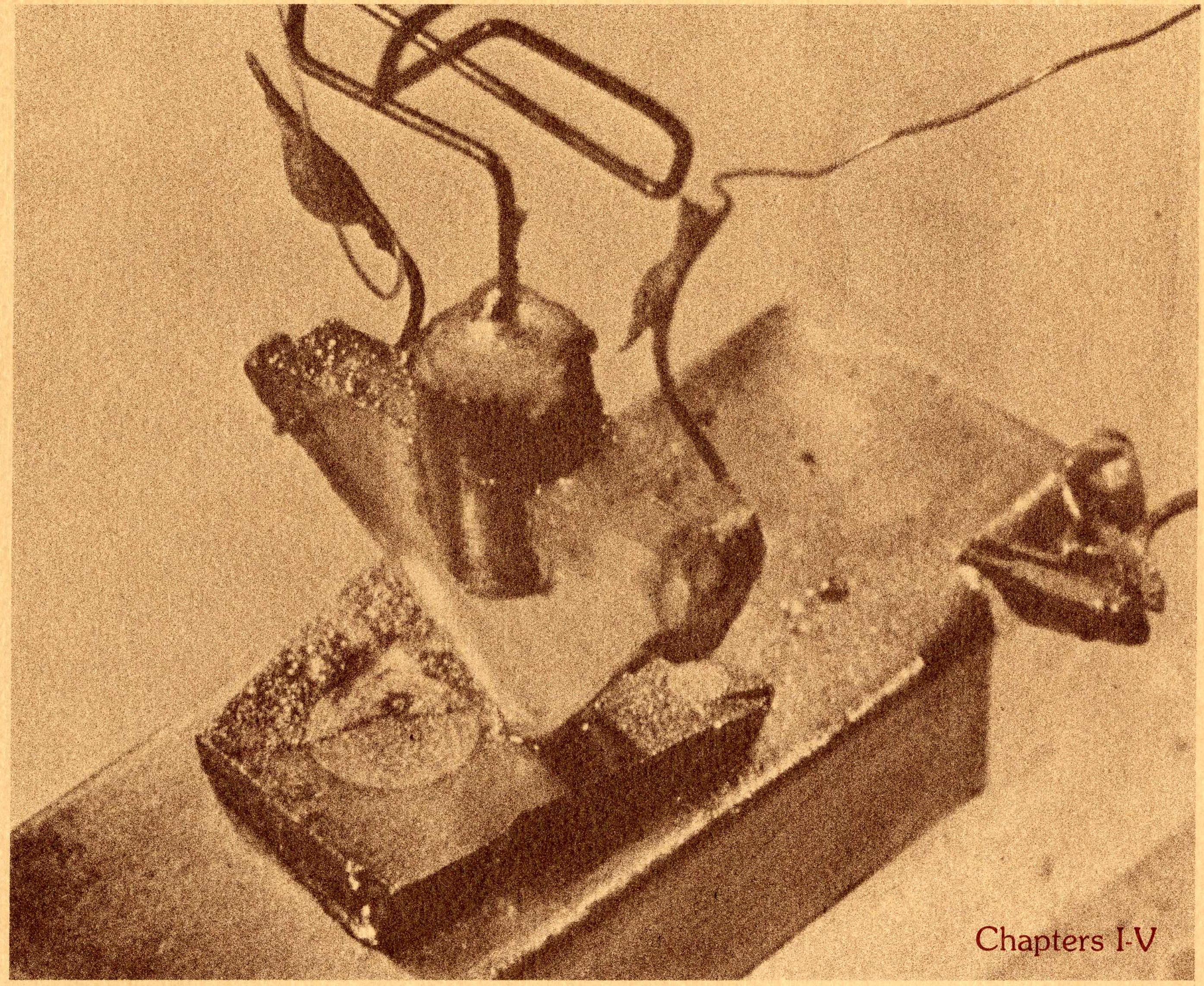
CIRCUIT NEWS

History of the Semiconductor Industry



Chapters I-V

Introduction

It is surprising that no one has attempted to produce an in-depth chronological record of the semiconductor industry until now. Following the announcement of the transistor in 1947, the solid-state industry went through an evolution of successes, disasters, breakthroughs, setbacks, trials and errors that no other industry has known or is ever likely to experience. That it eventually prospered and reached a state where it affects the life of almost every person on a daily basis would seem to indicate that its story must be told.

I've felt that way for many years. It was in 1969 that I first began thinking that someone should compile the history of the semiconductor industry. That was the year that the industry began to show strong signs of maturity and stability, although at first glance it didn't look like many significant developments were taking place in solid state.

Microprocessors were still two years away. The products in the spotlight, except perhaps for Gunn and other bulk-effect microwave devices, weren't all that dramatic. Commercially the emphasis was on metal-oxide-semiconductor random-access memories, new "successor" versions of the 709 operational amplifier and plastic-packaged semiconductor devices. But if you searched deeper, you could feel the momentum that was building.

The semiconductor industry was growing up. Visions of large-scale integration, computers on a chip and widespread penetration of mass markets, including automotive, were becoming more realistic. Clearly, improved semiconductor devices were coming off the production lines, yields were increasing, the threshold of medium-scale integration had been reached, and still better products were moving rapidly through research-and-development stages. It was still too early to anticipate the damaging recession of the coming year.

This was a pivotal time. The advancements in solid-state technology were not going unnoticed outside the semiconductor industry. Integrated semiconductor devices were being routinely designed into new products. The IBM System/3, introduced in 1969, marked the first use of monolithic integrated circuits throughout a new machine by IBM.

This was also the year that Hewlett-Packard, Digital Equipment Corp. and many other nonsemiconductor companies decided to set up their own facilities to build integrated circuits. David Packard, president of Hewlett-Packard at the time, said, "Maybe you can design computers whose circuits are repetitious and whose logic design is often more important than the hardware without a microcircuit capability, but you can't design sophisticated instruments without your own integrated facilities." It was one of Packard's last decisions before becoming Deputy Defense Secretary.

Signs of Progress

Within the IC industry, new processes, photolithography techniques and chip architectures were being discovered, refined and applied. It was an exciting year.

But it wasn't just the forward motion of the semiconductor industry in 1969 that encouraged my idea to record its advancements for those in the future to read. It was the incredible chain of events, the people with foresight, genius, faith and perseverance, the successful gambles, the failures and the blunders, all put together, that made the story worth telling.

It seemed to me at the time that the most logical person to relate at least part of the story was Dr. Robert N. Noyce, president of Intel Corp., formed the previous year by Noyce, Gordon Moore and Andrew Grove. I asked Noyce if he would be interested in participating in such a project, but he quickly declined. His only comment was, "It would be much too embarrassing for me and my friends."

Noyce was one of the eight founders of Fairchild Semiconductor in 1957. As research director, he had been responsible for the initial development of the company's silicon mesa and planar transistor lines. By early 1959 he had assumed the duties of vice president and general manager, and under his leadership Fairchild grew steadily and maintained a position at the leading edge of solid-state technology. Following his promotion to group vice president in 1965, Noyce headed both Semiconductor and Instrumentation Divisions of Fairchild Camera and Instrument. His employee force numbered more than 15,000.

But Noyce's regime had had its share of expansion-related problems and more than its share of key young employee defections, product timetable delays, repeated delivery complaints and general product snafus. A consulting firm brought in to investigate dissention was astounded to find that none of the employees on a diode assembly line knew the name of his immediate supervisor. In several instances products had to be recalled for redesign. In the case of the 3751, an analog-to-digital converter, a part of the circuit was inadvertently left off the chip when it was introduced, and the error went unnoticed until called to Fairchild's attention by customers.

But the most serious flaw in Fairchild's growth was its inability to provide adequate advancement opportunities for the young, talented and sometimes impatient people that it continued to attract. The continuing exodus of entrepreneurs resulted in its being tagged with names such as "Fairchild University" and "Mother Fairchild."

Exodus Begins

First to leave Fairchild was a group of eleven, including general manager Edward Baldwin, which formed Rheem Semiconductor in 1959. By 1975 approximately 50 companies in the Silicon Valley area could trace their roots to Fairchild.

To track the history of the semiconductor industry even for Noyce would be a massive undertaking. For anyone else it bordered on the impossible. Nevertheless the need existed.

In early 1970, Don Hoefler published a three-part article on the history of Silicon Valley in Electronic News that drew exceptional attention and rekindled my interest in the project. Over the next few months I assembled notes and began collecting stories, but as business conditions turned sour in late 1970, my attention was diverted to more pressing areas, and the research efforts were abandoned.

With the passing of time, the fading of memories and the departure from electronics of some of the early solid-state pioneers, it began to look like it would soon be too late to compile a semiconductor-industry history. Fortunately, the creation of the newspaper "Circuit News" in November, 1978, provided an organization to support a research program. Finally, ten years after I originally began thinking about compiling "The History of the Semiconductor Industry," the project was activated.

Circuit News began to tell its readers the story of the semiconductor industry by publishing a chapter in each edition, starting with the January 15, 1979, issue. No other industry evolution will ever produce the events that shaped the solid-state industry, but, perhaps by reading and understanding them, others will benefit.

The semiconductor industry produced a new breed of electronics-industry people. This is their story and an accounting of how they changed our way of life.

—Jerry Eimbinder

Chapter I

History of the Semiconductor Industry

The Invention Of The Transistor

"An amazingly simple device, capable of performing efficiently nearly all the functions of an ordinary vacuum tube, was demonstrated for the first time yesterday at Bell Telephone Laboratories where it was invented.

"Known as the Transistor, the device works on an entirely new physical principle discovered by the Laboratories in the course of fundamental research into the electrical properties of solids. Although the device is still in the laboratory stage, Bell scientists and engineers expect it may have far-reaching significance in electronics and electrical communication."

So began the press release dated Thursday, July 1, 1948, from Bell Telephone Laboratories that made the point-contact transistor first known to the general public six months after its invention. While the disclosure generated considerable excitement both among those intimately associated with the Bell Labs research effort and those involved in the overall field of communications, few could have predicted that midsummer day 30 years ago that the event would launch a worldwide semiconductor industry, lead to the invention of the microwatt junction transistor that ushered in the transistor era, and herald the age of microelectronics and the computer.

While research into the electrical properties of semiconductors had accelerated by 1925, the road that directly led to the realization of a solid-state amplifier began in 1946 immediately after World War II, with the formation of a solid-state research group at Bell Labs. That group included, among others, William Shockley, Walter Brattain and John Bardeen, who in 1956 would share the Nobel Prize in Physics for their research on semiconductors and the discovery of the transistor effect.

Of the three, only Bardeen had had no introduction to semiconductors until he arrived at the Murray Hill, NJ, Laboratories late in 1945. Born in 1908 in Madison, WI, where his father was a professor at the University of Wisconsin there, he received B.S. and M.S. degrees from Wisconsin in 1928 and 1929, respectively, then worked as a geophysicist with the Gulf Research and Development Corp. for about three years. He enrolled at Princeton, where he studied solid-state physics and received a Ph.D. in 1936. After post-doctorate research at Harvard, he taught physics at the University of Minnesota until 1941 when he went on leave to join the Naval Ordnance Laboratory.

Recalls Bardeen: "Following my Ph.D. under Eugene Wigner at Princeton and post-doctoral years with John H. Van Vleck at Harvard, I had been much interested in the theory of metals before the war. After the war, I was anxious to go back to solid-state physics. While at Harvard, I was a good friend of James B. Fisk [who in 1945 was director of research at Bell Laboratories] and also knew Shockley when he was a graduate student at MIT. It was they who persuaded me to join the group rather than return to my academic post at Minnesota. I was the first outsider to be recruited; the rest of the initial group had been at Bell Laboratories for some years."

William Shockley was born in 1910 in London, England, and received a B.Sc. degree from the California Institute of Technology. According to Shockley, research for his Ph.D. at MIT provided the impetus for his later involvement with solid-state electronics at Bell Laboratories.

Says Shockley, "I received my Ph.D. in 1936 and went to Bell Laboratories the same year. I was assigned to report to Dr. C.J. Davisson. Dr. Davisson and his colleague, Dr. Lester Germer, at Bell Laboratories, had first observed electron diffraction. After being formally assigned to Dr. Davisson, I was put on loan to the Vacuum Tube Development Department and worked on electron multiplier tubes and other problems on vacuum-tube theory. These experiences oriented me to practical electronic problems."

Shockley remembers that Dr. Mervin Kelly, then Bell Labs director of research and later president of the company, presented him with the idea of replacing electromechanical relays in telephone systems with electronic devices. "His [Kelly's] interest in this goal was very great. He stressed its importance to me so vividly that it made an indelible impression," emphasizes Shockley. "The atmosphere at Bell Laboratories was such that it was possible for me to change the emphasis of my work, and I was permitted to concentrate my efforts on the solid-state field."

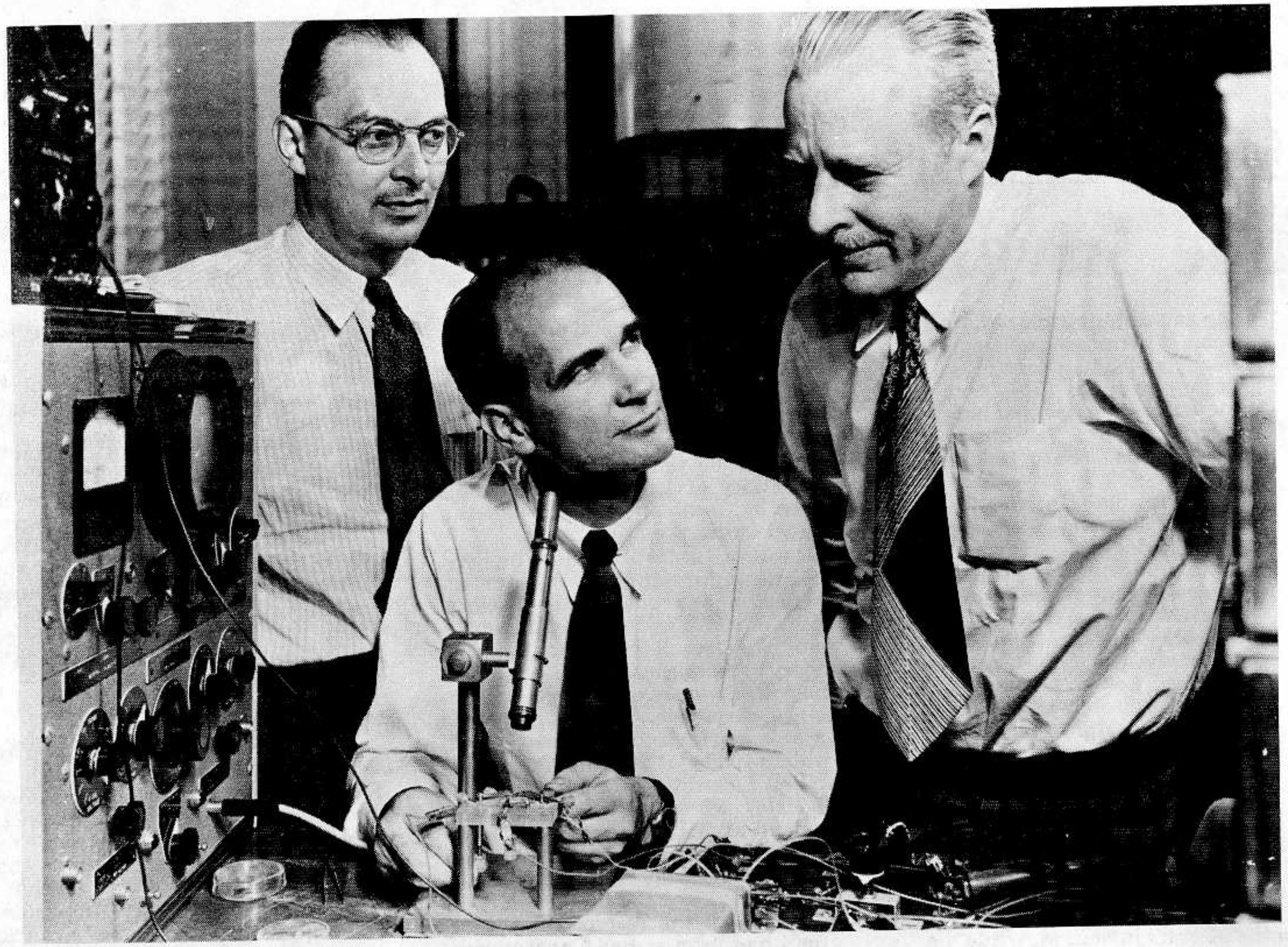
Walter Brattain, born in Amoy, China, in 1902, graduated from Whitman College in Washington in 1924 and received his M.A. degree from the University of Oregon in 1926. He continued his studies at the University of Minnesota and joined the National Bureau of Standards in 1928, then joined Bell Telephone Laboratories after receiving his doctorate at Minnesota in 1929.

