Before Qualcomm:

Linkabit and the Origins of San Diego's Telecom Industry

Joel West

Most San Diegans know that our largest high-tech enterprise of the past decade is Qualcomm, a Fortune 500 company.[1] Qualcomm—founded by Irwin M. Jacobs, Andrew J. Viterbi and five others—is recognized locally for the wealth that it created for founders, employees, and investors. It also enjoys a reputation for helping to fund many local philanthropic and charitable efforts.

Outside the local telecommunications industry, however, few people realize that Qualcomm was the second company founded by Jacobs and Viterbi, not the first. The earlier startup, Linkabit, moved from Los Angeles to San Diego in 1970 and, over the next twenty-five years, helped to generate more than two hundred separate telecommunications companies. A series of fortunate coincidences—rather than a carefully thought out economic strategy—is the main reason why San Diego has a significant telecommunications industry.

This article traces the paths of Jacobs and Viterbi from their New England childhoods to their Massachusetts Institute of Technology (MIT) engineering degrees to the founding of Linkabit. It shows that Linkabit—its early application of cutting-edge communications technologies, its eventual sale, and the eventual dispersal of the company's key engineering talent—was the catalyst that led to other new companies, including Qualcomm.[2]

From New England to San Diego

Both Irwin M. Jacobs and Andrew J. Viterbi spent their formative years in eastern Massachusetts.[3] Jacobs' path was simple. From his birth in 1933 to his graduation from the local high school in 1950, Jacobs lived in New Bedford, a fishing town near Cape Cod. He left to attend the School of Hotel Administration at Cornell University, but later switched to the School of Electrical Engineering. He met and married Joan Klein at Cornell, where he remained until his 1956 graduation. He then moved to the Boston area to enroll as an MIT graduate student.[4]

Viterbi took a more circuitous route. In 1935, Andrea Giacomo Viterbi was born in Bergamo, Italy, the only child of a prominent doctor and his wife. In 1939 they fled Jewish persecution to New York City. The family moved to Boston in 1941. Anglicizing his name to Andrew James Viterbi, he graduated from Boston Latin high school in 1952.[5] He then crossed the Charles River to MIT where he earned a dual SB/SM degree in 1957, paying for college using MIT's cooperative work-study program.[6]

Joel West is associate professor of innovation and entrepreneurship in the College of Business at San José State University. A graduate of Point Loma High School, he holds an SB from MIT and a PhD from UC Irvine. The material in this article is adapted from a planned book on the history of the San Diego telecommunications industry.

Although they do not recall crossing paths, both men were graduate students from 1956 to 1957 in MIT's top-ranked electrical engineering department. During the 1950s and 1960s, MIT researchers led the world's research in information theory, which would later enable the digital transformation of the communications industry. Claude Shannon, the father of information theory, was a professor in the department from 1956 to 1978, although he was semi-retired after 1966.[7]

Of the two young men, Viterbi was the first to come to California, interviewing for a series of aerospace-related jobs in the Los Angeles area. He chose a position in the communications group of the Jet Propulsion Laboratory (JPL) in Pasadena, the California Institute of Technology (Caltech) lab that was sponsored by the US Army until it was transferred to the newly created National Aeronautics and Space Administration (NASA) in October 1958. In June 1957, Viterbi moved with his parents out to Los Angeles. He met Erna Finci later that year, and they were married in 1958. Soon, his JPL salary was supporting his extended family that included his parents, his wife, and their first two children.

At JPL, Viterbi worked on communications with unmanned satellites, including Explorer I, the first American satellite, and then on probes to the moon, Venus, and Mars. Working full-time at JPL, he enrolled in a PhD program in engineering at the University of Southern California (USC) and eventually earned his doctorate in 1962. The following year, he joined the faculty at the University of California, Los Angeles (UCLA) as an untenured engineering professor. He continued to consult with JPL and, later, other NASA operations. While at UCLA, he made the scientific breakthrough on digital communications decoding—the Viterbi algorithm—which later brought him top awards in electrical engineering, communications, and information theory.[8]

In this picture featured on the back cover, JPL scientists review data from Explorer I after the January 1958 launch of the first American satellite. Andrew Viterbi, center, is looking at a printout of telemetry data. Courtesy of the USC Viterbi School of Engineering.

Jacobs, after completing his Sc.D. dissertation in 1959, remained at the MIT electrical engineering department as an assistant, then associate, professor. He began working with Prof. John Wozencraft on a textbook on digital communications, *Principles of Communication Engineering,* which eventually became the standard textbook for MIT's senior communications engineering class; a classic worldwide, it is still available on Amazon.com today.[9] In 1963, he met Viterbi at a conference and realized that they had a common interest. Jacobs, obtaining a leave from MIT, spent one year at JPL from 1964 to 1965, driving to and from California in a used van with his wife Joan and their three sons.

In the fall of 1965, after returning to MIT, Jacobs was invited to a job interview by one of his Cornell professors, Henry Booker, who had since moved to the University of California, San Diego (UCSD) to found its Department of Applied Electrophysics.[10] Jacobs flew out to San Diego for the job interview and then returned to Boston. As he told a 1999 interviewer:

Irwin M. Jacobs, a relatively new member of UCSD's Applied Electrophysics Department, in 1966-67. Courtesy of Irwin M. Jacobs.

> [Joan and I] talked it over, and as much as we liked California, and the idea of moving to a new university, and an opportunity to really start something from scratch, we had all our family back on the east coast, friends, and career. So we called up and turned the job down….For two days, we were miserable with the decision. The second day turned out to be a really rainy day, and I left MIT and took the subway up to Harvard Square. I got out and there were these huge crowds waiting for the buses to Arlington, and people were pushing their way through. I finally managed to get on the fourth bus, and I was standing in the rear of the bus, I had wet clothing, everybody's clothing was wet, and about halfway to Arlington, the clothing began to dry and this terrible odor filled the bus. I got home and I said, "You know, we really do want to go to California." So we called up and said, "Well, we're ready to come." And the position was still open, so out we came.[11]

Jacobs and his family moved to La Jolla where he joined the UCSD faculty in time for the 1966 fall quarter.

