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Chapter Two: "How Silicon Valley Came to be,"

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> During recent years the San Francisco Bay Area developed rather suddenly into one of the major centers of electronics research and industry in the United States. To those who knew the background it seemed a natural evolution in a region that has been the scene of radio and electronics pioneering since early in the Century (Frederick Terman, from preface in Morgan 1967).

The rise of Silicon Valley has garnered worldwide attention because it seemed to offer the possibility that a region with no prior industrial history could make a direct leap to a leading-edge industrial economy, given the right set of circumstances, without the time and effort required to pass through any intermediate stages of development. Here was "cowboy capitalism" in its most raw and dynamic form. The idea that so much growth could occur in so short a time within such a small geographic area sent planning bodies and government agencies from Albuquerque to Zimbabwe scrambling to "grow the next Silicon Valley" in their own backyard (Miller and Coté 1985). Thus, the model of Silicon Valley became the Holy Grail of economic development.

Unfortunately, the full story of how Silicon Valley came to be has not been told. Most accounts of the region's history begin in 1955, when William Shockley, who had co-invented the transistor at Bell Laboratories in 1947, founded Shockley Transistor Corporation in Palo Alto. The spin-off of Fairchild Semiconductor from Shockley Transistor and the "Fairchildren" that followed are widely believed to be the stimuli that set the Silicon Valley juggernaut in motion (Braun and MacDonald 1982; Scott and Angel 1986; Scott and Storper 1987; Morgan and Sayer 1988; Storper and Walker 1989).

More careful accounts push the origin of Silicon Valley back a bit further, to the formation of Hewlett-Packard Company in 1938, and Varian Associates in 1948, within the incubator of Stanford University (Hanson 1982; Rodgers and Larson 1984; Saxenian 1983; 1986; 1988a). The agglomeration of electronics companies around Stanford University is attributed, in this version of the Valley's genesis, to the vision of Frederick Terman, the dean of Stanford University's School of Engineering during World War II, and the influx of military-financed research and development that he brought to the area (Saxenian 1985, 1989).[1]

This chapter demonstrates that these accounts truncate Silicon Valley's history and divorce the region from the economic geography of the greater San Francisco Bay Area, within which it is situated (see the map of the region on the inside cover of this volume).[2] Hewlett-Packard and Varian were *not* the first important electronics companies to arise near Stanford, and Fairchild was *not* the region's first "spin-off." Frederick Terman was as much a *product* of local ferment in electronics as he was its catalyst. While these revelations do not make the emergence of Silicon Valley any less important, they do change the basic premise of a widely held model for economic development, inviting reconsideration of both policy and theory (for the latter, see Sturgeon 1992).

This chapter shows that there has been a vibrant electronics industry in the San Francisco Bay Area since the earliest days of experimentation and innovation in the fields of radio, television, and military electronics. My aim is to undermine the myth of "instant industrialization" that has been so central to the story of Silicon Valley's development. What emerges instead is a portrait much more typical of studies in economic and historical geography: industrial development takes a long time to build up momentum, is profoundly structured by place and historical context, and acquires path-dependent characteristics that continue to influence outcomes far into the future.

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1 History of science has generated a few more complete accounts of Silicon Valley's history. Arthur L. Norberg (1976), a historian and archivist who was at the University of California at Berkeley from 1973 to 1979, and James C. Williams (1987; 1990), who teaches at De Anza College in Cupertino and is Executive Director of the California History Center, have both made clear links in their work between the electric power industry, pre-World War II electronics development in the Bay Area, and the subsequent emergence of Silicon Valley. Hugh G.J. Aitken (1985) and David and Marshall Fisher (1996) provide detailed accounts of some of the activities described in this paper, but since these histories focus on the emergence of the radio and television industries, respectively, their focus is on contributions made to technological, not geographic development. An excellent history of the early electronics industry in the San Francisco Bay Area does exist (Morgan 1967), but it is a young person's book published through a small press and has thus escaped wide attention. The only widely circulated account of Silicon Valley that draws on this latter source is a journalistic account by Michael Malone (1984) entitled The Big Score: the Billion-Dollar Story of Silicon Valley. Unfortunately, none of these works have altered widespread misperceptions about the timing and nature of Silicon Valley's genesis.

2 For a discussion of the history of the San Francisco Bay Area, see Walker 1996.

One remarkable aspect of the material I present is that the characteristics of early Bay Area electronics companies closely match the structure of industrial organization so widely hailed in Silicon Valley today, albeit on a much smaller scale. A leading role for local venture capital; a close relationship between local industry and the major research universities of the area; a product mix with a focus on electronic components, production equipment, advanced communications, instrumentation, and military electronics; an unusually high level of inter-firm cooperation; a tolerance for spin-offs; a key role for local venture capital, and a keen awareness of the region as existing largely outside the purview of the large, ponderous, bureaucratic electronics firms and financial institutions of the East Coast—all of these well-known characteristics of Silicon Valley were as much in evidence in the 1910s, 1920s, and 1930s as they have been from the 1960s onward. In the jargon of the Valley, it seems that the key characteristics of Bay Area electronics, set in place so long ago, have proved to be readily “scalable” as the industry has grown in the region.

The Radio Industry Prior to World War I

To better understand the early days of electronics in the San Francisco Bay Area, the larger stage must first be set. While the roots of the electronics industry can be traced back to the rise of the telegraph, electric power, and telephone industries during the latter half of the Nineteenth Century, a more definitive ancestor is radio. Guglielmo Marconi transmitted the first radio telegraph signals in 1895, but by 1910 the radio industry was still very much in its infancy. Commercial broadcasting had yet to be developed and there were no in-home receivers available on the market.[3] Most early radio companies were established to compete with wire telegraph services, but due to problems with static over land surfaces and resistance from powerful telegraph companies, radio companies could

3 The first radio station in the United States with regularly scheduled programming was set up in 1909 in San Jose by Charles Herrold. At first, since commercial radio receivers were not widely available until the 1920s, he gave crystal receivers away to farmers and townspeople within range of his station. "Doc" Herrold had spent three years at Stanford, and soon after he established the Herrold College of Engineering

only hope to be competitive in transoceanic circuits, where expensive submarine cables drove up costs. The radio application with the greatest immediate potential was shipboard communications, either to shore stations or ship-to-ship. Steamship lines and the captive shipping operations of companies such as United Fruit proved to be ready customers for early radio firms, but by far the largest end-user was the United States Navy, which recognized the advantages of radio communication over searchlight and flag signaling.

The earliest radio systems relied on crude “spark gap transmitters” to generate radio waves. Spark transmitters were so called because an electrical current was forced to jump across a gap between two poles, causing long radio waves to be emitted by the resulting spark. By opening and closing the electrical circuit, electromagnetic pulses, or “damped” radio waves were emitted that were well suited to the dots and dashes of Morse code used in telegraphy.[4] Reception was achieved with “crystal” detectors. The only way to transmit signals over greater distances was to build ever larger spark transmitters. The key technical problems were to develop a reliable way to generate “undamped” continuous (or carrier) radio waves better suited to voice transmission, and to improve reception, either by increasing reception sensitivity or by amplifying weak incoming signals.

Although the Navy tried to award contracts to American firms whenever possible, the companies with the best radio communications systems at the time were Marconi, a British firm, and Telefunken, a German firm. Lee deForest, an American inventor who founded the Radio Telephone Company (RTC) in New York City, had yet to produce a working radiotelegraph system, and radiotelephones he was supplying to the Navy were proving to be of "doubtful practicability.” The National Electric Signaling Company (NESCO), founded by the Pittsburgh-based inventor Reginald Fessenden, was further advanced, but the alternator that he had invented to generate continuous waves was still

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and Wireless in the Wells Fargo building in downtown San Jose, where he also located his radio station. During World War I, more than 1,000 wireless operators trained there (Morgan 1967).

4 The idea for using continuous waves to improve radio transmission came from Nikoli Tesla, the Yugoslavian physicist.

under development at General Electric (GE). Further compounding the Navy's problems was the constant litigation that these companies engaged each other in to try to improve their patent positions. No single company held the patents for the all the best technology needed for a complete leading-edge radio system. For example, Marconi had the largest installed base and the most powerful spark transmitters, but NESCO had developed an improved means of reception called the heterodyne (Howeth 1963).

In January 1909 the United States Navy requested bids for a new shore station in Arlington, Virginia, just outside Washington D.C., and for two vessels. The Navy’s requirements intentionally exceeded prevailing technological capabilities to incite innovation in the field. The system had to be capable of reaching ships at a distance of 3,000 miles at all times of the day, in any weather, and during any season of the year (daylight and summer thunderstorms created static conditions that severely hampered long-wave radio signals, especially over land masses—the vacuum tube-based short-wave systems developed in the 1920s overcame this problem). The system was also required to have wireless telephone capability within a range of 100 miles. With the lowest bid, NESCO won the contract over American Marconi, Telefunken, and RTC. Over the next two years, while the Arlington station was under development, NESCO built approximately 75% of the Navy's radio equipment, sales from which represented all the company's revenues except for a few systems sold to the United Fruit Company (Howeth 1963).

In 1912 an engineer from a firm largely unknown on the East Coast arrived on the Navy’s doorstep with a system based on novel technology that proved to be far superior to the NESCO system, setting a pattern that, as we shall see, was to be oft repeated. The engineer was a Stanford graduate named Cyril Elwell; the company was Federal Telegraph Corporation (FTC), based in Palo Alto; and the radio transmission technology was the Poulsen arc, which generated continuous long radio waves with an electric arc operating in an atmosphere of hydrogen contained by a strong magnetic field. The system was so successful that FTC went on to design and install the world's first global-scale radio communications system using ever larger Poulsen arc transmitters.[5]

The role of FTC in the early radio industry has been widely overlooked (but see Aitken, 1985) because the reign of the Poulsen arc occurred during wartime and was to be short-lived as improved alternator, and shortly thereafter, vacuum tube technology arrived on the scene at the war's end. However, FTC continued to be one of the key players in the early San Francisco Bay Area electronics industry through the early 1930s. Many of the luminaries of the local electronics scene, such as Leonard Fuller and Charles Litton, began their careers working at FTC. In the early 1920s a young Frederick Terman spent a summer there as an intern before temporarily moving to the East Coast to attend MIT.