Van Vleck's Influence

Like Bardeen, Brattain was heavily influenced by courses he took from Professor Van Vleck. He studied quantum mechanics the first year that Van Vleck based this course on the Schrodinger wave equations and the Heisenberg-Born matrix mechanics at the University of Minnesota. "During this period, James Franck, Irwin Schrodinger and Arnold Sommerfeld, all of whom participated in this revolution, were visitors at Minnesota," says Brattain. "When I started work for J.A. Becker, Bell Laboratories was only four years old. The vacuum tube and thermionics were just shedding their baby teeth. It was Becker who dried my ears off as a green young Ph.D. and started me on my career as a surface physicist," he recalls, "first in thermionics and next in the study of rectification and the copper-oxide rectifier."

The years immediately preceding the U.S.' entry into World War II proved extremely crucial to the invention of the transistor. It was during this period that members of the "transistor group to be," especially Brattain and Shockley, conducted their own research and developed theories on the electrical properties of semiconductors that would one day spark the discovery of the transistor effect.

Brattain recalls that in 1931, when he and Becker began work on copper oxide, one of the better known semiconductors at the time, they convinced themselves that the flow of current in the body of a semiconductor was ohmic and that rectification occurred at the contact of the semiconductor and the metal; i.e., current flowed many times easier when the copper voltage was



Nobel Prize winners Drs. William Shockley (seated), John Bardeen (left) and Walter Brattain are shown here at Bell Telephone Laboratories with apparatus used in their first investigations that led to the invention of the transistor.

negative with respect to the oxide. They also knew that illumination of the contact would produce a flow of current in the easy direction without any applied voltage, whereas light on the main body of the semiconductor would only decrease the resistance to the flow in the body.

"Early in 1940," Brattain continues, "Mervin Kelly...called us into his office to witness a demonstration by Russell S. Ohl, a member of the staff who was working with silicon, a then little-known semiconductor. Ohl showed us all a small rectangular piece of black solid with two metal contacts. When light from a flashlight illuminated a narrow region near the middle of this piece of silicon, a photoelectromotive force (emf) of about 0.5 V was developed.

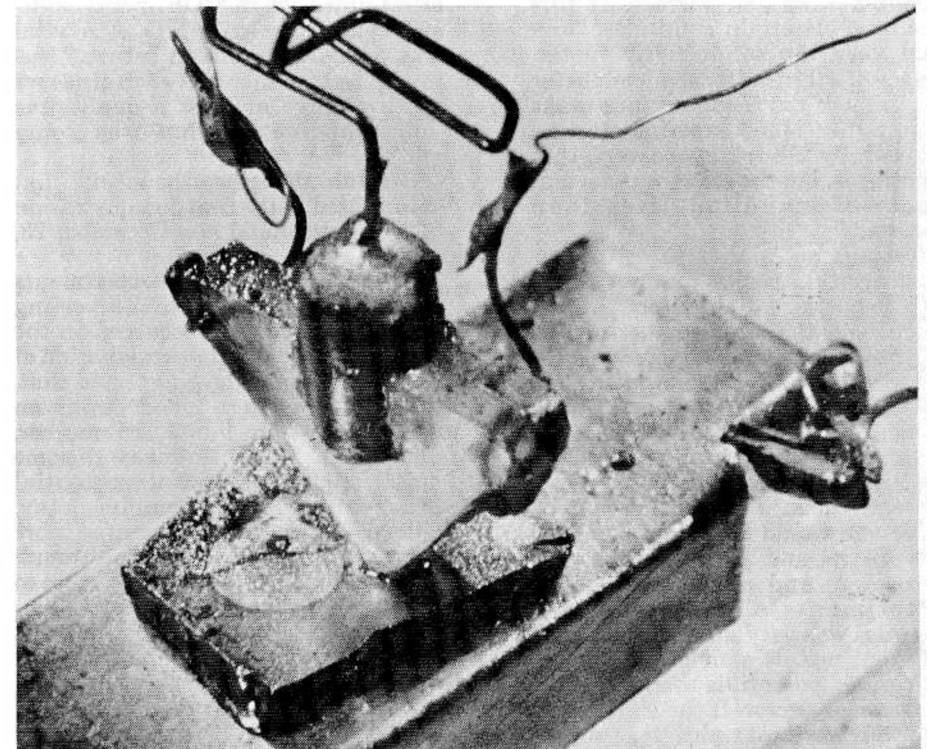
"This was hard to believe," Brattain remembers. "In the first place, the contacts were not being illuminated, and the photo emf was 10 or more times larger than any we had ever seen. Moreover, the silicon was black; that is, opaque to visible light. In fact, I did not believe what I saw until Ohl gave me a piece to work with in my own laboratory.

"This was the first p-n junction," Brattain states. "Some time before this, G.C. Southworth had been having trouble getting something to detect the short radio waves (microwaves) with which he was working. Vacuum tubes did not then work at these wavelengths. He remembered the old cat's whisker detectors that were used before vacuum tubes were invented and decided to give them a try. He went to the second-hand radio market in the Cortland Street section of New York [now the World Trade Center] and there found some cat's whisker detectors, dusted them off, and tried them. They worked."

"An amazingly simple device...demonstrated for the first time yesterday at Bell Telephone Laboratories..."

Brattain continues that Ohl heard about Southworth's success with the cat's whiskers and became interested, noting that these detectors were semiconductors made of either silicon or galena. "Ohl decided to concentrate on silicon," Brattain relates. "The silicon you could buy was very nonuniform in its detection properties. This detection involved rectification of the radio wave at the point of contact of the metal cat's whisker with the silicon. Sometimes the rectification would be in one direction and sometimes in the opposite direction, sometimes not at all.

"Ohl asked the metallurgists at Bell Labs to see if they could not make the silicon more uniform by purifying it," Brattain continues. "J.H. Scaff and H.C. Theuerer soon found they could purify the silicon by melting it in high vacuum. Sometimes the ingots that they made would rectify all one way, and another ingot would rectify all the other way. Those that conducted best when the silicon was negative were called 'n' type and the other 'p' type. One ingot that Scaff and Theuerer gave Ohl was all n type on one end and all p type on the other end, and a piece cut out to include the boundary between these two regions



The first transistor, a "point-contact" device, amplified electrical signals by passing them through a tiny slab of germanium, basically the same operation performed by today's silicon "junction" transistors.

was the one Ohl had demonstrated."

Brattain notes that Scaff and Theuerer soon found that the conductivity of silicon was due to small traces of impurities, which were elements in the fifth column of the periodic table that gave excess electrons when added and made silicon n type. Elements in the third column gave excess holes and made silicon p type.

Meanwhile, Shockley had realized that he might be able to achieve Kelly's objective of electronic switching using phenomena in solid-state physics rather than vacuum-tube techniques. "One possibility that occurred to me," says Shockley, "was a solid-state amplifier using carbon contacts or some other type of contact subject to pressure that was controlled by an input signal applied to a quartz crystal or some other piezoelectric crystal. The output power would be obtained through the change in resistance of the microphonic contact.

"Although I did not know it at the time," Shockley continues, "This was an old idea. Mr. Alan Holden and I made some attempts to make an amplifier this way, but concluded that this approach held very little promise indeed.

"At about the same time," Shockley recalls, "Dr. Brattain and...Dr. Becker involved me in their research on copper-oxide rectifiers. This stimulated me to study the theory by Schottky of rectification by metal-semiconductor contacts, a theory now made familiar in the phrases 'Schottky barrier' and 'Schottky gate'. While considering Schottky's theory and having ideas about amplification in the back of my mind, I recognized that possibilities of amplification were inherent in Schottky's depletion layer—the space-charge layer that spreads more deeply into the semiconductor as the reverse potential on the rectifier is increased. I saw that this spreading could be used as a kind of valve action so as to control conductivity in the semiconductor at a substantial distance from the contact."

"...may have far-reaching significance in electronics and electrical communication."

—Bell Labs' Press Release
July 1, 1948

December 29, 1939 marked Shockley's first notebook entry that proposed a semiconductor amplifier (see **Figure**, p. 8).

Brattain was soon made aware of Shockley's idea. "I vividly recall Becker's and my recognition of the close analogy between the copper-oxide rectifier and the vacuum-tube diode," he relates, "and of our calculations of the size of the grid that one might put into the space-charge layer of the rectifier to make a triode! It is an understatement to say that the results did not look promising. So I was somewhat amused when a year or so later, Shockley came to me with an idea of making an amplifier out of copper oxide. As I remember," he continues, "I nevertheless told him that any means of doing this was so important that I would try to get the copper-oxide device he had in mind made as near as possible to the way he wanted it. This attempt was not successful."

That experimental failure proved a turning point in the road to the invention of the transistor, for it was John Bardeen's later explanation in terms of surface states for Shockley's inability to observe any field-effect results that ultimately led to the discovery of the transistor effect.

But Bardeen's breakthrough would come later: World War II had erupted, and most of the individuals who would act out the drama of the transistor's invention became involved with war-related, nonphysics activity for about six years. Then, in 1945, Shockley returned from the Pentagon to Bell Laboratories. Kelly made him and Stanley Morgan coheads of a solid-state research group, within two years to become famous as the "pretransistor" group.

"Conditions were rather crowded when I arrived at the Murray Hill, NJ, Laboratories [in 1945]," Bardeen recalls. "The windup of World War II research was still going on. A new building was under construction but was not yet completed, so I was asked to share an office with Walter Brattain and Gerald Pearson.

"I had known Walter since my graduate student days at Princeton," he continues. "Although when I arrived at Bell Labs, I had not decided what field of solid-state physics I would work in, they soon got me interested in their problems, and I became deeply engrossed in trying to learn what was known about semiconductor theory.

"Like me," says Bardeen, "most of the group had worked in other areas during the war. Very helpful in bringing ourselves up to date were seminars and discussion groups in which we reviewed the literature. Of greatest relevance were the papers of Schottky and Spenke on semiconductor barrier layers and metal-semiconductor rectifiers, published just before the war, and reports of wartime research on silicon and germanium diodes."

"In January, 1946," says Brattain, "because of Bell Labs' interest in the use of semiconductors in circuit devices and the possibility of a solid-state amplifier, scientific research to enable us to understand semiconductors was resumed in earnest. ...Shockley, a theoretical physicist, worked as part of the research team he headed. John Bardeen, also a theoretical physicist, joined the group.

"The group also included G.L. Pearson, who was primarily interested in the bulk properties of semiconductors," Brattain continues, "R.B. Gibney, a physical chemist, and H.R. Moore, a circuit expert who aided greatly in making measurements and devising novel circuits for our experiments. I was primarily interested in what went on at the [semiconductor] surface where contact was made or at the boundary between n and p types. Of this group only Pearson and I had experimented extensively with semiconductors before the war.

"When we all first got together as a group," Brattain recalls, "this question was raised: 'How is it that with all the work that had been done on semiconductors before the war, in Russia, on the continent of Europe and in Great Britain, we still don't understand what's going on?' We realized then that the semiconductors we had studied before the war were very complex compounds, particularly copper oxide.

"We also reviewed vacuum-tube technology," Brattain continues. "The analogy had already been made between a two-element vacuum-tube rectifier and oxide of copper grown on copper, which also worked as a rectifier. So how were we to add a third electrode to make a solid-state amplifier?

"We were aware that elementary solids like silicon and germanium had become important during the war as rectifiers for detecting high-frequency microwaves," Brattain goes on. "Silicon and germanium have the same strong covalent bonding that diamond has and are therefore very free of defects. We also knew from Scaff and Theuerer that the elements on each side of germanium and silicon in the periodic table were the important impurities. So the decision was made to understand silicon and germanium, the two simple semiconductors.

"I should add," Brattain remarks, "that this was the best scientific-research group I'd ever worked with. We would get together at any time there was something to be discussed, and we went to the heart of the problem." He notes that Scaff and Theuerer were able to provide the group with polycrystalline ingots of either n- or p-type silicon or germanium of any specified resistance. "This, of course, was a great help," he says. "Based on the Mott-Schottky theory of rectification, Shockley had come to the conclusion during the war that it should be possible to control the density of electrons near the surface of the semiconductor by means of an electric field applied between the surface and a metal electrode insulated from the surface. If this were true," Brattain continues, "one could vary the conductivity in the surface of a thin-wafer semiconductor by means of the field and thus make an amplifier. Many experiments were devised by Shockley to test this hypothesis, but the effect was several orders of magnitude less than predicted."

Brattain notes that three or four experimental results did not agree with Schottky's field-effect theory, which held that the number of free electrons in a semiconductor was the same at the surface as in the interior. He explains, "In order for two electrical conductors to be in equilibrium, there must, in general, be an electrostatic potential difference between them. The prediction was that there would be such a potential between n- and p-type silicon and between n- and p-type germanium. Experiments showed that this potential was very small, almost zero. Different metals should have different contact potentials with respect to the semiconductor. If the sign of this potential were not right, there should be no rectification at the point of contact; yet, experimentally, all metal points worked more or less equally well."

Trapped Electronics

He continues, "Additionally, S. Benzer at Purdue [University] found that contact between two pieces of germanium, one n type and one p type, did not act as one would expect. I believe the group as a whole slowly realized that these results were all of a piece, and it was Bardeen who successfully explained them all by applying to this problem the concept of surface states; that is, that the electrons could be trapped at the semiconductor surface, and that the semiconductor was in equilibrium with its surface before any electrical contact was made to it. This, of course, implied a space-charge layer in the surface of the semiconductor equal and opposite to the charge trapped on the surface. Consequently," Brattain notes, "the electrostatic potential change between the interior of the semiconductor and the surface, which was necessary for rectification, was a property of the semiconductor and its surface—independent of the metal contact. This theory immediately suggested new experiments."

Bardeen recalls, "It was in following up some of the consequences of the proposed Schottky barrier layer at the free surface of a semiconductor that Walter Brattain and I initiated the series of experiments that led to the invention of the point-contact transistor. Very important to these experiments were Shockley's ideas on modulating the conductance of a semiconductor by an electric field, the effect now used in MOS (metal-oxide-semiconductor) and FETs. Also vital was a close interaction between theory and experiment; at each stage we tried to have at least a qualitative understanding of what was going on."

Brattain describes the events that culminated in the first demonstration of transistor action on December 23, 1947:

"Two suggestions for experiments came about as a result of the meeting and discussion that occurred on the occasion of Bardeen's presentation of his theory. Shockley suggested that, if trapping centers for electrons on the surface were limited in number, one should be able to measure some small change in contact potential between n-and p-type samples of, say, silicon as the samples became more strongly n type and p type through the introduction of more and more of the proper impurities.

