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"Serendipity and Symbiosis: UCSD and the Local Wireless Industry"

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INTRODUCTION

This chapter considers the evolution of the relationship between a young research university — the University of California, San Diego — and what has become one of the premier global centers of technological development in the wireless industry. San Diego's wireless industry emerged and grew out of a long history of military related communications R&D in the region that began with the Navy's earliest radio communication experiments with aircraft, and was institutionalized through sizable Federal investments during World War II that set the pattern for ongoing Department of Defense funding in the Cold War era.

The seeds for the wireless cluster came from the University of California's 1912 acquisition of a nonprofit marine research station, the Scripps Institution of Oceanography that during the 1920s and 1930s became a key marine research lab for UC faculty and graduate students, including Roger Revelle. As part of the war effort, in the 1940s, SIO became the Southern California base for the University of California's Department of War Research, and some key SIO employees joined with the Navy to found its West Coast sonar lab. In 1950s and 1960s, Revelle used the now influential and well-funded SIO scientists as the nucleus for founding the basic research-focused UCSD campus on city and Federal land adjacent to SIO.

The UC San Diego campus was strongly influenced by the national trend towards expanding basic science R&D in the 1950s and 1960s, especially science-driven engineering and technology development, particularly for defense and aerospace applications. Its early leaders, like so many university scientists of the time, were shaped by wartime and postwar experiences in efforts such as the Manhattan Project, Office of Naval Research and Lawrence Livermore Laboratory. Revelle organized local support for the new campus rallying defense contractors and civic boosters eager for basic science in the region. The early UCSD research programs in turn benefited from the tight links the founding faculty had to the Department of Defense and the numerous federal agencies that were providing research funds for basic science in the postwar era. And as a greenfield institution, the nascent engineering programs rejected the craft-like approach that had characterized engineering education during the preceding 75 years, instead embracing the new model of engineering as applied science pioneered at MIT and strongly supported by national engineering leaders such as Frederick Terman at Stanford — a model that later resulted in the transformation of communications engineering from analog to digital communications.

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Another factor that was that — unlike its contemporaries UC Irvine and UC Santa Cruz — from the start UCSD was expected to become “another Berkeley.” Building on the long relationship Scripps had with the national science and technology community and its success in attracting major federal funding, its leaders strove to achieve what was described as by Nancy Scott Anderson (1993)” instant greatness.” The campus strategy was to build world-class science programs in biology, chemistry, mathematics, and physics, by recruiting senior scientists who were among the best researchers in their fields. Many of the early elite UCSD hires had experience in securing Defense Department funded research and they brought these contacts with them. What attracted them was the opportunity to create a first-class, science-driven university from the ground up. From its inception UCSD focused on hiring established researchers from established elite research institutions such as Chicago, Cornell, MIT, and Princeton.

Among these early hires was Henry Booker, a physicist from Cornell’s School of Electrical Engineering, to be the founder of what eventually became the electrical engineering and computer science department. For our story, in turn, Booker’s most important hire may have been his former student, Irwin Jacobs, from a similar position at MIT. Jacobs later cofounded two of the region’s most influential communications companies, Linkabit and Qualcomm. After his enormous success with these two business ventures, he went on to become the university’s most generous donor.

The San Diego wireless communications companies founded by Jacobs were not university “spin-outs” in the usual sense. Rather than being formed to commercialize university IP, they benefited from the highly trained scientists and engineers that UCSD attracted to the region. These science-based engineering companies co-evolved in a symbiotic relationship with UCSD and its education and training programs. In particular, the firms benefited from both University Extension as well as UCSD’s early applied science departments that by the 1990s were reorganized to form the School of Engineering. During this evolutionary process, the firms provided resources to the university by hiring its graduates, sponsoring its researchers and collaborating in developing new cutting-edge communications technologies. This was most pronounced after 1990 as wireless communications expanded dramatically and the San Diego firms were perfectly positioned to benefit.

This chapter documents how UC San Diego serendipitously provided the seeds of the regional telecommunications cluster and symbiotically evolved with it. It also shows the extent to which a developing university worked closely with a developing wireless industry to build curricula, research and Ph.D. programs which have brought distinction to the UCSD campus as well as much needed talent to the industry, as part of a mutually beneficial symbiotic relationship. The success of this collaboration is measured not only by the emergence of Qualcomm, as one of the largest and most successful communications firms in the world, or the attraction of other global wireless telecommunication firm’s R&D operations to the region, but also by what *Forbes* magazine concluded was the highest *per capita* concentration of wireless employees in the United States (Fidelman, 2012).

SIO, Defense Research and the Birth of UCSD

Scripps and Navy Research

Founded in 1903 as a local nonprofit association and funded during its early years by the

Scripps family, as mentioned earlier, the Scripps Institution of Oceanography was acquired by the University of California in 1912. During World War II, SIO helped launch the Navy's west coast sonar research lab in San Diego (Raitt & Moulton, 1967; Shor, 1978; NOSC, 1990). The SIO collaboration with the Navy's Point Loma Station and the Radio and Sound Laboratory during World War II gave rise to significant connections in Washington, DC and meant San Diego was well positioned to take advantage of the continuing growth in defense-related R&D funding in the postwar era (Walshok & Shragge forthcoming, 2013).

Throughout the 1930s, 40s, and 50s, in addition to the active duty naval forces and defense contracting building up in the region, San Diego became a major site for military related R&D. In addition to the Navy's sponsorship of sonar and other oceanographic research at SIO, the Navy sponsored local research on communications building upon San Diego's unique location in the continental United States and its proximity to deep ocean waters. The links were strengthened by the concentration of facilities at the tip of Point Loma.

During the war, Vannevar Bush and the National Defense Research Council mobilized universities to conduct basic and applied research developing technology for the war effort. As one part of this massive mobilization, the NDRC and University of California teamed up to establish a Navy sonar research and training facility. With this the UC Division of War Research was established by UC President Robert Gordon Sproul in 1941 in Point Loma adjacent to the NRSL and was initially staffed by SIO employees. After the end of the war, the Navy combined these labs into a single Naval Electronics Lab which remains active to this day. (Raitt & Moulton, 1967; NOSC, 1990). Throughout the 40s and 50s, the Navy and Scripps collaborated on multiple forms of research funded by substantial sums of federal money. This contributed to an increased appreciation among San Diego elites of the role of the Navy and technology related R&D in the region's growth and prosperity.

Creating a New UC Campus

The defense contractors in San Diego were eager in the postwar era to advance technology development through science, in large part because of the role science played in winning the war. In the 1950s, SIO director Roger Revelle argued for a UC graduate institute of science in San Diego that built upon SIO's substantial research base. Significant industry lobbying and local community mobilization resulted in the 1957 approval of the UC San Diego campus and the unique Cold War science oriented research culture that shaped its formation and founding values.

Revelle leveraged both Scripps' existing resources and the expansion goals of two UC Presidents, Robert Gordon Sproul and Clark Kerr, to attract the resources necessary to create a UC campus in San Diego. He drew on his wartime and postwar ties to defense funders as well as local industries. All were eager to have an advanced science campus. Revelle's (1985)goal was to create "a publicly supported Caltech." Leaders of the local defense firms, such as General Atomics, Convair, Solar, Rohr, Cubic, and Ryan were great supporters. General Atomics, a spin-off of Convair dedicated to the study of atomic energy, was a particularly strong supporter and pledged $1 million in startup support at the time when the UC Regents were deliberating on whether to establish a new campus. The campus was poised to ride the postwar funding wave been unleashed by Vannevar Bush's influential *Science: The Endless Frontier* (Bush 1945).

