1

Defiant West

In 1947, Eitel-McCullough, a manufacturer of radio transmitting tubes located on the San Francisco Peninsula, sued the Radio Corporation of America and the General Electric Company, alleging patent infringement. GE and RCA, the giants of American electronics, had copied Eitel-McCullough's new line of tubes for FM radio and television broadcasting. The giants lost the lawsuit and were forced to halt production of these tubes. Exploiting its legal victory for commercial advantage, Eitel-McCullough transformed these mighty corporations into its own virtual sales force and distribution network by letting them buy its products and resell them under their own names.[1]

Such a lawsuit and its outcome would have been inconceivable 20 years earlier. RCA and GE thoroughly dominated American electronics in the late 1920s. They controlled all patents on vacuum tubes, and, along with Western Electric and Westinghouse, they dominated the manufacture of transmitting tubes in the United States. Firms that attacked their dominance were sued for patent infringement and driven into bankruptcy. How was Eitel-McCullough able to emerge as such a prominent manufacturer of transmitting or "power" tubes? How did it compete with RCA and GE and partially displace these mighty corporations in the field of power tubes? What forces at work in industry, government, and the international arena made the rise of Eitel-McCullough possible (Norberg 1976; Sturgeon 2000)?

Arthur Norberg briefly sketched the early history of power tube manufacturing on the San Francisco Peninsula in his article on the origins of the West Coast electronics industry. However, Norberg did not examine the unique social and economic context that sustained the rise of Eitel-McCullough. Nor did he explore Eitel-McCullough's history during World War II, when it emerged as a major electronics manufacturer. In this chapter, going beyond Norberg's analysis, I examine the emergence of Eitel-McCullough and of a closely allied company, Litton Engineering Laboratories, by following the careers of three innovator-entrepreneurs—William Eitel, Jack McCullough, and Charles Litton—from the early 1920s to the late 1940s.

These men started and grew the power tube industry on the San Francisco Peninsula. Eitel, Litton, and McCullough had become acquainted with the technology of power tubes through their activities in amateur ("ham") radio and their venture into tube production at local radio firms in the late 1920s and the early 1930s. In the midst of the Great Depression, these men established Eitel-McCullough and Litton Engineering Laboratories. While Litton Engineering specialized in tube-making equipment, Eitel-McCullough fabricated transmitting tubes for radio amateurs. The unusual requirements of radio amateurs and their innovative use of Litton's equipment put Eitel and McCullough at the cutting edge of the tube business. As a result, they were well positioned to supply advanced tubes for radar development programs in the late 1930s. Benefiting from the enormous demand for radar tubes during World War II, Eitel-McCullough vastly expanded the scale of its operations and became one of the largest US producers of vacuum tubes. In turn, because Eitel-McCullough and other firms heavily relied on Litton Engineering's machinery, Litton emerged as a major supplier of tube-making equipment during the war.

Training

William Eitel, Jack McCullough, and Charles Litton, unlike many subsequent electronics entrepreneurs on the San Francisco Peninsula, had deep roots in the area and came from families with a strong history of entrepreneurship. These men had been born and raised in, variously, San Francisco and the small communities of San Mateo and Santa Clara counties. Their families also shared common traits: they were middle class or lower middle class and had a strong technical and entrepreneurial bent. McCullough's parents had built a small wholesale lumber business in San Francisco. (His uncle owned a sawmill on the Peninsula.) Eitel's family had a strong mechanical orientation. His father had ventured into the design of aircraft engines in the 1910s. When the company developing his engine faltered because of a shortage of funds, he took a job managing a granite quarry. Subsequently, he ran a small stone-carving business. Eitel's uncle, E. J. Hall, had established the Hall-Scott Motor Car Company in Oakland, one of the first automotive corporations on the West Coast. One of Hall-Scott's specialties was the small-scale production of sports cars. The firm also designed and built an aircraft engine, the "Liberty engine," which was used in most American military aircraft during World War I.[2]

In addition to coming from comparable social backgrounds, Eitel, Litton, and McCullough received similar technical training in radio technology and metalworking. These men acquired a solid education in the mechanical arts by working in their families' enterprises and attending mechanically oriented educational institutions. Eitel, an energetic and resourceful youngster with limited interest in academics, gained his mechanical skills in the shop of Los Gatos High School and by working in his father's quarry as an assistant blacksmith and machine operator. One of Eitel's favorite places to visit was the shops of the Hall-Scott Motor Car Company. There he learned about machine-shop practice and the operation of complex machinery.[3]

While Eitel gained his mechanical skills mostly by doing, Litton and McCullough attended the California School of Mechanical Arts in San Francisco. One of the best technical high schools on the West Coast, it offered rigorous training in the mechanical trades and solid education in the humanities and the sciences. At the school, Litton and McCullough became excellent machinists. They also gained, as Litton later recalled, "a realistic 'feel' of materials and processes coupled with and at no sacrifice to a sound liberal arts background."[4] McCullough continued his technical education at a local junior college. Litton deepened his knowledge of mechanics and metalworking by enrolling in Stanford University's mechanical engineering department in the early 1920s. The department's curriculum at the time had a strong practical flavor. It was organized around courses in shop work and administration, machine drawing and design, and power plant engineering. It also included chemistry courses. The mechanical and chemical expertise Litton acquired at Stanford helped him greatly in his subsequent vacuum tube endeavors. Litton received a bachelor's degree in mechanical engineering in 1924.[5]

Litton, Eitel, and McCullough, like many technically minded middle-class youngsters, became interested in radio in the mid 1910s and the early 1920s. The San Francisco Bay Area was an excellent place to discover the new field of electronics. Since the turn of the century, this region had been, like Boston, one of the main centers of ham radio activity in America. By the mid 1920s, the Bay Area had more than 1,200 licensed amateurs, about 10 percent of all the radio operators in the

United States. The ham community in Northern California was remarkably dynamic. San Francisco and Oakland had radio clubs. Stanford University also had its own radio group. In addition, the Bay Area's amateur radio community generated a large share of the electronics hobbyist literature. Local clubs produced newsletters on "wireless" technology. *Radio*, one of the two magazines dedicated to amateur radio in the United States, was based in San Francisco.[6]

One might ask why an isolated and peripheral region, a continent away from important urban and industrial centers, nurtured such a large and vibrant ham radio community. A number of geographical and cultural factors seem to have played a role in the high concentration of radio amateurs in the Bay Area. Northern California had a strong maritime orientation, and San Francisco was one of the largest seaports on the West Coast. San Francisco Bay also had several military bases. The Navy and local commercial shipping firms relied heavily on radio communication to monitor their operations in the Pacific. As a result, they gave considerable visibility to the new technology—especially in the 1900s and the 1910s, when radio was used almost exclusively for ship-to-ship and ship-to-shore communication. In addition to exposing San Francisco youths to the new technology, the Navy and the shipping companies employed a significant number of radio operators, some of whom were involved in amateur radio (Pratt 1969).

The presence of a small but vital electronics industry in the area also contributed to the strength of the ham community in Northern California. The Bay Area was an active center of radio manufacturing in the 1910s and the 1920s. It was home to a number of electronics firms, including Remler (which made radio sets) and Magnavox (the leading American manufacturer of loudspeakers). Another small company, Heintz and Kaufman, designed custom radio equipment. Federal Telegraph, one of the earliest radio companies in the United States, operated a radio-telegraph system on the West Coast and produced radio transmitters in the 1910s. These firms made radio parts available to local hobbyists and hired radio amateurs (Norberg 1976; Morgan 1967).

General attitudes toward technical change in California may have reinforced the local interest in radio. Technological innovation seems to have been especially valued in California since the 1890s. California farmers, for example, mechanized their operations earlier than their counterparts in other parts of the country. In similar fashion, Californians rapidly embraced new technologies such as the automobile and the airplane in the 1900s and the 1910s (Pursell 1976).

Introduced to amateur radio through their families and their friends, Litton, Eitel, and McCullough embraced the new hobby. They rapidly found a congenial environment for their radio interests at their schools and in their communities. Eitel was tutored in the new technology by his mathematics teacher, a radio enthusiast. Eitel also learned about the new field by reading radio books and *QST*, an amateur radio magazine, in his school's library. These young men also became active in the Bay Area's radio clubs. In the process, they became acculturated to the world of amateur radio, and they soon acquired many of its values and behavior patterns.[7]

Ham radio was an unusual technical subculture in a number of ways. First, it was characterized by camaraderie and intense sociability. Hams used radio primarily as a way to make friends. In addition to communicating "over the air," radio amateurs socialized face to face in radio clubs and at conventions. They organized "hamfests" that attracted hundreds of amateurs living in the same area as well as commercial suppliers of radio equipment. By the early 1930s, an observer of the amateur community reported that radio amateurs in the United States organized more than twenty regional conventions and hundreds of "hamfests" annually. It was at one of these social gatherings that McCullough, Litton, and Eitel met (De Soto 1936; Douglas 1987). Second, the ham culture was characterized by egalitarianism and a democratic ideology. Radio amateurs gave little heed to traditional distinctions of class and educational attainment. The Santa Clara County radio club, which Eitel chaired in the mid 1920s, counted among its members farm boys, Stanford students, Federal Telegraph's technicians, and retired executives. Moreover, hams saw themselves as part of the "people." In their recurrent conflicts with the military services and with large corporations such as RCA over control of the airwaves, radio amateurs presented themselves as representatives of the citizenry against the interests of large and undemocratic organizations (Douglas 1987). Third, radio amateurs greatly valued technical innovation and resourcefulness. They were interested in extending the range and performance of radio technology. In particular, they sought to improve radio circuits and to explore new radio frequencies for long-distance communication. In short, radio amateurs built reputations among their brethren by innovating new circuitry, devising clever transmitter designs, and establishing contacts with faraway lands (Morgan 1967; De Soto 1936). Lastly, the ham culture was characterized by its mix of competitiveness and information sharing. "The predominant characteristic of the amateur," a radio hobbyist observed at the time, “is his altruism. The amateur wants every other amateur and the public to share in and benefit by his discoveries. The rivalry to accomplish something that has not been done before is intense. But it is rivalry of the friendliest sort, and no sooner does one make a new record that he wants to show all his brother amateurs not only how it was done, but how they also can do it. The slightest advance in technique, every individual discovery, any observation that promises improvement, is immediately the property of all.” (De Soto 1936) Competitiveness and free sharing of information were institutionalized by the Amateur Radio Relay League (ARRL), the main association of radio amateurs in the United States. The ARRL published the most advanced amateur work in its magazine, *QST*. It also gave awards for important technical accomplishments. In 1926, for example, the ARRL established a “worked-all-continents” prize for amateurs who had established radio contact with stations in Asia, Europe, and Australia (De Soto 1936).