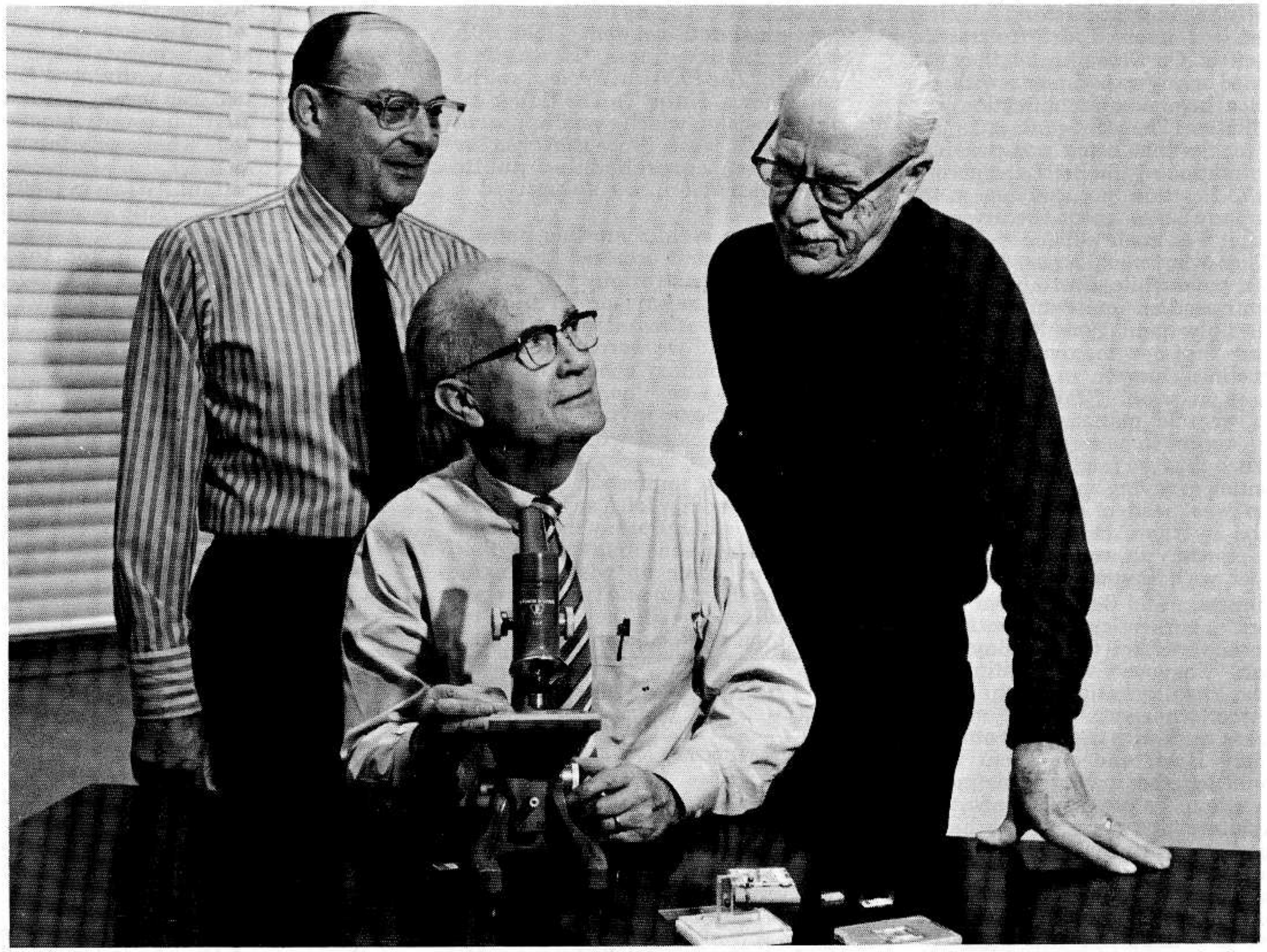
"I suggested that, if extra electrons and holes were excited by illumination in the surface region (where there must be an electric field due to the space charge), the electric field would tend to separate the excited electrons and holes, thus changing the surface charge and contact potential. Both these experiments were successfully performed.

"Another suggestion was to try to reduce the temperature low enough so electrons trapped at the surface could be frozen and a field effect observed. Experiments by Pearson and Bardeen showed that this was the case.

"Another experiment that I tried was to measure the change of potential at the germanium or silicon surface as a function of temperature. Condensation of moisture from the air on the cold semiconductor surface interfered with this experiment. As a result, it was decided to try immersing the system in an insulating liquid. The apparatus had been arranged to measure contact potential and photo emfs, and when liquids were tried, large changes in photo emfs were observed. Some of the liquids tried (such as water) were not strictly insulating but were electrolytes. When I was showing these phenomena to Gibney, he suggested varying the potential between the semiconductor surface and the reference electrode. When using an electrolyte, we could make the photo emf very large by this means. By changing the sign of the potential, we could make the photo emf go through zero and change sign.

"It was recognized that this was, in essence, Shockley's field effect. By using the electrolyte, we could vary the space-charge layer and potential inside the semiconductor near the surface.

"These results were presented to the group as a whole, and one morning one or two days later, Bardeen



Left to right, John Bardeen, William Shockley and Walter Brattain as they appeared 25 years after the invention of the point-contact transistor.

came into my office with a suggested geometrical arrangement to use this effect to make an amplifier. I said let's go out in the laboratory and do it. We covered a metal point with a thin layer of wax and pushed it down on a piece of p-type silicon that had been treated to give an n-type surface. We then surrounded the point with a drop of water and made contact to it. The point was insulated from the water by the wax layer. We found as expected that potentials applied between the water and the silicon would change the current flowing from the silicon to the point. Power amplification was obtained that day!

Evaporation

"Bardeen suggested trying this on n-type germanium, and it worked even better. However, the water drop would evaporate almost as soon as things were working well, so at Gibney's suggestion we changed to glycol borate, which hardly evaporates at all. Another problem was that amplification could be obtained only at or below about 8 Hz. We reasoned that this was due to the slow action of the electrolyte. Optimum results were obtained with a dc negative bias on the electrolyte when using n-type germanium.

"Under these conditions, we noticed an anodic oxide film being formed under the electrolyte. We decided to evaporate a spot of gold on such a film and, using the film to insulate the gold from the germanium, use the gold as a field electrode to eliminate the electrolyte. The film was formed, the glycol borate washed off, and the gold spot with a hole in the middle for the point was evaporated. When this was tried, an electrical discharge between the point and the gold spoiled the spot in the middle, but by placing the point around the edge of the gold spot, a new effect was observed.

"In washing off the glycol borate, we had inadvertently washed off the oxide film which was soluble in water. The gold had been evaporated on a freshly anodized germanium surface. When a small positive potential was applied to the gold, holes flowed into the germanium surface, greatly increasing the flow of current from the germanium to the point negatively biased at a large potential!

"Four days later, on 23 December 1947, two gold contacts less than two thousandths of an inch apart were made to the same piece of germanium, and the first transistor was made."

Brattain recalls that the name "transistor" was originated by J.R. Pierce. He explains, "Pierce knew that the point-contact transistor was the dual of the vacuum tube, circuitwise. The important parameter of the tube is 'transconductance', and the dual would be 'transistance', which he shortened to 'transistor' to fit in with 'varistor', our name for the rectifier, and 'thermistor', for a heat-sensitive resistor.

Transistor Effect

"With the 'reduction to practice' of the transistor effect, we knew we were onto something important," Brattain remembers. "We made various calculations, such as comparing transistor action with what goes on in the neurons of the human brain. We figured how much energy it took per bit of information with a transistor compared with those neurons, and we decided transistor action was a great deal faster, not to mention more economical!"

Brattain says that the group only

slowly began to understand fully just what was involved with the transistor effect. On December 24, they performed many experiments with the device involving amplification and oscillation. The point-contact transistor for the time being was classified information within Bell Labs; according to Brattain, not everyone at the company knew about the invention until it was made public.

That event would occur six months later; meanwhile, Brattain and Bardeen raised an important issue with Bell Labs management. "We were aware that new discoveries like this sometimes happen in two different places at once," Brattain explains. "So we told management that we didn't want to be responsible for the chance that we might end up in the position of saying 'me, too'. Dr. Bown, who was head of research at Bell Labs by then, responded, 'When you're ready to write your scientific paper, we'll announce it'."

Brattain and Bardeen then began work in earnest on documenting the transistor-effect theory. Says Bardeen, "They were very exciting days after the invention of the point-contact transistor. One of my jobs was to work with the patent attorney, Harry Hart, and we spent many hours together trying to define the invention. To get a good patent," he explains, "it's necessary to have a good understanding of the basic mechanisms, and there were still questions about just how the holes flowed from the emitter to the collector. How important was the surface barrier layer in the transfer of holes from emitter to collector?

"Shockley initially suggested the junction transistor structure to help understand the mechanism," Bardeen continues. "Independently, John Shive put the emitter and collector points on the opposite sides of a thin wafer of germanium and found that the arrangement worked as a transistor. I can still remember the excitement I felt when I first learned of this discovery, which showed definitely that the holes from the emitter could flow appreciable distances through the bulk of n-type germanium."

Brattain and Bardeen filed for the original patent on the point-contact transistor on June 17, 1948. In the interim, Mervin Kelly, before leaving for Europe for the summer, decided to get a picture of everything that was going on at Bell Labs before his departure. "In the middle of my presentation," Brattain recalls, "Kelly turned to Bown and said, 'When are we going to announce this?' Bown answered, 'When they're ready to write their paper'. Bown turned to us and said, 'Are you ready?' We said yes!

"I then had the honor of calling my thesis professor at Minnesota, John Tate, and telling him about the invention but adding that it had to be kept quiet until we went public with it," Brattain continues. "He was then editor of *The Physical Review*, and he asked for a 'Letter To The Editor' on the transistor, which would appear in the July 1 issue. Since that was the day after our scheduled public demonstration, we submitted a letter."

Brattain recalls another significant event that occurred before the public demonstration. "We didn't want the transistor to become classified information with the military, and we worried that if we asked the military about this, they'd be afraid to say 'no, it needn't be classified'. So we invited the military in just to see what we were going to tell the press the next week. They were suitably impressed.

"But after they left," says Brattain, "they called back to say they thought they had someone in their own group who had come up with the same effect, so Bardeen and I raced down to Washington. Well, they didn't have anything that could amplify!"

> *"The diffused-base transistor made it possible for a single wafer of semiconductor material to contain thousands of transistors."*
>
> *—Walter Brattain*

Bardeen recalls that after the demonstration of the point-contact transistor on June 30, 1948, in the auditorium of Bell Laboratories' West Street, New York, location, the lay press was at first indifferent, but the technical press picked up on the possibilities rapidly and industry responded enthusiastically.

Brattain adds that after the announcement, anyone could take the germanium high-back voltage rectifier that was then on the market, add another contact point, and make a transistor. According to Bardeen, Bell Labs was free in licensing the patents and set up seminars to help other companies get started with technical applications.

"In addition," Brattain remarks, "we did one thing. We decided that in honor of Alexander Graham Bell, who had tried to help deaf persons, we would accept no money for licensing to hearing-aid manufacturers."

Transistor technology took off faster than anyone could have expected, largely because of ongoing research. Only five weeks after the invention of the point-contact transistor, Shockley had designed a basic research experiment to diagnose the surface phenomena of the original device. "I discovered that I had an applied result," he says. "My research structure was itself a transistor. It was patented as the junction transistor.

"Exploiting its potential caused many headaches," Shockley continues. "A colleague branded it a 'persistor', because persistence was what it took to make it—several years and improved experimental facilities were needed before really good ones were fabricated. But three years later [1951], the first microwatt junction transistors were what really inaugurated the transistor era."

Recalls Brattain, "When in 1950 G. K. Teal and J. B. Little successfully made single crystals of germanium, it soon became possible for them, together with Morgan Sparks, to make a grown junction transistor at Bell Labs. A year or two after, the alloy transistor was developed, and later the diffused-base transistor made it possible for a single wafer of semiconductor material to contain thousands of transistors."

The microelectronics age had arrived, a twentieth-century phenomenon that has revolutionized the world and would have remained a dream of fiction were it not for the efforts of Bardeen, Shockley, Brattain and other participants in semiconductor research.

Brattain is particularly proud of the cardiac pacemaker as an application of transistor technology, but he believes the small, battery-powered transistor radio takes precedence over any other invention made possible by the events culminating the week of Christmas, 1947. "We used to think that unless everyone around the world could learn to read and write, there would be no peace on earth and civilization would be lost," he explains. "But almost everyone has language, and today the most primitive peoples in the world can gather around a fire at night and listen to radio broadcasts from the U.S. No government will ever again be able to pull the wool over its people's eyes."

Brattain cautions, however, that scientists who obtain understanding of natural phenomena are not responsible for the use a society makes of that knowledge.

"It is very easy to put misinformation into a computer," he notes. "Such mistakes are the fault of the user. Unless the user is intelligent enough to catch his mistakes, his use of the computer is a waste of time!" Brattain feels that many people hired to use a computer don't know what they're doing and accept any response from it as correct.

It's possible, then, that the greatest contribution Bardeen, Shockley and Brattain have made to society is an affirmation of the power of constructive thought, felt in every aspect of life today that has been improved by technology.

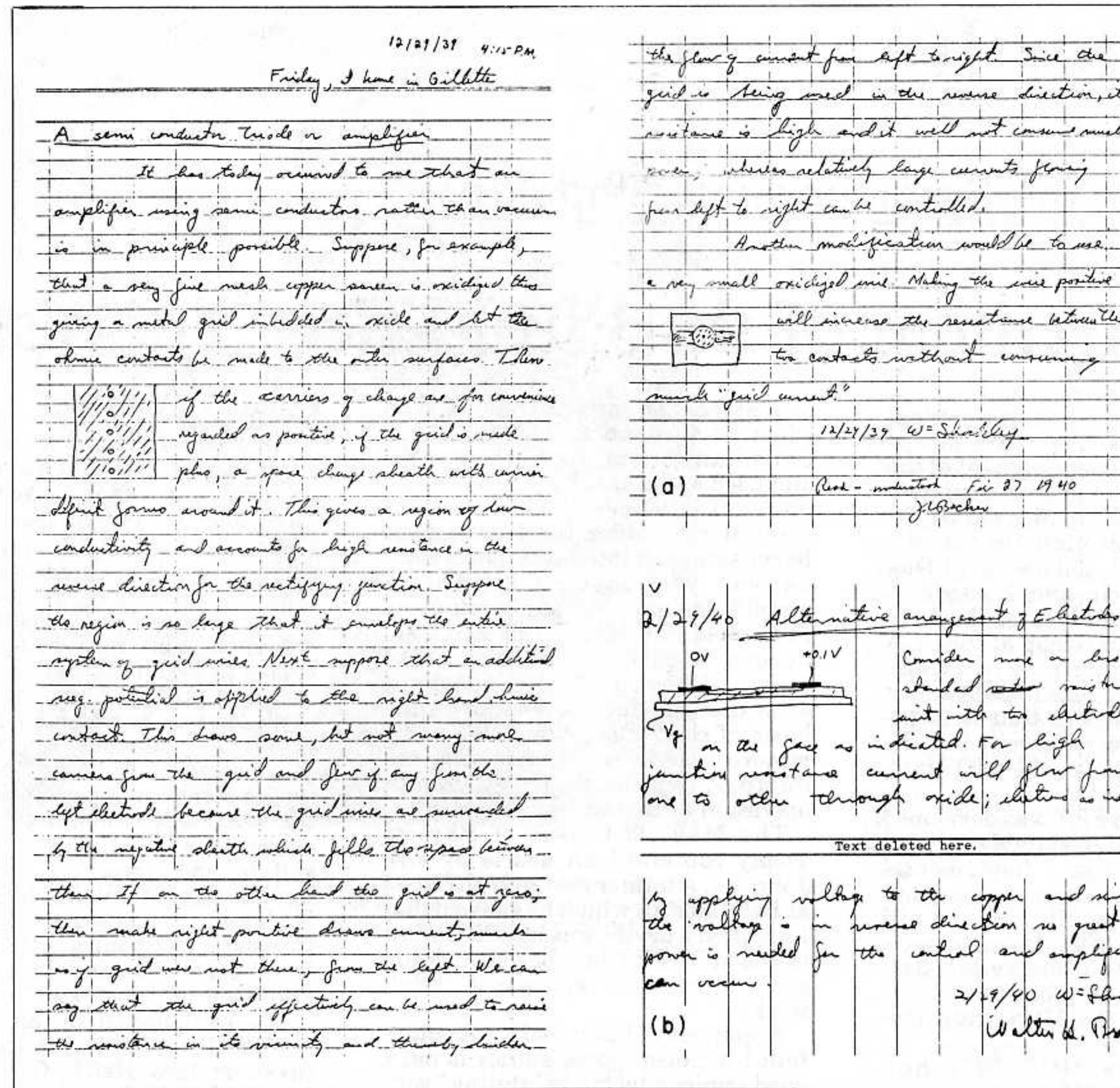


Figure (a)—Shockley's first notebook entry that proposed a semiconductor amplifier. (b) An improved structure dated two months later on February 29, 1940.

"12/29/39 4:15 P.M.
"Friday, at home in Gillette

"A semiconductor triode or amplifier

"It has today occurred to me that an amplifier using semiconductors rather than vacuum is in principle possible. Suppose, for example, that a very fine mesh copper screen is oxidized, thus giving a metal grid embedded in oxide, and let the ohmic contacts be made to the outer surfaces. Then if the carriers of charge are for convenience regarded as positive, if the grid is made plus, a space charge sheath with carrier deficit forms around it. This gives a region of low conductivity and accounts for high resistance in the reverse direction for the rectifying junction.

"Suppose the region is so large that it envelops the entire system of grid wires. Next, suppose that an additional negative potential is applied to the right-hand ohmic contact. This draws some, but not many more carriers from the grid and few if any from the left electrode because the grid wires are surrounded by the negative sheath, which fills the space between them.

"If, on the other hand, the grid is at zero, then make right positive draw current, much as if grid were not there, from the left. We can say that the grid effectively can be used to raise the resistance in its vicinity and thereby hinder the flow of current from left to right. Since the grid is being used in the reverse direction, its resistance is high and it will not consume much power, whereas relatively large currents flowing from left to right can be controlled.

"Another modification would be to use a very small oxidized wire. Making the wire positive will increase the resistance between the two contacts without consuming much 'grid current'.