Founding of Linkabit

In 1967 or 1968, Jacobs, Viterbi, and one of Viterbi's UCLA colleagues, fellow MIT alumnus Leonard Kleinrock, attended a conference on NASA communications held at the NASA Ames Research Center in Mountain View, California.[12] Flying back from the conference, Jacobs recalls saying that he had more consulting requests than he could accept; the three men agreed to create a company to consolidate their government and industry consulting efforts. The new firm, Linkabit, was incorporated in October 1968. At first, the corporation's offices were located at Kleinrock's Brentwood home. Later, they moved to Westwood, within walking distance of the UCLA engineering building where Viterbi and Kleinrock both worked.[13]

In 1969, Kleinrock and the others had a falling out and the former left Linkabit, retaining a minority equity stake. That year, Kleinrock installed in his UCLA lab the computer that was the first endpoint of what would become the ARPANET, forerunner of the Internet.[14]

The first engineer hired by Linkabit was Jerrold Heller, an MIT graduate student who had followed his advisor Jacobs to San Diego to finish his doctorate

The founders of Linkabit in front of their new San Diego headquarters in Sorrento Valley, ca. 1973. Pictured: Andrew Viterbi, unidentified, Irwin M. Jacobs, and Jerry Heller. Courtesy of Irwin M. Jacobs.

(MIT PhD '67). Heller then worked on digital communications problems at JPL before joining Linkabit in September 1969.[15] Over the next fifteen months, the company hired three other electrical engineers: Andrew R. Cohen (MIT '57), Klein Gilhousen (UCLA '69), and James Dunn (UCSD '70).

In 1970, Linkabit moved from Los Angeles to Sorrento Valley. Their offices at 10453 Roselle Street became the first of more than twenty Linkabit buildings along Roselle Street and Sorrento Valley Road. To run the office, Linkabit hired Adelia "Dee" Turpie, who had just graduated from Madison High School.[16] The existing employees moved south from Los Angeles to San Diego, except Viterbi, who moved south three years later. In 1971-72, Jacobs took a leave of absence from USCD to better organize Linkabit.

Linkabit's Launch Customer: NASA

Linkabit made the vast majority of its money from designing and implementing digital telecommunications. In its early days, Linkabit did not build anything. It began life with study contracts, research projects funded by clients to solve specific technical problems. As the company built its reputation and capabilities, it designed specific products and built components such as circuit boards, semiconductors, chips, and, finally, complete devices.

Today, high-technology analysts talk about a new tech startup company needing a "launch" customer. For Linkabit, that launch customer was NASA, supporting communications for its deep space missions. Linkabit did work for NASA research laboratories, both the Ames Research Center in Mountain View, California, and the JPL contract laboratory run by Caltech. NASA was not the company's first or only early customer — which also included NEL (later NELC and then NOSC) in Point Loma and the Virginia-based Defense Advanced

Research Projects Agency (DARPA) — but NASA was the customer that first allowed them to apply Shannon's theory.[17]

Theoretically, the coding theory developed over the two decades after Shannon's 1948 information theory manifesto allowed digital communications to gain nearly 10 decibels of signal strength (10 times stronger) at the same reliability.[18] When Linkabit was formed, however, that potential remained largely unrealized.

Over the next two decades, Jacobs and Viterbi would take the field of coding theory from journal papers and textbooks to practical applications. Their backgrounds made this possible. Jacobs, although not among the leading information theorists, was at MIT during the peak of the electrical engineering department's influence on information theory, working alongside those who had developed the major breakthroughs in the field. Jacobs applied these ideas to problems in practical communications, including them in his textbook on communications theory and paper on space communications based on his year at JPL.

Viterbi, while self-taught, understood information theory well enough to teach it at UCLA. More significantly, he had developed the decoding algorithm, known as the Viterbi algorithm, which for more than two decades was considered the world's best error-correction scheme for noisy digital communications. In 1991, he earned the top academic prize in information theory, the Shannon Award given by the IEEE Information Theory Society.[19]

Even more significantly, Viterbi and Jacobs had experience in space communications, one of the few markets in the 1960s where the benefits of coding theory, including Viterbi's algorithm, were worth the cost. Viterbi worked with JPL's communications group from 1957 onward, first as a full-time employee and then as a consultant. Jacobs also got to know this group during his 1964-65 visiting appointment.

Today, we take for granted that digital communications are possible in a consumer electronics device, whether a CD player, a DVD player or a high-definition television. Since the mid-1990s, the United States has enjoyed digital cell phones—using Qualcomm's technology—that can apply information theory in real time to voice communications using a postage-sized microchip that runs off a pocket-sized battery and costs under $20.

But in 1967—when Viterbi was inventing his algorithm and researchers were applying the Shannon-derived theory to deep space communications—computers were much slower, bigger, and more expensive. NASA researchers favored a Sigma 5 minicomputer while Viterbi used UCLA's larger Sigma 7 minicomputer in his early contract research for NASA Ames Research Center.[20] Each computer was from Santa Monica-based Scientific Data Systems (later bought by Xerox), requiring several refrigerator-sized cabinets. Each sold for $300,000 to $700,000 ($2 million to $4.6 million in 2009 dollars).

Digital coding, and especially decoding, required dedicated use of expensive and scarce computing power, making it impractical for ordinary uses. Since it was not being used commercially, it also required someone to pay the up-front development costs of the new technology. Despite these problems, the technology was ideally suited for receiving photographs and other telemetry from NASA's planned unmanned deep space probes to the outer planets, first Mars, then Jupiter, Saturn, Uranus, and Neptune. Because radio signals dissipated via an inverse

Klein Gilhousen, pictured ca. 1974, led Linkabit's efforts to develop one of the first digital signal processors on a chip, the Linkabit Microprocessor (LMP). Courtesy of Irwin M. Jacobs.