The Birth of Federal Telegraph in 1909

In 1908 Elwell, recently graduated from Stanford, was working in Palo Alto on a spark-based radio telegraph system.[6] Elwell was unable to get the system to work with either a spark transmitter or an alternator, so he wired Dr. Vladimir Poulsen, the inventor of the arc transmitter, in Copenhagen about the possibility of acquiring its U.S. patent rights. Elwell had seen the arc demonstrated at an exhibition in Paris in 1900. Poulsen agreed and Elwell soon traveled to Denmark to inspect the system and negotiate a deal.[7]

On his return to Palo Alto in 1909, Elwell turned to David Starr Jordan, the president of Stanford, and C.D. Marx, the head of Stanford's Civil Engineering

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[5] For an excellent history of the development of the radio, see Aitken 1985.

6 Elwell had received a request to evaluate the commercial potential of a wireless telephony system backed by two Oakland bankers, the Henshaw brothers. The Henshaw brothers had invested a significant sum of money in the development of the system but the inventor, Ignatus McCarty, had been killed when the horse car he was driving overturned (Rosa 1960).

7 When Poulsen offered Elwell the rights for $250,000, Elwell traveled to Copenhagen to inspect the Poulsen system, which could transmit speech messages ten miles, and telegraph signals 180 miles. He purchased the option on the patent rights and went to New York City, where he unsuccessfully courted investors, including a Mr. Lindlay, who had raised the capital to start AT&T. Undaunted, Elwell returned to Copenhagen where he struck a deal allowing incremental payment terms if the patents purchased included those on the telegraphone, a precursor to the tape recorder that allowed telegraph messages to be automatically recorded upon reception, allowing after-the-fact decoding. The price, including this device, was raised to $450,000. Elwell agreed on the condition that the patent rights cover not only the United States, but all United States possessions as well (Rosa 1960).

Department, to finance a new company to provide wireless telephone and telegraph services on the Pacific Coast using Poulsen arc technology. The company was initially called the Poulsen Wireless Telephone and Telegraph. It is notable that the heavy involvement of Stanford's administration and faculty in the formation of FTC came a full thirty years before Frederick Terman would help Hewlett and Packard to start their company.

Elwell built a small system and invited the public to demonstrations of wireless voice and telegraph communication between Stockton and Sacramento. At the time, wireless voice transmission was still extremely novel. The mayor of Sacramento, wealthy Chinese merchants, and local bank executives all tried the system. Beach Thompson, representing a group of San Francisco financiers, including the Crocker family[8], invested in the company. Beach Thompson became president, Elwell was named chief engineer, and the company was renamed the Federal Telegraph Company (Rosa 1960; Morgan 1967; Grass Roots Writing Collective 1969; Aitken, 1985).

Arc transmitters were installed on the fleet of the San Francisco-based Pacific Mail Steamship Company, which offered San Francisco to Los Angeles service and transpacific service to Australia. A chain of stations was built for FTC's radio-telegraph service along the Pacific Coast, and Elwell installed a 30kw radiotelegraph circuit between South San Francisco and Honolulu. While FTC's radio-telegraph service on the Pacific was profitable, stations that had been built in Phoenix, Dallas, Kansas City, and Chicago, lost money because static problems made transmission unreliable.

Federal Telegraph's World War I Navy Contracts

In 1912 Elwell convinced his backers to allow him to travel to Washington D.C. to generate interest in the Poulsen arc at the Navy. The 12kw transmitter he brought with him impressed Navy officials enough to win him a head-to-head comparison trial with the

8 Charles Crocker was the son of one of the "Big Four" transcontinental railroad magnates, including Colis Huntington, Mark Hopkins, and Leland Stanford.

NESCO transmitter that was just undergoing tests at the Arlington station. The Navy set the condition that the FTC apparatus be installed so it could be removed without any permanent marks left in the station's floor, walls or ceiling (Rosa 1960; Howeth 1963; Fuller 1976). The arc never was removed because the small, nearly silent arc transmitter by far outperformed the NESCO unit, which had a spark discharge that could be heard a mile away. Contact was made with South San Francisco and then with Honolulu. The arc was able to maintain contact with outbound Navy ships long after the transmissions from the NESCO unit faded to nothing as the vessels neared Key West, Florida (Rosa 1960). On the spot, the Navy ordered ten 30kw arc transmitters for shipboard use. Thus, FTC became known as "the Navy's darling of the World War I period" (Howeth 1963).

The Navy's demand for more powerful arc transmitters soon exceeded FTC's technical capabilities. On June 30, 1913, a 100kw unit was requested for the Panama Canal Zone. This was to be the first station in a "high-powered chain" that was to extend southward from Arlington to the Canal Zone and westward to the Philippines. The contract specified the use of arc transmitters, sparking a storm of protests by East Coast radio companies who complained that the Navy's Bureau of Equipment had written the specifications in a way that restricted competition (Howeth 1963).

Elwell accepted the contract but refused to guarantee the system's success because the design team at FTC had been unable to increase the power of the arc beyond 30kw. The FTC team, which included Charles Logwood, a local amateur, or "ham," radio enthusiast who had assisted Elwell with the spark-based system, and Peter Jensen, an engineer who had come over from Denmark as part of the agreement between Poulsen and Elwell, had thus far increased the power of the arc from 12kw to 30kw through the simple technique of "up rationing" the scale of the design drawings supplied by Poulsen (Fuller 1975; 1976).

The strength of FTC's design team was improved when Leonard Fuller was hired after a brief stint with NESCO in New York. Fuller knew about FTC because he had visited it in 1910 while on summer vacation from Cornell University, where he received his master's degree in electrical engineering.[9] Fuller, an avid ham radio enthusiast, was so impressed by the Poulsen arc transmitter that he built one on his return to Cornell. Innovations that he made with this small arc became the subject of his masters thesis. Fuller was hired as an engineer and led a research effort that soon increased the power output of FTC's arc transmitters to 60kw (and beyond) by tuning the magnetic field (Aitken, 1985).

The Stanford High Voltage Laboratory was of great assistance to FTC's efforts improve the Poulsen arc. Leonard Fuller, along with FTC employee Roland Marx (the son of Stanford Professor and FTC investor C.D. Marx), collaborated with Professors Ralph Beal and Harris Ryan on the development of antenna insulation. The Stanford lab had a better direct current power supply than the FTC and it was used for experimentation, continuing a pattern set by local electric power companies, which had used the high voltage lab at Stanford and U.C. Berkeley for the development of long-distance electric power transmission (Norberg 1976; Williams 1987, 1990; Sturgeon 1992). In return for the use of the lab, Fuller arranged for FTC to donate a 12kw arc to Stanford. Ryan and Marx used this transmitter to investigate the insulation characteristics of porcelain, quartz, glass, redwood, and oak, and published a paper in the Institute of Radio Engineers Proceedings in 1916 based on these experiments (Fuller 1976).

In December 1913 construction was begun on the Navy's 100kw Canal Zone station using Fuller's improved designs. The commercial station in South San Francisco Station was upgraded as well, but for Elwell, commercial expansion was not proceeding quickly enough, especially in the realm of maritime communications, where Elwell believed the real opportunity to be (Aitken, 1985). The economic failure of the Phoenix, Dallas, Kansas City, and Chicago stations had made the board of directors of FTC cautious about

9 Fuller's family physician in Portland, Oregon, had been solicited to invest in Elwell's company, so Fuller was sent down to inspect the system and give his opinion.

expanding too quickly. Frustrated, Elwell quit and moved to England where he was hired as Chief Engineer for the Universal Radio Syndicate, a company that held the Poulsen patents for the British Empire.[10]

When the United States entered World War I the entire radio industry was nationalized. FTC received orders for 300 2kw shipboard transmitters from the United States Shipping Board for the Liberty Ships. The Navy ordered 30kw transmitters for "probably all" of their battleships, a 20kw set for a cruiser, and a 5kw set for a Navy collier. The Navy continued to push FTC’s technical limits by demanding higher power transmitters as it extended its chain into the Pacific. With these large orders FTC out grew its old facility because the high-powered arcs required magnets too large for their building. The new facility, also located in Palo Alto, had increased office space, a large laboratory, a machine shop, an overhead crane, a stockroom, and a railroad siding. Orders for more shore stations for the Navy flooded in, including a dual 500kw station in Annapolis; a 200kw station in Puerto Rico; a 200kw set in Sayville, Long Island; another 200kw set for San Diego; a trans-pacific 500kw chain; 30kw sets in Alaska; as well as a string of smaller stations around the Gulf and Atlantic coasts. The Army ordered 20kw and 30kw sets for various Army posts around the country (Howeth 1963). Employment at FTC surged from 30 to 300 (Fuller 1976).

The war work at FTC culminated in installation of a pair of 1,000kw transmitters at the Lafayette Radio Station, 14 miles southwest of Bordeaux, France (Howeth 1963; Fuller, 1976; Norberg, 1976). Work began in May, 1918. The ground and antenna

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10 True to form, Elwell succeeded in persuading the British Admiralty to build an arc station at Portsmouth. The station was completed one month before the outbreak of World War I. He also installed small arcs on two battleships and two cruisers. During the war Elwell went "all out" designing sets for the British military (Rosa 1960). In 1914, he went to work for the French Signal Corps, installing arc stations in the Eiffel Tower, and at Lyons, Nantes, Toulon, and many French colonies and ships. In 1916, he built at station in Rome that included a set of antenna towers 714 feet high, then the tallest wooden structures in the world. This station, completed in just five months, was able to communicate directly with the station in Tuckerton, New Jersey, then run by the United States Navy. After the war, at the British Admiralty's request, he helped form the Mullard Company to supply vacuum tubes to the British Navy. This company became the largest tube manufacturer in England. In 1947, after nearly 30 years as the company's director,

system, supported by eight 820 ft. towers, was designed by Fuller. The work force to construct the towers, largely brought in from the United States, consisted of 600 riggers, steelworkers, bridgemen, and electricians. The only structure taller at the time was the Eiffel Tower. The war ended before the station was finished, but the French Government paid to have the construction completed. Upon completion in January, 1920, the station was by far the most powerful in the world and had cost $3.5M to build (Howeth 1963).

