product Engineer plus the average training cost, there might be average savings of $50K per student. TI is averaging 10-12 student conversions per year so that bumps up easily measurable savings to more than $0.5M per year. You could add additional returns on top of this due to TI being able to get more products to market faster and better long-term retention. This could easily drive the return on investment to multiple millions of dollars per year.

Bi-directional on-site visits by all participants (faculty, students, alumni, and other industry engineers) strengthen the initiative and clearly communicate the nature of the industrial environment and work expectations to the students. Mentoring of students by working engineers provides the necessary one-on-one guidance as critical employment path decisions are made. Visits by industry representatives to the university for recruitment and technical talks provide positive visibility to the company.

Example projects

Since PSPE's inception, more than 150 students have successfully defended an MS thesis and three completed a PhD. There have been a number of noteworthy projects, but the one with the most immediate impact was conducted by a student who interned with the Digital Light Processing (DLP) group. The DLP group produces the very successful digital micromirror device (DMD) that is found in numerous video display applications. The result of the internship work was put into production prior to the student even beginning his full time job with the group. The internship project involved developing an electrically based reliability test that decreased testing costs and provided new information about the DMD. The work demonstrated that important parameters could be calculated from the electrical tests that accurately reflect mechanical properties of the device. Prior to this work, only more expensive and time consuming optical methods were employed to perform functionality testing. Since the test could be implemented as an early failure detection strategy, money is not wasted testing bad parts using the optical testing tools.

A member of the first cohort of students in PSPE, Amy Podraza (nee Lohouse) has recently been promoted as the DLP® Quality Director. Prior to this she was a product engineering (PDE) manager who has been an integral part of DLP Products' growth since 1999. Amy's tenure includes more than seven years in several PDE branch/section manager roles and the remaining time in PDE/characterization/test engineering roles. During this time, she has led or contributed to the release and production support of the majority of DMDs. Over the last decade, she led and developed numerous DMD cost-reduction activities through test, process and design improvements that have enabled DLP to enter new markets. She engaged with the business to identify key competitive product attributes and led trade studies, which resulted in superior products. She collaborated with the quality organization to improve DMD quality through development and release of fab processes and test methodologies. Amy is a proven leader and a Member, Group Technical Staff (MGTS) Emeritus, with creative problem-solving approaches and an ability to navigate teams through highly complex situations.

Amy has been very active in various aspects of University Relations since she hired into Texas Instruments. For over a decade she has been a DLP® Sponsor for Texas Tech PSPE Co-op (Internship) Program, PSPE Advisory Board member and campus recruiting. During this time she mentored and hired several students. She pioneered the first DLP® Co-op student from the University of Puerto Rico. She is an advocate for encouraging females to enter into the Engineering fields and has done so through activities such as High Heels/High Tech Work shop for Plano ISD, University of Texas at Dallas "Introduce a Girl to Engineering" day and Texas Woman's University panel discussions. Amy was elected to the Texas Tech Electrical and Computer Engineering Industrial Advisory Board in the spring of 2011.

Course Development

In the mid 2000's, TI began to ramp up activities in systems engineering and power management. A program known as Advanced Electronic System Engineering (AESE) was developed as a new track for PSPE that focused on systems engineering and was created to meet the demands of system-on-a-chip designs – fully integrated cell phones, multifunction handhelds, etc.. Although TI invested heavily in this area, there was much confusion among the business groups at TI on what the common skill set was. As a result the AESE program was discontinued in 2012 in favor of concentration tracks within PSPE – wireless, power management, ultra-low power, *etc*.

Power management engineering opportunities have continued to grow, necessitating program modification. 60-70% of the recent co-op and full time hires were in groups that specialize in power converters, fuel gauges, and power management systems. To address this need a TTU professor proposed a new series of courses in power management in 2009 as shown in Table II. This proposal was championed at TI by a TI Fellow, who was also a TTU ECE alumnus. This person was active in helping to direct course content as suggested by a team of product and design engineers within TI.

TABLE II. New PSPE Courses

#	New Course	1st Semester Offered
1	DC to DC converter design and test	Spring 2010
2	Power semiconductor devices	Fall 2009
3	Power Analog/mixed signal design, simulation and test	Spring 2010

One primary concern when course offerings are heavily influenced by a particular company in a particular industry is the applicability to students who will choose other career paths. The power management classes have proven to be very popular to a broad range of electrical engineering students. Consistently, enrolment in the power management courses is a majority of non-PSPE students.

Student access to current semiconductor industry tools is one of the most daunting challenges facing the academy. The cost, complexity, and maintenance issues make the acquisition and sustainability of such tools difficult. Corporate donations, primarily from Texas Instruments, National Instruments, and X-Fab have resulted in an important contingent of tools for student use in classes and research. A VLCT (TI's Very Low Cost Tester) and a brand new National Instruments flexible testing tool are just two examples of systems that students gain hands-on experience with. Like the power management classes, the device testing classes are taking by student outside of PSPE, extending the program benefits to many more students.

Since approximately 2010, there has been a shift in the corporate needs of TI with an emphasis on recruiting more bachelor level engineers. Although there is still an interest in MS and PhD level engineers for some jobs, there is a desire for highly capable, BSEE graduates who do not require sponsorship.

For the first five years of the PSPE program, nearly 100% of the students in the program were domestic. At this juncture, approximately half of the PSPE students are domestic. Over the years, PSPE has been quite successful in enrolling a diverse contingent of students including many women (57/150) and minorities (34/150). Due to limitations in visas, Texas Instruments and other companies have preferred to see domestic students participate in the program, especially at

the BS level. While TI and TTU certainly value the high caliber foreign students that we have trained through PSPE, we realized that a number of things need to be done to produce more domestic students that are strong candidates for PSPE, other graduate degree programs, and immediate employment.

In 2011, TTU Electrical and Computer Engineering was awarded an S-STEM scholarship project from the National Science Foundation. The primary goal of the project was to provide a stronger pipeline to the semiconductor device industry for students with financially need and high academic capabilities. The TTU project is known as Scholarships in Semiconductor Engineering. It was designed to capitalize on the infrastructure and successes of PSPE. Over the first three years of the four year project, approximately 20 students per year are supported at some level by NSF funds while an additional 10 students per year are supported through PSPE funding from Texas Instruments. The undergraduate PSPE program is referred to as u-PSPE. All the students are treated as a single cohort for most purposes. These students take a 1-hour seminar each semester which has some overlap with the PSPE seminar. The undergraduate seminar helps prepare students for bi-annual engineering job fairs through resume critiques and mock-interviews. Students who have already completed internships share their experiences and tips for students trying to land their first one. Over 75 percent of the students in the program land internships, many with TI. Due to the oil boom in Texas, many of the students are aggressively pursued by oil and oil-services companies.

Conclusions

PSPE is a long standing program that has been successful through a close collaboration between the university and industry. Frequent communication, including site visits, has produced a

program that can meet the employment preparation needs of students. PSPE has had to adapt to changing industry needs and directions through the implementation of new courses and lab tools. New courses have proved to be popular and relevant to a broad range of electrical engineering students. The long internship and thesis work provide a strong tie to the company and allow a nearly seamless transition to full time employment.