"12/29/39 W=Shockley
"Read - understood Feb. 27, 1940
J.A. Becker"

Acknowledgements

The quoted material contained in this article was derived from recent interviews with the transistor's inventors, as well as from the following sources with permission:

1. "The Path to the Conception of the Junction Transistor," William Shockley, ***IEEE Transactions on Electron Devices,*** *Vol. ED-23, No. 7, July 1976.*

2. "Genesis of the Transistor," Walter Brattain, reprinted from ***The Physics Teacher,*** *March 1968.*

3. "Three Men Who Changed Our World—25 Years Later," reprinted from ***The Bell Laboratories Record,*** *Vol. 50, 1972.*

Some of the biographical information was obtained from ***Turning Points in American Electrical History,*** *Ed. James E. Brittain, the IEEE Press, 1977.*

Bell Laboratories also provided copies of the original press release, as well as relevant photos.

Chapter II

History of the Semiconductor Industry

The Invention of the Field-Effect Transistor

Late in 1962, two young electrical engineers only a few years out of college completed development of the first practical silicon insulated-gate field-effect transistor, also called the metal-oxide-semiconductor transistor or MOS FET. This work of Drs. Steven R. Hofstein and Frederic P. Heiman, then members of the Integrated Electronics Group at the RCA Electronic Research Lab in Princeton, NJ, is recognized today as a major achievement in that it transformed a laboratory curiosity into the first commercially feasible MOS integrated circuits.

While the MOS FET was developed in a form that was suitable for and ultimately served as a fundamental building block of current microelectronic technology, it wasn't until 1972, a decade after its announcement, that at least one author published an article that began with the question, "Has the MOS transistor finally arrived?"

Actually, the MOS FET had "arrived" nearly 50 years after a Polish-born, former professor of physics at the University of Leipzig, Germany, at the time living in Brooklyn, NY, conceived of a device comparable to Hofstein's and Heiman's insulated-gate field-effect transistor. The man was Julius E. Lilienfeld, and the year was 1925 when he began work on a method and device for producing electrical amplification in a thin copper-sulfide film. Yet, it took the invention of the point-contact device, independent of Lilienfeld's work, by Walter Brattain, William Shockley and John Bardeen at Bell Labs in 1947 to spark the transistor revolution. Someone along the way obviously dropped the ball.

Addresses Problem

During 1964, a year after Lilienfeld's death, two articles appeared in separate issues of *Physics Today* that addressed the problem. In the February issue, Virgil E. Bottom, director of research of the Motorola Semiconductor Div. in Phoenix from 1953 to 1958, wrote "Invention of the Solid-State Amplifier," in which he examined three patents granted to Lilienfeld in 1930, 1932 and 1935. Bottom concluded that "...Dr. Lilienfeld, at least as early as October 1925 when he filed an application for a Canadian patent, had constructed and used amplifiers having the basic characteristics of the modern transistor amplifier. His devices must be considered relatively crude in comparison with modern solid-state amplifiers, and his explanation of their operation is not in complete accord with modern solid-state theory. However, little doubt can exist that his devices operate on the basis of conductivity modulation by minority carrier injection in semiconductors, which is the basis of operation of the modern transistor."

The May 1964 issue of *Physics Today* contained an article by J.B. Johnson, a former research physicist at Bell Labs, in which he showed that Lilienfeld's device was indeed similar to the MOS FET but, based on Johnson's attempt to replicate it, didn't work.

Apparently, Lilienfeld's invention failed because copper sulfide is not a good semiconductor, exhibiting "very low mobility of holes," according to Johnson. In addition, Lilienfeld hadn't totally understood the operation of his device: He was unaware of the effect of surface states in semiconductors, a phenomenon that, 20 years after his investigations, John Bardeen hypothesized during the Bell Labs research group's successful attempt to devise a solid-state amplifier.

In light of Lilienfeld's capabilities—including his known assistance of Germany's Count Ferdinand von Zeppelin in hydrogen-filled dirigible design and of his experiments with roentgen radiation during the early 1920s, long before he became a U.S. citizen in 1935—Hofstein, now president of Princeton Electronics, speculates as follows:

Close to Working

"In 1928, Julius Lilienfeld filed a patent on a device that was so close to working that, had it worked, it would have soon revolutionized the world. His mistake was choosing copper sulfide as his medium because photocells and other devices that had an electronic characteristic dependent upon light were being made of copper at that time." If he had chosen cadmium sulfide, he would have succeeded in building a viable solid-state amplifier, because in 1959 Paul Weimer at RCA Labs fabricated a device identical in structure to Lilienfeld's, but with one change: Instead of copper sulfide he used cadmium sulfide, and it worked. "If Lilienfeld had chosen cadmium sulfide," says Hofstein, "we would have had transistor electronics by 1930, in time for World War II, and the world as we know it might not exist."

The next patent for an insulated-gate FET was issued to the German inventor Oskar Heil by Great Brittain in 1935. His device used a control electrode to modulate current flow through a thin layer of semiconductor material such as tellurium, iodine, cuprous oxide or vanadium pentoxide. The control electrode was close to, but isolated from, the semiconductor layer.

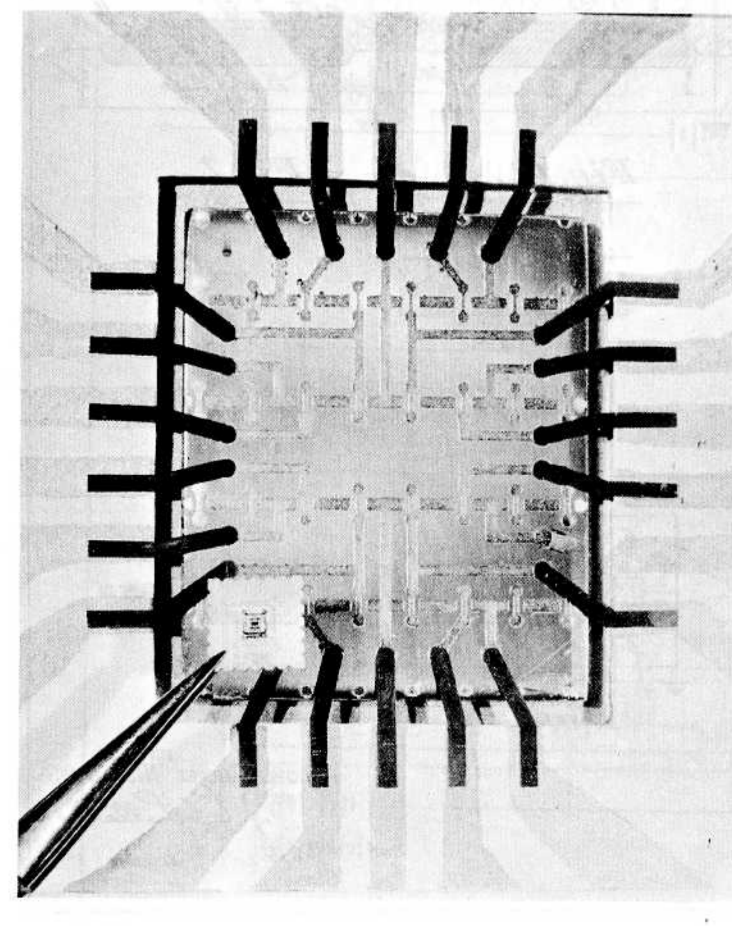
Still the field-effect transistor eluded the limelight. An obvious reason is that investigations into the surface properties of semiconductors were interrupted by World War II and then resumed only by a very few research groups, notably at Bell Labs, IBM and Purdue University. Also, advancements in electron-tube technology commanded center stage until the point-contact and junction transistors captured the lion's share of industry attention.

But in 1952, William Shockley, while still at Bell Labs, proposed a "unipolar field-effect transistor" that he described as a structure in which the adverse effects of surface states are eliminated. Shockley also coined the term "unipolar" to explain the device's amplifying action, which involves currents carried predominately by one kind of carrier in contrast to point-contact and junction transistors that are "bipolar" in this sense.

"If Lilienfeld had chosen cadmium sulfide, we would have had transistor electronics by 1930, in time for World War II, and the world as we know it might not exist."

—Steven Hofstein

Dr. Steven Hofstein, coinventor of the MOS FET, is shown here at about the time of RCA's announcement of the device in 1962. Below is the tiny circuit in a ceramic package held against a large mock-up model.



Field-effect transistors now generated widespread interest, and during the late 1950s, work by three men—J. Torkel Wallmark at RCA Labs, Paul Weimer, also at RCA, and Bell Labs' M.M. Atalla—laid the groundwork for Hofstein's and Heiman's first MOS integrated circuit.

Wallmark was granted a patent for an invention that "relates to field-effect semiconductor devices of the unipolar and bipolar type...[and] more particularly...to unipolar and bipolar germanium transistors having control means for selectively varying the electric field adjacent the surface of a transistor device." (U.S. Patent 2,900,531.) Wallmark had visualized the possibility of implementing logic functions for computers, which he called "integrated logic nets," the term that eventually would give way to "integrated circuits," using long strings of such transistors that had been batch fabricated. Weimer, later coinventor of the vidicon, implemented Wallmark's ideas with his thin-film transistors, using the cadmium sulfide Lilienfeld had overlooked for his medium. Independently, Atalla at Bell Labs investigated the use of discrete insulated-gate FETs, using silicon as the semiconductor and silicon dioxide as the insulator.

Silicon Tried

Thus, when Hofstein joined RCA Laboratories in 1959 as a trainee, he was assigned to the Integrated Electronics Group of the RCA Electronic Research Lab, then headed by Dr. William Webster, that was charged with developing Wallmark's integrated logic nets. The original proposal had been to use Shockley's unipolar transistor, thought by the group to be the transistor best suited to the building of large logical circuits.

Hofstein decided instead to try to fabricate an insulated-gate field-effect transistor for the task, which he originally conceived of as a combination of the thin-film transistor that Lilienfeld had attempted and that Weimer had built successfully. His immediate superior at the time was Thomas O. Stanley, who suggested to Hofstein that, instead of an exotic chemical like cadmium sulfide, he should attempt to utilize silicon as Atalla had done, since this material would most likely be used in future semiconductor electronics.

At that point the group was riven with politics, according to Hofstein. "Most of the members considered me a young engineer, and as such a 'hired hand'," he explains. "Each of them had his own approach to a device suitable for making integrated logic nets. That I was given the freedom to work on a new device, which, if you will, competed with their devices, was not accepted by them. A battle ensued, in which Tom Stanley personally interceded; had he not done so, Fred Heiman and I would not have developed the MOS FET."

Early Research

In the late '50s and early '60s, the basic physics relating to silicon were little known and the associated processes virtually nonexistent, except among a handful of research physicists at such companies as Bell Labs and IBM. The machines that we consider today to be standard—the diffusion, evaporation and plasma-etching equipment—all the tools basic to the silicon semiconductor industry, had yet to be invented. Hofstein and Heiman therefore had to design and build every machine they used after experimenting with the material itself.

Settles on Silicon

"At the time I began my investigation of the insulated-gate FET," Hofstein remarks, "I chose not to follow the path of thin films but to concentrate on processing techniques that would make the FET suitable for bulk or sliced silicon: My opinion was that it would only be in single-crystal sliced silicon that we would find a material of sufficient controllability and uniformity to make a commercially feasible device."

Thus, since the technology of bulk or crystalline silicon during the early '60s was still in the embryonic stage compared with thin-film techniques, that approach proved a major difficulty. "Every process step that we developed was done so on our own, with no assistance," says Hofstein. "What today are looked upon as obvious things to do sometimes took months to develop. It's like discovering, after many months of experimentation, that a cake tastes better with three eggs instead of two eggs; from that point on, everyone knows it's three eggs, but it took half a year to determine that."

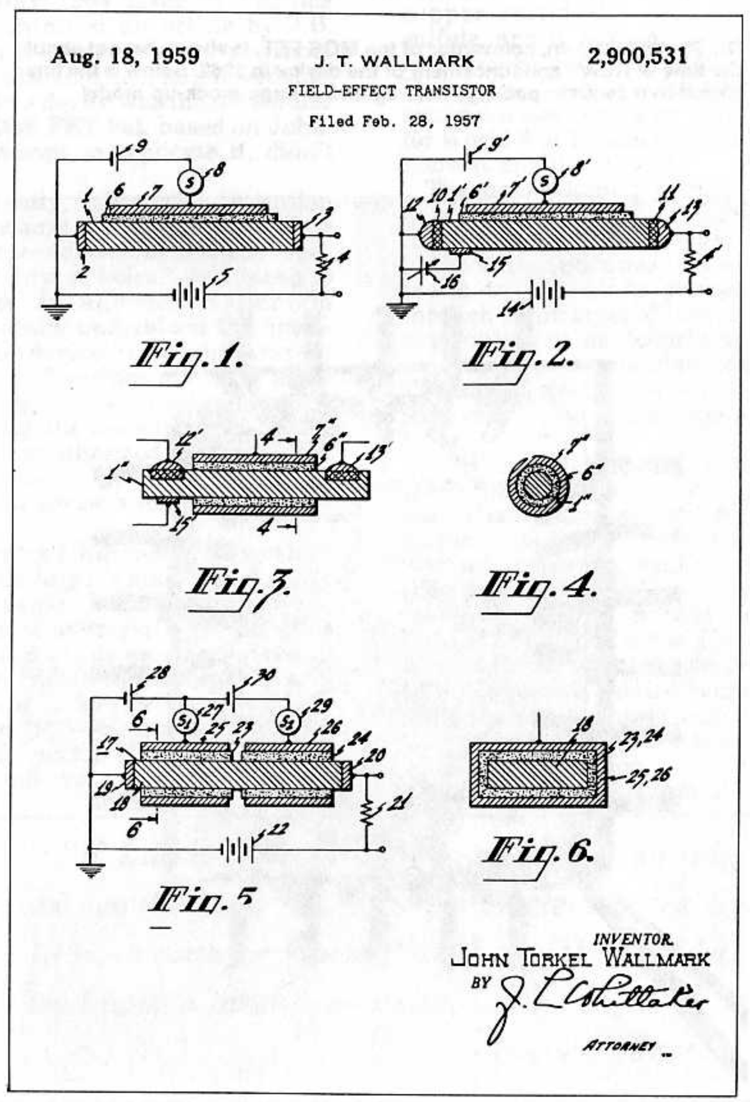
The significance of the MOS transistor's invention rests with Hofstein's and Heiman's early vision that this device by itself would be the only element required to form a complete integrated logic net. At the time the MOS FET was developed, the conception of these networks was that of hybrid circuits, combining transistors with resistors, capacitors and coils. Hofstein's and Heiman's goal was to fabricate a device that would be the only part needed to create a multithousand-transistor circuit.

The two inventors realized that goal by means of a significant departure from conventional unipolar FETs, which utilize the depletion region of a reverse-biased p-n junction to control the effective cross section, and therefore the conductance, of a bar of semiconductor material. They replaced the reverse-biased p-n junction with a metal-oxide-semiconductor control structure that, unlike the p-n junction, could be used to enhance as well as deplete the charge near the surface of a semiconductor, giving the device additional versatility. Hofstein and Heiman maintained that the geometry of the new structure lent itself especially well to integrated-circuit applications, and in late 1962 they succeeded in integrating a multipurpose logic block of 16 MOS transistors into a silicon chip that measured 50 × 50 mils. By 1963, they had fabricated an array of interconnected transistors with a packing density of 2200 transistors per square inch.

Important steps that were utilized in the development of the MOS FET included contributions by such innovators as Jean Hoerni, Bob Noyce and Jack Kilby, who originated the basic concepts of using silicon oxide as a shield against the diffusion of the controlled impurities used to modify the silicon. This application of silicon oxide is known as the planar process, and was patented by Hoerni, then at Fairchild.

The basic problem Hofstein and Heiman faced in the development of their device is one encountered eternally in the areas of research and development—reduction to practice. "It's one thing to have a concept—Julius Lilienfeld had a concept," Hofstein explains. "It's something else to reduce it to a practical formulation that makes for something that can work and be produced. The U.S. Patent Office insists now on a reduction to practice. In those days there were many concepts, but little practical formulation. What Fred and I did," he maintains, "was make the first commercially feasible silicon MOS transistors. We appreciated very much the work that had gone on previously, but what had been a laboratory curiosity and a subject of some technical papers now became a manufacturable device that in the decade to come would help transform electronics."

J.T. Wallmark envisioned the FET he patented for use in "integrated logic nets," later to be called "integrated circuits."