Early Vacuum Tube Developments

The end of World War I resulted in canceled orders for FTC**,** including a planned 2,000kw station in Monroe, North Carolina.[11] With the success with large systems, Fuller believed that a 5,000kw arc was possible. The problem with high-powered arcs was that they emitted strong harmonic radio frequencies that interfered with smaller stations. By contrast the alternator emitted no harmonics and broadcast on a sharply defined frequency. But the reign of the alternator was to be even shorter than that of the Poulsen arc. During the war vacuum tubes had been developed that could generate high-power, “short-wave” radio signals that overcame many of the static problems that plagued the long-wave systems of the day. In fact, by war’s end, vacuum tubes had been improved to the point where they could be successfully applied to all aspects of radio communications: transmission, reception, and signal amplification. It was only a matter of time before they came to dominate the radio industry. Vacuum tubes played a role in the electronics industry of the pre-World War II period analogous to that of the transistor during the post-war period: they opened vast and unforseen new market potential by increasing the capability and reliability

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Elwell returned to Palo Alto, where he studied aeronautical engineering at Stanford and worked as a consulting engineer for Hewlett Packard (Rosa 1960).

11 The surplus 80-ton magnets intended for this system were donated to Ernest Lawrence and Stanley Livingston of U.C. Berkeley for use in the construction of the 11-inch cyclotron, used for pioneering nuclear physics experiments in 1932. Charles Litton, who consulting on the cyclotron project, brought the existence of the magnet to Lawrence and Livingston’s attention.

of electronic systems while radically reducing their costs, power requirements, and physical size.

Itt is well know that Lee deForest perfected a vacuum tube in 1912 capable of greatly amplifying the faint electrical signals from long distance telephone and radio transmissions, a key innovation that is often referred to as giving birth the “age of electronics.” What is less well known is that deForest developed this tube in Palo Alto, in the laboratory of FTC .

Lee deForest Develops the Tube Amplifier at Federal Telegraph

In 1910 Lee deForest, who had earned a Ph.D. in electrical engineering from Yale in 1899, came to San Francisco to supervise the installation of wireless telegraph sets on two Army transport ships. The receivers used a vacuum tube, the "audion," that deForest had invented in 1906 and patented in 1907. This early vacuum tube, though unreliable, was a much more sensitive detector of radio signals than were the crystal detectors of the day. As the sets were being installed, deForest continued his experiments with voice transmission in a makeshift laboratory in San Francisco. He was convinced that the vacuum tube technology he was developing could overcome reliance on Morse code by transmitting voice messages over the air (Morgan 1967).

While deForest was working in San Francisco, his New York partners were arrested for mail and stock fraud because they had floated $1,507,505 worth of uncollateralized stock. A grand jury was called and the company was shut down, leaving deForest destitute in San Francisco (Morgan 1967; Lewis 1991). During his time in the Bay Area, deForest had met some of the participants of the local radio scene, including Elwell, who convinced Beach Thompson to hire deForest and provide him with a laboratory, two assistants, and free rein to develop his ideas. DeForest was taken aback at first by the lack of formal training of one of his assistants, Charles Logwood, but with time grew to respect his inventiveness and willingness to try out new ideas.[12] When Federal agents came to Palo Alto in 1912 to arrest deForest in connection with the stock fraud scheme, Thompson posted $10,000 bail, allowing deForest to continue his work (Morgan 1967; Lewis 1991).

At FTC, deForest tackled the problem of amplifying the strength of incoming telegraph signals to the level at which they could be better received by FTC's "rotary ticker", which sent audible signals to the operator's headset. Within a few months, deForest and his assistants had invented a three-element vacuum tube that greatly exceeded expectations in its ability to amplify faint signals. A few months later, the deForest team found that the tube could also function as an oscillator, a device to generate continuous radio waves.[13]

So, by 1912, deForest had developed vacuum tubes that could be applied to all three stages of wireless radio communication: signal generation (the oscillator), signal reception (the audion), and signal amplification (the amplifier). Because the amplifier could boost weak signals as much as a million-fold, high-power transmission eventually became less crucial and the cost of long distance wireless systems was radically lowered. But the three-element vacuum tube, which became known as the "telephone repeater," would have wider impact. In fact, it would be difficult to overstate its importance to the development of the nascent electronics industry. In 1931, Robert Millikan, then director of the Norman Bridge Laboratory of Physics and Chairman of the Executive Council of the California Institute of Technology, gave a nationally broadcast speech, introduced by President Hoover, in which he noted the importance of the deForest three-electrode amplifier.

> The essential device, not only for the whole broadcasting art, and not only for most of modern long distance wire telephony, but also for all forms of speech

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12 On his return to the east coast in 1913, de Forest was to bring Logwood with him as an assistant (Rosa 1960). De Forest's other key assistant, Herbert Van Etten, did have formal training as a telephone engineer (Aitken, 1985).

13 Whether and when de Forest realized the three-element vacuum tube's potential as an oscillator is the subject of some controversy, then and now. See Aitken (1985) for a full discussion.

> reproduction and amplification, and this includes the greater part of the whole modern motion picture industry—not to mention picture reproduction at a distance in all its forms [television]—the essential underlying device for all this is simply one new instrument, the electron tube, telephone repeater or amplifier. The multiplicity of the new and wholly unforeseen practical uses which one new device or principle introduced into physics seems invariably to find always astonishes even the physicist who alone realizes how small and often simple is the fundamental scientific advance that has been made. Knock out that single instrument, the telephone repeater, and much of the whole structure of modern long-distance telephony, and practically all of radio and talking pictures, comes crashing to the ground (Millikan 1931).

DeForest knew that his tube amplifier was an important development, and asked his friend John S. Stone to arrange a demonstration at AT&T's Bell laboratories. The telephone system was rapidly expanding at the time, but it was plagued by signals that weakened over long distances. Due to such “attenuation,” telephone transmission over land wires was limited to about 1,000 miles, and over submarine cables to 100 miles. DeForest's amplifier made it possible to amplify signals at various "repeater stations" along transmission wire routes, allowing telephone messages to be sent over indefinite distances. In the spring of 1910, AT&T had embarked on a crash program to develop an amplifier that would enable a long distance telephone connection between New York and San Francisco in time for the opening of the Panama-Pacific Exposition in 1915 (Millikan 1931).

Two years into the AT&T development effort, deForest walked into Bell Laboratories from California with what appeared to be a solution to the problem. AT&T did not invite deForest to join their effort, but instead asked to keep his apparatus for testing while they arranged to buy the patent rights for $100,000. DeForest agreed because he felt his new invention was covered by his 1907 patent for the "audion.” After a year of waiting back in Palo Alto, deForest was approached by a lawyer representing an anonymous party, who offered him $50,000 for the rights to the audion. DeForest, characteristically impatient, agreed to the deal only to find out later that the purchasing party had been AT&T (Aitken, 1985). With his $50,000, deForest left FTC in 1913 to begin yet another company that was to fail, the Radio Telegraph and Telephone Company, located in the High Bridge section of the Bronx (Lewis 1991).

The deForest team was very productive during its short tenure at FTC. Besides discovering the amplifying and oscillating properties of the three electrode vacuum tube, they established an innovative wire telegraph link between San Francisco and Los Angeles using a "duplex" system of telegraphy that allowed two operators to transmit simultaneously over a single set of wires. Telephone repeaters were used to boost the strength of the signal along the way (Lewis 1991). While the development of the amplifier at FTC did little for the company in the short term, it became significant during the 1920s, when the increasing dominance of vacuum tube technology forced FTC to make the change-over from Poulsen arc- to vacuum tube-based systems.

The Rise of RCA

> In those days, the Radio Corporation was such a monopoly that if they'd blow their fetid breath at you, you were supposed to fall over. And they blew their fetid breath at us, but we didn't fall over" (Heintz 1982)

The patent situation in the radio industry immediately after World War I remained fragmented. GE had just perfected the Alexanderson alternator and was seeking to recoup $1M in development costs by putting the alternator up for sale. When Marconi offered to buy 24 alternators from GE for $3M, including rights for exclusive use, the Secretary of the Navy asked President Wilson to oppose the sale, which he did. Radio had proven to be such a strategic asset during the war that it was decreed that no foreign company would be allowed to hold more than a 20% interest in any radio station on United States soil (Fuller 1976). By government order GE acquired American Marconi for $9.5M, creating a new company called the Radio Corporation of America (RCA). Owen Young of GE was named Chairman of the Board; Edward Nally, who had been vice president and general manager of American Marconi, became president; David Sarnoff, Nally's right-hand-man, became general manager; and Rear Admiral W.H.G. Bullard of the US Navy, took a seat on the new company's Board of Directors.

Westinghouse acquired NESCO in 1919, including Fessenden's patents on heterodyne reception, but continued to rely on outmoded spark transmission technology since AT&T held the key deForest vacuum tube patents. In 1921 Westinghouse asked FTC to supply arc transmitters, but before the deal could be consummated, Westinghouse joined in an elaborate patent sharing arrangement with GE and RCA, along with AT&T and United Fruit (Fuller 1976). The formation of the "radio group," as it came to be known, left FTC completely out in the cold. RCA had essentially been granted monopoly control over the key radio patents for radio transmission, amplification, and reception by the U.S. Government, which had orchestrated the deal. RCA acted as the marketing and systems operation arm for the group, while GE, Westinghouse, and AT&T manufactured equipment and components.

Because Marconi managers were installed to run RCA, the company inherited the monopolistic and predatory characteristics of Marconi corporate culture (Howeth 1963). Aggressive, litigious, and monopolizing, RCA emerged as the dominant force in the industry, ready to sue, buy out, or collect steep license fees from any fledgling electronics company in its path. While these traits were inherited from Marconi, RCA became vastly more powerful than its predecessor as electronics began to pervade more and more aspects of society. Commercial broadcasting had been almost completely unforeseen, but the number of in-home radio receivers grew from 5 thousand units in 1920 to 25 million units in 1924. The "radio craze" was on, and RCA was in unique position to profit from it. By 1925, RCA's commercial wireless revenues were about $4M while sales from home radio sets and related equipment were about $46M, and the gap was widening. As thousands of home-grown companies grew up in every major U.S. city to supply this burgeoning market, RCA moved aggressively to enforce its patent monopoly.