In tandem with their acculturation in the world of amateur radio, Eitel, Litton, and McCullough gained a solid knowledge of electronics and radio systems. They read hobbyist literature and radio textbooks and experimented relentlessly with their radio equipment. Through this intense work, these young men gained a thorough knowledge of radio circuitry. They also learned to design and build their own radio stations. Ultimately, they encountered the new field of short-wave radio.[8]

The short waves were then a largely forsaken portion of the radio spectrum. Judging the short waves (under 200 meters) to be worthless, the US Department of Commerce had given them over to radio amateurs in 1922. Waves over 200 meters, which seemed at the time to have more potential for long-distance communication, were assigned to the military, to RCA, to American Telephone and Telegraph (AT&T), and to broadcasting networks. As a result, electronics hobbyists explored the untrodden part of the radio spectrum. In 1923, radio amateurs discovered that they could use 100-meter waves to communicate with Europe. Furthermore, the radio amateurs soon found that short waves were far superior to long waves for long-distance radio transmission. Short waves made communication possible over distances greater than had ever been reached before. They also required only a fraction of the power used by the long-wave stations. This revolutionary discovery opened a new field of inquiry in which radio amateurs participated prominently. Intent upon furthering their explorations, radio amateurs experimented with ever shorter waves. They defined the characteristics of such waves and evaluated their potential for long-distance communication (De Soto 1936; Douglas 1987).[9]

Interested in joining this revolution, Eitel, Litton, McCullough, and many of their ham friends on the San Francisco Peninsula experimented with short waves. In the process, these young men made notable contributions to the art of high-frequency or short-wave radio. In 1924, Litton and a fellow member of the Stanford radio club were among the first American amateurs to establish communication in the high frequency bands with Australia and New Zealand. In 1928, Eitel pioneered the use of 10-meter waves for transcontinental communication. This important accomplishment opened the very high frequency (VHF) bands to radio communication. "I was bringing up the rear when the movement [toward the higher frequencies] started," Eitel later reminisced, "but by the time they got to 20 meters I was up with them. I beat them all in spanning the continent on 10 meters. In order to do this work, I had to build everything myself. This took an understanding of circuits and other components because most of them were marginal. In fact, they were inadequate. So I had to improvise with what was available. I worked with the circuits until I got the performance I wanted. Since I built everything myself, it was a matter of how I arranged the coils and condensers in the circuits."[10]

In conjunction with the design of transmitting stations and their innovative work in short-wave radio, Eitel, Litton, and McCullough learned about vacuum tubes, the main components of radio circuits and systems. Vacuum tubes made it possible to generate, to detect, and to amplify radio signals. A vacuum tube consisted of a glass envelope and a set of electrodes: a filament or cathode, which emitted a stream of electrons; a plate or anode, which collected them; and, finally, an open mesh grid, which controlled the flow of electrons between the filament and the plate. The grid acted as a valve, opening or closing the passage of electrons according to the voltage on it. When a vacuum tube was used as an amplifier, radio waves intercepted by an antenna came to the grid as a weak alternating current oscillating with the radio waves' frequency. The oscillating voltage thus applied to the grid modulated the flow of electrons crossing the tube to the same frequency. The electron stream then delivered an alternating current at the plate, which reproduced with great amplification the weak signal on the grid. Tubes had to be carefully evacuated of all gases to allow the flow of electrons between the cathode and the plate.

Amateur radio and especially the "exploration" of the short waves was a good school in which to learn about these complex devices. "Vacuum tubes," Eitel later recalled, "were the weak links in the chain. It was rather tricky to get them to perform properly at [high] frequencies. They were

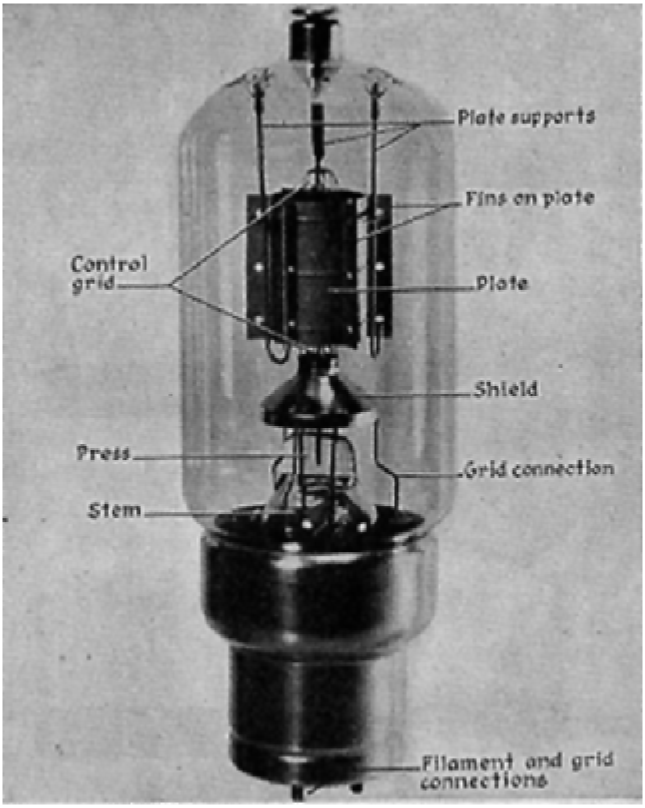

Figure 1.1
The structure of the Heintz and Kaufman 354 power-grid tube. Source: Terman 1938.

one of the components that required a sixth sense to get them to work. They had not been designed for these frequencies. They had been designed for the lower frequencies."[11] To push the tubes to their limits and get them to work at the higher frequencies, Litton, Eitel, and McCullough gained a solid knowledge of their construction and operating principles.[12]

Litton went one step further. He learned to fabricate vacuum tubes and, especially, power-grid tubes.[13] Mastering the fabrication of transmitting or "power" tubes was a remarkable achievement for an independent experimenter. These devices, which were used to generate strong radio signals for long-distance transmission, were very difficult to make. Indeed, General Electric, Westinghouse, and AT&T, which had developed high-power transmitting tubes in the early 1920s, encountered substantial difficulties in producing them in a consistent and reproducible fashion. The fabrication of power tubes required precise machining. It also required a mastery of glass blowing: transmitting tubes were made of special Pyrex glass. Their manufacture also rested on complex processing techniques. To create the high vacuum required for their operation, the tubes had to be baked at high temperatures for hours at a time in order to release the gases occluded in their metallic elements. Power tubes also required the use of exotic materials and sophisticated sealing techniques to make tight joints between the glass envelope and the metallic elements. Finally, the fabrication of high-vacuum power tubes necessitated the use of "getters"—magnesium pellets, attached to the inside portion of the tube envelope, that absorbed residual gases after the tube had been evacuated (Fagen 1975).

Although little is known about Litton's apprenticeship in vacuum tube practice, it is likely that he learned to make transmitting tubes by reading the technical literature and by playing with power-grid tubes. He also may have received technical advice from his neighbor Otis Moorhead. Moorhead, a radio amateur and a vacuum tube entrepreneur, had established a vacuum tube firm, Moorhead Laboratories, in San Francisco in 1917. Moorhead manufactured receiving tubes for radio sets until a patent-infringement lawsuit put him out of business in the early 1920s. Litton was fascinated by the complex techniques required to make power-grid tubes. In the early and mid 1920s, he experimented with materials and with tube processing techniques in his home laboratory. In parallel to this work on glass and metals, Litton mastered the design and construction of the specialized vacuum equipment required to make power tubes. He built, for instance, the vacuum pumps with which he evacuated his tubes. Litton also constructed his own ovens. By the mid 1920s, after years of trial and error, Litton was making sophisticated tubes: high-power triodes (vacuum tubes with three electrodes—cathode, plate, and grid) as well as thermionic rectifiers. He used these in his own radio transmitter and sold them to other radio amateurs on the San Francisco Peninsula (Litton and Scofield 1925; Norberg 1976; Sturgeon 2000).[14]

In 1925, to complement his training in electronics, Litton did graduate work in electrical engineering at Stanford University. At that time, Stanford's small electrical engineering department was oriented toward graduate education. Its three instructors offered a limited range of courses on electric circuits, AC machinery, and power transmission. One might speculate that in addition to these classes, Litton also took two of the few electronics-related courses that the university was offering at the time: a physics course on “ions and electrons,” which covered, among other things, the theory of vacuum tubes, and a course (first offered in 1925) on “communication engineering fundamentals.” The latter course included a brief treatment of electromagnetic theory and went into radio and telephony engineering in more depth. For his engineering thesis, Litton designed an instrument that recorded and helped visualize short radio waves. After graduating with an engineering degree in electrical engineering, Litton, like many West Coast engineers at that time, went East. He accepted a junior engineer position at the Bell Telephone Laboratories. There he joined a new engineering group that was developing a short-wave radio system for transatlantic telephony. Over the next 2 years, Litton designed measuring equipment and short-wave receivers. His work at the Bell Telephone Laboratories and his training in electrical engineering at Stanford transformed Litton into a professional radio engineer. But Litton never abandoned his ham radio roots and continued to play with radio transmitters and talk “over the air” for most of his life.[15]

Tube Design and Manufacture

In the late 1920s, Litton, Eitel, and McCullough found jobs with small electronics corporations on the San Francisco Peninsula. After two lonely years at the Bell Telephone Laboratories, Litton longed to return home. He had had a nervous breakdown, and he did not like the Eastern climate. In 1927 he moved back to California. With the help of Philip Scofield, a Stanford friend whom he had known through amateur radio, Litton secured a research engineer position at the Federal Telegraph Company. He negotiated a contract which stipulated that he would work only on the San Francisco Peninsula. Eitel too gained a foothold in the Peninsula’s electronics industry through his ham radio connections. In 1929, Heintz and Kaufman Incorporated hired Eitel as a mechanic on the recommendation of Colonel Foster, a wealthy radio amateur who was a customer of Heintz and Kaufman. One year later, Eitel recruited McCullough to work with him at Heintz and Kaufman. Litton, Eitel, and McCullough put considerable efforts and energy into their new jobs—so much so that Litton soon became known as “Charles Vigorous Litton” among his co-workers. Eitel and McCullough, who were industrious, put in many all-nighters at Heintz and Kaufman (Southworth 1962; Millman 1984; Layton 1976).