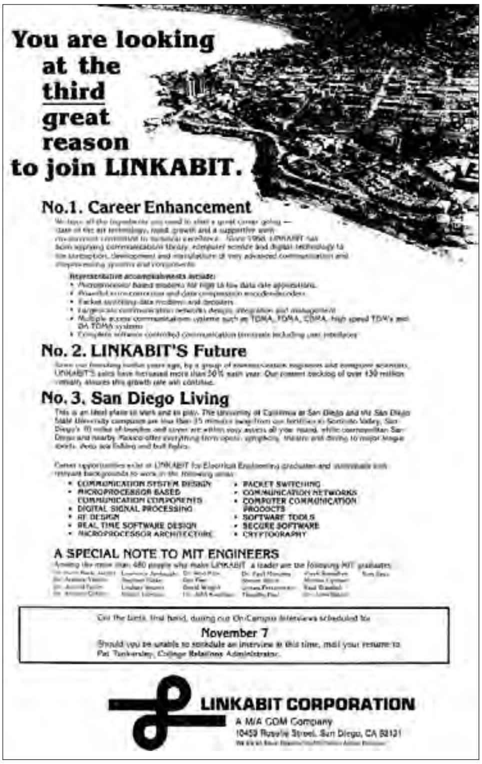
power law, moving a spacecraft from the Moon to Mars would reduce the radio signal power by a million-fold, while a visit to Saturn would reduce power by another ten-fold.

By 1968, NASA had made a decade's worth of improvements in its communications systems and was running out of alternatives. Boosting transmitter power would require more power than was available on the space probe; increasing the transmit antenna would require an antenna bigger than the standard US space boosters. Meanwhile, NASA's existing ground-based satellite dishes were 210 feet in diameter. It was impractical to make them any larger as they were difficult to maintain and cost hundreds of millions of dollars. Digital encoding and decoding cost far less than any alternative strategies to improve the communications efficiency of a handful of space probes and ground stations.[21]

NASA Ames, developing the Pioneer unmanned probes, was slightly ahead in the interdivisional space race. NASA had hired Dave Forney of the Codex Corporation (Newton, Massachusetts) and Prof. Jim Massey of Notre Dame to work on their communications problems. The two men, both with doctorates from MIT, came up with the solution used in Pioneer 10 (the first space probe to Jupiter) and Pioneer 11 (to Jupiter and Saturn), launched in 1972 and 1973.

NASA Ames also engaged Viterbi while he was at UCLA, sponsoring the dissertation research of three of his PhD students. One student, Joseph Odenwalder, proposed a solution that combined Viterbi's decoding algorithm with a coding approach from Forney's dissertation to produce better results than had been obtained on the Pioneer probes. After graduating, Odenwalder joined Linkabit as employee #26.[22] NASA then hired Linkabit for a follow-up study, completed by Odenwalder, Viterbi, Jacobs, and Heller in early 1973. The proposed solution was used by the JPL-designed Voyager space probes to the outer planets. Launched in 1977, Voyager 1 visited Jupiter and Saturn while Voyager 2 also visited Uranus and Neptune.

The NASA projects gave Linkabit the credibility and ability not only to display its knowledge of digital communications, but also to apply that knowledge to solve real problems. Linkabit also caught a lucky break when Codex faced a management crisis and decided to focus on an unrelated communications breakthrough, pioneering the then state-of-the-art 9600 baud modems. The company abandoned space communications and referred such business to Linkabit for several years.[23]



MIT's newspaper, The Tech*, ran an advertisement for Linkabit on October 31, 1980. The ad emphasized Linkabit's ability to help "start a great career going," its rapid growth rate, and its ideal location in San Diego with its research universities and "70 miles of beaches." Author's collection.*

Military Applications

Digital communications used in deep space also had military applications. In military communications, the interference might be man-made signal jammers rather than natural background radiation but the signal reliability benefits were the same. Digital coding also aided in goals unique to military (or intelligence) communications: avoiding interception, falsification or triangulation. A major difference was that military communications were higher volume than space probes, requiring the production of hundreds or even thousands of units, unlike the two-dozen units used by NASA projects. During the 1970s, military projects were able to exploit the faster and cheaper semiconductor components, as predicted by "Moore's Law," based on a 1965 article by Fairchild Semiconductor (and later Intel) cofounder Gordon Moore.[24]

As the NASA projects wound down during the 1970s and early 1980s, Linkabit developed a series of modulators and demodulators (modems) for digitally encoding and decoding military signals over UHF radio waves (0.3-3.0 GHz), allowing military commanders to use satellites to relay signals to aircraft and other units located anywhere in the world. Working as a subcontractor to major defense electronics companies, Linkabit gradually produced higher volumes of communications components and then entire devices for the US Air Force and later the US Army in the 1970s.

Linkabit began by providing hardware and software to the Air Force that assured secure and reliable communications for targeting strategic (i.e. nuclear)

Andrew J. Viterbi developed the decoding algorithm, known as the Viterbi algorithm, that made possible effective satellite communications. Andrew J. and Erma Viterbi Family Archives, University of Southern California.

weapons. As part of its efforts to reduce the cost and size of the military communication devices, Gilhousen led the company's successful efforts to develop one of the first digital signal processors on a chip, the Linkabit Microprocessor (LMP). In 1973, only two years after Intel released the world's first microprocessor, the Intel 4004, Gilhousen began writing the microcode describing the operations of the LMP. With Sheffield "Sheffie" Worboys and Franklin Antonio, he completed a "breadboard" prototype of the new chip in May 1974. The microprocessor operated at 3 million cycles per second, or about 1/1000 as fast as today's desktop computers. Later that year, Linkabit used the LMP to implement the Viterbi algorithm for decoding digital signals from outer space.[25]

Linkabit's Dual Modem, made possible by the development of the LMP, allowed communication by military units with two different US Air Force satellite communications systems, hence its name. The modem, developed by Klein Gilhousen, Franklin Antonio, and led by Jacobs, had both data and limited voice capabilities. The first significant manufacturing program for Linkabit, it was shipped beginning in late 1977 or early 1978.[26]

One of Linkabit's most sophisticated early products was the Command Post Modem/Processor (CPM/P) to send and receive SHF/EHF (3 GHz-300 GHz) satellite communications on US Air Force airborne command posts. The CPM/P was sold both for the Air Force EC-135 (adapted from a Boeing 707) and the E-4 (Boeing 747) and was intended to provide communications to US strategic bombers and missiles in the event of a nuclear war.