As we shall see, the early electronics industry in the San Francisco Bay Area labored under constant threat of RCA litigation. At the same time, the San Francisco Bay Area was far enough from the dominant industry centers in the East for many of its activities to go unnoticed, at least initially. A few Bay Area companies were persistent “thorns in the side” of David Sarnoff and some—as we shall see—we able to beat him in court, but many others were small enough and far enough away to simply “fly under RCA’s radar.” If the cooperative nature of Bay Area electronics companies during the 1920s, 1930s, and 1940s had any one source, it was in opposing the domination of the field by RCA. It is also likely that the dominance of RCA influenced the region’s product mix as well. As we shall see, early Bay Area electronics companies largely eschewed consumer electronics to specialize in electronic instruments, military electronics, advanced communications technologies, electronic components, and production equipment, just as Silicon Valley’s firms do today. This pattern may well have been set by the structure of the radio industry in the 1920s. As Frederick Terman put it during an interview in 1978:

> I think they were 'every man for himself' much more back [east]. ...[East Coast] manufacturers would never cooperate [on standards for vacuum tubes], partly because of the patent situation. RCA dominated the patents and you couldn't leave RCA out, and if RCA was brought in, it wanted to boss everything. The group out here was involved in military production, instruments, and specialized stuff, where RCA patents weren't such a dominating feature. RCA wasn't trying to build a monopoly in the instrumentation business, for example (Terman 1978).

Tube Production at Federal Telegraph

The sudden cessation of Navy contracts after World War I, the shift to vacuum tube-based transmission, and the rise of RCA left FTC in significantly reduced circumstances. To generate new business, FTC tried to build a trans-Pacific circuit for the Chinese Government. This was strongly resisted by RCA, which argued that it had a right to a monopoly in long-distance radio traffic. The Navy came to FTC’s defense and the deal was approved, but the political tensions that came with the rise of Chiang Kai-shek meant that the stations would never be built (Howeth 1963). Although some attempts were made at FTC to improve arc technology by using focused beams of higher frequency radio waves, the research team was never able to transmit further than 40-50 miles using this technique (Heintz 1982). As it became obvious that the heyday of the Poulsen arc was past, FTC returned to the business of commercial radiotelegraph service, and Fuller left to help found the Kennedy Radio Company in San Francisco to manufacture high-end home radio receivers under license from RCA (Fuller 1976). In the mid-1920s FTC was acquired by the Mackay interests, which controlled Postal Telegraph and Commercial Cable.[14] Mackay had good wire telegraph circuits in the Pacific and in South America; FTC's radio circuits in these regions were purchased to augment Mackay's cable business. In 1928, Mackay was purchased by ITT, giving FTC a new parent.

Federal Telegraph functioned as the manufacturing facility for Mackay's radio equipment, and needed to make a transition to vacuum tube-based short wave systems. A major stumbling block was that Westinghouse and GE would not sell vacuum tubes to FTC, since Mackay was perceived as a threat to RCA's near monopoly on long distance radio communications. FTC brought in Ralph Heintz, a local expert in short wave radio and vacuum tube manufacture as a consultant to help them determine what would be required to manufacture tubes. Heintz reminded FTC management that they held "shop rights" to manufacture vacuum tubes covered by deForest's patents because he had made his discoveries while under the employ of FTC. This allowed FTC to manufacture vacuum tubes for internal use without paying royalties. FTC officials immediately went to William Crocker, then the company's president, to obtain funding to establish a tube manufacturing facility (Heintz 1982).

Fuller returned to FTC, this time as Vice President, to help organize vacuum tube production. While FTC's shop rights allowed them to produce vacuum tubes for reception

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14 Clarence Mackay, the son of a gold miner who had struck it rich, had established Postal early in the Century to compete with Western Union. Mackay's original plans were to overtake and eventually absorb Western Union, but in 1927 Postal had only 17% of the U.S. telegraph market in comparison to Western Union's 83% (Sobel 1982).

and amplification, they still had to devise means to circumvent a host of additional RCA patents, particularly for large, high-powered, water-cooled transmission tubes. According to Norberg (1976), "They attacked the problem in a very structured manner. ITT's patent department provided information on all sorts of patents. The group at FTC analyzed the data and returned schemes to circumvent the patents. The patent lawyers then forwarded an opinion as to whether the device would withstand an infringement suit."

Federal Telegraph's Spin-offs

FTC generated some important spin-off companies including Magnavox, Fisher Research Laboratories, and Litton Industries. Spin-offs are common in many industries and in many locations, but the FTC spin-offs are worth mentioning because of the importance that has been placed on spin-offs in the dynamic process of new firm formation in Silicon Valley's post-Fairchild era. Firm spin-offs are a central feature of the "Silicon Valley Model" of economic development. The examples provided in this section, as well as in later sections, show that the spin-off process—including the proverbial garage start-up—has been alive and well in the San Francisco Bay Area since 1910, when Magnavox spun off from FTC.

Magnavox

Only one year after its founding, FTC produced its first spin-off. The two Danes who had come to America to help Elwell commercialize the Poulsen arc, Jensen and Albertus, along with FTC employee E.S. Pridham, who had earned a degree in electrical engineering from Stanford, left FTC in 1910 to start a research and development firm in a garage in Napa. By 1913, they had patented the "moving coil" loudspeaker, which was a vast improvement over existing speakers (standard texts state that this technology was invented by Ray Kellog in 1915). By 1917 they had perfected a design that most loudspeakers are still based on today. They named their company Magnavox, Latin for “big voice” (Morgan 1967).

During World War I Magnavox built public address systems for destroyers and battleships, which allowed captains to address all personnel on board. The company also developed an anti-noise microphone for the Navy that was installed on all of their four motored NC (Navy-Curtiss) flying-boats, allowing the crew to communicate with one another over the loud drone of the engines as they patrolled for German U-boats over the Atlantic Ocean. The company received a national medal for its war efforts. After the war Magnavox built public address systems for factories, hospitals, and sports stadiums nationwide. Magnavox built the first public address system used in a presidential speech; in September, 1919 a Magnavox system was used by President Wilson to speak to 50,000 people in San Diego.

Because Magnavox produced complete systems, they required powerful amplifiers to drive their loudspeakers. Since RCA had its own line of loudspeakers, they refused to supply Magnavox with vacuum tubes for their amplifiers. The company was forced to produce tubes in house, and turned to Ralph Heintz for designs that would not infringe on RCA tube patents. The chief engineer for Magnavox was Don Lippincott, who went on to become an important San Francisco patent attorney who worked closely with local electronics companies on their patent difficulties with RCA.

Eventually, Jensen split off from Magnavox to form a company to produce loudspeakers only (Heintz 1974). Magnavox, now a subsidiary of the Dutch electronics giant Philips, went on to manufacture a full range of consumer electronics products and released the very first home video game system in 1972, the Magnavox Odyssey.

The Single-Dial Radio Tuner

In 1925, a FTC draftsman-cum-research engineer named Harold Elliot, who had a prominent role at FTC working on various features of the arc transmitters, began experimenting with designs for a single-dial radio tuner for broadcast receivers. Home receivers of the day required users to manipulate four or five different knobs. One knob, controlling the local oscillator, had to be moved at a constant difference to the others, creating a process that was too complicated for the average user (MacLaurin 1949).

By 1927, Elliot had worked out detailed engineering and manufacturing specifications for a single-dial tuner. After careful research on various radio manufacturers, he brought the device to the attention of the Victor Phonograph Company. Victor, well known for its phonographs, had a license from RCA and was on the brink of entering the market for home radio sets. The company bought the rights to Elliot's device, which they dubbed the "microsynchronous tuner." Just as the company completed the design for the new receiver and was ready to go into production, Victor was acquired by RCA. The set went into production as the "Victor Microsynchronous Receiver," the first single-dial receiver on the market. In 1978 Frederick Terman said, "I believe probably more sets of that microsynchronous model were sold than any other single chassis built up to that point." Terman met with Elliot in 1938, shortly after the completion of the San Francisco-Oakland Bay Bridge and the Golden Gate Bridge. Elliot told Terman that, in terms of retail price, the dollar value of all the Victor Microsynchronous Receivers sold was more than enough to build both bridges (Terman 1978).

Fisher Research Laboratories

Gerhard Fisher came to FTC in 1926 from New Jersey, where he had worked for deForest. At FTC Fisher worked as an assistant to Frederick Kloster, who had developed an electronic direction finder for the Navy during World War I. After the war, Kloster came to FTC to develop this technology for commercial shipping applications (Howeth 1963). In 1928 Fisher invented the first metal detector in his Palo Alto garage. He called the device the "Metaloscope" or "M-scope". The M-scope found wide acceptance, becoming standard equipment for water and gas companies across the country that used it to locate buried pipes. Miners and treasure hunters soon began using the device as well. In 1929, Fisher developed airborne navigation aids that improved on designs from Kloster's radio direction finder. In 1936, Fisher opened Fisher Research Laboratories (FRL) in Palo Alto to manufacture a variety of electronics products, including radio telephones and marine radios (Morgan 1967). Today, FRL is located about 80 miles southeast of San Jose in Los Banos, where it still designs, manufactures, and sells metal detectors and related underground detection devices for industrial and hobby applications.