The Federal Telegraph Company and Heintz and Kaufman Incorporated offered attractive opportunities for ambitious young men eager to prove themselves in electronics. These were the most respected electronics firms in the Bay Area. They also had active research and engineering programs in short-wave radio. Federal Telegraph, which had been formed in 1909, had pioneered continuous wave radio in the 1910s. It had also helped to develop vacuum tube technology. It was at Federal Telegraph that Lee de Forest had invented the audion oscillator and amplifier, the first vacuum tube. Exploiting these innovations for commercial advantage, Federal Telegraph became an important supplier of radio equipment to the US Navy during World War I. After these notable beginnings, Federal Telegraph declined in the 1920s, becoming a rather insignificant supplier of radio-telegraph services on the West Coast. To revive its sagging fortunes, the firm sought to gain a position in short-wave radio, as it became apparent that the new technology offered great commercial possibilities for long-distance communication.[16]

In 1927, to finance its research and development efforts in short-wave radio, Federal Telegraph secured a large contract from International Telephone and Telegraph (IT&T), a New York-based telecommunication conglomerate with operations in Europe and South America. IT&T was interested in building a global short-wave radio communication network. It contracted out the development of the required high-frequency transmitters and receivers to Federal Telegraph. Under the terms of the agreement, Federal Telegraph became the sole supplier of short-wave radio equipment to IT&T. In return, IT&T financed a large share of Federal Telegraph's research and engineering program and paid royalties to Federal Telegraph on its sales of radio communication services. With this contract, in 1927 and 1928 Federal Telegraph built a large R&D organization with more than 60 engineers and scientists working on all aspects of short-wave radio.[17]

Heintz and Kaufman was also an important player in the new field of short-wave radio. It had actually pioneered the commercial exploitation of short waves in the mid 1920s. The firm had been established in 1921 by Ralph Heintz, an inventive radio amateur and electro-mechanical engineer. At first, Heintz had repaired scientific instruments and produced radio sets and broadcasting transmitters. Sensing the future commercial importance of short-wave radio, Heintz re-oriented the firm toward the design and manufacture of high-frequency radio equipment in 1924. The corporation produced high-frequency transmitters and receivers on a custom basis for a wide variety of users. Among these were the Army, the Navy, the Boeing Airplane Company, and wealthy radio amateurs. Heintz and Kaufman's transmitters were also used in various expeditions to Antarctica and the North Pole. In addition to these custom jobs, Heintz and Kaufman secured a large procurement contract from the Dollar Steamship Company. Dollar, a large shipping company based in San Francisco, asked Heintz and Kaufman in 1929 to build an extensive short-wave radio network in the Pacific. These transmitters would connect its fleet with shore stations in Hawaii, Guam, China, and the Philippines as well as major ports in the United States. In conjunction with this large contract, Dollar also acquired a controlling interest in Heintz and Kaufman, transforming it, in effect, into its in-house supplier of radio equipment (Olson and Jones 1996; Niven 1987).[18]

Working for Federal Telegraph and Heintz and Kaufman, Litton, Eitel, and McCullough soon gravitated toward the design and production of power-grid tubes. In less than a year, Litton and Eitel respectively became the heads of Federal Telegraph's and Heintz and Kaufman's tube shops.[19] The manufacture of transmitting tubes was a new activity for these corporations. Until then, Federal Telegraph and Heintz and Kaufman had specialized in the operation of radio-telegraph systems and the manufacture of radio transmitters and receivers for long-distance transmission. It was only in the late 1920s that they moved into power tube manufacturing. They did so because they could not procure transmitting tubes on the open market. RCA, GE, Western Electric, and Westinghouse—the sole producers and distributors of power-grid tubes in the United States—refused to sell these tubes to Federal Telegraph or Heintz and Kaufman. RCA went one step further and threatened to sue Federal Telegraph and Heintz and Kaufman for patent infringement in case they procured transmitting tubes from European suppliers.[20] The reasons for this refusal were clear. RCA, which had been set up in 1919 at the instigation of GE and the Navy to ensure American predominance in radio, controlled ship-to-shore and transoceanic communication in the United States. It considered Federal Telegraph and Heintz and Kaufman threats to its domination of long-distance radio communications. Allowing Federal Telegraph and Heintz and Kaufman to buy power-grid tubes would permit them to establish transoceanic radio circuits for IT&T and the Dollar Steamship Company in direct competition with RCA. RCA could deny the sale of transmitting tubes to Federal Telegraph and Heintz and Kaufman because of its control of radio technology. RCA, which was partially owned by GE and Western Electric (AT&T's manufacturing arm), had signed a series of exclusive cross-licensing agreements with AT&T, GE, and Westinghouse. These cross-licensing agreements gave RCA control of more than 2,000 patents in the field of radio, including all the important vacuum tube patents. Making the most of these patents, RCA aggressively sued firms that infringed on its intellectual property rights and put them out of business.[21]

RCA's monopolistic practices forced Federal Telegraph and Heintz and Kaufman to manufacture their own power-grid tubes. Litton's and Eitel's job was to produce power tubes and to make them sufficiently different from General Electric's, Western Electric's, and Westinghouse's devices so that they would not fall under RCA's patents. As Litton and Eitel soon realized, designing and making transmitting tubes that did not infringe on the patents of the radio monopoly was an enormously difficult task. RCA had a seemingly impregnable patent position. It controlled more than 250 patents which covered all aspects of tube design and manufacture. Furthermore, RCA held the fundamental patents on device structures and tube elements such as cathodes, getters, and glass-to-metal seals. Circumventing these patents was highly risky. In the late 1920s, large electronics firms such as Sylvania tried to manufacture transmitting tubes that would bypass RCA's intellectual property rights, but they failed to circumvent some of RCA's key patents. As a result, RCA sued Sylvania and forced the firm to stop manufacturing power-grid tubes (Stokes 1982).

Litton and Eitel also had to confront some challenges that were specific to their location on the West Coast. Unlike Sylvania, which was located in Massachusetts and had ready access to a workforce skilled in vacuum tube manufacture, Federal Telegraph and Heintz and Kaufman operated in an industrial backwater. Though Litton and Eitel could find good mechanics in the Bay Area, they lacked access to a workforce skilled in vacuum tube practice. There were few operators with a knowledge of vacuum techniques and chemical handling in the Bay Area. Glass blowers too were rare, and Eitel considered the local ones incompetent. Furthermore, most suppliers of the special materials required for the fabrication of power tubes were located on the East Coast. For instance, the Corning Glass Works, which produced the Pyrex glass used in tube envelopes, had its main plant in New York State. Ordering materials required long and expensive trips to the East and entailed high shipping costs. In other words, the Bay Area's industrial infrastructure was inadequate for the manufacture of complex electronic devices such as power-grid tubes.[22]

But Litton, Eitel, and McCullough had access to significant technical and financial resources. Because the production of transmitting tubes was essential for the development of short radio communication systems, the managers of Federal Telegraph and Heintz and Kaufman allocated significant resources to the tube laboratories. Litton, for instance, directed a group made of ten college-trained engineers and scientists as well as a number of draftsmen and machinists. He had an ample budget, which allowed scouting trips to the East Coast to identify potential suppliers. Litton received considerable support from IT&T's legal department and the engineering groups of its European subsidiaries. A group of French engineers, for example, was dispatched from IT&T's research laboratory in Paris to aid with Federal Telegraph's tube-development efforts in 1930. Although the Dollar Steamship Company did not have IT&T's financial resources, Eitel was able to build a team of a dozen mechanics, glass blowers, and radio amateurs at Heintz and Kaufman. He could also rely on the counsel of patent lawyers and on the inventive mind of Ralph Heintz, who participated in the design and construction of transmitting tubes.[23]

The two groups at Federal Telegraph and Heintz and Kaufman also collaborated with each other in the late 1920s and the early 1930s. Their tight collaboration was predicated on common interests. They had to solve similar legal and design problems and solve them fast. They also had to make power-grid tubes, a difficult undertaking. The collaboration was also facilitated by the fact that they did not compete directly with each other and by the fact that they had a common enemy: RCA and the Eastern radio monopoly. One can also speculate that the cooperation between Litton, Eitel, and Heintz was also shaped by the friendships they had built and the values they had acquired through amateur radio. In the late 1920s and the very early 1930s, these men shared substantial information on tube design and production. Litton, who had more experience with transmitting tubes than his counterparts at Heintz and Kaufman, taught them the fundamentals of tube processing and manufacture. He also gave them production blueprints of tube-making machinery and detailed information on material suppliers. As Eitel, Heintz, and McCullough became more proficient in the tube art, the two groups frequently discussed the difficulties they were facing. "We learned from each other," Heintz later reminisced. "We went through the same agonies of decisions on how to do this and on how to do that. [Litton's] mind and mine were running pretty parallel."[24] The cooperation was so close that Federal Telegraph and Heintz and Kaufman jointly ordered their glass blanks from Corning.[25]