The Dual Modem was succeeded by the Tri-Modem, a communications modem that added an additional mode to support US Army communications.[27] Variations of these modems for the three major services (Army, Navy, Air Force) continued in production into the 1990s. Martha Dennis, one of Linkabit's few female executives, led the Tri-Modem development project, one of the largest and most strategically important Linkabit ventures of the 1970s. A PhD student at Harvard University in the Applied Mathematics department, she moved to San Diego in 1970 when her husband accepted a position as an assistant professor in the UCSD Chemistry Department. She met Irwin Jacobs at the La Jolla Democratic Club and worked with him at UCSD while completing her 1971 doctoral thesis on computer graphics. In 1976, she joined Linkabit as a leader of its software development efforts.[28]

Civilian Business

In the late 1970s and early 1980s, Linkabit continued to expand. By 1978, its annual revenues reached $10 million. In hiring new engineers, it sought intelligent but inexperienced college graduates from top schools like MIT, Illinois, Stanford, and the University of California schools. Linkabit's early recruiting efforts focused on MIT. Later, as UCSD's engineering program developed in size and stature, the company pulled talent from its local school. Linkabit offered engineers interesting work and a culture that emphasized technical prowess ahead of other goals. Viterbi and Jacobs, meanwhile, had the respect of colleagues at leading universities throughout the country.

To grow its business beyond government contracts, Linkabit applied its satellite communications expertise to commercial problems. In the late 1970s, Linkabit was among several government contractors doing research on the use of satellites to route transatlantic ARPANET communications. Linkabit engineers found how the ARPANET could work with the longer delay from bouncing signals off of satellites orbiting 22,000 miles above earth.[29]

For commercial uses, Linkabit worked to deploy a new technology—Very Small Aperture Terminal (VSATs)— that allowed satellite communications with ground dishes of 4 to 8 feet in diameter. It began building equipment for Satellite Business Systems (SBS), initiating its largest effort to date to provide commercial applications for satellite communications. SBS began in 1975 as a joint venture between IBM, Aetna Life and Casualty, and COMSAT, the US-based communications satellite company. SBS originally focused on high-speed data communications for US businesses and, later, shifted to long-distance telephone calls. In 1984, it was sold to MCI.

After winning a contract with oil services contractor Schlumberger, Linkabit worked to sell VSAT systems to other firms that needed business communications. Mike Lubin, a manager, targeted the Fortune 500 companies that needed to connect hundreds of locations across the country. Linkabit's next major contract was with Wal-Mart, allowing the company's Arkansas headquarters to receive data and send video to more than 700 stores around the country. Linkabit later landed similar deals to service 7-11 convenience stores and Holiday Inn hotels.

Linkabit's largest volume commercial project, however, came with VideoCipher, an encryption system for satellite TV broadcasts. Home Box Office (HBO) was one of many pay television services frustrated by consumers who watched their cable TV channels for free via large backyard satellite dishes. After seeking proposals from various electronics companies, HBO chose to award the contract to Linkabit whose engineers had submitted the only digital solution to the problem of encrypting TV channels. The VideoCipher team included three men with MIT doctorates: Jerry Heller, Woo Paik, and Paul Moroney. After HBO selected the technology and installed transmitters and receivers for cable TV systems, Linkabit worked to build a mass-market decoder to be sold to consumers. It started its first high-volume commercial factory, built in Puerto Rico due to tax incentives. In 1986, the VideoCipher team won a technical Emmy award from the Academy of Television Arts & Sciences.

Finally, Linkabit designed and built an early model of a TDMA (time division multiple access) digital mobile phone for Pennsylvania-based International Mobile Machines Corporation (IMM). In 1992, IMM acquired a rival firm and renamed itself InterDigital. Today, it competes with Qualcomm to license technology and sell integrated circuits to cellular telephone makers.

Acquisition and Dismemberment

Linkabit's expansion into commercial businesses— particularly its need to build a consumer-scale manufacturing plant for the HBO decoders—required more capital than it had. In November 1979, Linkabit agreed to be bought by the NYSE-listed M/A-COM. The acquisition was completed in August 1980 for $25 million. As Jacobs recalled two decades later:

> We were approached by M/A-COM, located back in Boston, about the possibility of joining them. They were acquiring us really, by a stock-merger. We had been thinking about whether to go public in time. They had a lot of components. It sounded like a very good idea, in the sense that we would be a very vertically integrated company. They were already on the New York Stock Exchange, so that would take care of the issue of providing liquidity to the stock that various people owned. It sounded very positive. Further, the CEO and Chairman of the company [was] Larry Gould, a person who had graduated at age 21 or 22, with the PhD from MIT So we could get along very well together. So we decided to merge.[30]

An advertisement for the Tri-Modem, produced by M/A-COM Linkabit, stated, "In the next 20 years, SAC [Strategic Air Command] will use three different UHF SATCOM systems, but will need only one modem." M/A-COM Linkabit, Inc. Andrew J. and Erma Viterbi Family Archives, University of Southern California.

M/A-COM Linkabit retained a distinct identity but the company's operations were combined with related M/A-COM divisions, in particular, the former Digital Communications Corp. of Germantown, Maryland, acquired by M/A-COM in 1978. For several years after the acquisition, M/A-COM Linkabit expanded dramatically. As it grew—and as Jacobs and Viterbi assumed more senior responsibilities within M/A-COM—the culture of the company changed. As engineer Steve Hart recalled: "Linkabit was a real fun place to work, but it started changing after the M/A-COM acquisition."[31]

Jacobs and Viterbi separately left M/A-COM Linkabit in April 1985. They both cited the 1982 decision of M/A-COM's board to remove the Chairman and CEO Lawrence Gould whom they trusted, having worked with him to negotiate the deal.

M/A-COM, facing financial troubles, sold off the various pieces of Linkabit after Jacobs and Viterbi left. In 1986, General Instruments purchased VideoCipher and other television-related technologies before selling itself to Motorola in 2000. M/A-COM's telecommunications division, which included both Linkabit and DCC, became Hughes Network Systems after its 1987 purchase by Hughes Electronics, the division of General Motors that later created the DirecTV satellite television system. In 1990, the Titan Corporation, a San Diego-based defense electronics company founded in 1981, purchased the remainder of Linkabit, the government contracting division.[32]

Qualcomm and Other Linkabit Spinoffs[33]

M/A-COM Linkabit employees responded to the change in corporate culture, the dismemberment of Linkabit, and the resignation of the two founders by leaving the company. Between 1984 and 1990, they founded ten new telecommunication companies in San Diego.[34] The brain drain cost M/A-COM Linkabit not only its key executives and top engineers, but also much of its ability to develop and deliver new technologies.