The founding members of the UC San Diego campus spoke euphorically about the opportunity to create a completely new kind of modern research university. This can be seen in a 1999 interview with Sol Penner, head of UCSD's first engineering department. Penner described what attracted him to the campus in the 1960s, as well as the approach to faculty recruitment that shaped the early culture of the campus:

> "Our focus was an exceptional person rather than a particular subject… [Harold] Booker, for example, was a physicist in Systems and Control, and we brought him to the campus in order to build an applied physics and information sciences program. He built the nucleus of the department. I was Vice Chancellor for Academic Affairs when [Irwin] Jacobs was hired [by Booker]. (Penner 1999)"[1]

Penner also believed that during this postwar era, basic and applied science — rather than traditional engineering — had become the focus of the federal government and the defense establishment. He described:

> "In the early '60s, the Cold War was the driver of basic research and engineering companies. Engineering was becoming indistinguishable from physics… like at Cal Tech, where 70 engineers and scientists might be working together all in one group."

The importance of these social and cultural dynamics to the efforts that created the UCSD campus in the decade from the mid 1950s to the mid 1960s is that 1) the Cold War research funding linked many of the early UCSD scientists to entities interested in "applying" science to new technology solutions simultaneously with 2) enabling the campus to rapidly achieve a national reputation for its research programs. For example, UCSD gained admission into the prestigious American Association of Universities (AAU) in 1982, less than 20 years after its founding. Building on the research dollars and reputation SIO had already established, senior-level professors arrived with and then attracted to UCSD the major grants, graduate students, and post-doctoral students that enabled the young campus to realize its aspirations to rapidly become a first-rank scientific institution. The young university's faculty, research output, extramural funding and concomitant rise in reputation also eventually allowed it to contribute in diverse ways to the region's growth of highly robust clusters of commercially oriented R&D companies, initially in the defense contracting sector and subsequently in commercial sectors such as wireless. It is important to underscore that local industry actively supported this strategy by UCSD. Primarily engaged in defense, space and security issues, their technology development was informed by the basic and applied science to which the campus was committed.

In his 1999 interview, Penner noted the extent to which most of the early hires at UC San Diego were people who had worked on the Manhattan Project and other war-related research programs at institutions such as Princeton, Chicago, and Berkeley (see Table 1). He referred to many of them as the postwar era McNamara "whiz kids" reflecting back on the Kennedy era of space exploration and expanding Cold War tensions. In other words, the establishment of UCSD significantly contributed to the growth in the region's general intellectual capital.

Communications Engineering as Applied Science

In the early 20th century, communications engineering had been a series of loosely related arts, organized around disparate communication technologies such as telephony, radio and, acoustics. The transformation of communications from craft to applied science — and later from analog to digital — was led by MIT researchers in radar and radio communications from the 1920s through the 1960s, funded by the Federal government to address military and space

1 Untranscribed interview with Stanford S. Penner, May 5, 1999, UCSD Archives.

applications. The theoretical foundations of this transformation were provided by the information theory of Claude Shannon, who joined MIT in 1956 (Wildes & Lindgren, 1985; Pang, 1990; West, 2008).

Reflecting the school's initial emphasis on science — both in its leadership and their research — UCSD did not have a single engineering department until 1964. As the first dean of Revelle College, Keith Brueckner (1994) put it: "In engineering I felt that UCSD in the beginning should concentrate on applied science rather than conventional engineering". In doing so, UCSD bypassed the early 20th century conception of engineering as craftwork, and instead reflected the postwar paradigm of engineering as building upon advances in math, physics and other basic sciences.[2]

Perhaps influenced by the strength of San Diego's local aerospace industry, the first engineering department was Aerospace and Mechanical Engineering Sciences, created in April 1964 and headed by Sol Penner. Communications research was housed in a second department, termed "Applied Electrophysics," which covered what elsewhere would be considered the radio engineering component of electrical engineering and would soon include the nascent field of computer science. The department would not be renamed "electrical engineering" for more than a decade.[3]

Following the launch pattern of UCSD as a whole, the Applied Electrophysics department was inaugurated with graduate courses but soon added undergraduate courses that came to account for the bulk of enrollment. Brueckner hired Henry Booker as one of two faculty to launch the department in July 1965, and Booker served as chair from 1965-1971.[4] Booker exemplified the university and department's view of communications as being applied physics.

Born in England, Booker earned his PhD from Cambridge, where he did seminal work on the physics of radio waves propagation in the ionosphere. He headed theoretical communications research for the English air ministry during World War II, where he "was involved in development of new ideas on antennas, electromagnetic wave propagation, and radar systems, all of which were critical to the defense of Britain" (Gordon, 2001). He was recruited to Cornell's electrical engineering department in 1948, where his 1952 paper (Bailey et al, 1952) provided the science necessary to implement the Defense Early Warning System (DEWS), a series of Cold War forward-scatter radar stations that searched for incoming Soviet ICBMs (Gillmor, 1986).

Not surprisingly, Booker repeatedly sought to push engineering education away from

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2 Wildes and Lindgren (1985) document how this paradigm shift from craftwork to applied science was implemented at MIT's largest academic department, the Department of Electrical Engineering (later Electrical Engineering & Computer Science).

3 The Applied Electrophysics department was renamed Applied Physics and Information Systems in 1969 and then Electrical Engineering and Computer Sciences in 1978. In 1987 it was divided largely along hardware/software lines into its current configuration, with separate departments of Electrical and Computer Engineering and Computer Science and Engineering.

4 The other faculty member hired in 1965 was Ken Bowles, a former Booker student who in the 1970s headed the campus computing center and created UCSD Pascal (Bowles, 2003). In 1979, those efforts were spun off to create San Diego-based SofTech Microsystems, a new division of Boston-based SofTech Inc.

application skills and towards a strong theoretical understanding. In 1954, he suggested that the goal of undergraduate engineering education is to teach what is known, while graduate education should emphasize research and creating novel ideas (Booker, 1954). In a 1963 letter to *Science*, he argued that for university education, "even in an engineering department, the objective of the operation is mental development" (Booker, 1963: 488).

The research of many early faculty related directly or indirectly to radio communications. For example, Carl Helstrom was a former Navy radio technician and prominent information theorist; J. Pieter M. Schalkwijk was a leader in information theory, Elias Masry in remote signal processing, Victor Rumsey (an expert in radio antennas), and Jules Fejer, who like Booker pioneered research on radio propagation in the ionosphere.

It was not surprising that upon arriving at UCSD in 1965, Booker sought to hire 32-year-old Irwin Mark Jacobs, then an associate professor at MIT. In the 1950s and early 1960s, MIT had created and led the efforts to develop a probabilistic approach to communications based on Shannon's theory of information. Jacobs was among seven MIT graduate students who turned the graduate lectures of famed mathematician Norbert Wiener into a monograph. He had also co-authored the first undergraduate textbook on digital communications (Wiener, 1958; Wagner, 2005; West, 2008). Jacobs later recalled:

> "At Cornell, I had taken electromagnetic theory courses from Henry Booker and antenna courses from William Gordon and was leaning towards graduate work in that area. …The fact that it [UCSD] was a public university meant a broader selection of students, and the opportunity to form a new curriculum was a challenge." (Morton, 1999)

Jacobs chaired three computer science dissertations at UCSD, and served on two information theory Ph.D. committees while there.[5] He began to do consulting with the Navy on its important fundamental problems of communications research. Although he spent only five years in the department, his impact on the regional economy and on UCSD spanned the following five decades.