Mixed Emotions

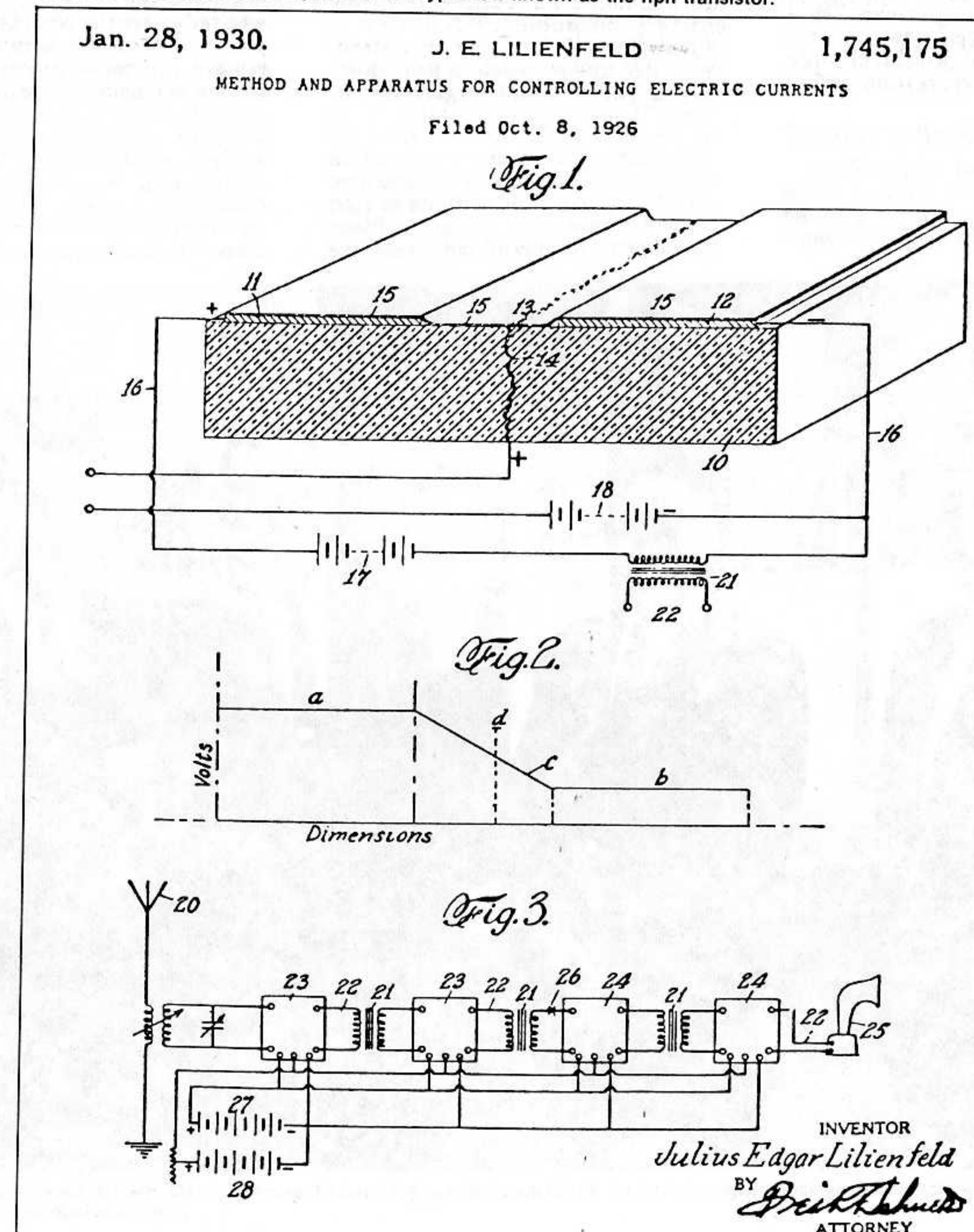
The success of their transistor was greeted with mixed emotions by the group at RCA. Those who had alternative approaches and were pursuing alternative development paths were extremely upset, according to Hofstein, that two young engineers had succeeded while on a graduate-study program in developing a device that ultimately proved the foundation of a major portion of today's electronics.

When RCA announced the device in 1962, it triggered immediate revelations by several other companies that they were also working on such a transistor.

"Every person involved with these investigations tried to claim his own place in the sun," Hofstein says. "But in today's world we have no more Leonardo da Vincis, no 'sole sources' of a particular invention. The development of the MOS transistor, the IC and even today's microprocessors is a continuous chain of events, and every person participating in that chain builds upon the work of the persons before him. The complexity of technology today is so great that it is no longer possible for a single person, or even a single company, to begin from zero and create a new industry. The era of Shockley Transistor Laboratories and early Fairchild is over."

Shortly after the first MOS transis-

The drawings of U.S. Patent 1,745,175, issued to J. E. Lilienfeld on January 28, 1930, show a device that seems to be a solid-state amplifier of the type now known as the npn transistor.



tors were announced, at least one company, General Microelectronics, headed by ex-Army officer Colonel Arthur Lowell, was established in an attempt to capitalize on the device. The company and Lowell foundered, apparently in part because of Lowell's personality and in part because the development of any new device represents the solution to a nonexistent problem.

Good Timing

"Before a device is developed, there is no problem," Hofstein explains. "Ultimately, though, an invention that at first was considered a luxury can become integrated within the workings of an industry and so become a necessity.

"That's what happened with the MOS transistor," he continues. "Had it been developed yesterday, its disappearance today would change nothing. But as the years from 1962 to 1972 passed by, its presence became an absolute requirement. The problem with the early entrepreneurs, like General Microelectronics and the Victor Calculating Co., whose machines first attempted the use of MOS circuits and failed, was that they started their stores before their product was really necessary."

The primary setback to widespread use of the MOS FET was its instability. It was discovered that even at room temperature the device drifted; its characteristics changed. Efforts in the industry ultimately proved that the presence of sodium, one of the most common elements on earth, was the culprit, and the processing used now is built around a sodium-free environment.

Today, the MOS FET has grown into a billion-dollar business, and the entire semiconductor industry a multibillion-dollar one. Hofstein attributes this stupendous growth in only about 15 years largely to the personalities that created the semiconductor industry and are still running it.

"It took the aggressiveness and foresight of people like Bob Noyce, Andy Grove and Gordon Moore, today at Intel," he notes, "to recognize the potential of a device like the MOS FET and push it into the technological limelight, convinced of its practicality. Oddly enough," he continues, "some of the men who received worldwide recognition for their contributions to transistor technology played only a minor role in the development of the semiconductor industry. Credit must also be given to the Lilienfelds, the Heils and the Atallas for their accomplishments, but it was the people who at one time sat over a bar in places like Boulder, CO, and discussed the work they were doing who today are the presidents and vice presidents of the companies that remain the major innovators in the field of semiconductors."

Chapter III

History of the Semiconductor Industry

Shockley Transistor Labs Is Formed in Palo Alto

In 1947, Walter Brattain, John Bardeen and William Shockley invented the point-contact transistor, a device initially heralded by Bell Labs as demonstrating the best properties of vacuum tubes. In 1957, eight young men, all under 30 and at the time collectively representing one of the most awesome pools of talent yet to direct itself to transistor technology, founded Fairchild Semiconductor—and, as far as the West Coast semiconductor industry is concerned, the sun began to rise over Silicon Valley.

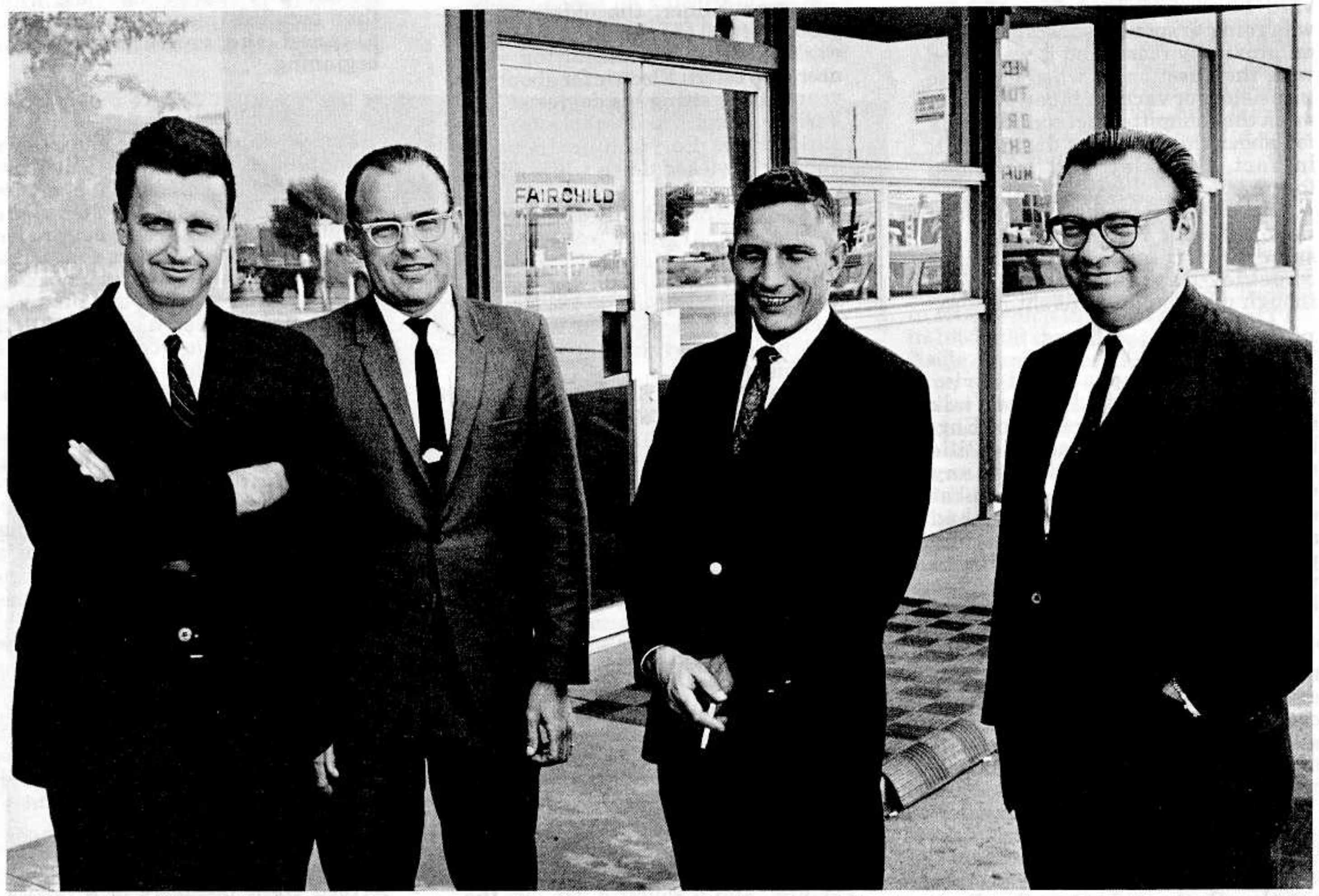
By no means did Victor Grinich, Jean Hoerni, Jay Last, Sheldon Roberts, Eugene Kliner, Julius Blank, Gordon Moore and Robert Noyce happen to bump into each other on the road to the diffusion furnace. Someone recognized at least a glimmer of star potential in each one, and, considering that pre-1960 the brains behind semiconductor technology were generally still scattered far and wide across the continent, managed the remarkable feat of getting all eight men together in the same place at the same time.

The man who executed that masterstroke was William Shockley. His ability to do so rested primarily with his reputation for technical brilliance, the magnet that drew the eight to Shockley Semiconductor Laboratories, later called Shockley Transistor Labs, in 1955. That they left en masse two years later to start their own company is attributable in large part to another Shockley quality: He could recognize good men when he saw them, but he couldn't keep them.

Still, had Shockley not the goal of setting up a business venture, no matter how poorly managed, based on transistor technology, it's doubtful that a Fairchild would have occurred. Bardeen and Brattain, who like Shockley would continue to gain recognition for technological breakthroughs (Bardeen won a second Nobel Prize for his theory on superconductivity), chose not to stray far from their roles as research physicists. In fact, Brattain remained at Bell Labs until his retirement in 1967.

Raytheon Backing

But Shockley had other ideas. His most famous attempt at gaining backing for founding his own semiconductor firm after he left Bell in



Left to right are Victor Grinich, Gordon Moore, Robert Noyce and Julius Blank, four of the eight Shockley Transistor Labs alumni who founded Fairchild Semiconductor in 1957.

1955 was aimed at Raytheon, headquartered in Massachusetts, one of the first companies to become interested in transistors primarily because of its holdings in the hearing-aid industry.

Today, Shockley maintains that he doesn't remember much of his dealings with Raytheon, which reportedly included an unsuccessful bid for $1 million (after taxes) guaranteed him over three years. He says that, as a native Californian, his most pressing desire was to get back to the West Coast, and after approaching other potential backers, including the Rockefeller brothers, he accepted Arnold Beckman's offer and returned to Palo Alto, where he finally set up his laboratories.

However, Norman Krim, during the early '50s vice president of Raytheon's receiving-tube division which then included the company's semiconductor operation, upholds the million-dollar story. He was also well-acquainted with Shockley by then.

"I met Shockley during the Korean War," Krim remembers. "We were both on the Baker Committee, which was set up under General Tom Larkin, then in charge of all materials procurement for the military, by General George F. Doriol, who taught manufacturing courses at the Harvard Business School. The military was going to spend a substantial sum on proximity fuses, and it was faced with the question of whether to use transistors or vacuum tubes. Those of us on the committee met continuously for about three months during 1951; in fact, Shockley and I roomed together."

Frank Dukat, product manager of radio tubes for Raytheon during the same time frame, recalls another Shockley-Raytheon transaction, though of a wholly different nature.

Defective Parts

"Shockley approached Krim because he was invited to give a talk on the transistor before one of England's most prestigious scientific societies, and he didn't have any transistors to demonstrate," Dukat says. "At the time, Raytheon had acquired all the hearing-aid companies, except perhaps for Zenith, so we were heavily into alloy transistors because they were supposedly quiet.

"The only problem," he continues, "was that we were having difficulty making them work properly—they emitted loud 'squawks'. We had been connecting the indium dots that were alloyed into the germanium with tungsten wire, and the connections were slipping.

"Now, you can't connect tungsten except by welding, and you can't weld indium," Dukat explains, "but it took us a while to put two and two together. So the upshot was that Raytheon handed over to Shockley devices that didn't work, and he ended up passing out defective transistors to his British audience."

Looks For Talent

Shockley's dealings with Raytheon safely behind him and his backing by Beckman Instruments secure, his next step was to stock his new laboratories with the talent he needed to exploit transistor technology and market workable devices. While he sought to fill positions that ranged from physicists to metallurgists to chemical and mechanical engineers, the men who met his requirements and landed at Shockley Transistor Labs all shared common traits: They were only a few years out of college but already noted for proficiency in their respective disciplines; they had glimpses into the possibilities of semiconductor technology; and they were drawn to the man who had earned worldwide recognition for his part in the invention of the point-contact transistor.

Newspaper Ad

Vic Grinich, for instance, then working as a research engineer at the Stanford Research Institute, responded to an ad Shockley had placed in a local newspaper.

Eugene Kliner, the oldest of the group but still only about 29, had been working as a manufacturing engineer at Western Electric for about five years after getting his degree at New York University and a short teaching stint at the Polytechnic Institute. Shockley tracked down while still at Bell Labs.

Jean Hoerni had earned one Ph.D. in physics at the University of Geneva and another at Cambridge University. He did post-graduate work at the California Institute of Technology between 1952 and 1955, just before arriving at Shockley Transistor Labs.

"I had heard of Shockley while he was still at Bell Telephone," Hoerni remembers. "I applied for a job at Bell by getting in touch with him, and he then told me he was starting his own business and induced me to go there instead."

Gordon Moore was doing research at the Applied Physics Laboratory of Johns Hopkins University in a field totally removed from semiconductors, and he was debating about getting into something that was "practical." Moore was also another native of California seeking to return to the West Coast.

"Shockley was just getting his labs started then," he says, "and he got my name from one of the companies that had offered me a job I turned down. He thought he needed a chemist, so he gave me a call one evening, and it sounded like just the kind of thing I wanted to do. I had heard him give at least a talk or two before that; I was certainly aware of his technological reputation at the time."

Moore recalls that he arrived at Shockley Transistor Labs on a Monday and that Bob Noyce had beaten him by three days.

"Bob and I were both coming out from the East," he explains, "and Shockley had arranged for the two of us to stop by and visit at Bell Labs on the way, so I met Bob back there. He then came out directly, and I stopped over the weekend at the University of Illinois to learn something about semiconductors."