In July 1985, a group of seven Linkabit alumni met at Jacobs' La Jolla home: the two Linkabit founders (Viterbi and Jacobs), three of the earliest engineers (Andrew Cohen, Klein Gilhousen, and Franklin Antonio), and two senior financial managers

Andrew and Erma Viterbi, left, at MIT's 25th year class reunion, June 1982. Andrew J. and Erma Viterbi Family Archives, University of Southern California.

Martha Dennis, center, with a group working in the Linkabit lab on their first large commercial project, the Data Aggregator, ca. 1980. Back row: Geoff Tollin, Tom Seay, Rob Gross, Butch Weaver, John Ratzel. Front row: Dennis, unidentified. Courtesy of Martha Dennis.

(Adelia Coffman and Harvey White). They decided to build a company that delivered "QUALity COMMunications" and called their new company, Qualcomm.

At first, Qualcomm continued along the Linkabit trajectory with government contracts to provide digital communications services. After starting with smaller projects, it developed high-speed data communications for the three major armed services to transmit data at military test ranges. It also completed projects for large defense contractors, including Ford Aerospace in Newport Beach, California, and Hughes Electronics based in Germantown, Maryland.

Qualcomm's first major source of ongoing revenues came from OmniTRACS, a satellite-based mobile communications system that allowed companies to locate their trucks anywhere and contact them anytime. On the strength of OmniTRACS, Qualcomm completed its initial public offering in December 1991, the first of the Linkabit spinoffs to do so. Qualcomm's greatest fortunes, however, came with a digital cell phone technology it called Code Division Multiple Access (CDMA).[35] The technology was adopted by three of the seven of the "Baby Bell" spinoffs of AT&T—Bell Atlantic, NYNEX and US West—as well as AirTouch Communications, GTE, and Sprint PCS.[36]

In 1999, Qualcomm's stock had its best year ever with a 2,600 per cent increase, leading all stocks on major US markets. This was based on the strength of CDMA sales in the United States, Korea, and Japan.[37] The rapid rise turned ordinary employees and investors into millionaires; three such "Quillionaires" were featured on the cover of *Money* magazine.[38]

Qualcomm, although the best known and most financially successful of the companies founded by former Linkabit employees, was one of many startups that sought to recreate the Linkabit culture of the late 1970s and early 1980s. Interactive Concepts was founded two years earlier, in 1983; Sciteq and ComStream followed in 1984.

Of the three new companies formed by Linkabit alumni in 1986, the most financially successful was ViaSat of Carlsbad, started by the manager of Linkabit's satellite modem business, Mark Dankberg, who recruited as cofounders Linkabit engineers Steve Hart and Mark Miller. Like Qualcomm, ViaSat maintained its independence through an initial public offering in December 1996. Today, ViaSat still attempts to maintain the culture created by Jacobs and Viterbi. As cofounder Steve Hart recalled: "It was definitely intentional. We liked working there, all of us....We really liked the culture. We wanted that culture and were very influenced by it."[39]

In 1987, five former Linkabit executives founded Pacific Communications Sciences, Inc. (PCSI): Martha Dennis, Mike Lubin, David Lyon, Philip Wilson, and Warren Weiner. They focused on both speech compression and Cellular Digital Packet Data (CDPD) created to transmit wireless digital data over analog cell phone networks. PCSI's greatest success came from making radio frequency integrated circuits for the Personal Handyphone System, a low-cost digital mobile phone network that began service in Japan in 1995. PCSI was purchased in 1993 by Cirrus Logic, which later sold the bulk of the company to Rockwell International in 1997. Both Dennis and Lyon went on to form new San Diego telecom companies.

Jacobs speaks at the tenth anniversary celebration of the founding of Qualcomm in 1985. Six of the founders are pictured, left to right: Klein Gilhousen, Franklin Antonio, Dee Coffman, Irwin M. Jacobs, Andrew Viterbi, and Harvey White. The seventh founder, Andrew Cohen, is not shown. Courtesy of Irwin M. Jacobs.

The VideoCipher was one of Linkabit's largest volume commercial projects. Jacobs, right, is pictured with a box containing VideoCipher #10,000. Courtesy of Irwin M. Jacobs.

The 1980s startups leveraged Linkabit's strong knowledge of satellite-enabled digital communications and built on Viterbi and Jacobs' earlier work on military and NASA projects. Many received key early revenues from satellite communications, whether satellite-based truck tracking (Qualcomm), government satellite communications (ViaSat), improving the efficiency of live remote TV broadcasts transmitted via satellite (Tiernan Communications), or decoding satellite signals for airline radio listeners or home TV viewers (ComStream).

In fact, the Linkabit alumni kept coming back to satellites, whether or not they wanted to. ViaSat CEO Mark Dankberg originally targeted the fast growing dialup modem business at a time when modem speed was then improving from 2400 to 9600 bits per second (en route to 56,000 bps a decade later). However, as another ViaSat founder later recalled, venture capitalists would not fund the idea: "[The venture capitalists] said: 'Well, that's all real interesting, but you don't know anything about that commercial wireline modem business. But if you want to do what you know, we're glad to fund you.' (Laughing) And so our business plan was pretty much doing what we were doing at Linkabit."[40]

Conversely, the founders of PCSI, who left the following year, avoided satellite communications for fear of retaliation from the M/A-COM Linkabit management that replaced Jacobs and Viterbi: "There was a tremendous fear that if we showed up in satellite communications that possibly they would try to sue us for violating confidentiality agreements. So I think we decided to be squeaky clean and potentially not go into the satellite business."[41] Despite this decision, PCSI later worked on its own satellite-related topics, including a project for INMARSAT, the global satellite-to-ship telephone system.