Birth of the Local Telecom Industry

UCSD's Serendipitous Role

Jacobs joined the Applied Electrophysics department in the fall of 1966 as one of eight new faculty. More importantly, two years later he co-founded Linkabit Corporation to pool his consulting efforts with those of two UCLA engineering colleagues. One of the UCLA professors, Leonard Kleinrock, had completed his doctorate at MIT in 1963 — four years after Jacobs — and had shared the same dissertation advisor. The other, Andrew Viterbi, earned a master's at MIT and then took a job at JPL in 1957 — so he could support his wife and immigrant parents — and while working, completed his Ph.D. at USC before joining UCLA with Kleinrock in

5 James Tiernan completed his Ph.D. in 1972 under Schalkwijk, and later worked for Jacobs at Linkabit before starting two companies on his own. Jacobs also served on the USC Ph.D. committee of Bob Gray, who later joined Stanford's faculty and became a top information theorist.

1963.[6]

Linkabit's first offices were in Los Angeles, near UCLA. Kleinrock soon left the company, but later would become one of the pioneers of the ARPANet, which evolved into the Internet (Leiner et al, 2009). Jacobs became the natural administrative leader of the firm, based on his two years of business courses in Cornell's hotel school before switching to engineering. In 1971-1972, he took a leave of absence from UCSD to straighten out the company's finances. Facing exploding demand for computer science classes, in December 1970 Booker wrote a memo to the chancellor and provost complaining about budget cuts to the department and a shortage of qualified C.S. faculty, correctly predicting that Jacobs would never return to UCSD:

> The senior professor in computer science desires to go on unpaid leave of absence next year. This is to look after his prospering business instead of spending time on a UCSD computer science program whose status is becoming absurd. He may never return to the campus. I have no current reason to believe that the campus would replace him either temporarily or permanently. (Booker, 1970).

In an interview with this chapter's second author Jacobs noted, "running Linkabit turned out to be challenging and fun, so I resigned from academia after 13 years to continue full time and I have been in industry ever since".

One of Jacobs' first acts was to move the company and its employees (except Viterbi) to light industrial space in Sorrento Valley near the intersection of two Interstates, 5 and 805, approximately four miles from his UCSD office. The company eventually expanded to other rented space throughout Sorrento Valley, setting the pattern for the development of San Diego's telecom industry in the valley and Sorrento Mesa on the east side of I-805, where Qualcomm is headquartered today.

Linkabit hired Jacobs' and Viterbi's students from MIT, UCSD and UCLA, and later aggressively sought MIT graduates with ads promising "70 miles of beaches." In interviews with the second author, Linkabit hiring managers said that recruiting electrical engineers from Stanford and Berkeley proved largely unsuccessful during the 1970s and 1980s due to the abundant job opportunities in Silicon Valley. Eventually UCSD was to become a valuable source of talent for the growing wireless cluster and most especially Qualcomm throughout the 1990's.

Spinoff and Cluster Formation

From 1984-1990, at least 10 companies were founded by Linkabit employees.[7] All told, from 1984-2004 more than 200 communications companies were founded in San Diego — some created by employees of existing firms, and later others by entrepreneurs seeking access to the region's infrastructure for communications startups (Simard, 2004). In some cases, employees of these spinoffs formed yet other spinoffs (Figure 1). This explosive growth in companies was less the result of UCSD faculty or patenting than the effect of UCSD-educated scientists and engineers choosing to work for local companies, whether Linkabit in the 1970s or the dozens of

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6 This discussion of how Linkabit was founded and its growth from 1968-1985 is adapted from West (2009), and is based on interviews with all three Linkabit founders and various other primary and secondary sources.

7 Data for this section is adapted from Simard and West (2003), Simard (2004), West (2009) as well as unpublished databases of San Diego telecommunications firms provided by Martha Dennis and Caroline Simard.

companies formed after its eventual sale. These applied science companies both developed their own IP and (as discussed below) built upon talent and IP developed by UCSD.

The first round of startups tended to be variations of Linkabit's approach to technologies, markets and competencies in digital communications. This included satellite communications for the government (ViaSat) and communications chips for cellular phones (PCSI). The best known was Qualcomm, founded in 1985 by Jacobs, Viterbi and five Linkabit colleagues, which grew rapidly and had an initial public offering in 1991 and in 1999 joined the *Fortune* 500.

Extending the probabilistic communications theory first used with NASA, in the 1990s Qualcomm introduced its Code Division Multiple Access (CDMA), which promised higher capacity than GSM and other digital ("2G") cellular standards and was quickly adopted as the sole 2G technology by South Korea. Although CDMA won a narrow majority of US carriers such as Verizon Wireless, Sprint, MetroPCS and Leap Wireless — and had market wins with selected carriers in Japan, Hong Kong and Latin America — it never achieved more than 20% global market share among 2G subscribers. However, the CDMA approach (and Qualcomm's CDMA-related patents) was incorporated in the world's major 3G cellular standards, cdma2000 and the GSM-derived W-CDMA (Mock, 2005; Bekkers & West, 2009).

In addition to patent licensing, Qualcomm also developed a successful business selling mobile communications semiconductors, which by 2001 made it the world's largest "fabless" semiconductor vendor. To help promote adoption of 3G data services, it created the BREW software platform, which made it easier for software developers to write applications for all 3G phones sold for use on the Verizon (US) and KDDI (Japan) networks.

The success of Qualcomm's various technologies attracted other firms to the region. In addition to startups, this also included branch offices of major cellular manufacturers such as Nokia, Sony and Ericsson — some of which had unsuccessfully fought against adoption of Qualcomm's 2G and 3G technologies (Simard, 2004). The region demonstrated all the normal characteristics of a cluster: a common supplier base, buyer-seller relationships among the firms, opportunities to found firms that provided third-party complements (such as software or training), and high labor mobility among regional firms. Many firms exited by being sold, whether to local companies (notably Qualcomm) or to out of town firms seeking their technology (as with TI's $475 million purchase of Qualcomm spinoff Dot Wireless).

As the industry grew, so did UCSD's communications capabilities and the ties between the wireless industry and the university. The original collection of engineering sciences departments became the "Division of Engineering" in 1982, and was organized as the School of Engineering in 1993. With a $15 million donation by Irwin and Joan Jacobs, in 1998 it was renamed the Jacobs School of Engineering. In the 1990s, UCSD created an industry-funded research center in the Division of Engineering while UCSD Extension trained hundreds of already credentialed engineers in CDMA and other emerging wireless technologies.

Co-Evolution of University and Industry

Linkabit seeded San Diego's communications industry in the 1980s, and from then on, the industry and UCSD grew together in a mutually beneficial relationship. The university has become a home for multiple forms of research important to the wireless industry (i.e. in science, engineering and public policy vital to the industry's competitiveness) and has been a continuing source of talent. The industry in turn has contributed equipment, helped fund facilities, and provided matching funds for collaborative research including state and federal grant proposals, endowed professorial chairs and graduate fellowships, as well as participating in a variety of general support, corporate affiliate programs.

From UCSD to Industry

UCSD had an impact on the wireless telecom industry in San Diego in three distinct ways over four decades: 1) indirect support for Linkabit in the 1970s, 2) direct and significant support of talent development for the startup companies after 1985, and 3) strategic R&D partnerships for Qualcomm's CDMA ecosystem after the mid-1990s (Table VI).