Shockley's facility as Moore, Hoerni, et. al., first saw it could not have been too impressive; they describe it as a small, typical commercial building with a bare concrete floor, bare walls and a low ceiling. Located at 391 South Antonio Rd., it's now a Pacific Stereo store and so "still in the solid-state business," as Moore puts it.

One of Moore's first tasks was to start setting up fusion furnaces, "since that's the way the world appeared to be going," and the rest of the staff set off to develop the other basic tools they would need. A problem that arose immediately was that no one was exactly sure just what that entailed; insufficient direction plagued the venture from the beginning.

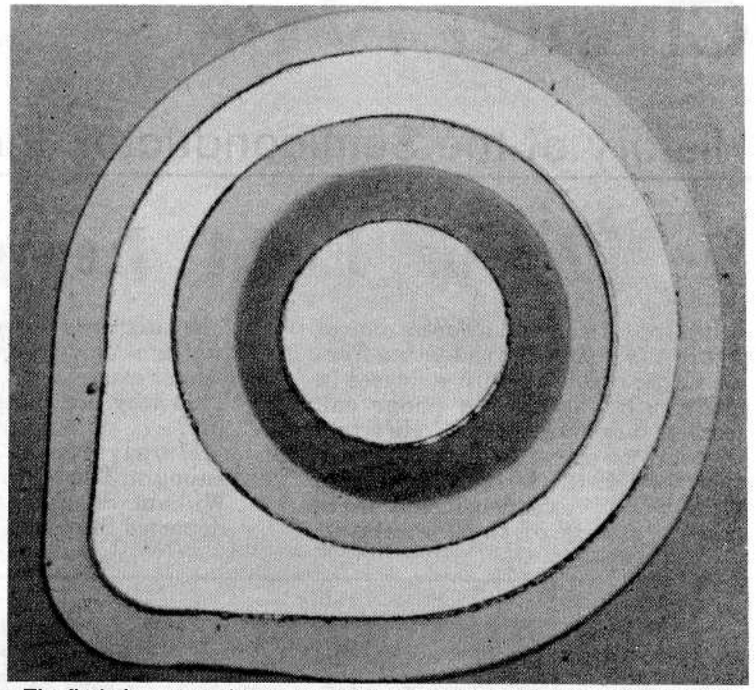
A 5¢ Transistor?

Moore maintains that Shockley's original idea was to make a 5¢ transistor, which, while such a device could be sold for that price today, he admits seemed an overly aggressive goal in 1955. Hoerni says that what he was supposed to do at Shockley Transistor Labs wasn't at all clear to him from the outset; it appeared that although Shockley could generate innovative ideas, the company couldn't focus on a particular product.

"It was evident that Shockley was expecting to invent another milestone product and exploit it commercially," Hoerni asserts. "And when he didn't immediately succeed in doing so, he continued to expend everyone's time and effort on trying new things instead of working to improve transistor technology."

Shockley did market a four-layer diode, similar to a pnpn type, but his recruits remained primarily interested in working with transistors. Discontent took root and quickly spread, although it was first manifested only by private rumblings, and by 1957 each had independently begun to consider leaving.

Hoerni believes one of the most fortunate turns of events that transformed eight members of a laboratory's staff into Fairchild's founders was Shockley's managing to antagonize all of them simultaneously.



The first planar transistor developed by Fairchild Semiconductor in 1959.

"Most people become dissatisfied and choose to leave a place at their own pace," he explains, "but we all decided to depart at the same time."

"We were all considering a next career step," Moore agrees, "and one of us happened to write a friend of his father who worked for Hayden Stone, a New York brokerage firm. He said something like, 'Hey, there's a bunch of us out here thinking about leaving this company and who like working together, so do you think there's anybody who'd like to hire the whole group?'

Fairchild Contacted

"Hayden Stone contacted Sherman Fairchild," Moore continues, "who introduced them to John Carter, president of Fairchild Camera and Instrument at that time. Carter financed us as a separate semiconductor venture, and in two years FC&I exercised its option to buy."

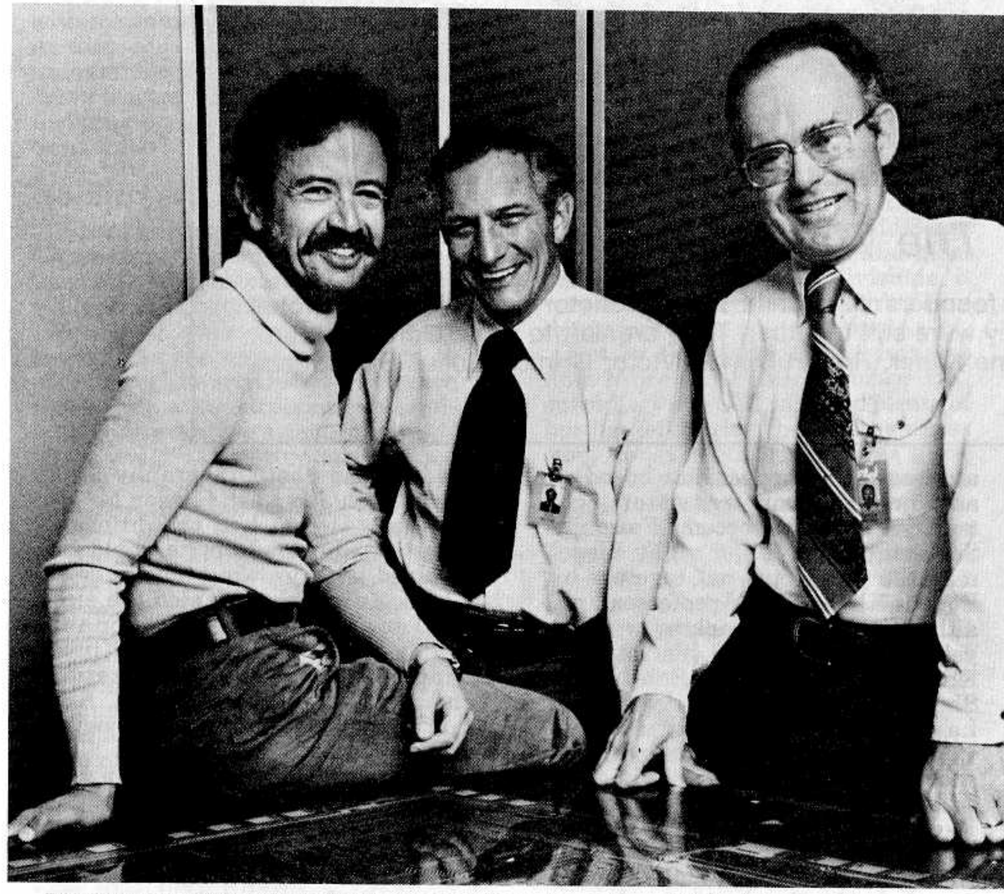
The group's first product was the realization of the idea it used as its selling point and which Hoerni maintains should have been the focus of Shockley Labs—the 2N696, -97 double-diffused-base silicon transistor. Bell Laboratories had developed the diffusion process in 1955, whereby impurities are diffused into the surface of a germanium or silicon wafer by heating the material in an atmosphere containing gaseous dopants. The newly created semiconductor operation made the first commercially feasible devices using this process at a time when the market was ripe for expanded transistor technology based on silicon rather than germanium. The first hundred units were sold to IBM's Federal Systems Div. at $150 apiece for use as memory code drivers.

A Running Start

So Fairchild Semiconductor got its running start, jumping from sales of $500,000 in 1958 to $7 million in 1959. During that year Hoerni used diffusion and oxide masking to develop the planar technique, and Noyce patented a practical integrated circuit based on the concept.

The paths that Fairchild Semiconductor and Shockley Transistor Labs then followed couldn't have been more wildly divergent. The latter suffered an early death: Beckman Instruments sold the labs to Clevite in 1960, which in turn was sold to ITT in 1965 and then closed down in 1968. Aside from all of the technological innovations Fairchild Semiconductor has fostered, it early secured its place in the annals of electronics by becoming the prolific parent that spawned a regional semiconductor industry. During the first year of its existence, the firm lured Ed Baldwin from Hughes Semiconductor Div. to head the operation, and when Baldwin left two years later to found Rheem Semiconductor (he was replaced by Bob Noyce as Fairchild's general manager), the Fairchild spinoffs had begun.

Three of the founders—Hoerni, Last and Roberts—left Fairchild in 1961 to form Amelco, later renamed Teledyne Semiconductor. When in 1968 Moore and Noyce departed to form Intel and Julius Blank to join Ness Industries, they left none of the eight behind at the giant in semiconductor technology they had created. But they had also set a world in motion—and that's another chapter.



Bob Noyce (center) and Gordon Moore (right) are shown here with Andy Grove, who left Fairchild with them in 1968 to form Intel Corp., one of the most successful Fairchild spinoffs.

Chapter IV

History of the Semiconductor Industry

'Traitorous Eight' Leave Shockley Labs

It's June, 1957, and a young man of 26 or so, just prior to graduating from an Eastern college with a degree in engineering, receives a phone call from a former instructor. He's told there are job openings of a technician-type level at the West Coast laboratories set up two years before by one of the inventors of the transistor. Naturally, the young man jumps at the chance to share some of the limelight, embarks on a cross-country jaunt, accepts the job offer and returns East for the summer to tie up loose ends with the prospect of basking in California sunshine come fall.

It's now September, 1957, and the young man has just arrived for what he hopes will be a permanent stay in Palo Alto. He calls up the former instructor and now fellow employee, who advises him not to go down to the laboratory facilities but to come to a party that night instead. He does and finds congregated there eight men whom he assumes will be his co-workers at the labs—but their employer is conspicuously absent. He immediately discovers that the job for which he moved across a continent no longer exists.

So why are these eight men smiling?

Murray Siegel found out soon enough. The "Traitorous Eight"—William Shockley's term—had just departed Shockley Transistor Laboratories to start an operation based on advancing silicon transistor technology that would become Fairchild Semiconductor. That night Siegel read the prospectus put together by Eugene Kliner, his old professor, and, although financial backing was not yet secured, threw in his lot with Kliner, Gordon Moore, Bob Noyce, Sheldon Roberts, Vic Grinich, Jay Last, Jean Hoerni and Julius Blank. Whatever else Siegel has or will accomplish during his lifetime, he will always be known as Fairchild Badge #009.

"Not only didn't we have backing, we didn't even have a building yet," Siegel recalls, "but we knew what we had to do. We were set on working out a method of mass-producing silicon transistors using a chemical-etch system called the 'mesa' process, so we immediately started determining what our initial requirements would be."

Siegel took over responsibility for the applications lab and would work with Vic Grinich. Bob Noyce would head up the photolithography techniques with Jay Last, Gordon Moore and Jean Hoerni had the diffusion expertise, Sheldon Roberts would get involved with growing silicon crystals, and Grinich was also the electrical engineer who would define and specify device characteristics. Kliner handled the initial administration and running of the business. And that's how the organization stood by mid-September, 1957.

Around October 1, the group had reached an agreement to occupy a new building that was going up on Charleston Rd. Meanwhile, Grinich and Siegel carried out the initial layout work for crystal probers in Grinich's garage, which still stands at 615 Georgia Ave. in Palo Alto.

The Way They Were

Here are shown all eight founders of Fairchild Semiconductor in one of the few photos taken of them while they were still together. They are, left to right, Gordon Moore, Sheldon Roberts, Eugene Kliner, Robert Noyce, Victor Grinich, Julius Blank, Jean Hoerni and Jay Last.

The most immediate requirement at the time for the new venture was to build test equipment, since none was available. For that matter, diffusion furnaces and bonding equipment were in no great supply. "There was no such thing as an instrumentation marketplace in those days," says Siegel. "If you wanted something, you sat down and started drawing it. Someone would look over your shoulder, make a suggestion, and you'd try it. It was that simple—and that complicated. There were no standards to go by."

So the group devised standards. A wooden work bench that is still used uniformly throughout Silicon Valley was designed by Grinich and Siegel in the Georgia Ave. garage. "We had no idea how high it should be," Siegel relates, "so one day in my motel room (I still hadn't bought a house yet) Vic and I took telephone books and stacked them on a table while we stood next to it. When the telephone books hit our midsections—we're both about the same height—we decided that was the height of the table we'd want. That ridiculous bench is an industry standard today."

In another instance, the organization bought one of the first curve tracers manufactured by Tektronix and developed a close relationship with that company's field engineer. The tracer was sent back to Tektronix with recommendations for improving it, and consequently much of the innovations Tektronix applied to its curve tracers had their origins in the fledgling operation's garage-applications lab.

This is how the garage that 21 years ago housed the beginnings of Fairchild Semiconductor looks today at 615 Georgia Ave., Palo Alto.

No Electricity

When the group first moved into the Charleston Rd. facility, the building was still under construction; the walls were in, but it had no electricity. "We would work until dark," says Siegel. "As the days got shorter, so did our work hours. Outside, however, there was a construction line pole with power that we attached wires to so we could at least do sawing and such. I remember seeing Vic Grinich out there that fall with gloves on, a muffler, a hat and his pipe, with a heater nearby plugged into the line."

Electricity or no, the nine upstarts still managed to convince Fairchild Camera and Instrument of the propitiousness of developing the mesa transistor using silicon instead of germanium, and they proceeded with FC&I's financial blessing. It might seem extraordinary that a company of that magnitude and respectability should have decided to back a group of men all under 30 who appeared to have little more than a conceptual idea that they wanted to reduce to practice. The common explanation is that at the time FC&I had no other growth areas left to it and didn't know where else to go with its money.

Fairchild's Foresight

Also, Sherman Fairchild must have realized that electronics would one day revolutionize the American lifestyle and that semiconductors would revolutionize electronics. The possibilities were probably irresistible to a man who had already successfully exploited numerous other marketplaces. Considering that at least as early as 1966 Fairchild Semiconductor was the largest and most profitable of FC&I's 13 divisions, it was undoubtedly the wisest decision the parent company ever made.

But by November, 1957, what was now Fairchild Semiconductor Co., subsidiary of FC&I, still had plenty of hurdles left to clear before its success story could begin. Hiring was a tremendous problem in that the organization had to set up some sort of testing procedure for prospective employees, and no one had ever taken a course in semiconductors. Most of its first production workers were literally graduate students out of Stanford University. Employers and employees alike, many with backgrounds in vacuum tubes, simply set about reeducating themselves.

The payoff came as early as January, 1958, when IBM placed its first order for 100 silicon transistors based on the mesa process. That order was certainly cause for celebration, but once the group collectively got its feet back down on the ground again, it did so with a resounding thud. The task ahead was monumental.

Siegel recalls that deliveries on the order weren't made until at least May. "We had gotten all our equipment into place," he says, "but those transistors probably came off about three wafer runs. FC&I had invested about a million and a half dollars for us to produce 60 wafers to make 100 workable devices, and they cost approximately $200 each. One of them would sell for 3¢ to 6¢ today."

Siegel adds that while IBM was somewhat impatient to receive its deliveries, the company exerted little pressure on the semiconductor operation.

"IBM knew that the mesa process, which had been patented by Bell Labs, was up to that time still little more than a laboratory curiosity," he explains, "and it was ecstatic at the prospect that it might be able to get operating transistors based on the concept—at whatever price."

Tom Bay, who had come on board in November and assumed the position of marketing manager, recalls that a big decision regarding those devices was whether to make them npn or pnp.

"Two teams were set up," he says, "with Gordon Moore heading the npn effort and Jean Hoerni the pnp. The npn types won for various reasons, primarily because in those days we were more successful in producing reasonable yields with them."

These early devices were designated the 2N696 and 2N697. The next generation were higher voltage versions, followed by smaller area devices with higher frequency. Then came a pnp version of the same product, the 2N1131 and -32—all part of the organization's thrust to make silicon transistors with properties as good as those of germanium devices and then push the state of the art.

"It wasn't difficult to decide what to market," Bay remembers. "It depended on product capabilities at that time. We were competing both with the people who made germanium devices and those who made silicon ones.