Not all of the Linkabit spinoffs involved wireless communications. Primary

Access built telephone multiplexors for CompuServe and other large operators of dialup information services. The company was founded in 1987 by a team of six Linkabit alumni, two of whom were working for the Linkabit division acquired by General Instrument. Jim Dunn, their first president, had been Linkabit's longest-serving employee after the Qualcomm spinoff and the General Instrument acquisition. Joe Markee, another founder, joined Linkabit in 1979 and went on to become CEO of two other San Diego telecommunications firms.

Primary Access may be best known for its last CEO, William Stensrud, who remained at the helm until the company's 1995 acquisition by 3Com of Santa Clara. Stensrud became managing director of San Diego's largest venture capital fund, Enterprise Partners Venture Capital, which had more than $1 billion of technology investments when Stensrud resigned in 2006.[42] He is also the only telecom veteran (other than current or former Qualcomm officers) to make a recent list of the twenty-five richest San Diegans.[43]

Conclusions

The San Diego telecommunications industry developed from a single startup company—Linkabit—into major locus of entrepreneurial activity during the 1980s. In the eight year period, 1983 to 1990:

- M/A-COM Linkabit, formerly Linkabit, was sold off in three major parts totaling $359 million;
- Ex-Linkabit employees formed ten startup companies in San Diego and another three formed elsewhere; and,
- Employees of these thirteen companies and the three former Linkabit divisions founded another six startup companies, including Tiernan Communications (1989) and Boatracs (1990).

Jacobs speaks in 1995 about Qualcomm's success during the previous ten years. Courtesy of Irwin M. Jacobs.

Among all the telecommunications startups, the greatest wealth creation came from Qualcomm.[44] Its retired executives are associated with multimillion dollar donations to the San Diego Symphony, La Jolla Playhouse, Old Globe, the Museum of Contemporary Art, the Jewish Community Center, Scripps Research Institute, the San Diego Natural History Museum, and the San Diego Food Bank, as well as to UCSD and San Diego State University.

Linkabit, however, fueled significant economic growth in the San Diego region by seeding a large cluster of telecommunications firms. Martha Dennis, onetime president of the San Diego Telecommunications Council, compiled a list of more than seventy-five direct spinoffs (founded by Linkabit alumni) and indirect spinoffs (founded by alumni of other spinoff companies) from 1983 to the present, most of them in San Diego. This infrastructure has brought more than two hundred telecommunications startups to the San Diego region since 1980, including seven NASDAQ listed companies: Qualcomm, Leap Wireless, ViaSat, Novatel Wireless, Maxwell Technologies, Dot Hill Systems, and Entropic.[45]

Two factors were key to the creation of the local telecommunications industry. The first was Jacobs' role in moving Linkabit to San Diego. If, instead of Jacobs, Viterbi (or Kleinrock) had become the administrative head of the company, then Linkabit would have remained in Los Angeles. Of course, if Jacobs had stayed at the world's pre-eminent communications research program in Massachusetts—rather than taking the risk of moving to a new and unproven university in southern California—then he would not have been in San Diego in the first place.

The second key factor was the dispersal of Linkabit's technical talent to form the first generation of unofficial spinoffs from 1984 to 1989. Such a rapid exodus of Linkabit's best engineers during its first two decades had no precedent at more stable, high-tech companies like HP, Intel, or Genenech.[46] Whether their departures were the result of M/A-COM's botched acquisition of Linkabit or a loss of confidence after Jacobs and Viterbi left, these talented men and women formed dozens of direct and indirect Linkabit spinoffs in San Diego. These spinoffs, in turn, formed the nucleus of about two hundred wireless communications startups formed in San Diego from 1980 to 2003.[47]

Together, these two factors brought about the current concentration of telecommunications talent in San Diego, as well as the close cooperation

In 1997, the Qualcomm Corporation paid $18 million to rename Jack Murphy Stadium in Mission Valley, home of the San Diego Chargers and former home of the San Diego Padres. The sports arena is now known as Qualcomm Stadium. In this picture, Jacobs speaks on behalf of his company, post-1997. Courtesy of Irwin M. Jacobs.

between industry and local universities, particularly UCSD. When combined with the parallel growth of local biomedical industries, the result has been the transformation of San Diego from a sleepy Navy town to one of the nation's leading high-technology regions.

Founded	Firm	Status
1984	ComStream	Acquired by Spar Aerospace in 1992
1984	Sciteq	Acquired by Osicom in 1996
1985	Qualcomm	NASDAQ public company since 1991
1986	ViaSat	NASDAQ public company since 1996
1986	MultiSpectra Engineering	Acquired by Tachyon Networks in 1997
1987	Pacific Communications Sciences, Inc. (PCSI)	Acquired by Cirrus Logic in 1993
1987	Indra Technology	Acquired by CenterStone Technologies in 2006
1988	Primary Access	Acquired by 3COM in 1995
1989	Milpower	Remains privately held
1990	Torrey Science	Liquidated in 1998

Table 1: First generation startup firms formed in San Diego by Linkabit employees and alumni, 1984-1990. Sources: See note 34.