Linkabit Era. UCSD's promise of doing basic science to further new technology applications attracted Henry Booker and brought Irwin Jacobs to San Diego. Jacobs moved Linkabit to San Diego in 1971. Linkabit was enormously innovative designing a variety of radio related products and proceeded to grow very rapidly. Perhaps, even more important, it was the nucleus for the region's telecom cluster.

While we lack the personnel records of Linkabit that would enable us to measure the number of UCSD graduates employed by the company, there are other measures of the impact of UCSD alumni on Linkabit and its spinoffs. For example, according to the Simard (2004) database of San Diego-area telecom startups, 13 of the 16 local telecom startups formed by UCSD graduates included at least one Linkabit alumnus among the founders. While interviews of Linkabit executives from the 1970s emphasized the importance of initially hiring from MIT, two Southern California universities — USC and UCSD — became central to Linkabit and the local industry in the late 1970s and early 1980s (Simard & West, 2003; West, 2009).

As has been the case in other high technology regions, the rapidly growing Linkabit hired summer interns and other part-time employees from UCSD. After graduation, many of these became permanent employees[8]. The earliest UCSD graduate to join Linkabit was Jim Dunn (2004), who had taken a course from Jacobs at UCSD and joined Linkabit as employee #10 upon graduating from the now renamed Department of Applied Physics and Information Science in December 1970.

In another example, in the early 1980s Ladd Wardani (2005), a UCSD undergraduate student in communications engineering was among about 20 students that were employed by Linkabit as summer interns. Upon graduation, Wardani joined Linkabit full time and remained until 1991 when he left to join ComStream, a Linkabit spinoff company. As Linkabit grew, it hired an increasing number of UCSD students, graduate and undergraduate.

Linkabit's Spinoffs. Direct involvement of UCSD faculty in founding local telecom companies was minimal. Beyond Irwin Jacobs, Simard's (2004) data on local telecom startups identifies only one other UCSD professor who started a local telecommunications company: Ronald Fellman, a professor of Electrical and Computer Engineering from 1988-1996 who in 1998 founded Path 1 Networks. Of course, faculty also worked on consulting and sponsored research for industry clients; for example, UCSD Professor Jack Keil Wolf, who like Viterbi was awarded the IEEE Information Theory Society's top research prize, was a consultant to Qualcomm for more than a decade.

The Simard (2004) database of San Diego telecom company founders identifies 18 local telecom companies with UCSD alumni among the founders — the best known of which is Qualcomm (Table 2).

The earliest UCSD graduate at Linkabit, Jim Dunn, later cofounded two local startups: Primary

[8] Linkabit's first employee, Jerry Heller, visited UCSD for a year to finish the MIT Ph.D. that he started under Jacobs.

Access (1989) and AirFiber (1998). The next earliest UCSD graduate to become a local telecom entrepreneur was James Tiernan, who finished his UCSD PhD in 1972 with Jacobs as a committee member, and after working at Linkabit founded two companies: Tiernan Communications (1988) and La Jolla Networks (2001).

However, Dunn and Tiernan were not the earliest UCSD alumni to become founders of Linkabit spinoff companies. The first was Franklin Antonio, an engineer who was one of the seven ex-Linkabit employees to found Qualcomm in 1985.[9] Next came Mark Miller and Steven Hart, two of the three founders of ViaSat (1986), which later went public in 1996. Two members of the UCSD class of '82 later founded companies with successful exits: Rick Kornfeld with Dot Wireless (1997) — which was acquired by Texas Instruments for $475 million in 2000 — and Ladd Wardani, co-founder of Entropic (2001) that went public in 2007.

Other UCSD alumni founded local companies without working at Linkabit. For example, Ronald Reedy (PhD, electrical engineering, 1983) and Mark Burgener (PhD, physics, 1989) joined in 1989 to form Peregrine Semiconductor, a radio frequency semiconductor design firm.

Talent Synergies

The spinoffs and other local telecom companies benefited not only from UCSD's engineering programs, but also its programs in management education. By the early 1980s, the university's Extension program offered a variety of technology management, project management curricula that engineers working in the growing industry took advantage of on a course-by-course basis. UCSD Extension also organized two executive education programs after Richard C. Atkinson became UCSD chancellor in 1980. One program, known as the Executive Program for Scientists and Engineers (EPSE) targeted Masters and PhD-level engineers who needed to hone their management skills. The other was the Leadership and Management Program (LAMP) which targeted bachelor-level engineers working in local industry. Over a 25 year period, these programs have graduated approximately 1,500 scientists and engineers from local industry and they continue to be fully enrolled today. (1985-2010) During this same period William Decker of UCSD's Office of Technology transfer reported licensing agreements with" more than two dozen wireless companies" representing in the neighborhood of 30-40 individual licenses, modest numbers compared to the thousands of Extension enrollments and hundreds of Masters and PhD students during this same period.

Extension Support for the CDMA Ecosystem. As Qualcomm grew in size, wealth and importance to the telecom industry, it worked with UCSD to strengthen its teaching and research related to the company's wireless communications needs. From the beginnings of its efforts to promulgate CDMA adoption, Qualcomm worked directly with UCSD to address the shortage of engineers competent in the new CDMA technology. UCSD alleviated the education gap that Qualcomm faced in disseminating its complex and little-understood CMDA technology. While the company was able to demonstrate technical performance that was superior to the European GSM and US D-AMPS technologies that were closer to market release, if hardware manufacturers and network operators were unable to build and install the necessary systems, the technology would have little practical value. Qualcomm thus needed new CDMA-specific

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[9] In addition to UCSD alumnus Antonio, the other Qualcomm founders were two former University of California professors (Jacobs of UCSD and Viterbi of UCLA), two other engineers — Andrew Cohen (an MIT grad), Klein Gilhousen (a UCLA grad) — and two finance executives, Harvey White and Dee Coffman. UCSD Chancellor, Richard Atkinson was an early member of Qualcomm's board of directors.

training to support its ecosystem of suppliers and partners and to train its ever-increasing roster of engineers. The UCSD Extension division thus became an important partner of Qualcomm in enabling communications engineers to develop their capabilities in working with CDMA in systems design and integration.

In 1991 Qualcomm approached University Extension and offered their senior-level R&D people, as well as their facilities and computing capabilities, to work collaboratively to develop a CDMA curriculum that could be made available locally and online. In fact, Qualcomm scientists and engineers developed the curriculum, served as instructors and helped the University's Extension division at that time to launch its first online learning provision thanks to advanced skill in building web-based learning programs.

All told, UCSD Extension developed and offered more than a dozen certificate programs to serve the local wireless telecommunications industry, including programs in CDMA engineering fundamentals, digital signal progressing and wireless engineering (Table 3). Enrollments grew dramatically in the 1990s, declined after the burst of the telecom bubble in 2001, but have recently recovered to approach the earlier levels (Table 4).

The curriculum developed by Qualcomm has been updated over time and is still available online. Extension's online courses 14 years later enroll more than 21,000 students in a wide variety of programs that began with the courses initially developed collaboratively with Qualcomm.

Communications-related Research and Graduate Education. The research areas and courses offered by the faculty and staff of UCSD's School of Engineering also evolved in conjunction with the specialization of the local industry in CDMA and other areas of communications engineering. For example, graduate degrees in communications awarded annually by the School of Engineering have grown from less than 50 in the early 1990s to more than 250 in 2011 (Figure 1).