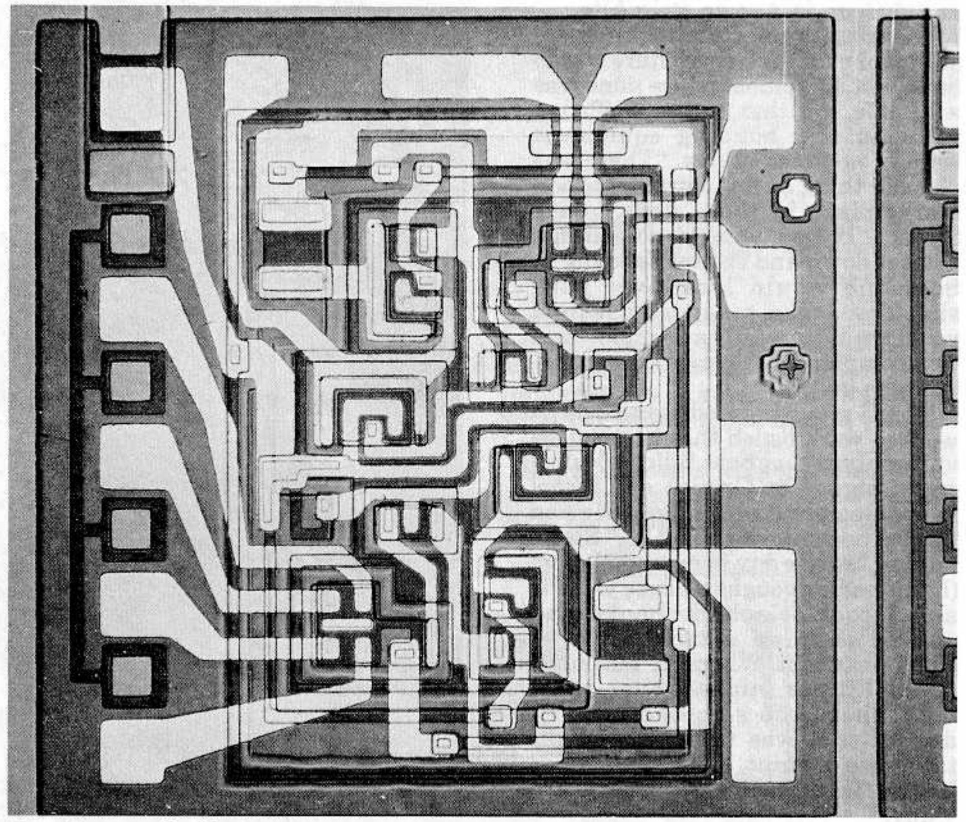
"We were then ahead of everyone making germanium types," he continues, "but behind those working with silicon. You could produce higher frequency devices with germanium but use higher power densities with silicon, because germanium is a lower temperature material. The transistors IBM wanted were for use in a digital computer as memory drivers. Silicon was the only alternative because the application was intended for aircraft and involved stringent temperature requirements. The only transistors available in silicon from other manufacturers just weren't good enough, and we came in as a last hope. Finally, we succeeded where others had failed."

Other IBM applications followed, and the company began to accumulate customers from around the country. Sales volumes allowed it to break ground for an expanded facility in Mountain View before the organization was a year old.

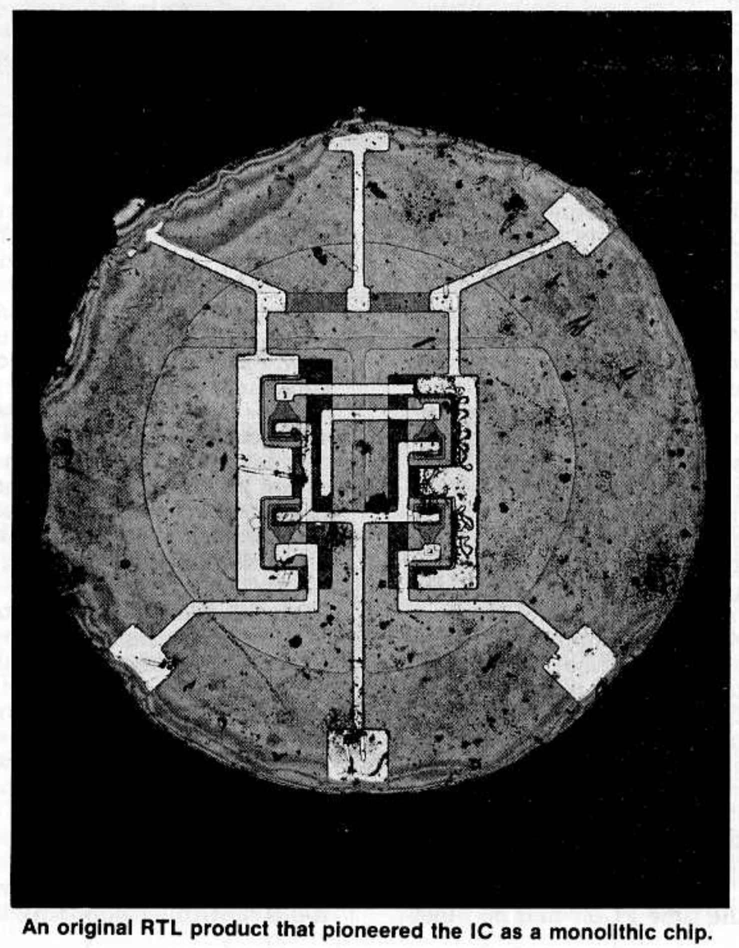
The next big step from a technology standpoint was the development of the planar process. According to Bay, Jean Hoerni said something on the order of, "All right, the bastards want a better npn, I'll make them a better npn product than they've ever seen!" He did.

While Bob Noyce is generally acknowledged to hold the patent on the first planar integrated circuit, Bay maintains that it's hard to attribute that innovation totally to any one individual. "As soon as the planar process was developed," he says, "we were all saying that now we can put devices on a chip, interconnect them and not have to worry about shorting the junction. Bob Norman, a chip designer we hired from Sperry, was probably most responsible for choosing the type of circuits to make. He was also familiar with RTL, the circuit chosen to implement Fairchild's original Micrologic product line in 1961."

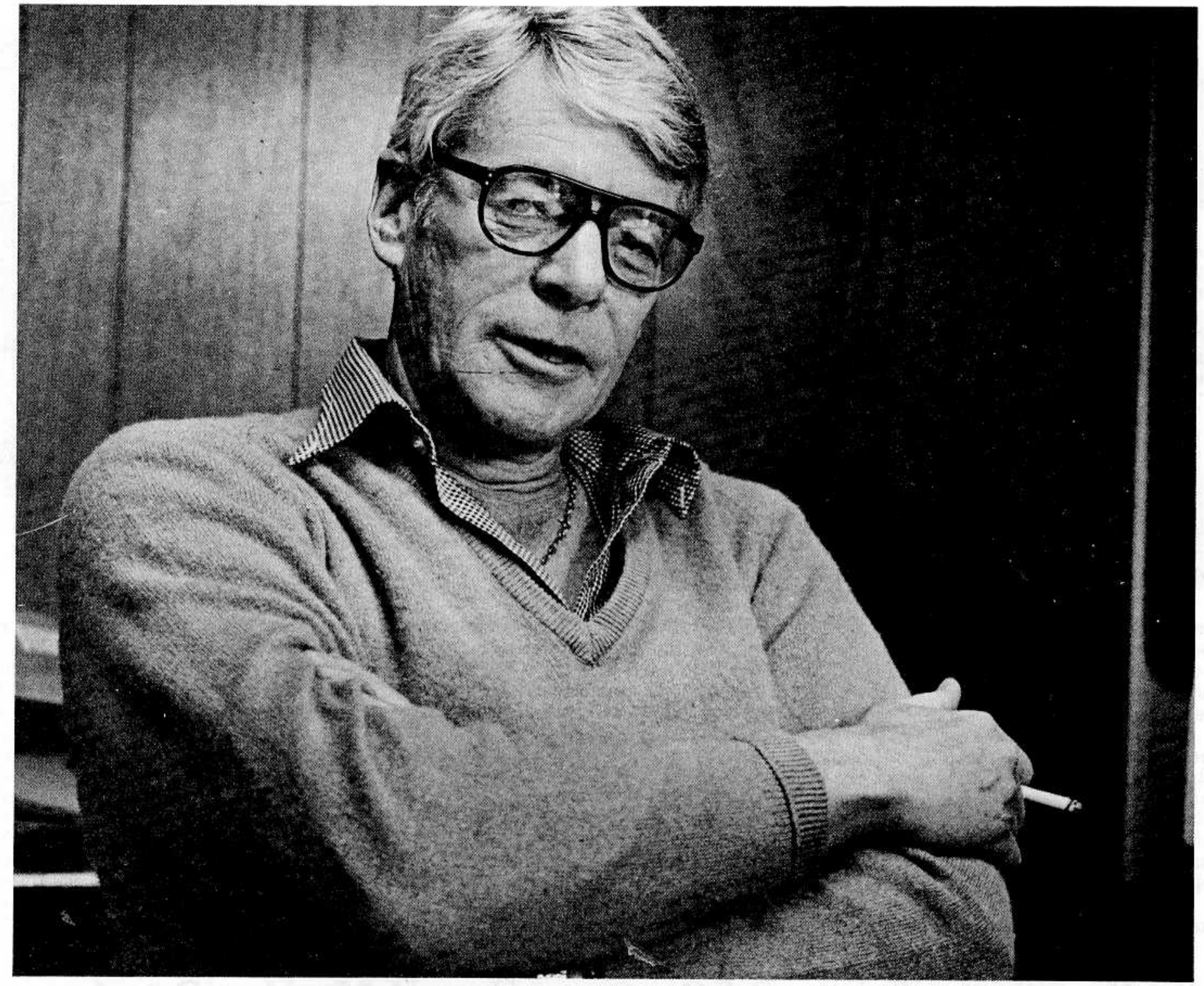
Everyone knows that the planar process spawned an entire IC industry during the 1960s. However, probably the single biggest occurrence to put Fairchild Semiconductor early on the map was its being chosen by the North American Autonetics Div. to provide the 2N697 and 2N1132 to the Minute Man I missile program in 1959. "We were little nobodies,"



Chip photograph of the second-generation Fairchild RTL device that was the first to incorporate buried-layer isolation technology.



An original RTL product that pioneered the IC as a monolithic chip.



Tom Bay, who came on board Fairchild Semiconductor in November, 1957, was the operation's first marketing manager.

Bay emphasizes, "and the devices Autonetics was considering were made by Texas Instruments. No one takes a contract like that away from Texas Instruments."

That year the company also produced a line of diodes, and a separate plant in San Rafael was erected to handle the volumes. By 1960, FC&I, obviously more than pleased with the performance of the subsidiary company that had originated in a garage, exercised its option to buy and made Semiconductor a division.

Early Contributions

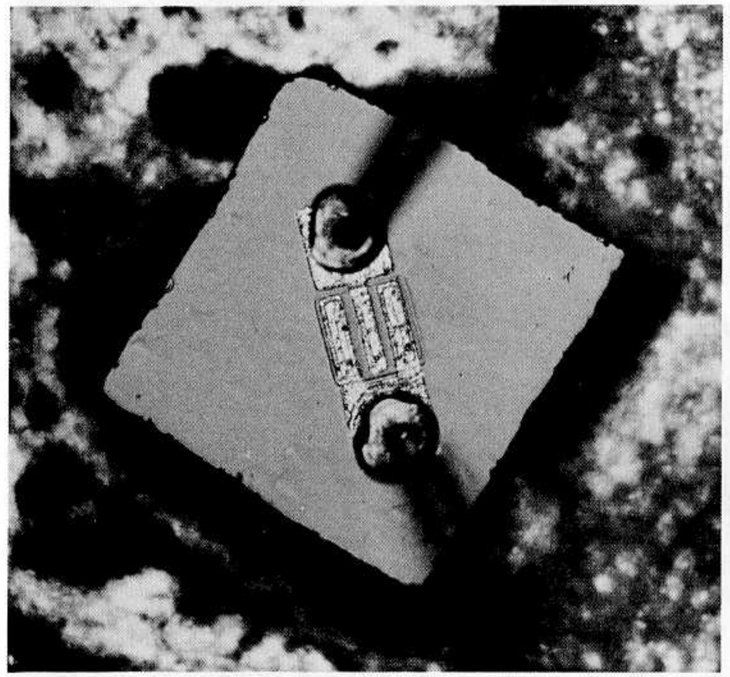
The next most significant contribution that the division would make to the industry as a whole was an operational linear integrated-circuit amplifier, the 709, developed by Bob Widlar in 1965. Other innovations throughout the 1960s included the first IC as a monolithic chip, the first widely accepted epitaxial gold-doped npn transistor, a custom design for the first commercial application of TTL, and bipolar LSI.

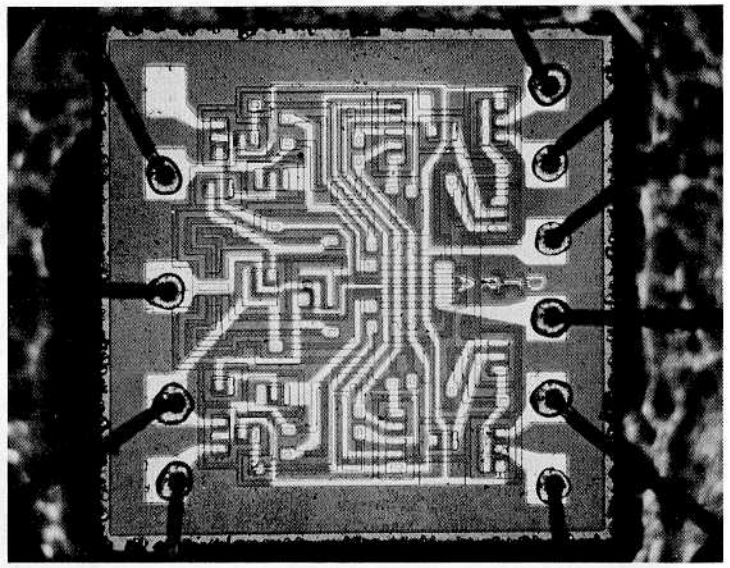
However, the complexion of the division changed radically during that decade. Ed Baldwin had signed up in 1958 to head the growing operation—there were at least 100 employees on board by then—and he brought along a team of individuals who were totally loyal to him and left with him a year later. Hoerni, Last and Roberts departed in 1961 to form Amelco, the result of growing disillusion with FC&I management policies that mushroomed into turbulent unrest over the next few years. The original founders resented their division's reporting to a group vice president while other divisions reported to FC&I chairman John Carter. They seethed when Fairchild Semiconductor's profits were used as seed money by Carter for startup operations and to help unprofitable divisions instead of to buy badly needed equipment for Semiconductor. The general exodus of the founders plus early employees like Siegel and Bay, Carter's resignation and the unprecedented lure of Lester Hogan, in terms of financial enticement, from Motorola in 1968 are a separate story.

Nevertheless, the dissension bred during the '60s doesn't alter the

"The thing that triggered the explosion was our having technology ahead of everyone else."

—Tom Bay





Fairchild's first widely accepted epitaxial gold-doped npn transistor (left) and its original static flip-flop (the industry's first).

remarkable early success of Fairchild Semiconductor that is rooted in the years from its inception until its acquisition by FC&I. What were the reasons?

Talent, for one, which few will dispute. Bay remarks that "the thing that triggered the explosion was our having technology ahead of everyone else. That helps you attract people in every area—marketing, manufacturing, etc. People like to be with technology leaders."

Another factor was the glamour associated with the semiconductor industry that was already felt by many during the late '50s and is still a drawing card today. "We could attract good people a lot easier than if we were making hairpins," Bay continues. "Certainly for a scientist there was no place else to go to get the kind of status and challenge that a Fairchild offered. Our only problem was that we were so small in the beginning compared to a Texas Instruments or a Philco."