NOTES

1. Qualcomm has been on the *Fortune* 500 list since 1999, ranking #297 in 2008. It was followed by another San Diego company, SAIC (#289), first listed in 2006, whose primary business is providing technical and professional services to the US government. The only other San Diego company on the list during this entire period was Sempra Energy (#232), parent of SDG&E.
2. Caroline Simard, "From Weapons to Cell-Phones: Knowledge Networks in the Creation of San Diego's Wireless Valley" (PhD dissertation, Stanford University, 2004). The author is grateful for permission to use both this work and Simard's database, "San Diego Wireless Valley" (July 2005), that identifies 346 wireless-related companies or branch offices formed in San Diego through 2004. Simard and West have acquired individual and joint data collections on the San Diego telecom industry, including archival data and more than sixty interviews conducted with local founders and employees since 2003. See also: Joel West and Caroline Simard, "Balancing Intrapreneurial Innovation vs. Entrepreneurial Spinoffs During Periods of Technological Ferment," *Sloan Industry Studies Working Papers* WP-2007-32 (2007).
3. In the financial press, San Diego's Irwin Mark Jacobs uses his middle name to distinguish himself from Irwin L. Jacobs of Minneapolis, a well-known corporate raider of the 1970s and 1980s who was on the *Forbes* list of four hundred richest Americans from 1986 to 1988. In 1999, *Forbes* itself confused the two when it ran Irwin L.'s photo for an article on Irwin M. as a new entrant to the Forbes 400. One of the few articles to mention both men is Barnaby J. Feder, "New Economy: An Old-Style Deal Maker Takes up the Cause of High Technology with Manufacturing over the Internet," *New York Times,* August 21, 2000. Campaign finance reports routinely mingle the Democrat contributions of I. M. Jacobs with the Republican contributions of I. L. Jacobs.
4. Daniel S. Morrow, "Irwin Mark Jacobs Oral History," interview transcript, *Computerworld Honors Program International Archives,* March 24, 1999; David Morton, "Oral history conducted with Irwin M. Jacobs," Institute of Electrical and Electronics Engineers (IEEE) History Center, October 29, 1999; Irwin M. Jacobs, interviewed by author, August 29, 2006, and May 3, 2007. See also, Dave Mock, *The Qualcomm Equation: How a Fledgling Telecom Company Forged a New Path to Big Profits and Market Dominance* (New York: AMACOM American Management Association, 2005).
5. Viterbi explained, "I didn't need citizenship papers until I got a passport. I needed a passport to go to Italy in '48. So, we put down Andrew Jack and it came out Andrew Jackson. I said, 'Well, I respect the President but I don't want to be Andrew Jackson,' so we decided to make it James." Andrew Viterbi, interviewed by author, December 5, 2006.

6. Riccardo Chiaberge, *L' algoritmo di Viterbi* (Milan: Longanesi, 2000); Morton, "Oral history conducted with Andrew Viterbi"; Viterbi, interviewed by author, June 15, 2004, and December 5, 2006.
7. West, "Commercializing Open Science: Deep Space Communications as the Lead Market for Shannon Theory, 1960-1973," *Journal of Management Studies* 45, no. 8 (December 2008): 1506-32. Information on Shannon's role at MIT was compiled from the *MIT Tech* student newspaper, MIT course catalogs, MIT catalog of graduate theses, and the Shannon holdings at the MIT Archives.
8. Andrew J. Viterbi, "Error Bounds for Convolutional Codes and an Asymptotically Optimum Decoding Algorithm," *IEEE Transactions on Information Theory* 13, no. 2 (April 1967): 260-69. For a discussion of the history and impact of the Viterbi algorithm, see G. David Forney, Jr., "The Viterbi Algorithm: A Personal History," presented at Viterbi Conference, University of Southern California, March 8, 2005, revised April 29, 2005, http://arxiv.org/abs/cs/0504020v2 (accessed March 7, 2009); Andrew J. Viterbi, "A Personal History of the Viterbi Algorithm," *IEEE Signal Processing Magazine* (July 2006), 121-23, 142.
9. John M. Wozencraft and Irwin Mark Jacobs, *Principles of Communication Engineering* (New York: Wiley, 1965).
10. For information on the UCSD's Department of Applied Electrophysics, now the Department of Electrical Engineering and Computer Science, see Nancy Scott Anderson, *An Improbable Venture: A History of the University of California, San Diego* (La Jolla: UCSD Press, 1993).
11. Morrow, "Irwin Mark Jacobs Oral History."
12. As NASA records do not establish the date of the conference, conflicting reports of the initial meeting have been published. In interviews with the three founders, one placed the conference and plane flight in 1967, one in 1968, and one did not recall the date 40 years later. However, a copy of the company's first income statement confirms the date of Linkabit's initial operations.
13. Leonard Kleinrock, interviewed by author, October 22, 2008. See also the Jacobs and Viterbi interviews and oral histories.
14. Kleinrock's early role is mentioned in Barry M. Leiner, et. al., "The Past and Future History of the Internet," *Communications of the ACM* 40, no. 2 (February 1997): 102-108.
15. "2005 Speaker's Bios: Jerry A. Heller," USC Viterbi School of Engineering, http://viterbi.usc.edu/news/events/viterbi_lecture/2005_bios.htm (accessed March 7, 2009).
16. Known as Dee Coffman after her marriage, she earned a BS in business at SDSU in 1976. Coffman was one of the seven Qualcomm founders, serving as its CFO from July 1985 to February 1989, and as a board director from January 1992 to March 2007.
17. Shannon published his seminal paper in the *Bell System Technical Journal*: C. E. Shannon, "A Mathematical Theory of Communication" 27, *Bell System Technical Journal* (July and October, 1948): 379-423, 623-56. The paper was later published with an introduction by Warren Weaver in Shannon and Weaver, *The Mathematical Theory of Communication*, (Urbana, IL: University of Illinois Press, 1949).
18. Ibid.
19. Beginning with Claude Shannon in 1972, the IEEE Information Theory Society has given the award to thirty individuals, with the list of earliest recipients dominated by MIT and Bell Labs alumni.
20. Joseph Odenwalder, "Optimal Decoding of Conventional Codes" (PhD, University of California, Los Angeles, 1970); "The Sigma Family," *Scientific Data Systems* (1967), Computer History Museum archives; author's collection.
21. Douglas J. Mudgway, *Uplink-Downlink: A History of the NASA Deep Space Network, 1957-1997*, NASA SP-2001-4227 (Washington, D.C.: National Aeronautics and Space Administration, 2001); Mudgway, *Big Dish: Building America's Deep Space Connection to the Planets* (Gainesville: University Press of Florida, 2005).
22. Joseph Odenwalder, interviewed by author, October 9, 2006.
23. Viterbi, interviewed by author, December 6, 2006.
24. Gordon E. Moore, "Cramming More Components Onto Integrated Circuits," *Proceedings of the IEEE* 38 no. 8 (April 19, 1965): 114-17.