The development and manufacture of power-grid tubes was as much a legal endeavor as a technical one. To engineer transmitting tubes that would not infringe on RCA's patents, Litton, Eitel, and Heintz worked closely with their patent attorneys. "The patent department," recalled a former engineering manager at Federal Telegraph, "would point out that the elements of a proposed high-power tube would have to be designed to avoid infringing upon RCA's patents. The actual method we followed was to start with a group conference with two or three engineers and one or two men from the patent department. All present would discuss tube problems."[26] At these meetings, Litton would propose ways of circumventing RCA's patents, which the patent experts would then discuss. Based on their response, Litton would then work on the tube's detailed design. Eitel and Heintz proceeded in the same way at Heintz and Kaufman.[27]

These legal constraints guided the design of transmitting tubes. Litton, for example, devised a clever tube design that bypassed an important structure patent controlled by RCA. The patent covered a tube with a grid that "surrounded" the cathode. Taking advantage of the patent's phrasing, Litton devised a grid that, instead of encircling the filament, went 179° around it. Because of the grid's unusual shape, Litton decided to support both the grid and the plate from the side rather than at the end of the tube envelope. He also attached the filament to the tube's extremities. The resulting tube (nicknamed "the crying pig" for its odd shape) was less efficient than Bell's and General Electric's products. It was also much more difficult to make. But it did a reasonable job at the high frequencies, and it made possible the building of IT&T's short-wave radio communication system. Similarly, Eitel and Heintz made use of an old tube design that had fallen into the public domain—a design with a filament and two plates instead of the standard filament, grid, and plate. Experimenting with this old design, Heintz, Eitel, and McCullough engineered the gammatron, a rugged power tube that worked well at high frequencies.[28]

Because of the complexity of these designs, Litton and Eitel were forced to use new materials and develop new manufacturing techniques. They also had to circumvent manufacturing-process patents held by RCA. That corporation had a solid portfolio of patents on tube-manufacturing processes and evacuation techniques. For example, it had patents on the manufacture of special metal-to-glass seals intended to withstand high thermal stresses. RCA also controlled the use of getters. To circumvent these patents, Litton, Heintz, Eitel, and McCullough used new materials and developed novel techniques. To replace getters, Eitel and Heintz made tube plates of tantalum, a rare and exotic metal. When pre-heated at very high temperatures, tantalum acted as a getter and absorbed the gases released by the tube elements. Litton invented and patented a new technique for making shock-resistant seals. The use of tantalum and Litton's seals were important innovations. They made it possible to create a high vacuum in the tubes' envelopes. Because the quality of the vacuum was closely related to tube reliability, these new techniques allowed the fabrication of transmitting tubes more reliable than those distributed by RCA.[29]

Litton also made innovations in tooling. Relying on his mechanical and glass blowing expertise, he invented the glass lathe, an apparatus that mechanized tube-making operations such as assembly, glass blowing, and sealing. Litton developed this new machine to overcome the production and manpower difficulties he was encountering at Federal Telegraph. The tube he had designed to bypass RCA's patents was hard to make: because the grid and the plate were attached to the side of the glass envelope rather than to its extremities, the tube required complex glass work. Most glass blowers in the Bay Area did not have the advanced skills required. Furthermore, they were not amenable to strict industrial discipline. Glass blowers had the habits of pre-industrial craftsmen: they worked irregular hours and got drunk in the shop. As Litton and Eitel attempted to discipline them, some turned violent. In 1929 an irate and drunken glass blower at Heintz and Kaufman destroyed Heintz's new automobile and ransacked the shop.[30]

To rid himself of rebellious glass blowers and make complex tubes in large quantities, Litton invented the glass lathe, an ingenious machine that made it possible to simultaneously form a complex glass envelope and seal it to the tube's elements. A glass lathe's two heads rotated in synchronism and supported the glass blank as well as the tube's filament, grid, and plate. The machine operator would fabricate the tube envelope by applying a fire to the glass blank and blowing gas into it. At the same time he would join the metallic elements to the glass and seal them into the tube envelope. The glass lathe enabled the production of high-precision tubes. It was soon adopted at Heintz and Kaufman and later became one of the most important pieces of manufacturing equipment in the power-grid tube industry.[31]

In the process of designing and producing power tubes and tube-making machinery at Federal Telegraph, Eitel, Litton, and McCullough gained expertise in product engineering and vacuum tube manufacturing. They learned about the importance of process technology for the engineering of high-quality, high-precision transmitting tubes. They also

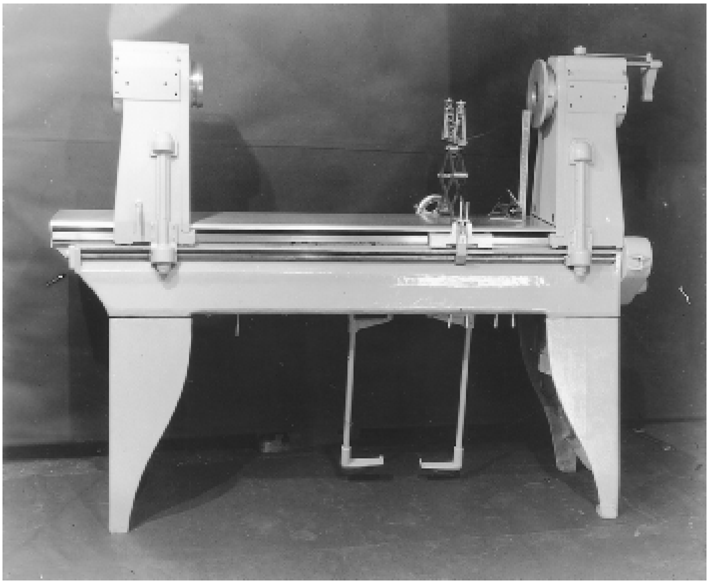

Figure 1.2
Litton's glassworking lathe, late 1930s. Courtesy of Bancroft Library, University of California, Berkeley.

gained intuitive knowledge of materials and a deep understanding of the functioning of power-grid tubes. For example, Eitel and McCullough gained the ability to visualize the complex interrelationships that governed the design of vacuum tubes. Litton became an expert in materials and manufacturing processes. One of Litton's associates later reported that at Federal Telegraph "Litton [gained] a fantastic feel for Mother Nature. He knew exactly what he could do with what Mother Nature gave him in the way of physical materials: the elements, tungsten, copper, glass, and so forth; just how far he could push Mother Nature to where she finally cried 'uncle' and gave up. He developed this at Federal Telegraph building the tubes, how to get a high vacuum."[32] This manufacturing expertise shaped much of their latter careers in electronics and informed their approach to the vacuum tube business. At Federal Telegraph and Heintz and Kaufman, Litton, Eitel, and McCullough also acquired solid management skills. They learned to direct engineering projects, to oversee the production of transmitting tubes, and to handle personnel relations. These supervisory skills, along with their technological competence and the development of new manufacturing processes, helped them greatly in their subsequent entrepreneurial activities.[33]

Building Power Tube and Tube Machinery Businesses

The Great Depression had a severe impact on Federal Telegraph and Heintz and Kaufman and their power tube-making operations. Bank credit was hard to get. Sales of manufactured goods plummeted. IT&T, the Dollar Steamship Company, and the small electronic corporations they controlled in San Mateo and Santa Clara counties were deeply affected by these economic conditions. In the early 1930s, IT&T ran into severe financial difficulties. In 1931, to reduce its operating costs, it consolidated its manufacturing operations on the East Coast. It forced Federal Telegraph, which it had recently acquired, to move its plant and technical staff to New Jersey at this time. Similarly, the Dollar Steamship Company, Heintz and Kaufman's parent company, experienced huge losses. To avoid bankruptcy, Dollar sharply cut its operating expenses. Dollar's management forced Heintz and Kaufman to fire 75 percent of its fifty-odd workers in September 1930. Four months later, Dollar dismissed the remaining employees. Only Heintz and Eitel were retained to do maintenance work on Dollar's radio system. In late 1931, Eitel was allowed to hire back McCullough and a few other employees to repair transmitting tubes. But their position remained precarious, as it was dependent on the evolution of the trans-Pacific trade and Dollar's shipping business.[34]

The dire economic conditions of the early 1930s compelled Litton, Eitel, and McCullough to start new businesses. When Federal Telegraph moved to New Jersey, Litton, who had no interest in living in the East, decided to stay in California. In 1932, with $6,000 in savings, he established a small proprietorship, Litton Engineering Laboratories. He also built a vacuum tube shop on his parents' property in Redwood City. Around the same time, Eitel and McCullough built a new commercial business at Heintz and Kaufman. Their primary incentive was to create new revenue streams and thereby safeguard their jobs. To generate these monies, they commercialized a new transmitting tube, which they had developed for their own use in amateur radio, under the Heintz and Kaufman brand name. Dissatisfied with the power-grid tubes that were then on the market, Eitel and McCullough set out to engineer a ham radio tube for their own use in early 1932. They wanted to make a power tube that would be more reliable than the one marketed by RCA. The RCA tube had the added disadvantages of operating poorly at the very high frequencies and working only at low voltages. These were serious limitations for ham radio use. At the time, radio amateurs applied high voltages to their tubes in order to get a high output. By doubling the voltage applied to the tube, they could increase the power of their radio frequency signal by a factor of 4.[35]

To make a better tube, Eitel and McCullough used the unique tools and processes they had developed for their first tube project at Heintz and Kaufman. They assembled and sealed the tube directly on a glass lathe. They also used tantalum for the grid and the plates. But Eitel and McCullough also appropriated the latest vacuum tube innovations developed on the East Coast. They used a new tube structure, developed at RCA, that enabled the electrons to better focus on the plate. They also took advantage of the development of new cathodes at General Electric. In the early 1930s, engineers at GE devised new filaments made of thoriated tungsten. Thoriated filaments emitted more electrons than conventional cathodes. They also could last a long time, and they were resistant to high voltages. As a result of these design and processing choices, Eitel's and McCullough's new power tube lasted longer and withstood higher voltages than RCA's products. Unlike its East Coast counterparts, it could also operate efficiently at high and very high frequencies. In other words, it was an excellent amateur radio tube, as Eitel and McCullough soon verified by using in their own radio transmitters.[36]

Eitel and McCullough thought this tube would sell well in the ham radio market. They also felt that the time was ripe for commercializing power-grid tubes. RCA, GE, Western Electric, and Westinghouse had lost some of their control of vacuum tube technology with the expiration of several of the most important tube patents in the early 1930s. And in 1930 the Department of Commerce filed an antitrust lawsuit charging RCA, GE, Western Electric, and Westinghouse with violations of the Sherman Antitrust Act. In its brief to the court, the government claimed that these corporations had conspired to restrain competition. According to the Department of Commerce, they had "continuously refused except on terms prescribed by them to grant licenses to any individuals, firms, or corporations for the purpose of enabling the latter to engage in radio communication, radio broadcasting, or interstate commerce in radio apparatus, independently or in competition with the defendants." After 18 months of negotiations, RCA and the other corporations accepted to sign a consent decree by which all the cross-licensing agreements were made non-exclusive. GE and Western Electric also divested themselves of all their RCA holdings. In addition, RCA became an independent company manufacturing its own power tubes and radio equipment. Though RCA, Westinghouse, GE, and Western Electric remained major players in the vacuum tube business, they had to use more restraint when dealing with their smaller competitors. They could not put them out of business as easily as before (Sobel 1986; Maclaurin 1949).