The audience for UCSD's expertise in wireless technology extended beyond Qualcomm and the other local startups, attracting leading foreign wireless firms. As Qualcomm and CDMA grew in importance in the wireless industry, major electronics companies such as Sony, Nokia, Ericsson, and Texas Instruments established R&D operations in the region to access the knowledge from UCSD, Qualcomm and the other local wireless communications firms (Simard 2004). These firms joined Qualcomm in supporting wireless research efforts at UCSD.

An important advance in these collaborative research efforts was the establishment of the Center for Wireless Communications within the Jacobs School of Engineering in 1995. The Center enlists member companies such as Ericsson, LG, Qualcomm, Mitsubishi and Nokia Siemens Networks to annually invest in research projects that are of equal interest to the companies and faculty/graduate students at UCSD. Research areas range from wireless applications, digital communication systems and high speed integrated circuits. The corporate members work with UCSD researchers to identify research priorities and participate in a variety of monthly seminars and networking events.

A second and larger effort came with the establishment of the California Institute for Telecommunications and Information (Calit2), an ambitious public-private partnership and one of four California Institutes for Science and Innovation at UC campuses. The program was part of an initiative announced by Governor Gray Davis and the then President Richard

Atkinson[10] in December 2000 -- a time when the state enjoyed abundant tax revenues generated by the capital gains of the dot-com bubble.

Calit2 was funded as a collaboration of UCSD and UC Irvine, with UCSD as the lead partner. As with other Institutes, state funding of $100 million was conditioned upon industry pledges of $200 million. Among the initial pledges were $15 million each from Qualcomm and Swedish telecommunications giant Ericsson. More than a decade after its founding, Calit2 represents a major hub of research programs involving academia, government and industry. Its website is explicit about its commitment to contributing to the economic competitiveness of the state and the nation.

> "Calit2 is taking ideas beyond theory into practice, accelerating innovation and shortening the time to product development and job creation. Where the university has traditionally focused on education and research, Calit2 extends the focus to include development and deployment of prototype infrastructure for testing new solutions in a real world context." (Calit2, 2012)

Calit2's members include many of the leading firms in the telecommunications equipment and software industries, including AMCC, AT&T, Broadcom, Ericsson, Fujitsu, Hughes, Intel, IBM, Microsoft, Nokia, Oracle, Qualcomm, Samsung, Sun Microsystems and Texas Instruments. Calit2 receives millions of dollars in funding every year for research intended to be of direct interest to industry. However, in acknowledgement of its primary source of industry funds, in the spring of 2013 the UCSD branch of Calit2 was renamed the Qualcomm Institute for Telecommunications and Information Technology (or Qualcomm Institute for short).

From Industry to UCSD

In recognition of the value of UCSD's research and education to the local telecommunications cluster, the local wireless firms have provided significant resources to support UCSD, especially in engineering. In addition to resources, industry demand for engineering students increased the legitimacy of the engineering programs within UCSD; industry also worked to encourage interaction and linkages with faculty and students.

As was noted above, the UCSD School of Engineering was renamed the "Irwin and Joan Jacobs School of Engineering" upon their gift of $15 million in 1998. In 2003, the couple pledged another $110 million: $10 million over five years, and a $100 million bequest — the largest gift in the university's history. Commemorating Jacobs' original faculty role, the couple endowed a chair of Information and Computer Science in the Jacobs School. Qualcomm also endowed a chair in Communications and Technology Policy at the Graduate School of International Relations and Pacific Studies. Many related chairs in engineering were endowed during this period thanks to the growth of this sector as the tables below indicate. As of early 2012, the School of Engineering had four chairs endowed by Qualcomm, one endowed by Ericsson, and a Communications Industry Professorship funded through CWC member companies.

Other local executives made contributions to UCSD's new business school, including a

[10] Prior to becoming President of the University of California System, Atkinson had been the Chancellor at UCSD and was a founding board member and major shareholder in Qualcomm (Potter 2001; Ainsworth 2002).

founding gift in 1993 of $5 million from Bill Stensrud (former CEO of Primary Access) and an endowed chair funded by Harvey White, co-founder and former president of Qualcomm and later became CEO of Leap Wireless.

The growing telecommunications cluster provided an important source of employment for UCSD graduates, which was no small concern during the 1970s and 1980s, before the region's high tech employment in other sectors began to grow. The local firms also brought national engineering and communications conferences to the region, such as those sponsored by the Cellular Telecommunications Industry Association. These events provide visibility and access for faculty and students.

The shared growth and success of UCSD and the San Diego economy were summed up in a June 2012 column in *Forbes* (Fidelman, 2012) which described San Diego as the "World's Wireless City."

> "The San Diego community is not only the largest wireless community but is also the origin of the wireless industry with Qualcomm at the center of it all. Even beyond the traditional uses of wireless technologies, research institutes like West Wireless are helping to usher healthcare into the wireless age to cut costs and provide whenever, wherever health care support," Dexcom's CEO Terry Gregg told me when explaining why the company is located in San Diego. As it turns out, Gregg believes it's a competitive advantage to be located at the convergence of wireless technology and healthcare – and there's no better place than San Diego.

Forbes calculated per capita employment in wireless-related industries to illustrate San Diego's strength:

> The concentration of wireless employees in San Diego is 484 per 100,000 residents, compared to Silicon Valley's 375 per 100,000 and Los Angeles's 141. San Diego also boasts the fastest growth in wireless employment (275%) and in payroll (371%) in the last decade. While the City declares it America's Finest, the local economy suggests its America's most Wireless.

UCSD's centrality to the San Diego wireless industry can be illustrated geographically (see Figure 2). The largest concentration of IT and communications jobs in the county are found in an area located 10 miles to the north and east of UCSD — an area that includes both Linkabit's original 1970s location underneath the I-5/I-805 interchange, as well the more than dozen buildings that comprise the Qualcomm campus today east of Interstate 805.

Conclusions

The Symbiosis of UCSD and the Wireless Industry

The growth of UCSD and rise to excellence of its engineering programs enabled and later was enabled by the rise of the wireless telecom industry. UCSD's early focus on basic science attracted a number of eminent researchers in radio-related fields to the region. They were enormously successful in attracting research funding from the Department of Defense and some of these projects developed technology that would be commercially valuable. In the case of Irwin Jacobs, his expertise was such that he was able to establish a firm, Linkabit, which eventually begat dozens of new firms, including Qualcomm. In the 1960s and 70s these small but rapidly growing firms had to rely almost exclusively upon skilled engineers and scientists recruited from outside the region. However, by the 1980s and 90s UCSD had become a major source of highly trained personnel particularly for Qualcomm and the wireless industry. In the last decade, the relationship between UCSD and the wireless sector deepened as demonstrated by the increase in industry research partnerships through such mechanisms as the Center for Wireless Communications and Calit2.

The development of San Diego's wireless industry was seeded by the presence of the University of California, and the relationship between UCSD and this regional industry seems likely to remain strong in the century ahead. This is in large part due to the continuing alignment between the values and practices which animate UCSD and those at the heart of the telecom cluster's success; a belief in the industrial value of basic science, aspirations to be the best, effectively garnering resources, attracting (and retaining) exceptional talent, and using those resources and talent to deploy cutting edge technologies.