Litton Industries

In 1928 Charles Litton, who had just graduated from Stanford at the age of 23, was hired by Fuller to manage FTC’s in-house vacuum tube manufacturing department (Morgan 1967; Fuller 1976; Heintz 1982). Litton built his first ham radio set at the age of 10, and soon made his own vacuum tubes, which he sold to other hams. He operated his home-made radio set through two 100-foot antenna towers at his parent’s house in Redwood City, with which he was able to establish voice communications with stations as far away as Australia and New Zealand (Morgan 1967). According to Alexander Poniatoff (1974), Litton's father said that his son began operating a foot-pedal-driven metal lathe when he was so small that he had to pump the pedal by hand and then jump up on a chair to cut metal. Litton attended the Lick-Vilmerding High School in San Francisco (later known as the California School for the Mechanical Arts), which had an amateur radio club on campus. While at Stanford Litton continued experimenting with vacuum tubes for his ham sets, constructing most of the Communications Laboratory's vacuum tube manufacturing and test equipment from surplus parts scavenged from FTC’s yard (Fuller 1976). At FTC, besides creating original designs for high-power vacuum tubes, Litton built innovative equipment for the entire tube manufacturing process, including glass blowing lathes, radio-frequency electric furnaces, bake-out ovens, vacuum pumps, and test set-ups (Fuller 1976; Norberg 1976).

In 1931, because of the Depression, ITT decided to consolidate Mackay's manufacturing facilities, including FTC, in Newark, New Jersey. Both Fuller and Litton had clauses in their contracts stating that they would only work on the West Coast. Fuller left the company to take a position as Professor of Electrical Engineering at U.C. Berkeley, where he later became department chairman.[15] Litton stayed on at FTC as Chief Engineer to manage the transition. The vacuum tube factory in Palo Alto was kept in operation to ensure a steady supply of tubes for Mackay's radio network. A testament to the degree of expertise needed to run this operation is found in the fact that it took two years, with Litton's active consultation, to get the new facility in Newark running satisfactorily (Fuller 1976).

With the departure of FTC to New Jersey in 1932, Litton formed Litton Engineering Laboratories to design and manufacture vacuum tube production equipment. Litton's glass-blowing lathe was able to mass produce glass tube blanks at uniform quality, a huge improvement over the hand-blown blanks of the day (Morgan 1967). These machines were unique and were used for mass production by virtually all major vacuum tube makers, including GE, Westinghouse, and RCA (Fuller 1976).

In 1940 Litton began manufacturing large, high-powered "magnetron" vacuum tubes for ground-based radar systems that were available from no other source. Although these tubes, some of which stood four feet high, were highly sought after by the U.S. military, Litton began by fabricating them from scratch in his backyard. According to Fuller, Litton “could do the seemingly impossible with metal and glass" (quoted in Morgan 1967). During World War II, tube production expanded and, as Litton said, "I woke up one day, and out of the clear blue sky...found myself the sole owner of a million-and-a-half-dollar concern" (Morgan 1967). In 1946, Litton separated the tube business from his research laboratory and machinery business.

15 Fuller had earned his doctorate from Stanford in 1919 with a dissertation based on the improvements he had made to FTC’s arc transmitters.

In 1953 Litton sold his tube business to "Tex" Thornton and moved his laboratory to Grass Valley, east of the Sierra Nevada Mountains. Thornton saw "the opportunity for a new type of company: one that was technologically oriented and could develop and apply these high technologies, primarily electronics, to different types of products and industries" (O'Green 1989). The plan was to grow the company, initially dubbed the Electro Dynamics Corporation, into a diversified giant through the acquisition of small, innovative electronics companies. The company's first acquisition was Litton Industries, which reached three million dollars in sales from Litton's state-of-the-art magnetron tubes in the first year. When he found that the name of Charles Litton carried a great deal of weight with the Navy, Thornton changed the company's name to Litton Industries (O'Green 1989). By 1980 Litton Industries had grown to $4.2 billion in annual sales.

Philo Farnsworth Develops Electronic Television in San Francisco

Philo Farnsworth was an inventive prodigy. In 1924, at the age of fourteen, Farnsworth, studying on his own in his native Utah, combined the concepts of the photocell (for the camera) to the cathode ray tube (for the picture tube), thereby conceiving a full-blown system for electronic television (Everson 1949; Fisher and Fisher 1996).[16] Until the 1920s, the television systems under development had used a mechanical scanning disk to translate images into electrical impulses. Farnsworth continued to work on the theoretical details of his system, but lacked the money to build a prototype. In 1926 he met a businessman from San Francisco, George Everson, and impressed him with a confident and enthusiastic description of his idea. Everson provided Farnsworth with seed money and eventually arranged for him to meet William Crocker in San Francisco. Farnsworth's

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16 Farnsworth's ideas may have been based on the published work of the Scottish scientist, A.A. Campbell-Swinton, who in 1908 proposed a method of electronic scanning where the cathode ray tube could be used as the camera as well as the picture tube. Campbell-Swinton's theory forms the essential features of today's television system.

enthusiasm and depth of knowledge proved impressive and Crocker agreed to back the venture (Everson 1949; Morgan 1967; Fisher and Fisher 1996).

Farnsworth was installed in a crude laboratory at 202 Green Street in San Francisco, at the base of Telegraph Hill. Farnsworth's brother-in-law, Cliff Gardner, although he had no training as a glass blower, developed an extraordinary talent to fabricate the oddly shaped tubes that Farnsworth needed for his electronic scanner, which he called an "image dissector." RCA was also working on a television system at the time. In 1931, as news of Farnsworth's progress began to filter back to the East Coast, David Sarnoff sent Vladimir Zworykin, who was heading up RCA's research effort, to visit Farnsworth's laboratory (Sarnoff visited personally in 1931, but his offer to buy the company for $100,000 was rejected). Zworykin was very impressed with what he saw, particularly with Gardner's oddly shaped tube envelopes, which glass blowers at RCA had told him were impossible to fabricate. Farnsworth's work convinced Zworykin that an electronic method of image scanning was possible, and on his return to RCA he set out to develop his version of an electronic scanner, which he called the "ionoscope."

Farnsworth achieved the first all electronic transmission of a television image in 1927, and was able to win a solid patent on the system in 1930, thanks to the help of his patent attorney Donald Lippincott. Farnsworth's strong patent position eventually prevailed in court and RCA was brought to heel for the first time when an agreement to pay continuing royalties to use the ionoscope was signed in 1939 (Fisher and Fisher, 1996). Still, Farnsworth's activities in San Francisco during the 1920s remain little-known and Zworykin is widely considered to be the inventor of electronic television (hopefully, the work of Fisher and Fisher (1996) will help to remedy this). Ralph Heintz (1982) put it very succinctly. "Phil was so frustrated, because they gave Zworykin credit for his invention. The press was loath to give credit to a poor little guy like Phil Farnsworth. Zworykin, of course, was a big shot, he was a Ph.D. and he was at Westinghouse, and they just snowed Phil under."

In 1931, Farnsworth's television system had been perfected to the point where commercial production seemed feasible. The San Francisco backers, eager to see some return on investment, sold the company to Philco, then the largest home radio manufacturer in the United States. Farnsworth and his team moved to Philadelphia to continue the development of the system (Morgan 1967; Fisher and Fisher, 1996). According to Fisher and Fisher (1996), Farnsworth’s team did not fit in well into Philco’s more conservative corporate culture. The team from California refused to wear suits, vests, and long sleeves as they toiled in their stifling laboratory. As a result, William Grimditch, director of Philco’s research department referred to them as “animals,” and they became known by the rest of the Philco staff as “those mavericks from the West.” Tensions reached the breaking point when RCA threatened to withdraw Philco’s license to manufacture radio sets if Farnsworth’s laboratory was not shut down. In 1933 Farnsworth left Philco and struck out on his own. Despite a series of landmark victories in his patent litigation, Farnsworth’s company was never able to compete with the R&D, marketing, and political muscle of David Sarnoff and RCA. In 1949, Farnsworth’s still struggling company was sold to ITT, where Farnsworth became vice president in charge of research and advanced engineering (Fisher and Fisher, 1996).

In San Francisco, Farnsworth had drawn heavily on local talent for the research effort. Russell Varian, an electrochemist recently graduated from Stanford, worked on the project for four years (Russell Varian would go on to found Varian Associates with his brother in 1948). Varian experimented with new phosphors for the picture tube and with new oscillators for transmission. Farnsworth was visited and encouraged regularly by local electronics luminaries including Leonard Fuller, Frederick Terman, and Ralph Heintz (Morgan 1967). Heintz, who’s activities are discussed at length below, worked with Farnsworth "from the very beginning," visiting his laboratory "several times a week." “I helped them and they helped us" (Heintz 1982). Gardner was provided with a great deal of coaching and equipment by Bill Cummings, head of the University of California at

Berkeley's glassblowing shop (Fisher and Fisher, 1996). Throughout his career, Farnsworth's ties to the electronics and financial communities of the San Francisco Bay Area remained strong. The television laboratory in San Francisco remained in operation as a branch laboratory though the 1930s. When Farnsworth invented the cold cathode ray tube, or "multipactor," in 1934, the first public demonstration was conducted by Ralph Heintz in South San Francisco (Everson, 1949; Fisher and Fisher, 1996).

Ralph Heintz: Short-Wave Radio Pioneer

As has already been mentioned, one of the leading figures in Bay Area electronics during the 1920s was Ralph Heintz, a Berkeley ham radio enthusiast who had attended Lick-Vilmerding High School in San Francisco and both U.C. Berkeley and Stanford. During World War I, Heintz developed an early radio-controlled missile guidance system for the British military. After a brief stint as a chemical engineer with Standard Oil after his graduation from Stanford in 1920, Heintz opened a small shop to repair scientific apparatuses in San Francisco. At the time radio broadcasting was just beginning and Heintz built most of the early radio stations in the area. He also worked for the Army, installing a radio station in Mazatlan, Mexico, and a system to relay telephone messages from British Columbia, where the wires stopped, to military bases in Alaska (Heintz 1982).

In 1924, the British Marconi Company announced successful experiments with long distance communication using short wave radio, prompting Heintz to begin to experiment with the technology. In 1925 Heintz installed a set on a private yacht, the first short wave radio system to be installed on any ship in the Pacific (Morgan 1967). During this period Heintz also built five short-wave transmitters for the San Francisco-based Hearst newspapers, allowing them to disseminate news world wide (Heintz 1982).