25. The LMP and its technical design are described in Klein S. Gilhousen, "A Multi-Stack Microprocessor for Satellite Modems," delivered at the National Telecommunications Conference, San Diego, CA, December 2-4, 1974. The development of the prototype is described in a note signed by Gilhousen, part of a scrapbook presented by Linkabit employees to Jacobs in May 1985. Access to the scrapbook was graciously provided by Dr. Jacobs during an August 2006 interview.
26. Characteristics of Linkabit modems sold during the early 1980s—including the MD-1035A Dual Modem, MD-1094/G Tri-Modem and the MD-1093 Command Post Modem/Processor—can be found in the Andrew J. and Erna Viterbi Family Archives of the USC Libraries, specifically "M/A-COM LINKABIT, Inc., Product Information" (record ID vit-m2371) and "M/A-COM Product Information" (record ID vit-m2372), and Nicolas L. Abel, Irwin M. Jacobs, and Klein S. Gilhousen, "Built-in Test For Microprocessor Based UHF Satellite Modem," *Proceedings of the National Aerospace and Electronics Conference, Dayton, Ohio* (May 1977): 1196-99. The date of the Dual Modem can be found in Morrow, "Irwin Mark Jacobs Oral History."
27. The Tri-Modem was mentioned in interviews with several Linkabit alumni, in the Linkabit newsletter, *A Bit of News,* as well as the previously mentioned 1999 oral histories with Jacobs and Viterbi published by the IEEE History Center.
28. Martha Dennis, interviewed by author, June 22, 2006; Andrea Siedsma, "Investor's Hub: Spotlight on Martha Dennis," *UCSD Connect Newsletter,* October 20, 2004.
29. Early ARPANET experiments are summarized in Vinton G. Cerf, "Packet Satellite Technology Reference Sources," RFC829, Internet Engineering Task Force, November 1982.
30. Morrow, "Irwin Mark Jacobs Oral History," 20.
31. Steve Hart, CTO and cofounder of ViaSat, interviewed by author, July 3, 2008.
32. Jeffrey L. Rodengen and Richard F. Hubbard, *The Legend of the Titan Corporation* (Fort Lauderdale: Write Stuff Syndicate, 2002). In 2004, Titan was acquired by L-3 Communications, a 1997 spinoff of Lockheed Corporation.
33. Some writers confine the term "spinoff" to new firms created with the sanction of the parent company, but entrepreneurship researchers tend to use the term to refer to any firm created by former employees. Henry Chesbrough draws a distinction between a "voluntary spin-off" (decided by the parent) and non-voluntary. The latter term describes the spinoffs in this article. Chesbrough, "The Governance and Performance of Xerox's Technology Spin-Off Companies" *Research Policy* 32, no. 3 (March 2003): 403-21
34. Names and dates for the Linkabit spinoffs from 1983-1990 come from three sources: the author's research from trade journal articles, Internet websites, and interviews with founders of six of the eleven companies; Simard, "From Weapons to Cell-Phones: Knowledge Networks in the Creation of San Diego's Wireless Valley"; Simard, "San Diego Wireless Valley," unpublished database (July 2005); and finally the "Linkabit Tree" spreadsheet compiled by Martha Dennis, a version of which was published online at the *San Diego Union-Tribune* website in January 2008 at http://www.signonsandiego.com/news/business/images/080122linkabit.pdf (accessed March 7, 2009).
35. CDMA stands for Code Division Multiple Access, but it is normally referred to by its acronym.
36. Verizon Wireless continues to use Quacomm's CDMA technologies, combing the previous cellular license of five of the eight major local phone companies that remained after the AT&T breakup: four Baby Bells (Pacific Telesis, US West, Bell Atlantic, NYNEX) and GTE. AirTouch Communications was created in 1994 as a spinoff of the high-growth cellular and paging franchises of Pacific Telesis, acquired the US West cellular operation in 1998, and was in turn acquired in 1999 by London-based Vodafone PLC. Bell Atlantic acquired Nynex in 1997 and merged with GTE in 2000 to form Verizon Communications. Together, Verizon Communications and Vodafone combined their US operations to launch the Verizon Wireless joint venture in 2000, which continues today.
37. Qualcomm's 2,621 percent appreciation was listed as being the largest of all the "small and madcap stocks," i.e. those that, "Started year with market value of at least $100 million but no more than $5 billion." This put it well ahead of the fastest-growing large-cap stock that grew 616 percent. "Year-End Review of Markets & Finance," *The Wall Street Journal,* January 2000, R4.
38. Michael Kinsman, "Truly, Being Rich Is All About Change," *San Diego Union Tribune,* January 17, 2000, C1; Suzanne Woolley and Adrienne Carter, "Hitting the Jackpot," *Money* (March 2000), 92.

39. Hart, interviewed by author, July 3, 2008.

40. Ibid.

41. Mike Lubin, cofounder of Pacific Communications Sciences, Inc., interviewed by author, July 16, 2008.

42. Mike Freeman, "Stensrud's Leaving May Shift Venture Capital Firm's Focus," *San Diego Union Tribune,* November 23, 2006.

43. Stensrud was ranked #25 on the 2007 list of San Diego's richest people, with a net worth estimated at $100 million. Jessica Long, "San Diego's Wealthiest, 2007," *San Diego Business Journal,* December 10, 2007. Stensrud did not make the 2008 list.

44. In 2007 and 2008, three former and one current Qualcomm executive ranked among the twenty-five wealthiest San Diegans: retired CEO Irwin Jacobs, retired CTO Andrew Viterbi, current CEO Paul Jacobs, and former president Richard Sulpizio. Long, "San Diego's Wealthiest, 2007"; Kevin Black, "San Diego's Wealthiest, 2008," *San Diego Business Journal,* December 29, 2008.

45. A list of seven publicly traded San Diego-based telecommunications companies is given by Joel West, "Exit Strategies by San Diego Firms," San Diego Telecom Industry weblog, January 29, 2008, http://sdtelecom.blogspot.com/2008/01/exit-strategies-by-san-diego-firms.html (accessed March 7, 2009).

46. Such a brain drain is common at high-tech companies that face management turmoil or business difficulties, whether Shockley Semiconductor in the 1950s, National Semiconductor in the 1960s, or Apple Computer in the 1990s. In addition, many large tech companies lost promising young engineers to venture capital-funded Internet startups in the late 1990s.

47. Simard's database reports 244 startup organizations created in San Diego with at least some wireless-related business, with about 30 prior to 1980. Simard, "San Diego Wireless Valley."