Implications Beyond San Diego

Policymakers and researchers have gone to considerable lengths to document the role of Frederick Terman and Stanford University in the success of Silicon Valley. Despite the latter's unique characteristics, it is important to consider the parallels (and differences) in the shared development of UCSD and the local tech industry. As in the Bay Area, universities were essential in training workers to provide the human capital necessary to support local high-growth technology companies. San Diego was similar to the Santa Clara Valley two decades earlier, in that it first relied on out of town sources of technical talent (notably MIT) but gradually strengthened its support for and use of the hometown engineering school (Stanford and UCSD, respectively).

However, the outcomes differed considerably in scale. The Bay Area built a highly diversified technology cluster that (at various times) included semiconductors, hard disks, personal computers, Unix workstations, software, Internet services, computer networking, biotechnology and clean technologies. San Diego's clusters are dominated by telecom and biotechnology (Chapter 3) companies, but particularly in electronics, the San Diego firms are smaller and there are fewer of them than in the Bay Area. Nonetheless, UCSD has played a subtle, but critical role in the growth of the local wireless industry. The San Diego case suggests that the potential contributions of research universities to regional growth include more than star researchers or patented intellectual property. The regional wireless cluster in San Diego has benefited from UCSD's role in a) educating and training the engineers and scientists who are building the emerging cluster and b) in collaborative research activities which contribute to the sectors growth and sustainability. UCSD's role in the growth of the wireless cluster has some parallels with the role of UC Berkeley in the growth of the semiconductor industry in the Silicon Valley described in Chapter 2 in this volume. Both the regional economy and a UC Campus have benefitted from this symbiosis.

Acknowledgements

We thank Nathan Owens and Josh Shapiro for their assistance in compiling UCSD data for this chapter, and Caroline Simard for generous use of her database on San Diego wireless startups.

Tables and Figures

Table 1:
Early leaders of UCSD
Founding administrators listed in **bold**

Name	PhD	Earlier Positions	Honors	UCSD Positions
Roger Revelle	Geology, UC Berkeley, 1936	US Navy: Sonar officer, 1941-1942; Bureau of Ships, 1942-1946; Office of Naval Research, 1946-1948 SIO: researcher, 1931-1941; Associate Director, 1948-1950; Director, 1950-1958	Member, National Academy of Sciences, 1957 President, AAAS, 1974 National Medal of Science, 1991	Director, Institute of Technology and Engineering 1958-1960 Chief Administrative Officer, 1960-1961
Herbert York	Physics, UC Berkeley, 1949	UC Berkeley: Physicist, Manhattan Project, 1943-1945; Assistant Professor, 1941-1954 Lawrence Livermore Laboratory: **Director,** 1952-1958 Department of Defense: **Chief scientist,** ARPA, 1958; **Director,** Defense Research & Engineering, 1958-1961		Professor, Physics, 1961-1988 **Chancellor,** 1961-1964; acting chancellor, 1970-72 Dean of Graduate Studies, 1969-1970 **Director,** Institute on Global Conflict and Cooperation, 1983-1988
Keith Brueckner	Physics, UC Berkeley, 1950	Institute for Advanced Study, Member, 1950-1951 Indiana U.: Assistant professor, 1951-1955 Brookhaven National Laboratory: physicist, 1955-1956 U. Pennsylvania: Endowed chair, 1956-1959	Member, National Academy of Sciences, 1969	Professor, Physics, 1959-1991 **Chairman,** Department of Physics, 1959-1961 **Dean,** School of Engineering, 1963 **Dean,** Letters and Sciences, 1963-1965

Name	PhD	Earlier Positions	Honors	UCSD Positions
Harold Urey	Chemistry, UC Berkeley, 1923	Johns Hopkins: 1924-1929 Columbia: associate professor, 1929-1934; professor, 1934-1945; project leader, Manhattan Project, 1942-1945 U. Chicago: chaired professor, 1945-1958	Nobel Prize, Chemistry, 1934 Member, National Academy of Sciences, 1935 Medal of Merit, 1946 National Medal of Science, 1964	Professor, Chemistry, 1958-1970
James R. Arnold	Chemistry, Princeton, 1946	U. Chicago: postdoc, 1946-1947; research associate, 1948-1950; assistant professor, 1950-1955 Princeton: Manhattan Project, 1943-1945; assistant professor, 1955-1957; associate professor, 1957-1958	Member, National Academy of Sciences, 1964 NASA Exceptional Scientific Achievement Medal, 1970	Associate Professor, Chemistry, 1958-60; Professor, Chemistry, 1960-1983; Urey Chair in Chemistry, 1983-1993 **Chairman,** Department of Chemistry, 1960-onward
Stanford (Sol) Penner	Chemistry, Wisconsin, 1946	US Army Allegany Ballistics Laboratory, 1944-1945 Caltech: research engineer, Jet Propulsion Laboratory, 1947-1950; professor, 1950-1962 Institute for Defense Analyses: 1962-1964	Member, National Academy of Engineering, 1977 NAE Founders Award, 2007	Professor, Engineering Physics, 1964-1991 **Chairman,** Department of Aerospace and Mechanical Engineering Sciences, 1964-1968 Vice Chancellor, Academic Affairs, 1968-1969

Name	PhD	Earlier Positions	Honors	UCSD Positions
Henry Booker	Physics, Cambridge, 1936	Cambridge University: Fellow, 1935-1948 U.K. Ministry of Aircraft Production: principal scientist, Telecommunications Research Establishment, 1940-1945 Cornell: Professor of Electrical Engineering and Engineering Physics, 1948-1965; director, School of Electrical Engineering, 1959-1963	Member, National Academy of Sciences, 1960	Professor of Applied Physics, 1965-1988 **Chairman,** Department of Applied Electrophysics, 1965-1971

Table 2:
SD telecommunications companies founded by UCSD alumni, 1985-2001

Organization	Date Founded	UCSD Alumnus
Qualcomm¶	1985	Franklin Antonio†
ViaSat¶	1986	Steven Hart†, Mark Miller†
Primary Access	1988	Jim Dunn†
Tiernan Communications	1988	James Tiernan (PhD) †
Peregrine Semiconductor	1989	Ronald Reedy (PhD), Mark Burgener (PhD)
Broadband Innovations	1990	Ron Katznelson (PhD) †
CommQuest	1991	Mark Lindsey†
VIA Telecom	1995	Mark Davis (PhD) †
ComCore	1996	Sreen Raghavan (PhD)
Dot Wireless	1997	Rick Kornfeld†
Path1 Networks	1998	Doug Palmer†
AirFiber	1998	Jim Dunn†
RF Magic	2000	Dale Hancock†
La Jolla Networks	2001	James Tiernan (PhD) †
Entropic Communications¶	2001	Ladd Wardani†, Anton Monk (PhD)
Vativ Technologies	2001	Sreen Raghavan (PhD)

† Employee of Linkabit or M/A-Com Linkabit prior to 1985

¶ Went public via IPO

Source: Adapted from Simard (2004)

Table 3:
UCSD Extension certificate programs serving the local telecommunications industry

Certificate	Certificate Name	*First Course Offered	Total Enrollment	**Total Graduates
EMHA	Embedded Computer Hardware	1995	51	29
EMSE	Embedded Computer Systems Engineering	1995	22	6
EMSO	Embedded Computer Software	1995	224	105
MENG	Embedded Computer Engineering	1995	311	50
SYSE	Systems Engineering	1995	534	272
CPMA	CDMA/WCDMA Engineering	1998	378	218
VLSI	VLSI Digital Design	2002	23	4
BBMWE	Broadband Mobile Wireless Engineering	2003	8	4
CMENG	Communications Engineering	2003	37	19
DSPR	Digital Signal Processing	2003	42	21
RFENG	RF Engineering	2003	122	41
CDMA	CDMA Engineering Fund.	2004	0	0
ICDE	Integrated Circuit Design Engineering	2006	8	0
ICDSG	Integrated Circuit Design Engineering	2008	15	3
WLENG	Wireless Engineering	2009	35	8
MADVL	Mobile Applications Development	2011	11	0
MDPRG	Mobile Device Programming	2011	31	2
	Grand Total		**1,852**	**782**