Heintz became a leading figure in the development of short wave radio systems for aircraft. In 1927 he equipped the airplanes participating in a Oakland to Honolulu race sponsored by James Dole, the pineapple magnate, with short wave radios, likely the first ever to be installed on aircraft. In 1928 he equipped the first successful flight from Oakland to Sydney, Australia. By this time Heintz had improved his systems to send and receive both long and short wave signals. Included in this equipment were waterproof distress transmitters that raised their aerials with either a kite or a gas balloon. In 1929, he built all the radio gear for Admiral Byrd's pioneering flight over Antarctica. Besides the system installed on Admiral Byrd's plane, the ground stations and the dog sled rescue teams were equipped with Heintz's short wave sets (Morgan 1967).

In the late 1920s Heintz was approached by William Boeing's son-in-law, Thorpe Hiscock, to design and manufacture a short wave radio telephone system for Boeing's fleet of aircraft carrying mail between Seattle, Portland, and Chicago. The company was beginning to carry passengers with increasing regularity and needed extra safety measures. Western Electric, AT&T's manufacturing arm, controlled the patents rights for the manufacture of commercial radio systems, but refused to build the system because they believed that air passenger travel would not develop into a significant business. Heintz built a prototype set for one of Boeing's airplanes and a series of ground stations that worked well. When officials at Western Electric heard of it, they agreed to build the system if Boeing would cease all relations with Heintz. The equipment was sold back to Heintz at ten cents on the dollar, and he in turn sold the used components to ham radio enthusiasts in the area (Heintz 1974; 1982).

In the course of developing his airborne radio systems, Heintz fulfilled the increased power requirements necessary for the larger and more powerful radios he was installing by perfecting an innovative AC polyphase electric alternator that was about one-sixth the weight of the DC systems currently in use. Heintz wrote some technical papers on the subject, and had been flying them since 1925, but no one took his ideas seriously until Warren Bowten of Douglass Aircraft contacted Heintz in the early 1930s. Bowten questioned Heintz about the system and Heintz readily shared information about the system with him (Heintz 1982).

Soon afterward, Heintz learned that Bendix, Douglass's alternator supplier, had been awarded a large contract by the Air Force to manufacture AC polyphase power systems that closely matched his designs. Heintz traveled to Washington and threatened the Air Force that he would ask his Congressman to "bring before the people what is happening to the poor lonely inventor who brings out something new." The Air Force agreed to split the contract between Bendix and Heintz. When the prototypes were finished the Bendix system failed, so Bendix bought the project out for $150,000 (Heintz 1982).

Bendix insisted that the deal include the services of Heintz, and he agreed to a two year contract since his other business was slow during the early years of the Depression. Heintz brought people with him from the Bay Area that he knew and trusted and set up what was effectively a separate engineering division within Bendix. Hientz lasted about as long as Farnsworth had at Philco, apparently for similar reasons. After two years, Bendix tried to get Heintz to extend his contract and stay in New Jersey, but Heintz refused. "I didn't want to, because I didn't like their outfit. Their engineering stank. So, I had to tell them. 'There's no use. I'm going home. I'm a Californian. I can't live in this atmosphere'" (Heintz 1982).

Heintz & Kaufman Develop the Gammatron Tube

In 1926 Heintz, along with his partner Jack Kaufman, had started working on ship-to-shore radio communications systems for the Dollar Steamship Company. In 1928 Dollar acquired majority share of Heintz and Kaufman (H&K) to create a subsidiary to manufacture the short wave communications equipment needed for its fleet of steamships. H&K moved to a larger facility in South San Francisco, where they employed 20-40 people. Heintz retained a one-third share in H&K, and Heintz and Kaufman Inc. was incorporated as a separate company, leaving Heintz free to work on outside contracts (many of which were discussed in the preceding section). At the same time, Globe Wireless was incorporated to manage the operation the radio network. Jack Kaufman was named manger of Globe Wireless and Heintz remained president of H&K (Heintz 1982). By the time the Globe system was completed in the early 1930s, H&K short wave equipment was installed at shore stations in Los Angeles, Long Beach, Portland, Seattle, New York, Hawaii, Manila, Guam, and Shanghai, as well as on 160 merchant ships (Morgan 1967; Heintz 1974).

Because RCA, GE, and Westinghouse perceived H&K as a competitor, they refused to sell them vacuum tubes. Tubes from England were extremely expensive, and H&K was thus forced to manufacture tubes in-house. In the course of developing the Globe system Heintz developed a two-element, electrostatically-controlled tube that he dubbed the “gammatron.” This tube did not infringe on RCA’s patents because it was based on expired patents and other unpatented technology and used tantalum elements (Norberg 1976).[17] Charles Litton, who knew the specifications on tube blanks available from Corning Glass in New York, helped H&K get started in tube production by helping them pick out glass tube blanks and buy Pyrex stock for glass blowing. Local ham radio enthusiasts William Eitel and Jack McCullough were hired to help develop the tube operation. When the Globe system was complete, H&K reverted to production of replacement tubes (Heintz 1974; 1984).

Dollar would not let H&K sell tubes on the open market because a patent suit brought by RCA in 1929 had made the company cautious. The sole reason that Dollar was in the electronics business was to supply its ships and Globe Wireless with radios. However, during the Depression internal demand almost disappeared and Heintz convinced

17 The increased power from this tube allowed Globe Wireless to get through to Manila during daylight hours. Because regular mail service from Manila took 26 days, the company instituted a "radio mail" service at a 25% cost reduction over RCA and FTC. San Francisco was the collection point for the U.S., teletype messages from across the Pacific. There they were printed, put in envelopes, and sent on to U.S. destinations through the postal service. Alternatively, the messages were forwarded through wire telegraph systems. Federal Telegraph was linked to Postal Telegraph, while RCA was linked to Western Union (Heintz 1974; 1984).

Dollar to let him sell on the outside to keep the business functioning. H&K began to sell gammatron tubes to ham radio operators, and, according to Heintz, they "got a tremendous reputation right off the bat because the hams would run them white hot...just beat the tar out of them." For ham radio applications, H&K gammatrons were better than anything available on the market at that time (Heintz 1974; 1984).

The animosity between RCA and Globe Wireless was quite strong. As Ralph Heintz put it: "We [Globe Wireless] were a monkey on [RCA's] back, because we had a mechanism of handling [radio] traffic across the Pacific that they seemed unable to stop. They tried to harass us by having Western Union refuse our traffic in every conceivable way" (Heintz 1982). In 1937 RCA again filed suit against Globe Wireless for patent infringement. Heintz, fed up with RCA harassment, constructed a series of "breadboard" demonstration sets to compare various vacuum tube technologies that could be used to send and receive radio signals. One set was based on the deForest patents, which RCA controlled. The other sets were based on technology that RCA did not own the patents on, including those owned by Larson (Norway), Vreeland (USA), Simpson (USA), and Goddard (USA). These patents, plus others held by Heintz, covered the technology on which Globe's system was based.

Heintz asked his friend and classmate from Stanford, Frederick Terman, to appear in court as a technical expert. Donald Lippincott provided legal advice. When the day in court came, the request to have Heintz's "breadboard" sets entered as evidence was accepted by the judge. When the six RCA patent attorneys realized that losing the case could jeopardize RCA’s entire patent position, they immediately approached the bench and asked that the suit be withdrawn (Heintz 1982).

Eitel and McCullough Establish High-Volume Tube Production

In 1934, when tube production for the Dollar system began to increase, Dollar demanded that H&K stop selling gammatrons on the open market. He agrred, but Eitel and

McCullough became frustrated and struck out on their own to form a company to supply the ham market (Norberg, 1976; Heintz, 1984). At first they simply used the same vacuum tube technology that had been developed at H&K. When Heintz was asked during a 1974 interview why he chose not to sue them, his response strongly echoes the tolerant attitudes found in modern-day Silicon Valley by Saxenian (1989; 1994):

> I didn't have any desire to sue. They were nice fellows and my partner [Kaufman] was very burnt up. I was more amused than burnt up and what amused me was that they went to the Dollar Company and said, 'Look, we can supply you with what you need for your communication system cheaper than H&K.' They were immature at business…They could be forgiven, because they were highly successful after that. Very innovative and very, very industrious and they're good friends of mine (Heintz 1974).

Eitel and McCullough set up shop in an old meat packing plant in San Carlos. Aiming at the amateur radio market, they advertised their tubes in QST, a national magazine for ham radio enthusiasts, and sold them through small distributors nationwide (Norberg 1976). Their tubes were so much more durable than anything else available on the market that the abbreviated company name printed on each tube, "Eimac," became known worldwide. By 1940, the company had grown to about 20 employees and moved to San Bruno (Morgan 1967).

In early 1941, Eitel and McCullough unexpectedly received an order from the U.S. military for $500,000 worth of tubes. To their surprise they learned that their tubes had been used in Army and Navy radar experiments for more than four years (Norberg 1976). War tensions were increasing and the military was ready to go into mass production with its newly perfected radar system, for which it needed tubes. After the bombing of Pearl Harbor and the U.S. official entry into World War II, the company was ordered to build a new plant in Salt Lake City, away from potential bomb targets. By 1942, the company had 1,800 employees working three shifts to produce 4,000 tubes each day (Morgan 1967).

After the war, these high production levels came back to haunt Eitel and McCullough. Just as the military orders abruptly ended, the market was flooded with surplus Eimac tubes selling below cost. The company survived the post-war transition by developing new military and commercial markets for their tubes. They built large "klystron" tubes for airborne radar, tubes for aviation, nuclear resonance, radio and television broadcasting, telephone systems, oceanography, factory automation, and early computers. By 1959, when the company moved into a large facility in San Carlos, Eitel and McCullough was the largest merchant manufacturer of vacuum tubes in the world (Morgan 1967). In 1999, Eitel and McCullough still existed in San Carlos as the Eimac Division of Varian Associates.

The vacuum tube industry in the San Francisco Bay Area, while certainly smaller than the captive operations of the large East Coast firms, was nevertheless an important one. The activities of Elwell, Fuller, deForest, Farnsworth, Litton, Heintz and Kaufman, and Eitel and McCullough, reveal an unbroken lineage in leading-edge electronic component design and production in the San Francisco Bay Area that precedes the birth of the region's semiconductor industry by nearly four decades. It is clear that—from the dawn of the radio industry to the present day—San Francisco Bay Area companies have played a central role in developing and commercializing many of the key technologies that have served to drive the "electronics revolution" forward. Indeed, it may be the uncanny ability of Bay Area companies and entrepreneurs to successfully identify and make the leap from one underlying technology to the next that best explains the region's ongoing success.