Taking advantage of this change in the legal environment, Eitel and McCullough convinced the Dollar Steamship Company to allow them to sell their tube on the open market under the Heintz and Kaufman name. They advertised their product in ham radio magazines and rapidly built a small tube business. But Eitel and McCullough soon met substantial resistance from Dollar when they sought to expand the scope of their tube activities and introduce more products to the market. Dollar had no interest in building a substantial component business, which lay outside of its core activities. It may also have been concerned about a possible lawsuit from RCA. Dollar's lack of interest in the ham radio tube business led Eitel and McCullough to consider starting their own tube operation. Their determination to form a new firm was reinforced by Dollar's decision to lay off some of their subordinates in the tube shop in 1934. At this time, the Dollar Steamship Company suffered from a general strike on the San Francisco waterfront. This strike and the financial crisis that it brought about led Dollar's managers to lay off 25 percent of Heintz and Kaufman's workforce in the spring of 1934. In spite of its profitability, the tube shop saw its manpower reduced by one-fourth. "McCullough and I," Eitel later reminisced, "figured out that if that was the way [Dollar] operated, there was not very much future there. We decided we were wasting our time trying to develop a complete line of tubes and market them."[37]

In September 1934, Eitel and McCullough left Heintz and Kaufman to set up their own transmitting tube corporation, Eitel-McCullough Inc., with the financial support of two small businessmen, Walter Preddey and Bradshaw Harrison. Harrison was a real-estate agent in San Bruno; Preddey operated a chain of movie theaters in San Francisco. According to the terms of the agreement, Harrison and Preddey invested $2,500 each in the partnership, and Eitel and McCullough brought their know-how to the table. The first profits were to be shared equally between the two investors until they had reached $2,500; Eitel and McCullough then would become equal partners. Preddey was the president, Eitel a vice-president.[38]

Establishing a power tube business in the midst of the Great Depression was risky if not foolhardy. The market for transmitting tubes shrank in the early 1930s. Furthermore, in spite of the partial breakup of the radio monopoly, RCA, GE, and Westinghouse thoroughly dominated the main markets for power tubes used in commercial broadcasting and long-distance radio communication. To survive in this inauspicious environment, Litton, Eitel, and McCullough focused on niche markets, which large East Coast firms did not fully control. To compete in these markets, Eitel, Litton, and McCullough emphasized quality, customer service, and technological innovation (especially through the development of new manufacturing processes). The entrepreneurs also introduced a series of products, which met the multifaceted needs of their customers. They adjusted flexibly to new business opportunities and exploited them aggressively. Following the practices they had started at Federal Telegraph and Heintz and Kaufman, Litton, Eitel, and McCullough also cooperated closely. Litton helped Eitel and McCullough set up their own vacuum tube shop by giving them the castings and engineering blueprints of his glass lathe. This gift enabled Eitel and McCullough to construct their own high-quality glass lathe at low cost. In the next few years, Litton, Eitel, and McCullough freely exchanged technical and commercial information in order to reduce the many risks, including the manufacturing risks, associated with the running of small tube-related businesses.[39]

Litton Engineering Laboratories had a difficult start and nearly collapsed in the early 1930s. "Litton," an employee recalled, "was struggling very desperately. That was at the depth of the Depression. He struggled, making various tubes, doing a little bit of research work and development work, and so forth, some for RCA and some for Federal Telegraph. He had to scrounge around and look for business."[40] Litton's situation started to improve in 1935. At this time, he discovered that there was a demand among East Coast tube manufacturers for the glassworking apparatus he had invented at Federal Telegraph. Federal Telegraph, for instance, asked him to produce precision glassworking equipment for its New Jersey plant. Similarly, RCA and Westinghouse ordered glass lathes from Litton Engineering. As a result, Litton re-oriented his small shop toward the design and production of glass lathes and other pieces of machinery used in tube manufacturing.[41]

To meet the demand for precision glassworking equipment, Litton designed four different types of glass lathes in close consultation with East Coast manufacturing concerns. Each lathe was developed to make transmitting tubes of a specific size. Litton also developed a machine that could seal irregularly shaped tubes. A manager at Litton Engineering later reported that "each year, as new tubes were developed, changes in the design of the glass working lathes were made by Litton Engineering

Laboratories. New type glass working lathes were designed and manufactured and consultations with leading tube manufacturers were held to obtain their reactions to proposed design changes."[42] To meet the requirements of its customers, Litton produced high-quality glass lathes. These machines were carefully designed and produced with the utmost precision. To enable the fabrication of advanced tubes, the lathes had tolerances on the order of 0.001 inch—very unusual in machine-shop practice at the time. These machines were also characterized by their near-perfect alignments.[43]

Litton later diversified into the manufacture of vacuum pumps. In 1938, he designed and constructed a new pump, which used low-vapor-pressure oil as its evacuating medium. Until then, most vacuum pumps relied on mercury. Mercury pumps required, among other disadvantages, that the mercury vapor traps be cooled by liquid air. This made them bulky and ineffective. Unlike its mercury-based counterparts, Litton's vapor oil pump was compact. It also operated at higher speed and made possible the attainment of higher vacuum. Because low-vapor-pressure oils were not available on the market, Litton invented a new distillation apparatus and produced his own pumping oil out of a commercial brand of motor oil. Exploiting these inventions, Litton built a small manufacturing equipment business. By the late 1930s, Litton Engineering devoted 90 percent of its activity to equipment manufacture. The other 10 percent was devoted to tube development and consulting, notably for Federal Telegraph. By 1939, Litton Engineering had $25,000 in sales and employed five machinists.[44]

While Litton concentrated on the design and production of glass lathes and vacuum pumps, Eitel and McCullough oriented their new business toward the production of transmitting tubes. Their objective was to manufacture high-quality tubes for radio amateurs. Eitel and McCullough viewed product reliability and performance as key to survival in the ham radio business—for a number of reasons. Eitel-McCullough had to compete with the tube they had developed themselves at Heintz and Kaufman. After Eitel's and McCullough's departure, the managers of the Dollar Steamship Company actively commercialized the tube the pair had recently designed for radio amateurs. Eitel and McCullough also faced direct competition in the radio-amateur market from RCA, from GE, from Raytheon, and from Taylor Tubes (a new Chicago-based venture). In addition to their brand names, financial resources, and intellectual property rights, these firms had a definite cost advantage over Eitel-McCullough: they were located close to their markets and material suppliers and, as a result, had lower shipping costs. "We had real handicaps to overcome in building [a company on the San Francisco Peninsula]," Eitel later reflected. "We had to ship our goods further, to the big centers of use; there we had to pay disproportionately high costs for many of the commodities we used for production. We had to learn to offer something better to the world."[45]

In addition to these competitive pressures, Eitel and McCullough had a further incentive to produce high-quality products. Radio amateurs were the most demanding users of power tubes in the mid 1930s. They applied very high voltages to their components to increase the power output of their transmitters. Radio amateurs also required tubes, which operated efficiently in the short-wave portion of the radio spectrum. In 1936, 82 percent of all radio amateurs in the United States used high frequencies. Another 10 percent were active in the very-high-frequency (VHF) band.[46]

To compete with RCA and Heintz and Kaufman and to meet the reliability and performance requirements of radio amateurs, Eitel and McCullough concentrated their efforts on improving manufacturing. They perfected the processing techniques they had developed at Heintz and Kaufman and devised new ones. In particular, they developed a novel sealing and assembly technique, which relied heavily on the use of Litton's glass lathe. The new assembly procedure worked as follows: using their glass lathe, Eitel and McCullough first sealed the plate to the top of the glass envelope. They would then hold the filament and grid on one head of the glass lathe while attaching the glass envelope and plate assembly to the other. The grid was aligned with the plate by carefully melting the glass stem to which the filament and grid were attached. In the final step of the process the two heads were joined together, which allowed the insertion of the grid at the center of the plate. This was an important technique and one of Eitel-McCullough's most closely guarded secrets. This technique enabled the close spacing of the tube elements. Because the spacing of the cathode, grid, and plate was closely related to tube performance, this process made possible the fabrication of VHF transmitting tubes. The close alignment of the tube elements also enabled radio amateurs to operate the tube at high voltages.[47]

Paralleling this new assembly technique, Eitel and McCullough designed a highly efficient system to evacuate transmitting tubes. Their system enabled them to outgas the power tubes thoroughly and thereby create a very high vacuum. At Heintz and Kaufman, Eitel and McCullough had removed the occluded gases in the tube's metallic parts by shooting electrons at the grid and the plate. Electrons emitted by the filament would heat a tube's elements to remove the occluded gases (gases that were contained in the tube's metallic parts before its operation). This technique, however, did not drive all the gases out of the grid. The grid would receive fewer electrons than the plate and, as a result, would be heated to lower temperatures. To attain identical temperatures for both the plate and the grid, Eitel and McCullough devised a new technique. They heated the grid and the plate separately. They then alternately bombarded the grid and the plate with electrons, thereby effecting the independent but concurrent heating of the plate and the grid. As a result, both elements were maintained at very high temperatures, and all occluded gases were eliminated from the tube. This new technique, soon patented by Eitel and McCullough, was a major process innovation. It decreased the time and cost of manufacture. The new procedure also made it possible to evacuate tubes thoroughly for greater reliability.[48]