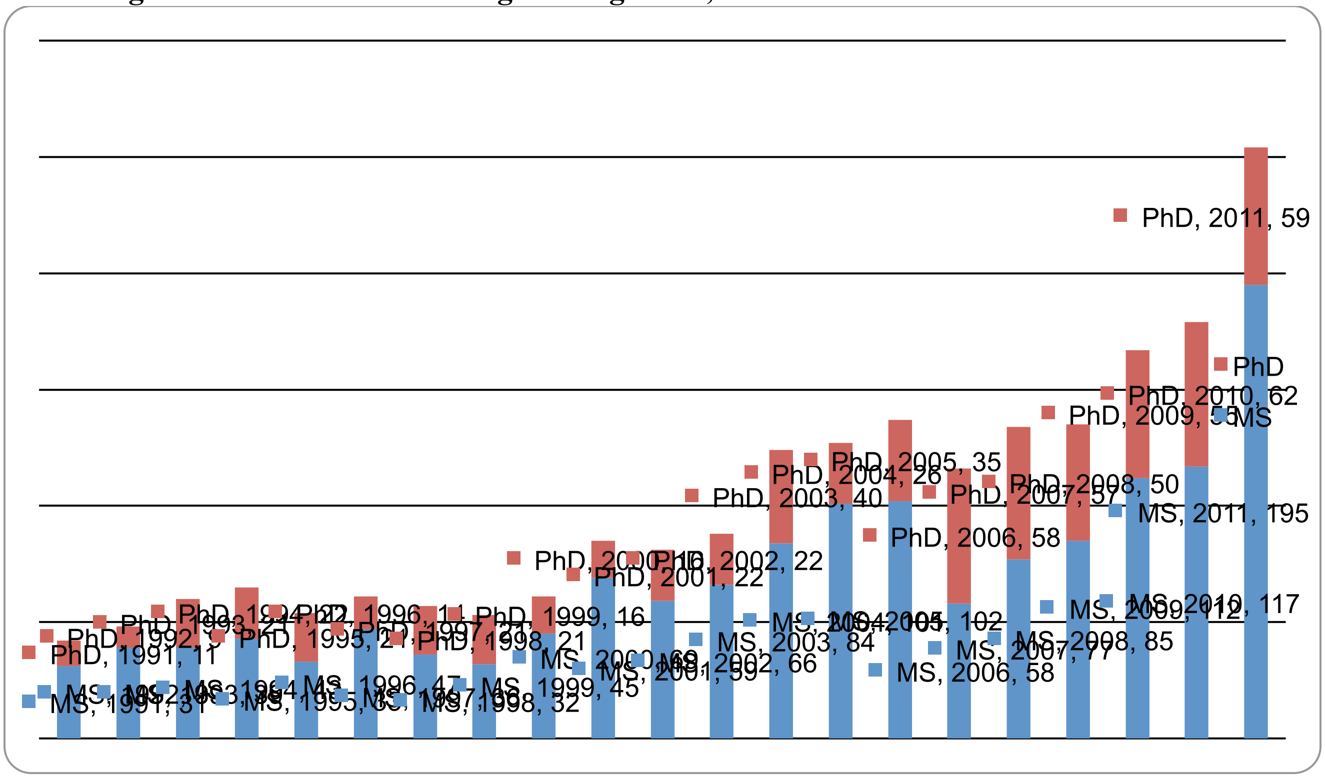
Source: UCSD Extension Student Services Internal Data
*Totals may vary slightly due to changes in data gathering systems between the 1990's and 2010.

Table 4:
Telecommunications-related Extension enrollment by year

Year	Program Enrollment
1995	46
1996	43
1997	50
1998	74
1999	103
2000	90
2001	105
2002	104
2003	160
2004	200
2005	109
2006	96
2007	100
2008	114
2009	110
2010	113
2011	142
2012	93
Grand Total	**1,852**

Note: Total enrollment in certificate programs listed in Table 3

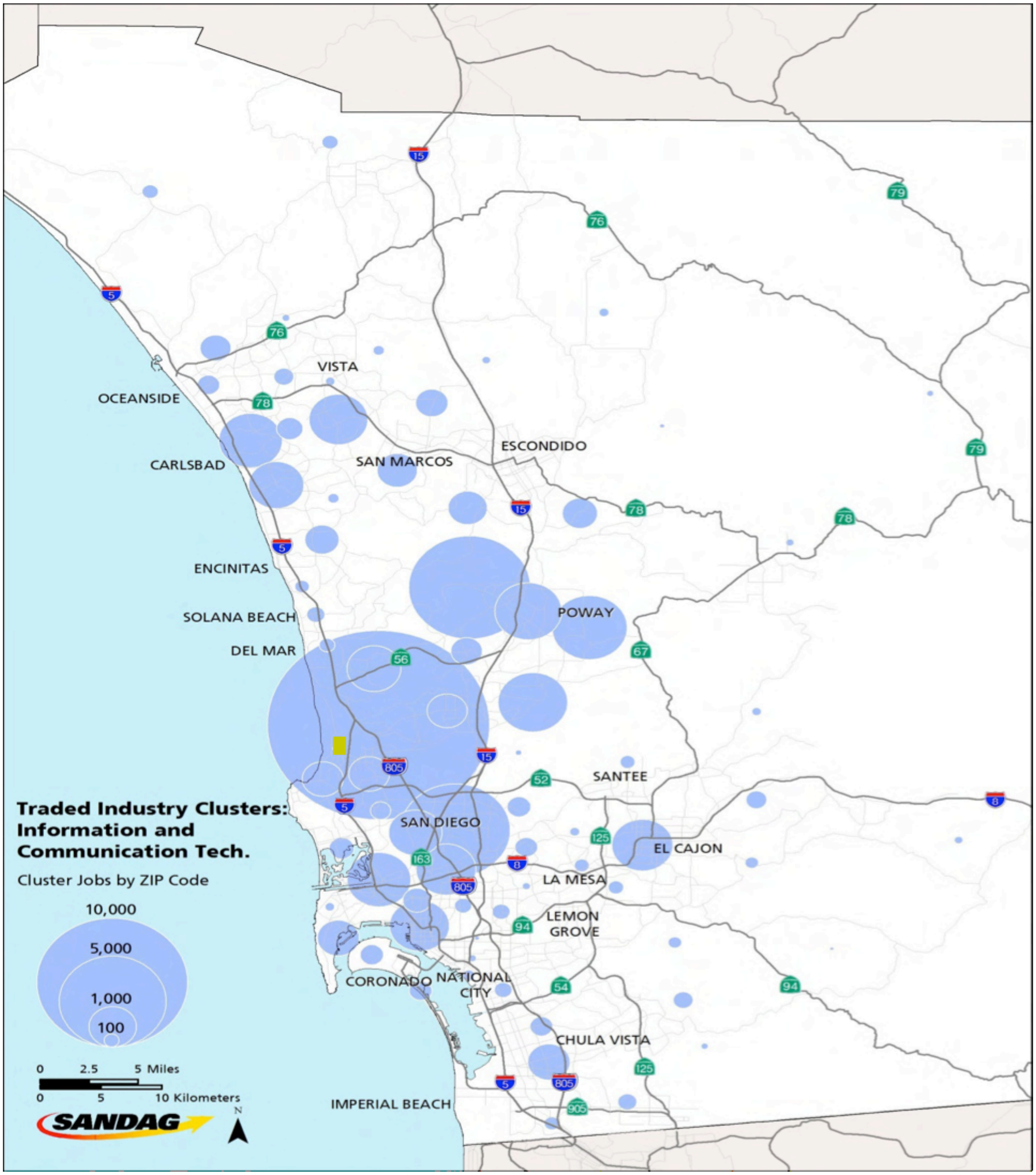
Figure 1:
Graduate degrees in wireless-related engineering fields, 1991-2011