Dalmo-Victor Develops an Airborne Radar Antenna

While a student at Mt. Tamalpias High School in Marin County, located across the Golden Gate from San Francisco, Tim Moseley was the foreman of the school's machine shop. In 1921, when he was nineteen, Moseley established his own machine shop in San Francisco, the Dalmo Manufacturing Company. He often improved on the designs he was given by his customers, and was soon inventing his own products (Morgan 1967).

In 1934 Moseley hired an immigrant Ph.D. Russian research engineer named Alexander Poniatoff to help with the development work. Poniatoff had come to San Francisco by way of Shanghai, where he worked at a power station. He then worked for GE in Schenectady, N.Y. as a research engineer for three years, and for PG&E in San Francisco for four years. Bored with his work at PG&E, Poniatoff quit his secure job and approached Moseley, stating that he would work on a trial basis for no pay. Moseley agreed. Poniatoff's first assignment was to fix a problem with a hair-styling machine that Moseley was building for a local distributor. They patented the improved design, sold it to the distributor, and Moseley shared half of the proceeds with Poniatoff (Poniatoff 1974).

Poniatoff worked for Moseley until 1939 when the company was bankrupted by a patent infringement suit brought by the Schick Company for an electric shaver they had developed. Poniatoff went back to work for PG&E until 1944, when Moseley asked Poniatoff to help him work on a prototype airborne radar antenna for the Navy. According to Poniatoff, Moseley said to him, "Do you know anything about radar?" Poniatoff replied, "I don't, not a damn thing." "Neither do I," Moseley said, "but the contract says the unit must be completed in 100 days, so you can't waste time" (Poniatoff 1974). In the Dalmo shop in San Carlos, they worked for 100 days without a break, often sleeping in the shop. Surprisingly, they won the contract. At a banquet in their honor, a Navy admiral told them this story (as related by Poniatoff during an interview in 1974): "This contract was issued to Westinghouse, GE, and another company. Then this Moseley arrived, out of the woods, nobody knew who he was. He wanted the contract. When the models were brought in, we studied all of them. Moseley's model was so obviously ahead of the others we told the other companies good-bye" (Poniatoff 1974).

Westinghouse offered to manage the contract, arguing that high-volume production would be too difficult for a small company like Dalmo Manufacturing. Moseley agreed, and the company, now Dalmo-Victor, moved to a larger facility in Belmont to produce the unit (Poniatoff 1974). By the end of World War II, Dalmo-Victor had emerged as the leading manufacturer of airborne radar antennas. By 1966 the company was also producing 90 percent of the nation's submarine antennas, and was building antenna systems for NASA's lunar missions (Morgan 1967). Dalmo Victor was eventually acquired by the General Instrument Defense Systems Group, which in turn was acquired in 1991 by Litton Industries Applied Technologies Group, headquartered in San Jose. The Dalmo Victor Division is still located in Belmont and has manufacturing operations in Grants Pass, Oregon.

It is worth commenting on the role of gifted mechanics and ham radio enthusiasts in the development of the Bay Area's early electronics industry. It seems that the best results were achieved when such practical mechanical brilliance was wedded to advanced technical training and theoretical knowledge. Such combinations existed in the development teams that paired Charles Logwood with Lee deForest, Philo Farnsworth with Russell Varian, and Tim Moseley with Alexander Poniatoff. Even more potent, perhaps, were the instances where this mixture of tacit ability and formal training were embodied in individuals. Leonard Fuller, Ralph Heintz, and Charles Litton built on their boyhood fascination with ham radio by studying electrical engineering at Cornell, U.C. Berkeley, and Stanford, thus gaining a theoretical understanding of what they already knew so well tacitly.

Perhaps the strongest thread that runs through the Valley's past and present is the drive to "play" with novel technology, which, when bolstered by an advanced engineering degree and channeled by astute management, has done much to create the industrial powerhouse we see in the Valley today. Indeed, the caricature of the "ham" radio enthusiast—the shy but intelligent teenage boy who, bent over his home-made radio set in his bedroom late at night, taps into a secret world known only to him and his far-flung community of fellow hams—bears a striking resemblance to that of the "computer geek," "code hacker," and "web surfer" of more recent vintage.

Ampex Develops the Tape Recorder

Key components of Dalmo-Victor’s radar antenna system were two small precision electric motors to aim the device and a tiny generator to supply power. Motors and generators of this sort were unavailable on the open market at the time. In late 1944 Moseley asked Poniatoff to form his own company to manufacture them. Poniatoff was initially shocked at the suggestion, but after few days of thought he agreed, adding $5,000 of his savings to $25,000 invested by Moseley to capitalize the start-up. Poniatoff also got an additional loan from the First National Bank, and set up shop in an attic above Dalmo-Victor. Poniatoff called his new company Ampex using his initials (he was known as Dr. AMP around the Dalmo shop) plus "ex" for excellence (Poniatoff 1974).

As Ampex expanded with wartime production, the company moved into a larger facility in San Carlos. Most of the military work went to supply the Pacific theater, particularly antennas for the airplane known as the "black widow.” The news of Japan's surrender in August, 1945, was almost immediately followed by telegrams from the military canceling all orders. Although some advised Poniatoff to close his company and quit while he was ahead, Poniatoff decided to develop home high fidelity sound systems. A $40,000 order for 10,000 precision motors from a Berkeley furnace manufacturer kept the company afloat as they developed their new product (Poniatoff 1974).

As the development of the hi-fi system progressed, it became clear to the team that the weakest link was the phonograph disk player. It was then that a key Ampex engineer attended an Institute of Radio Engineers meeting in San Francisco, where he witnessed a demonstration of a German tape recorder called "The Sound Mirror.”[18] Poniatoff perceived the tape recorder as "the missing link in the hi-fi system" and set on a program to

18 Tape recording was first developed by the Telefunken Company in Germany during the 1930s. During World War II, the German military played tapes of speeches and music over makeshift radio stations set up in the remains of cities that had been destroyed by Allied bombs. The tapes were too long and of too high sound quality to have been recorded onto phonograph disks, confusing Allied intelligence about the success of bombing raids and as to the whereabouts of important political figures who’s voices could be heard on the tapes.

reverse-engineer the German unit. Although Ampex's small precision electric motor technology was well suited for tape recording, the technology involved with the magnetic tape heads was entirely new to them. A representative from 3M Company, who had heard of Ampex's development efforts, came to San Carlos with a sample of the new magnetic tape they were developing. The two companies worked together to improve the quality of magnetic tape, clearing up a crucial development problem for the team at Ampex (Poniatoff 1974).

When it was learned that Bing Crosby was shooting a film in San Francisco, a just-completed Ampex tape recorder was brought to him for a demonstration. On hearing the quality of the recording, Crosby ordered 20 units for $3,000 each, and negotiated a deal for Crosby Enterprises to become sole distributor for the product. Soon Jack Benny, Bob Hope, and Michael Todd, the developer of Cinerama, became Ampex customers (Poniatoff 1974). Ampex abondoned the development of a complete system and switched production exclusively to tape recorders, but it continued to receive orders for precision motors. Poniatoff encouraged an employee named Walter Cabral to start his own company to produce them. "I said, 'Why don't you start your own company like Moseley [helped] me [to do]' I talked him into it. 'Supply it," I said, 'Here is the order'" (Poniatoff 1974).

Through many of the lean times, Poniatoff was able to secure loans through First National Bank in San Francisco. When First National was sold to Wells Fargo Bank, Poniatoff was told of a "very remarkable consultant to new companies" at Wells Fargo who "has had a lot of experience helping struggling young companies like yours." This was Stanfield Rayfield, who set up a meeting between Poniatoff and Henry McMicking, a wealthy investor with interests in the Philippines. McMicking invested $365,000 in Ampex, forming a 50/50 partnership with Poniatoff. McMicking brought in an IBM salesman from the Philippines named Kevin Mallen to be general manager. Mallen set up new distribution channels, breaking the exclusive distribution contract with Crosby.

McMicking was well connected in Washington D.C., and helped to secure contracts from the National Security Agency.

McMicking set a five-year plan for the company to grow to $11 million in annual sales, a target well beyond Poniatoff's imagining but which the company greatly exceeded. McMicking drastically reorganized the marketing structure of Ampex, but held a strict policy not to interfere in any way with engineering. By 1957 Ampex had 1,500 employees, and a wide range of products for professional recording, commercial aviation, and the U.S. Government (Poniatoff 1974). Ampex later went on to develop multi-track recording in 1954, the first video tape recorder in 1956[19], and become a major force in the field of tape back-up drives for large computer systems. In 1999, the company was still in operation in Redwood City.

The approach that Rayfield, McMicking, and Mallen took to Ampex's development bears a striking resemblance to the role that modern venture capitalists have played during the post-Fairchild era. It is likely that Rayfield, in particular, played a wider role in the Bay Area electronics industry during the 1940s and 1950s, and research into his activities would be a fascinating study. Based on the current work, however, it can be said that William Crocker, the banker and railroad magnate's son from San Francisco, was Silicon Valley's first true venture capitalist.

Conclusion

The confusion over Silicon Valley's beginnings is deep-seated. There is a plaque at 367 Addison Ave. in Palo Alto entitled "The Birthplace of Silicon Valley" (California State Historic Landmark #976) that reads:

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[19] The video tape recorders development team at Ampex included Charles Ginsburg and Ray Dolby. A portable version was introduced in 1967. In 1965, Dolby went on to found Dolby Laboratories in London. Dolby Laboratories became a leader in audio noise reduction and "surround sound" technologies and was still producing equipment specifically designed to work with Ampex's professional audio recorders in the mid-1980s.

> This garage is the birthplace of the world's first high-technology region, "Silicon Valley." The idea for such a region originated with Dr. Frederick Terman, a Stanford university professor who encouraged his students to start up their own electronics companies in the area instead of joining established firms in the East. The first two students to follow his advice were William R. Hewlett and David Packard, who in 1938 began developing their first product, an audio oscillator, in this garage.