These new manufacturing techniques enabled Eitel and McCullough to design a series of high-quality power triodes (tubes with three electrodes) for radio amateurs. They first produced the 150T, an improved version of the amateur-market tube they had developed at Heintz and Kaufman.[49] They also developed both a small and a large version of this tube to fill differing needs of radio amateurs. Because of their unique processing, Eitel-McCullough's tubes were substantially more reliable and had better electrical characteristics than products then on the market (including the radio tube they had designed at Heintz and Kaufman). Eitel-McCullough's tubes operated efficiently at the high frequencies. They could resist tremendous overloads and were characterized by long lifetimes. The average life of a power tube was then between 600 and 1,000 hours. Eitel-McCullough's tubes could last as long as 20,000 hours. In 1936 the firm introduced more powerful tubes for airline radio transmission. Eitel and McCullough distributed their tubes through manufacturing representatives and ham radio shops. They also actively advertised their products in *QST*, the journal of the Amateur Radio Relay League, and in *Radio*.[50]

Eitel-McCullough's tubes soon gained wide acceptance among radio amateurs and small manufacturers of aircraft radio equipment. By 1937, the firm's sales reached $100,000, half to airlines and half to radio amateurs. It was also highly profitable, which enabled Eitel and McCullough to finally become full partners. To meet the growing demand for their products, Eitel and McCullough gradually enlarged their workforce.

Figure 1.3
An advertisement featuring Eitel-McCullough's first tube, the 150T (1936). Courtesy of Varian, Inc.

The two entrepreneurs had started the firm with just one mechanic in 1934. Three years later, they had 15 employees. To fill the new positions, Eitel and McCullough relied almost exclusively on the electronics hobbyists they had met at radio clubs on the San Francisco Peninsula. Radio amateurs had the skills Eitel and McCullough needed: familiarity with transmitting tubes and expertise in the design of radio systems. Furthermore, they had an intimate knowledge of Eitel-McCullough's ham radio market. As their new hires had no prior knowledge of vacuum tube practice, Eitel and McCullough trained them on the job in glass blowing, assembly, evacuation, and sealing. As a result of the founders' employment and training practices, Eitel-McCullough was an unusual firm. Most of the employees were in their early twenties. The culture of amateur radio was influential. Technical resourcefulness and innovation were valued highly. Other important characteristics were camaraderie, competitiveness, and a democratic ideology.[51]

Wartime Expansion

In the late 1930s, because of growing threats to international peace from Japan and Germany, President Franklin D. Roosevelt and his administration rebuilt American military and naval power, expanding the Army and the Navy and procuring new airplanes, cruisers, and aircraft carriers. A significant aspect of this rearmament effort was the development and deployment of an entirely new electronic system: radio detection and ranging (radar). This new system came out of secret research programs in short-wave radio at the Naval Research Laboratory (NRL) and the Signal Corps Engineering Laboratories (SCEL) at Fort Monmouth, New Jersey. In the late 1920s, radio engineers at these military laboratories discovered that ships and airplanes reflected high-frequency radio signals. This finding had great military potential: it promised the detection and location of enemy ships and airplanes at great distances. Building on their strength in short-wave radio, engineering groups at these laboratories developed experimental radar systems in the mid 1930s. These systems used VHF radio pulses to detect approaching airplanes. Though these radar sets helped identify incoming aircraft, they could only do so at close range (Van Keuren 1994; Allison 1981; Gebhard 1979; Page 1988; Zahl 1972).[52]

To extend the reach of their radar systems to 100 miles or more, the engineering groups at NRL and SCEL needed transmitting tubes that could function at high voltages. The transmitting tubes for radar had to operate with momentary voltages many thousands of volts higher than the normal voltage applied to radio communication tubes. The radar tubes also had to work efficiently at very high frequencies. None of the tubes manufactured by RCA, Westinghouse, Western Electric, or Raytheon met these requirements. Only the new Eitel-McCullough tube, which the firm introduced to the amateur market in 1937, had the desired performance and reliability characteristics. Engineers at NRL and SCEL, who knew about the tube through their ham radio activities, procured it from electronics parts dealers on the East Coast and soon incorporated it into their experimental radar systems (Van Keuren 1994; Allison 1981; Gebhard 1979; Page 1988; Zahl 1972).

In December 1937, NRL and SCEL engineers asked Eitel-McCullough to adapt its tubes to the specific requirements of their radar systems. They wanted Eitel and McCullough to make modifications to their transmitting tubes so that these tubes would better fit the electrical characteristics of their radar circuits. To better understand the radar systems, Eitel and McCullough visited the military laboratories and conferred about their requirements. Out of these discussions came two different versions of Eitel-McCullough's amateur tube. Because the SCEL engineers wanted tubes with short leads, Eitel and McCullough changed the tube's shape and lead arrangement. The new tube had a rectangular envelope. Its leads came from each side of the glass envelope rather than from its extremities. Eitel and McCullough also developed another version of the same tube for the Navy.[53]

When hostilities began in Europe, the Army and the Navy decided to bring their prototype radar systems to production and opened bidding for manufacture of the radar systems that had been developed at NRL and at SCEL. The military services selected RCA and Western Electric to do the job. The award of these production contracts to RCA and Western Electric created both an opportunity and a challenge for Eitel-McCullough. It opened a large potential market for the firm's radar tubes. But Eitel-McCullough would have to convince RCA and Western Electric to use its tubes in their radar systems. RCA and Western Electric, which produced their own power-grid tubes, had no interest in buying transmitting tubes from Eitel-McCullough. They wanted to use their own tubes in their radar transmitters. Only the steadfast support of radar engineers at NRL and SCEL helped Eitel and McCullough secure large subcontracts from RCA and Western Electric in the summer of 1940. The tube orders they received from RCA and Western Electric were significant indeed for a firm as small as Eitel-McCullough. Western Electric, for example, ordered 10,000 tubes for $500,000—five times the company's annual sales in 1939.[54]

These large orders created considerable dissension between Eitel and McCullough and their financial backers. Walter Preddey, who had helped finance the firm's formation and who was its president, opposed its going into high-quantity production for the military services. He worried that these large military contracts would make the firm too dependent on a few customers. He also thought the firm was not ready to execute such large contracts. On the other hand, Eitel, McCullough, and the other investor, Bradshaw Harrison, were eager to transform Eitel-McCullough into a larger operation. They forced Preddey to resign from the presidency of Eitel-McCullough in December 1939. Eitel replaced him as president, and McCullough became the firm's vice-president. In May 1941, Preddey sold his shares to Eitel and McCullough for $57,500. Eitel and McCullough were now in full control of their business.[55]

In 1940 and the first half of 1941, to meet RCA's and Western Electric's large orders for radar tubes, Eitel and McCullough converted their firm to volume production. With financing from the Bank of America, they constructed a new plant in San Bruno. Eitel and McCullough also greatly expanded their workforce, from 17 employees in July 1940 to 125 in May 1941 and to 170 in July 1941. The entrepreneurs hired local radio amateurs and machinists. (There were many precision machinists in the Bay Area, many of Swiss or German origin.) As Eitel and McCullough soon exhausted the supply of radio amateurs on the Peninsula, they increasingly hired women for delicate assembly operations such as the making of grids, plates, and filaments. To train and manage the fast-growing workforce, Eitel and McCullough relied heavily on the crew of radio amateurs they had assembled in the 1930s. These men instructed the new hires in the complex techniques of power tube production. They also built large departments around specific manufacturing processes such as pumping, glass working, and assembly.[56]

In 1939 and 1940, labor unions based in San Francisco sought to organize the plant. The Bay Area was the largest and most active center of trade unionism in the western United States. Its labor unions were particularly powerful and militant. They were also eager to extend their sway to the electronics industry on the Peninsula. Unwilling to relinquish control of the shop floor to union organizers, Eitel and McCullough fought vigorously against the unions. To thwart these organization efforts, they adopted managerial techniques that had been developed in the 1930s at Eastman Kodak, at Sears, Roebuck, at Thomson Products, and at other large corporations. These techniques were corporatist in nature. They sought to define the world of work not in terms of a sharp divide between employer and employee, but in terms of cooperation and mutual obligations between managers and workers in the same firm. To do so, these corporations gave pensions and job security to their employees. They also established profit-sharing programs, whereby a portion of the company's profits would be distributed to its employees. Inspired by these corporatist programs, Eitel and McCullough set up a medical unit, and a cafeteria that offered subsidized meals. In December 1939 they instituted a profit-sharing program that transferred one-third of each year's profits to the employees. These policies enabled Eitel and McCullough to keep the labor unions out of the plant in the 1940s.[57]

In conjunction with the hiring of a much larger workforce and the development of new personnel practices, Eitel and McCullough reengineered their radar tubes and their manufacturing processes. Producing radar tubes in quantity, as Eitel and McCullough soon discovered, was particularly difficult. The tubes regularly failed after 50 hours of operation. The high peak powers required by radar systems heated up the tube elements to unprecedented temperatures. As a result, the thorium in the filaments would evaporate and deposit itself on the grids. In turn, the grids would emit electrons, which led to uncontrolled current flows to the plates. To solve this problem, Eitel and McCullough made the grids out of platinum, a material known as a poor emitter of electrons. The use of platinum eliminated electron emission, but the new grids lacked rigidity. They would short the filaments and thereby ruin the tubes. Eitel and McCullough also discovered that their seals would fail at high temperatures. Finally, when the firm started to make thoriated tungsten filaments in large quantities, it had difficulty in maintaining uniformity in the process and in producing filaments with comparable electrical characteristics.[58]

To tackle these difficulties, Eitel and McCullough expanded the firm's research laboratory, which they had established in 1938 to develop new products. They also hired some chemistry graduates from the University of California, and some inventive radio amateurs. These men concentrated their efforts on the reliability problems of radar tubes. To develop non-emitting grids, the laboratory's chemists developed a new grid-making process. They coated molybdenum wires with carbon, platinum, and zirconium, and later they sintered these elements into the wires in a high-temperature furnace. Grids fabricated with this process were mechanically strong and emitted fewer electrons than the standard grids.