Includes degrees in: Computer Science, Computer Science (Computer Engineering), Electrical Engineering (Communication Theory & Systems), Electrical Engineering (Electrical Circuits & Systems), Electrical Engineering (Signal & Image Processing), Electrical Engineering (Nanoscale Device & Systems), Electrical Engineering (Intelligent Systems & Robotics), Electrical Engineering (Computer Engineering).

Source: UCSD Office of the Registrar Internal Data.

Figure 2: Information and Communication Technologies (ICT) jobs in San Diego County



Note to typesetters: put "UCSD" with arrow pointing to yellow box

Source: Sandag 2012.

References

Ainsworth, B., 2002. Technology trailblazers: At UCSD institute, academic and business worlds converge on a new frontier of innovation. *San Diego Union-Tribune,* 5 May, A-1.

Anderson, N. S., 1993. *An Improbable Venture: A History of the University of California, San Diego.* University of California San Diego Press, La Jolla, CA.

Bailey, D. K., Bateman, R., Berkner, L. V., Booker, H. G., Montgomery, G. F., Purcell, E. M., Salisbury, W. W., Wiesner, J. B., 1952. A new kind of radio propagation at very high frequencies observable over long distances. *Physical Review* 86(2)(April), 141-45.

Bekkers, R., West, J., 2009. The limits to IPR standardization policies as evidenced by strategic patenting in UMTS. *Telecommunications Policy* 33(1-2) (February-March), 80-97.

Booker, H. G., 1954. What is wrong with engineering education? *Proceedings of the Institute of Radio Engineers* 42, 513.

Booker, H. G., 1963. University education and applied science. *Science,* 141(3580) (9 August), 486-488, 575-576.

Booker, H., 1970. Cut-back in AP&IS. Dec. 12 memorandum to Herbert York and John L. Stewart, UCSD Special Collections, Office of the Chancellor (RSS 1), Applied Physics and Information (Box 22, Folder 5).

Bowles, K., 2003. Computers: 50+ years coping with science vs. technology. *Chronicles: Newsletter of the UCSD Emeriti Association* 3(1)(October), 4-7.

Brueckner, K. A. 1994. First years at the University of California at San Diego, 1959 to 1965. UCSD Libraries (downloaded on 28 June 2013 http://libraries.ucsd.edu/historyofucsd/bruecknerfirstyears.html).

Bush, V., 1945. *Science - The Endless Frontier.* Government Printing Office, Washington, DC.

Calit2, 2012. Calit2 : California Institute for Telecommunications and Information Technology. (downloaded on 28 June 2013 from http://www.calit2.net/about/).

Dunn, James. 2004. Interview by Joel West, UCSD Libraries. (January 30).

Fidelman, M., 2012. Why the real wireless capital of the world is San Diego - not Silicon Valley. *Forbes,* 27 June (downloaded on 28 June 2013 from http://www.forbes.com/sites/markfidelman/2012/06/27/why-san-diego-beats-silicon-valley-as-the-wireless-capital-of-the-world/).

Gillmor, C. S., 1986. Federal funding and knowledge growth in ionospheric physics, 1945-81. *Social Studies of Science* 16(1), 105-133.

Gordon, W. E., 2001. Henry G. Booker. *Biographical Memoirs* 79, National Academies Press, Washington, DC.

Leiner, B. M., Kahn, R. E., Postel, J., Cerf, V. G., Kleinrock, L., Roberts, L. G., Clark, D. D., Lynch, D. C., Wolff, S., 2009. A brief history of the internet. *ACM SIGCOMM Computer Communication Review* 39(5)(October), 22-33.

Mock, D., 2005. *The Qualcomm Equation: How a Fledgling Telecom Company Forged a New Path to Big Profits and Market Dominance.* AMACOM American Management Association, New York, NY.

Morton, D., 1999. Oral history conducted with Irwin M. Jacobs. *IEEE History Center*, 29 October (downloaded on 28 June 28 2013 from http://www.ieeeghn.org/wiki/index.php/Oral-History:Irwin_Jacobs).

NOSC., 1990. *Fifty Years of Research and Development on Point Loma, 1940-1990.* Naval Ocean Systems Center, San Diego, CA.

Pang, A. S. K., 1990. Edward Bowles and radio engineering at MIT, 1920-1940. *Historical Studies in the Physical and Biological Sciences* 20(2), 313- 337.

Penner, S. S. 1999. Stanford S. Penner interviewed by Stanley Chodorow. UCSD Library Oral History Archives. (May 5).

Potter, M., 2001. I don't do operational stuff. *San Diego Reader,* 25 January (downloaded on 28 June 2013 from http://www.sandiegoreader.com/news/2001/jan/25/i-dont-do-operational-stuff/).

Raitt, H., Moulton, B., 1967. *Scripps Institution of Oceanography: First Fifty Years.* Ward Ritchie, Los Angeles, CA.

Revelle, R. Untranscribed interview with Roger Revelle by Kathryn Ringrose, UCSD 25th Anniversary Oral History Project. UCSD University Library Archives. May 15, 1985.

SANDAG. 2012. *Info: Traded Industry Clusters in the San Diego Region*. December.

Shor, E. N., 1978. *Scripps Institution of Oceanography 1903-1978.* Scripps Institution of Oceanography, La Jolla, CA.

Simard, C., 2004. From weapons to cell-phones: Knowledge networks in the creation of San Diego's Wireless Valley. Unpublished Ph. D. dissertation, Department of Communication, Stanford University, Stanford, CA.

Simard, C., West, J., 2003. The role of founder ties in the formation of San Diego's "Wireless Valley." DRUID Summer Conference on Creating, Sharing and Transferring Knowledge, 14

June.

Wagner, K., 2005. The future depends on innovation: An interview with Irwin M. Jacobs. *IEEE Design & Test of Computers* 22(3)(May-June), 268-279.

Walshok, M., Shragge, A., 2013. *San Diego's Innovation Heritage.* Stanford University Press, Palo Alto, CA.

Wardani, L. 2005. Interview by Joel West. UCSD Libraries. (August 25).

West, J., 2008. Commercializing open science: Deep space communications as the lead market for Shannon Theory, 1960-1973. *Journal of Management Studies* 45(8)(December), 1506-1532.

West, J., 2009. Before Qualcomm: Linkabit and the origins of the San Diego telecom industry. *Journal of San Diego History* 55(1-2)(Winter/Spring), 1-20.

Wiener, N., 1958. *Nonlinear Problems in Random Theory.* MIT Press, Cambridge, MA.

Wildes, K. L., Lindgren, N. A., 1985. *A Century of Electrical Engineering and Computer Science at MIT, 1882-1982.* MIT Press, Cambridge, MA.