Just a few blocks away, on the southeast corner of Emerson St. and Channing Ave., there is another plaque, this one entitled "Electronics Research Laboratory" (California State Historic Landmark #836). It reads:

> Original site of the laboratory and factory of Federal Telegraph Company, founded in 1909 by Cyril F. Elwell. Here, with two assistants, Dr. Lee deForest, inventor of the three-element radio vacuum tube, devised in 1911-13 the first vacuum tube amplifier and oscillator. World-wide developments based on this research led to modern radio communication, television, and the electronics age.

The founding of FTC predates Hewlett-Packard by nearly forty years, but when bus-loads of visitors come to Palo Alto to pay their respects to the birthplace of Silicon Valley, they stop at the first plaque, not the second. The argument of this chapter is not only about establishing precedent and assigning credit where it is due. The shadows of Frederick Terman and William Shockley loom large, not just in Silicon Valley, where they have honored places as the region's founding fathers, but in countless other localities throughout the world that are trying to emulate the region's success. Development schemes derived from Silicon Valley include the incubation of "sunrise" technologies (following the William Shockley theme), the encouragement of cooperation between universities and industry in "high-tech" commercial ventures (following the Frederick Terman theme), and the provision of "high tech" industrial parks (an extension of the Terman theme following the model of Stanford Industrial Park). As economic development tools these schemes have met with very limited success (Malecki 1981; Taylor 1983; Saxenian 1988b). However, they continue to absorb the resources of planning agencies and universities in countless locations (Engstrom 1987).

Stripped of its *tabula rasa* antecedents, Silicon Valley retains its millionaires; its legacy of boom and bust, cowboy entrepreneurialism; its record of astonishing urbanization and skyrocketing land values; its polluted air and groundwater; its daily traffic snarls; and its reputation as the hearth of innovations that have transformed the way humans relate to nature and to each other. What is lost is the notion that *anyplace can be Silicon Valley*.

The fact that the San Francisco Bay Area's electronics industry began close to the turn of the Twentieth Century should lay to rest the notion that industrialization and urbanization on the scale of Silicon Valley can be quickly induced in other areas. Silicon Valley is nearly 100 years old. It grew out of a historically and geographically specific context that cannot be recreated. The lesson for planners and economic developers is to focus on long-term, not short-term developmental trajectories. Silicon Valley was the fastest growing region in the United States during the late 1970s and early 1980s; but that growth came out of a place, not a technology. Silicon Valley's development is intimately entwined with the long history of industrialization and innovation in the larger San Francisco Bay Area.

Bibliography

Aitken, Hugh. 1985. The Continuous Wave: Technology and American Radio: 1900-1932 (Princeton: Princeton University Press).

Braun, Ernst. and Macdonald, Stuart. (1982): Revolution in Miniature, second edition, Cambridge University Press, Cambridge, Mass.

Brechin, Gray (1990): *Imperial San Francisco*, Headlands Journal, Vol. 2, Headlands Center for the Arts, Sausalito, California.

Coleman, Charles (1952): PG&E of California, the Centennial Story of Pacific Gas and Electric Company, 1852-1952, McGraw-Hill, New York.

Cortada, James (1987): Historical Dictionary of Data Processing: Organizations, Greenwood Press, New York.

Engstrom, Therese (1987): *Little Silicon Valleys*, Technology Review, January, 1987, pp. 24-32.

Everson, George (1949): The Story of Television: the Life of Philo T. Farnsworth, W.W. Norton and Company, New York.

Fisher, David and Marshall Fisher. 1996. Tube: The Invention of Television (Washington, DC: Counterpoint Books).

Fuller, Leonard (1975): Interview by O.G. Villard, June 25, 1975, for the History of Science and Technology Project, University of California at Berkeley.

Fuller, Leonard (1976): Leonard Franklin Fuller: Research Engineer and Professor, interviews conducted by A.L. Norberg in 1973, 1974, and 1975 for the History of Science and Technology Project, University of California at Berkeley.

Grass Roots Writing Collective (1969): The Promised Land, a Grass Roots Report on Mid-Peninsula Land Use, Grass Roots Writing Collective in cooperation with Stanford Chaparral, Palo Alto (Pacific Studies Center).

Hanson, Dirk (1982): The New Alchemists: Silicon Valley and the Microelectronics Revolution, Little & Brown Co., Boston, Mass.

Heintz, Ralph (1974): Interview conducted by Thornton Mayes on June 30, 1974 for the History of Science and Technology Project, University of California at Berkeley.

Heintz, Ralph (1982): Technical Innovation and Business in the Bay Area, an interview conducted by A.L. Norberg for the History of Science and Technology Project, University of California at Berkeley.

Henderson, John. and Scott, Allen .J. (1987): *"The Growth and Internationalisation of the American Semiconductor Industry: Labour Processes and the Changing Spatial*

Organization of Production", in The Development of High Technology Industries, Breheny, M. and McQuaid, R. eds., pp.37-79, Croom Helm, London, U.K.

Joss, John (1990): *"Ron Johnson, Silicon Alchemist*, Silicon Valley Engineer, vol. 2, no. 1.

Lewis, Tom (1991): Empire of the Air: the Men Who Made Radio, HarperCollins, New York.

MacLaurin, W.R. (1949): Invention and Innovation in the Radio Industry, MIT studies in innovation, MacMillian, New York.

Malecki, Edward. (1981): *Science, Technology and Regional Economic Development: Review and Prospects*, Research Policy, 10(1): 312-34.

Malone, Michael (1984): The Big Score: the Billion-Dollar Story of Silicon Valley, Doubleday and Co., Garden City, N.Y.

Markusen, Ann, et. al. (1991): The Rise of the Gunbelt: the Military Remapping of Industrial America, Oxford University Press, Oxford.

McWilliams, Carey (1949): California: the Great Exception, Current Books, A.A. Wyn, New York.

Miller, Roger. and Cote, Marcel. (1985): *Growing the Next Silicon Valley*, Harvard Business Review, July-August, 1985, pp. 114-123.

Millikan, Robert (1931): Radio's Past and Future, lecture series sponsored by the National Council on Radio in Education, University of Chicago Press.

Morgan, Jane (1967): Electronics in the West: the First Fifty Years. Palo Alto: National Press Books.

Morgan, K, and Sayer, A. (1988): Microcircuits of Capital: Sunrise Industry and Uneven Development, Westview Press, Boulder

Norberg, Arthur L. (1976): *The Origins of the Electronics Industry on the Pacific Coast*, Proceedings of the Institute of Electrical and Electronics Engineers, Vol. 64, NO. 9, September 1976.

O'Green, Fred (1989): Putting Technology to Work: the Story of Litton Industries, Newcomen Society of the United States, New York.

Poniatoff, Alexander (1974): Interview conducted by A.L. Norberg, History of Science and Technology Project, Bancroft Library, University of California at Berkeley.

Pursell, Carroll (1976): *The Technical Society of the Pacific Coast 1884-1914*, Technology and Culture, vol. 17, no. 4, University of Chicago Press, Chicago, Illinois.

Rogers, E. and Larsen, J. (1984): Silicon Valley Fever. New York: Basic Books.

Rosa, Felix (1960): Radio Telegraph and Telephone Pioneer 1909-1959, Inception of the Electronics Era: a Biography of C. F. Elwell, unpublished manuscript, History of Science and Technology Project, Bancroft Library, University of California at Berkeley.

Saxenian, AnnaLee. (1983b): *The Genesis of Silicon Valley,* Built Environment, vol. 9, no. 1:7-17.

Saxenian, AnnaLee. (1985): *Silicon Valley and Route 128: Regional Prototypes or Historic Exceptions?*, in M. Castells, ed. Technology, Space, and Society, Urban Affairs Annual Review, vol. 28, Sage Publications, Los Angeles.

Saxenian, AnnaLee. (1986): *In Search of Power: the Organization of Business Interests in Silicon Valley and Route 128*, Working Paper, E53-470, Department of Political Science, MIT, Cambridge, Massachusetts.

Saxenian, AnnaLee. (1988a): *The Political Economy of Industrial Adaptation in Silicon Valley,* Unpublished Ph.D. dissertation, Department of Political Science, MIT.

Saxenian, AnnaLee. (1988b): *The Cheshire Cat's Grin: Innovation and Regional Development in England*, Technology Review, no. 71, February/March, pp. 67-75.

Saxenian, AnnaLee. 1994. Regional Advantage: Culture and Competition in Silicon Valley and Route 128. Cambridge, MA: Harvard University Press.

Scott, Allen. and Storper, Michael. (1987): "High Technology Industry and Regional Development: a Theoretical Critique and Reconstruction", International Social Science Journal. 112: 215-232, Paris.

Scott, Mel (1985): The San Francisco Bay Area: a Metropolis in Perspective, University of California Press, Berkeley.

Sobel, Robert (1982): ITT: The Management of Opportunity, Times Books, New York.

Storper, Michael. and Walker, Richard. (1989): The Capitalist Imperative: Territory, Technology and Industrial Growth. Oxford and Cambridge (US): Basil Blackwell.

Sturgeon, Timothy J. (1992): The Origins of Silicon Valley: The Development of the Electronics Industry in the San Francisco Bay Area. Masters Thesis, Department of Geography, University of California at Berkeley.

Taylor, Tony (1983): "High-Technology Industry and the Development of Science Parks." Built Environment, 9:1.

Terman, Frederick (1978): Interviews conducted by A.L. Norberg, Charles Susskind, and Rodger Hahn, History of Science and Technology Project, Bancroft Library, University of California at Berkeley.

Walker, Richard. 1996. "Another Round of Globalization in San Francisco." Urban Geography 17 (1): 60-94.

Williams, James C. (1987): *Regional Development in the Technical Sciences in California's Electric Power Industry, 1890 - 1920,* in Technology and Technical Sciences in History, Proceedings of the ICOHTEC-Symposium, Dresden, 25-29 August, 1986, Rolf Sonnemann and Klaus Krug, eds., VEB Deutscher Verlag der Wissenschaften, Berlin.

Williams, James C. (1990): *The Rise of Silicon Valley*, Invention and Technology, Spring/Summer.