Eitel-McCullough chemists also perfected the filament-making process and worked out a series of procedures that could be followed by inexperienced operators. Finally, these men developed a new material, Pyrovac, to replace tantalum in the tubes' plates. Pyrovac, which was made out of zirconium and carbon, absorbed gases much better than tantalum and, as a result, made possible the fabrication of tubes with much longer lives. These important process innovations were carefully patented. The new manufacturing processes enabled the firm to produce reliable radar tubes in quantity and to obtain good manufacturing yields. (The yield is the proportion of good products coming out of the manufacturing line.) In turn, these tubes enabled the Army and the Navy to deploy a significant number of radar systems in late 1940 and the first half of 1941.[59]

The rapid expansion of Eitel-McCullough and the growing military demand for transmitting tubes encouraged others to enter the power-grid tube business. In May 1941, Charles Litton, Philip Scofield, and Ralph Shermund established a new power tube corporation, Industrial and Commercial Electronics (ICE). At Stanford, Litton had befriended Scofield and Shermund through their common interest in amateur radio. In the second half of the 1930s, Shermund, who had graduated from Stanford with a bachelor's degree in bacteriology, had gained substantial experience in tube manufacturing. Because of a recommendation from Litton, Shermund found a job at Raytheon, a Massachusetts-based tube maker. He later directed Heintz and Kaufman's tube shop after Eitel's and McCullough's departure in 1934. After several years at Heintz and Kaufman, Shermund, like his predecessors, ran into difficulties with Dollar's management. He sought to convince Dollar to spin out the tube shop and sell it to him—to no avail. Seeing the great commercial potential of power-grid tubes, Shermund decided to leave Heintz and Kaufman and start a company of his own. Litton soon joined the project. He was keenly interested in the power-grid tube business, but he knew that he could not produce power-grid tubes in his own shop and under his own name. Litton Engineering supplied glass lathes and other pieces of manufacturing equipment to most makers of transmitting tubes. Producing power tubes under the Litton label would make him compete directly with his own customers and would soon lead to the downfall of his equipment business. Investing in ICE and assisting Shermund discreetly on the manufacturing side of the business would permit Litton to participate in the financial rewards of tube manufacture without losing his own glass lathe business. Litton, Shermund, and Scofield each owned a third of the new corporation.[60]

In the summer of 1941, Shermund and Litton incorporated the new organization and built a tube-making shop (all the manufacturing equipment came from Litton Engineering). They also set up a profit-sharing program for their employees—mostly as a way to avoid labor unrest. (Litton Engineering Laboratories also had a profit-sharing plan, which gave half of the profits to the employees.) Thanks to Litton's reputation and his wide contacts in the US electronics industry, he and Shermund soon received contracts from Bendix and the Navy for the manufacture of vacuum relays and power-grid tubes. Litton worked at ICE two days a week, supervising tube production and working on manufacturing processes. He and Shermund had a business running by the end of the year.[61]

The attack on Pearl Harbor led to expansion of the transmitting tube companies on the San Francisco Peninsula. The Army and the Navy procured and deployed tens of thousands of high-frequency radar systems during the first years of the war. They also built a worldwide network of radio communication stations. These systems required millions of transmitting tubes every year. Eitel-McCullough, ICE, and Heintz and Kaufman, with their competence in the manufacture of reliable tubes, benefited from the enormous growth in the military demand for transmitting tubes. They were inundated by tube orders from the Navy and the Army, and also from prime military contractors such as RCA, Bendix, GE, Hallicrafters, and Wilcox Electric. For example, ICE received a large number of production orders for power-grid tubes from the Navy and the Army. These tubes had often been designed elsewhere, including at Eitel-McCullough. Because Litton became the manager of Federal Telegraph's vacuum tube division in November 1942, it was Shermund who ran ICE during much of the war.[62] Under Shermund's direction, ICE expanded rapidly. Its sales grew from $51,142 in 1942 to $1,333,693 in 1944. By that time, ICE had several hundred employees. It was also enormously profitable. With sales of $817,000 in 1943, ICE had a net profit of $305,693. Similarly, in spite of recurrent managerial infighting, Heintz and Kaufman expanded substantially during the war. By January 1943, Heintz and Kaufman had 300 employees.[63]

But it was Eitel-McCullough that benefited the most from the exploding demand for transmitting tubes during the war. After Pearl Harbor, Eitel-McCullough received very large orders for its transmitting tubes. The firm also secured second-source production contracts for components designed by General Electric and other East Coast manufacturers (including receiving tubes that could operate at very high frequencies). These huge orders led Eitel and McCullough to expand their workforce by a factor of 20 between Pearl Harbor and mid 1943. By the summer of 1943 they employed 3,600 operators and technicians. Extensive training programs for supervisors, foremen, and operators were needed. In conjunction with the rapid growth of its workforce, Eitel-McCullough hastily expanded its plant in San Bruno. It also opened a new factory in Salt Lake City. The primary impetus for the building of this new plant came from the military services. The services were concerned about Eitel-McCullough's proximity to the Pacific Coast, which made it vulnerable to a Japanese attack. In the spring of 1942, Eitel and McCullough chose the site of the new factory. The plant was operational by August 1942. The Salt Lake City plant was financed by the Defense Plant Corporation (a federal agency recently established to fund the construction of manufacturing plants for the war effort) and was owned by the federal government.[64]

To handle mass production of power-grid tubes, Eitel, McCullough, and their associates thoroughly transformed their manufacturing methods. In particular, they reinforced the production-control function. They set up a traffic department to schedule and expedite the flow of materials, tube elements, and semi-assembled tubes throughout the plant. In an effort to better control manufacturing, Eitel-McCullough's management also split up large production departments into smaller ones. For example, in 1943 the assembly department was divided into three divisions: punch press, grid making, and plate assembly.[65]

Eitel and McCullough also mechanized the manufacture of power-grid tubes. Until that time, transmitting tube manufacture had been, to a large degree, a craft-based activity requiring highly skilled workers. To mechanize the production of power tubes, Eitel and McCullough hired mechanical engineers with solid experience in machine-tool design. Many had worked in local shops producing machine tools for canneries and other Bay Area industrial establishments. Among the production bottlenecks they mechanized were the exhaust process and the fabrication of grids. The latter was a very labor-intensive operation. Each grid had to be delicately wound and spot welded. Because the production of a single grid required tens of operations, Eitel-McCullough's grid department could not meet the demand for its products. At the peak of production, the firm used more than 250,000 grids per month. The mechanical engineers developed a machine that could automatically produce grids of remarkable uniformity in huge quantities.[66]

Eitel, McCullough, and the head of the pump department designed an ingenious machine to evacuate and de-gas transmitting tubes. "We used stand pumps," Eitel later recalled, "when our volume was small. [The pumps] were arranged in rows and one operator could man four sections, which at most meant sixteen tubes. This was a bottleneck because skilled operators were required to constantly monitor and adjust the current to the tubes. There was no way we could have attained the volume necessary to meet our commitments with that system."[67] To solve this problem, Eitel-McCullough's founders invented a rotary exhaust machine. This machine was made of sixteen exhaust setups attached to a rotary wheel. Each setup had five vacuum pumps. The rotary machine could evacuate 768 tubes in 24 hours and could be tended by a relatively unskilled worker. Because the exhaust schedules were pre-programmed, the operator's only task was to seal the tubes on the exhaust setup and seal them off when the wheel had made its revolution.[68]

As a result of these and other innovations, Eitel, McCullough, and their associates were able to raise production rates from a few thousand tubes per month in mid 1941 to 150,000 tubes per month in 1943. At the peak of production, in late 1943, Eitel-McCullough had sales revenues of about $2 million a month. By the end of World War II, Eitel-McCullough, having manufactured more than 3 million transmitting tubes for military applications, was one of the largest US manufacturers of vacuum tubes and by far the largest electronics firm on the San Francisco Peninsula.[69]

Because of large orders from Eitel-McCullough and other transmitting tube firms, Litton Engineering grew substantially—from a few machinists in 1939 to 85 employees in 1944.[70] In early 1942, to meet the growing demand for its lathes, Litton built a new plant in Redwood City and tooled up for larger-scale production. Litton also transformed the organization of production. Whereas lathes had been built one at a time in the 1930s, the firm produced batches of standard machines during the war. As a result, its output increased substantially. Before 1940, Litton Engineering fabricated fewer than 10 glass lathes a year; in 1943, it produced 222. These lathes were allocated by the War Production Board to Eitel-McCullough, ICE, RCA, Westinghouse, Raytheon, Heintz and Kaufman, Western Electric, GE, Sperry Gyroscope, and Federal Telegraph. By making possible a dramatic surge in the production of power tubes, they played an important part in the war effort.[71]

Postwar Crisis and Renewal

After the enormous boom brought about by the war, the Peninsula firms experienced a difficult transition to peacetime production. In the immediate postwar period, Litton Engineering saw its orders for tube machinery decline. But the power-grid tube firms were even harder hit than Litton Engineering. Starting in March 1944, the Signal Corps, which had large inventories of power-grid tubes, canceled many of the production contracts it had placed with Eitel-McCullough, ICE, and Heintz and Kaufman. As a direct result of these contract cancellations, Eitel and McCullough laid off 1,100 workers and closed their Salt Lake City plant. With the capitulation of Japan, the military services canceled most of their remaining contracts with tube manufacturers. As a result, vacuum tube corporations drastically reduced their workforce. By December 1945, Eitel-McCullough had only 390 employees, a far cry from the 3,600 it had had in mid 1943. ICE and Heintz and Kaufman also slashed their workforces.

But the worst was still to come. Starting in late 1945, the military dumped its enormous inventories of surplus vacuum tubes on the market. Radio amateurs and manufacturers of electronics equipment could now buy advanced vacuum tubes for roughly 10 percent of their original price. As a result, Eitel-McCullough, ICE, and Heintz and Kaufman saw their tube sales decline to almost nothing in late 1945 and 1946. The military essentially killed the market. ICE and Heintz and Kaufman never recovered. ICE, also weakened by fights between Shermund and Litton over stock ownership, went bankrupt in 1949. After years of anemic sales, Heintz and Kaufman closed down in 1953.[72]

Eitel-McCullough survived and prospered by developing a new line of power-grid tube products. These new tubes made the components produced during the war obsolete. For example, Eitel and McCullough introduced new triodes to the market in late 1945 and 1946. They also commercialized a family of power tetrodes that could operate at very high frequencies. A tetrode (a tube with four electrodes) had the usual plate, cathode, and control grid. In addition, it had a screen grid, which helped screen or isolate the control grid from the plate. With this additional grid, a tetrode had lower capacitance than a triode. The screen grid also had an electron-accelerating effect and increased the gain dramatically. In other words, tetrodes amplified signals better than triodes. Eitel-McCullough engineers had designed their first four-electrode tube in 1941. But after Pearl Harbor, they had shelved this design for the duration of the war. When it became imperative to introduce new products to the market, Eitel-McCullough engineers resurrected this tube design. In 1945 and 1946, these men also engineered more powerful tetrodes.[73]

The more powerful tetrodes found a ready market. FM (frequency modulation) radio broadcasting had been developed in the 1930s by Edwin Armstrong, an independent inventor. In spite of its advantages over AM (less static, less station interference, more faithful reproduction of a wide range of tones), FM radio had little commercial success in the late 1930s. The war years, however, brought a surge of interest. Numerous business groups applied to the Federal Communications Commission for licenses to set up FM radio broadcasting stations after the war. In the last years of the war, the growing demand for FM equipment led many electronics firms to develop FM radio transmitters and the vacuum tubes they required. But in June 1945, in a surprise decision, the FCC decided to change the frequency band it had allocated for FM radio from 42–50 megacycles to 88–108 megacycles. It was widely suspected at the time that the FCC made this decision at the request of AM radio stations and the Radio Corporation of America, which wanted to thwart or at least slow down the adoption of FM radio. The FCC decision had the immediate effect of making the FM transmitters that had been developed during the war obsolete. Electronics firms had to design new FM transmitters capable of operating at very high frequencies. They also needed new power-grid tubes for them.[74]

The decision of the FCC had the unanticipated consequence of creating a large market for Eitel-McCullough's new line of power tetrodes. Eitel-McCullough's products were among the rare vacuum tubes on the market that had the frequency and power characteristics needed for the new FM radio transmitters. Eitel-McCullough also benefited from the reputation it had acquired during the war among many electronic system designers for making high-quality products. As a result, many system firms chose to design their FM radio transmitters around Eitel-McCullough's tetrodes. When these corporations moved their new transmitter designs to volume production (in 1946 and 1947), Eitel and McCullough received large orders for their power-grid tubes. Not surprisingly, the commercial success of Eitel-McCullough's tetrodes encouraged RCA, GE, and other companies to produce similar tubes. To protect their sales, Eitel and McCullough sued these corporations for patent infringement. Because of the strong patent position Eitel-McCullough had acquired during the war, Eitel and McCullough won the patent lawsuits and forced RCA and GE to halt the production of tetrodes. Exploiting their victory for commercial advantage, the entrepreneurs let RCA and GE buy their products and resell them under their own brand names. RCA and GE had become Eitel-McCullough's de facto distributors. These commercial and legal victories made Eitel-McCullough the largest American manufacturer of transmitting tubes. In 1947, with sales of about $1.5 million, it controlled more than 40 percent of the US market for power-grid tubes.[75]

Conclusion

Reflecting on Eitel-McCullough's rise to prominence in the 1930s and the 1940s, Jack McCullough attributed its success to its ability to meet the component needs of new electronics systems: "We were the ones that were able to supply the missing link. For instance, we made the first tubes used in radar and in FM radio." Eitel-McCullough's ability to supply reliable high-performance power-grid tubes for radar sets and other advanced systems (including FM radio transmitters) was predicated on its unique assemblage of competencies. Because of their training in amateur radio, Eitel, McCullough, and their employees had solid expertise in electronic circuit and system design. They also acquired competence in high-vacuum processing and electron tube manufacturing. Eitel and McCullough developed some of these processing methods at Heintz and Kaufman in order to bypass RCA's patents. They then improved upon them to meet the requirements of radio amateurs, and later to meet the requirements of the radar-development groups at the Naval Research Laboratory and at the Signal Corps Engineering Laboratories. They also made innovative use of Litton's advanced tube-making equipment.

Eitel-McCullough's manufacturing processes had no counterparts on the East Coast. East Coast engineers who had visited Eitel-McCullough's San Bruno factory during the war had been struck by the unusual production methods. "Engineers from Westinghouse," Eitel later recalled, "came to our plant to familiarize themselves with our production methods. After they had gone through our plant and saw how we made our tubes, we met with them to see if they had any questions on our methods. One engineer spoke up and commented that we could not make tubes the way we were making them! Everything he saw in our plant was foreign to him and he was unable to comprehend our approach to tube making."[76] With its innovations in tube manufacturing, its system expertise, and its leadership in processes and in products, Eitel-McCullough rose to prominence in the power tube industry and outcompeted GE and RCA.[77]

Eitel and McCullough, in collaboration with Litton, not only built a strong power tube industry on the Peninsula but also drove much of the area's subsequent growth in the engineering and manufacturing of electronic components. In the late 1930s and the first half of the 1940s, Litton helped make Stanford University an important player in vacuum tube technology. In the mid 1930s, Frederick Terman, a young and ambitious professor of radio engineering in Stanford's electrical engineering department, became interested in setting up a teaching and research program in vacuum tube engineering. Terman knew Litton well through amateur radio and had become acquainted with Eitel and McCullough by consulting at Heintz and Kaufman in the late 1920s. Terman closely followed Litton's, Eitel's, and McCullough's work and their development of new power tube designs and high-vacuum processing techniques. Terman reasoned that their presence on the Peninsula offered a wonderful opportunity to build a program in vacuum tube engineering at Stanford. The acquisition of tube-making techniques from local firms would enable him to establish a research program on electron tubes and transform vacuum tube electronics into an academic discipline. His goals were to create new courses, to write new textbooks, and to establish a well-equipped research and teaching laboratory.[78]

Terman enticed Litton to join Stanford's teaching staff. In 1936 he appointed Litton a lecturer in the electrical engineering department. In the late 1930s and the early 1940s, and again after World War II, Litton lectured regularly on vacuum tubes and their processing techniques to electrical engineering students. He also shared his knowledge of vacuum tube making with faculty members at Stanford. For example, Litton trained Karl Spangenberg, a young instructor whom Terman had recently hired, in the fabrication of vacuum tubes. He also helped Spangenberg establish a vacuum tube laboratory on campus. This new laboratory and his knowledge of vacuum tube production techniques enabled Spangenberg to initiate and conduct research projects on electronic phenomena and vacuum tube design in the late 1930s and the early 1940s. These projects were funded by IT&T and by Sperry Gyroscope, a military contractor based on the East Coast.[79]

Litton also supported the tube program in the electrical engineering department by giving a $1,000 grant to Terman in 1938.[80] With this grant, Terman brought one of his favorite students, David Packard, back to the university for further studies. During his year at Stanford, Packard worked with Litton on vacuum tubes and established a close friendship with him. With another Stanford student, William Hewlett, Packard also established Hewlett-Packard, an electronic instrumentation company, at this time. Litton was their business mentor. In parallel with his collaboration with Terman and his group of electrical engineers, Litton helped another research group in the physics department develop the klystron, a revolutionary vacuum tube that could operate at extremely high frequencies. These innovative research projects and the writing of highly respected textbooks on vacuum tubes enabled Stanford University to rise to prominence in vacuum tube electronics after World War II.[81]

In addition to sharing their production expertise with Stanford University, Litton, Eitel, and McCullough also applied their unique tube-making skills to the development and manufacture of an entirely new class of vacuum tubes. Vacuum tubes capable of generating microwaves were even more difficult to make than power-grid tubes. They required a higher vacuum, tighter tolerances, more complex processing procedures, and a much higher level of cleanliness than the transmitting tubes for radio transmitters and high-frequency radar sets that Litton, Eitel, and McCullough had fabricated in the 1930s and during World War II. Litton, Eitel, and McCullough pioneered the microwave tube industry on the San Francisco Peninsula. In the late 1930s and the early 1940s, Litton diversified into the development of klystrons for IT&T. He later established Litton Industries, which specialized in the manufacture of magnetrons (another type of microwave tube used primarily in radar transmitters). Similarly, Eitel and McCullough conducted a few magnetron-development projects during World II. In 1951, they branched out into the production of microwave devices. They applied their firm's manufacturing competence to the production of klystrons for long-distance communication and television broadcasting. By the late 1950s, Eitel-McCullough and Litton Industries were among the largest manufacturers of microwave tubes in the United States.[82]

Litton, Eitel, and McCullough created an infrastructure and a predisposition for electronic component manufacturing on the San Francisco Peninsula. They attracted suppliers of specialized inputs, and they trained a workforce skilled in vacuum techniques and chemical handling. They also helped develop a culture of collaboration in the region. In the postwar period, this infrastructure and this modus operandi facilitated the formation of other corporations in San Mateo and Santa Clara Counties. Litton, Eitel, and McCullough also showed that it was possible to build successful electronic component businesses in the area. Local firms, in order to establish themselves in industries pioneered by large East Coast firms, had to concentrate on the development and constant improvement of manufacturing processes. They also had to commercialize high-quality products. These lessons were not lost on other innovator-entrepreneurs in the area. In the late 1940s and the 1950s, product quality and a commitment to manufacturing processes became the hallmarks of the San Francisco Peninsula's electronic component industries.