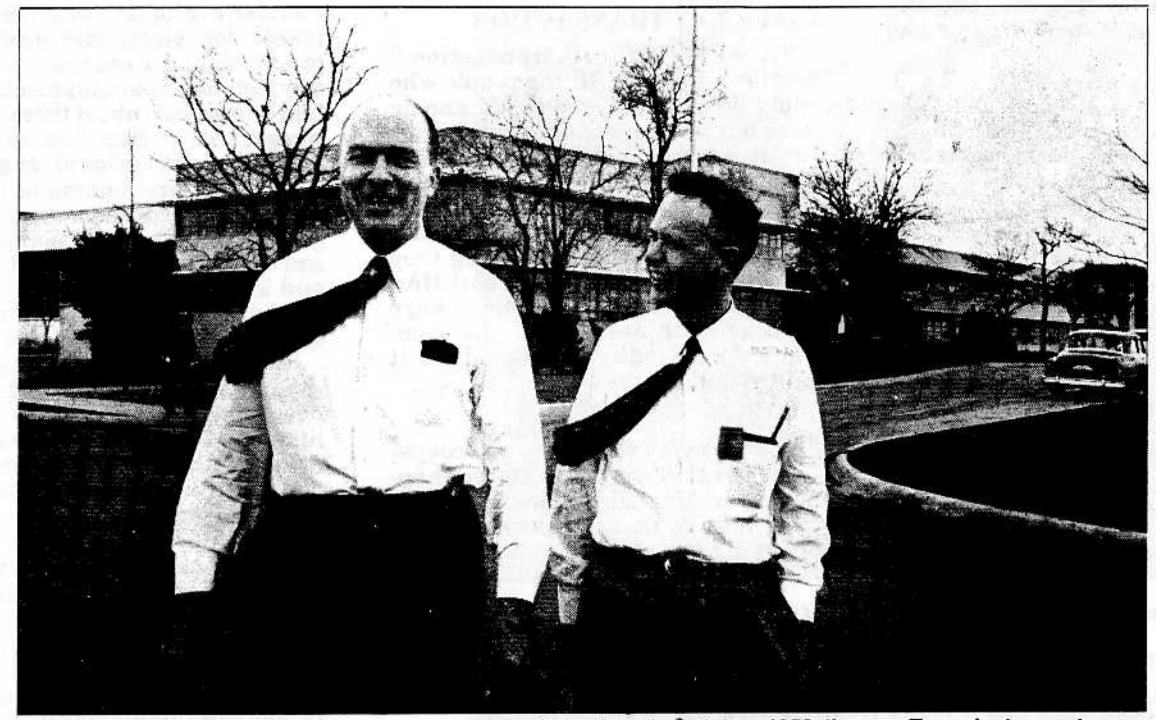
What is even more puzzling is that a group "whose collective lack of management experience would have made the AMA fall on the floor," as Siegel puts it, could have run itself so expertly that sales jumped from $500,000 in 1958 to $7 million in 1959.

The answer is simple, according to both Siegel and Bay: Each of the original founders could work independently and assumed full responsibility for what he could do best, egos apparently surfaced but rarely, company focus was in place from the beginning, and the group as a whole was blessed with a necessary naivete.

"We just never expected to fail," Siegel concludes.

Chapter V

History of the Semiconductor Industry



J. Erik Jonsson (left) and Patrick E. Haggerty are shown here in October, 1953, the year Texas Instruments was listed on the New York Stock Exchange.

The Birth of Texas Instruments: Founders Give Up 25-Year Focus On Oil Search To Build a Radio

Twenty-three years before William Shockley, John Bardeen and Walter Brattain invented the point-contact transistor, what is today one of the largest manufacturers of semiconductors in the world had its beginning in an office waiting room in St. Louis. There, in 1925, Clarence Karcher and Eugene McDermott signed the papers to found the Geophysical Research Corp. of Tulsa as a subsidiary of the Amerada Petroleum Co. Five years later, the two young scientists formed an independent company, Geophysical Service, Inc. (GSI), located in Dallas and renamed Texas Instruments in 1951.

Considering the firm's current status in the semiconductor industry, the most astounding fact of TI's inception is that the company's early focus had no basis in semiconductors or even research into solid-state physics, but rather in the search for oil. Back in 1917, Karcher, while studying physics at the University of Oklahoma, had determined that reflected sound waves could be used to pinpoint areas in the earth where oil might be found, and he and McDermott exploited that technique to make GSI the leading company in geophysical exploration in the U.S. during the worst years of the Depression.

The firm designed and built its own equipment in its Newark, NJ, laboratory, and that's where the need for a man like John Erik Jonsson came in. McDermott and Karcher only knew then that they wanted someone to manage the manufacture of geophysical instruments, but it was Jonsson's pivotal decision after World War II to expand GSI into electronic and military manufacture that laid the groundwork for its entry into the transistor business.

THE EARLY YEARS

Jonsson's story again underscores how the beginning years of Texas Instruments radically differed from those of a competitor in semiconductors like Fairchild Semiconductor: Most of Fairchild's founders and early management had backgrounds, if not in semiconductors, then at least in electrical engineering and some exposure to solid-state physics. Jonsson, who later rose to chairman of the board of TI and then to mayor of Dallas, was a mechanical engineer by way of a degree from Rensselaer Polytechnic Institute; he recalls that he hadn't much footing in electronics when Karcher and McDermott offered him a job at GSI.

"I worked at a couple of jobs before I went into this business," Jonsson says, "one for myself as an automobile dealer, which crashed along with just about everything else in 1929, and the other at Alcoa as a so-called sales engineer—'peddlar' would have been more like it. I had built radio sets on my own to make money on the side in order to eat, and that's about all the electronics background I had."

Jonsson continues that after he got Karcher's telegram in his office at Alcoa, he telephoned Karcher, asked him a few questions and said, "O.K., I'll go"—even though he felt he knew little about instrumentation.

"It was a dangerous thing to do in 1930," he admits, "because I was safe with Alcoa and this venture offered a little bit beyond ordinary risk. But I knew my man Karcher and his partner McDermott, and I knew they had the mental and physical resources as well as the financial backing that meant they were going to make it.

BRILLIANT PEOPLE!

"Karcher was a brilliant physicist," Jonsson adds. "McDermott had a master's degree in physics from Columbia, and if he was behind Karcher in I.Q., it wasn't by much. They were both just brilliant people, and they could lose me pretty fast. But they never let me know that—which was kind of them—and I still haven't caught up."

Jonsson spent from 1930 to 1934 working in the Newark laboratory, far from the inquisitive competition in the Texas oil-drilling fields. "I let contracts for parts," he recalls, "bits and pieces of equipment that were to be fitted together in a shop that was kept tightly locked. The competitors didn't quite know what we were up to, and we didn't have any intention of helping them out any more than we had to."

"I knew my man Karcher and his partner McDermott, and I knew they had the mental and physical resources that meant they were going to make it."

—J. Erik Jonsson

After four years, Jonsson was invited to come down to Dallas, and within a week he was made secretary of GSI.

"That was a pretty anomalous title," he says. "It was sort of a general manager's job, except that I didn't have the authority to fire anyone but the office help. It was kind of hard at times," he remembers, "but very instructive. I learned enough flying by the seat of my trousers to become a kind of general manager."

Toward the end of the 1930s, GSI began to change focus. Jonsson recalls that since the company was searching for oil for the major oil companies, sometimes two or three contracts would expire simultaneously. "When that happens," he says, "your choice is to lay people off and lose all their know-how, then hire new people later at great expense. So we kept them on and let them explore for our own account.

"Finally, in 1941," he continues, "we decided that the best thing to do was to separate into an oil company and a geophysical company." The oil division was named the Coronado Corp., with GSI its geophysical subsidiary. Karcher and others who controlled the stock in the oil company decided to sell their shares to four GSI employees—McDermott, who became president; Jonsson, vice president and treasurer; Cecil Green and H. Bates Peacock.

DIFFICULT TRANSACTION

"It was a difficult transaction," recalls Jonsson. "All the people who could have engineered the financing were out of town except myself. But I arranged the deal with the public bank in Dallas, and the day we signed the papers was December 6, 1941."

It must have seemed to the four new GSI owners that the last thing they needed at that point was Pearl Harbor. However, the war would change Jonsson's thinking and the company's entire direction—and, as it turned out, for the better.

"I was on my way to the golf course when I got the word on what was happening in Hawaii," Jonsson remembers. "I knew that if we were shut out of buying any of the key materials for our geophysical work, like B batteries to feed the vacuum tubes or photographic material to make seismograms, we'd be out of business. Fortunately," he continues, "the Government thought oil-finding was going to be pretty important to it, so we got sufficient military contracts, including for manufacturing magnetic airborne detection equipment, to actually expand the business during World War II."

That was the context from which Jonsson got the idea to expand into military manufacturing as a major company focus. "It seemed very clear to me that often we had a number of crews laid up waiting for new contracts, and all the profits we made were in the backyard rusting in terms of idle equipment," he explains. "Another batch of the profits was going up in smoke just carrying people, so I suggested to my partners that we go into the manufacturing business. They agreed."

GSI had only made about a million dollars' worth of instruments that were reasonably akin to what the company used in its geophysical work, according to Jonsson. Aerial magnetometers and "black boxes," or electronic subsystems, formed the basis of its manufacturing activity at that point, and any expansion called for major personnel additions. So, a few days after the war ended, Jonsson went to Washington and invited Patrick Eugene Haggerty to lunch.

Haggerty had been as ensign in the Navy's Bureau of Aeronautics where he was involved in electronic-manufacturer evaluation and placing contracts for electronic and electromechanical devices similar in function to GSI's equipment. Jonsson had known him about three years and recognized in him "an exceptional mind, an exceptional engineering capability, and complete integrity. You don't need much more to find a good man." Haggerty accepted Jonsson's lunch invitation and job offer, and in 1945 he became general manager of GSI's laboratory and manufacturing division.

Five years after Haggerty went on the payroll, he approached Jonsson, now president of the firm that had just been renamed Texas Instruments, with the idea that was to complete its transformation into a major manufacturer in the electronics industry.

Says Jonsson, "Haggerty came to me and said he's been reading some dope on the latest thing that Bell Labs had accomplished, and he couldn't sit still about it. He convinced me that we should immediately get into manufacturing germanium transistors."

So, in the fall of 1951, Jonsson went to New York and met with a group of lawyers from Western Electric, which was selling licenses for manufacturing the transistor for $25,000. Texas Instruments came up with the money, says Jonsson, "but I had a hell of a time convincing Western Electric to sell me a license.

"They just didn't think we could make a transistor," he recalls. "They thought we were too young and inexperienced. We finally got the license the following May, because I wouldn't leave until I got it. I guess they didn't want to have to tear that AT&T building down to get rid of me."

That spring Bell Labs held a symposium to teach transistor technology to the new licensees, and Texas Instruments sent four men, including Haggerty and assistant chief engineer Mark Shepherd, Jr., today TI chairman, to learn all they could in eight days.

COPIOUS NOTES

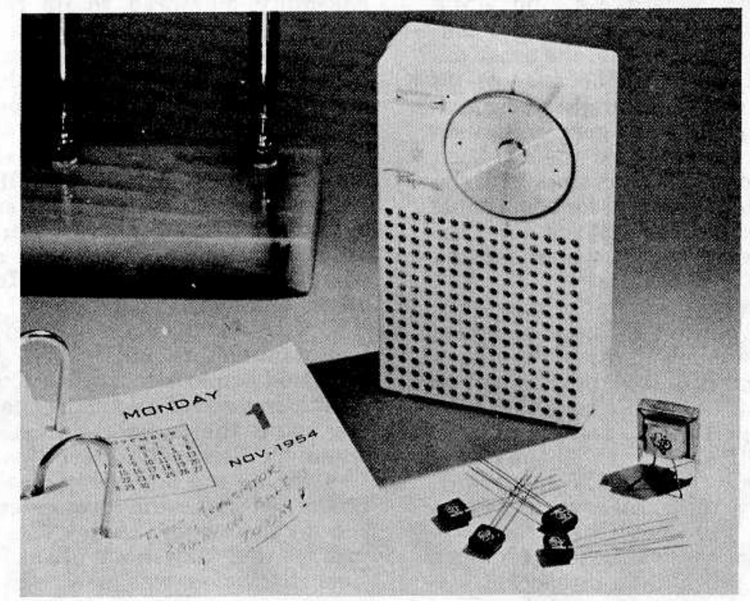
"When our four people came back to Texas, they brought with them copious notes, but not much information," Jonsson recalls. "Nevertheless, we set out to make a transistor on our own before the first of the year, with Shepherd head of the group that would become the semiconductor-components division. And by Christmas, we had done what they said we couldn't do—we had our transistor. The first sale was an order for 100 devices from the Gruen Watch Co."

That was a monumental feat, since all anyone then had at TI that could be applied to solid-state physics was plenty of nerve and brain power, and little to no experience. More than 20 years later, Haggerty, speaking during the 1976 Salzburg Seminar on Multinational Enterprise as former TI board chairman, would note that prior to the spring of 1952, "not one single hour of effort had gone into research and development on semiconductor devices at Texas Instruments." But less than two years later, the semiconductor division made a name for itself with the mass-production of high-frequency germanium transistors, and the man who contributed largely to that breakthrough was Gordon Teal, working with Shepherd's transistor group.

"By Christmas of 1952, we had done what they said we couldn't do — we had our transistor."

—J. Erik Jonsson

Patrick Haggerty (left) congratulates Regency president Edward Tudor on the announcement of the first commercial transistor radio.



The transistor radio went on sale November 1, 1954 for $49.95.

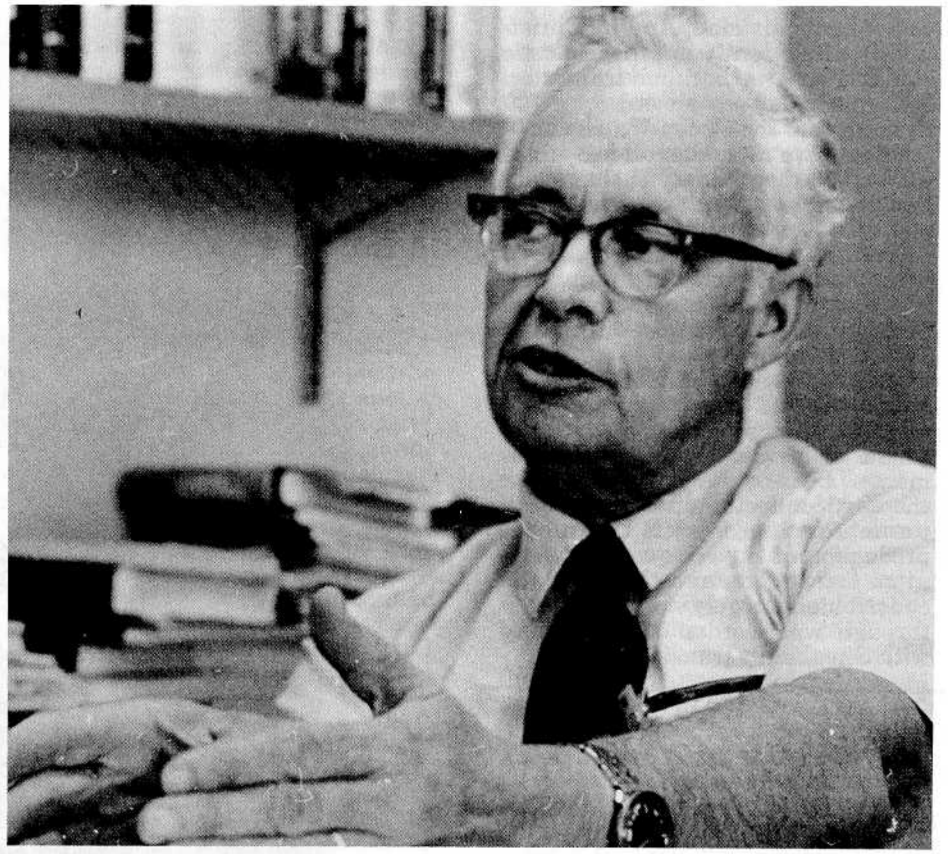
Teal, who came on board Texas Instruments in December, 1952, had worked with Shockley, Bardeen and Brattain at Bell Labs and was one of the inventors of the single-crystal grown-junction technique of making semiconductors. He answered a blind ad in the *New York Times* for an engineer to head up research, and when he learned that TI had the transistor in mind, the native Texan decided to go back home. What followed, according to Jonsson, was a quick setup for germanium-transistor manufacture and a technique for reducing the price of those transistors from $16 to $2.50 a apiece. And that's what made Haggerty's idea of the "shirt-pocket" transistor radio a reality in 1954, which put Texas Instruments on the map for good and made the transistor a household word.

"To sell a pocket radio at that point," Jonsson recalls, "it was our opinion that it would have to list at $50. But four transistors times $16 wouldn't do it, so we had to design a manufacturing process so much better than any other at the time that we could sell them for $2.50 each. We figured that if we could get $10 for four transistors, the manufacturer could put the rest of the parts together for $17 or $18, sell a $50 radio and still have a little left over for himself after paying a dealer. Well, we came up with the technique, Regency bought the idea, and that radio went on the market at $49.95."

Still another TI breakthrough occurred that year that made people sit up and take notice of what was going on down in Texas. And again, Teal was highly instrumental in generating the shock waves that shook up the electronics industry on May 10, 1954.

He was a speaker before the National Conference on Airborne Electronics to be held that day in Dayton, OH, and his topic was "Some New and Recent Developments in Silicon and Germanium." The title of his talk gave no clue to what Teal would announce to the crowd

Former TI board chairman Patrick E. Haggerty once noted that prior to the spring of 1952, "not one single hour of effort had gone into research and development on semiconductor devices at Texas Instruments."



gathered at the Dayton Engineering Club: The germanium transistor was certainly no longer news. And, while industry-wide research had been conducted for some time on the use of silicon for transistors because of its ability to withstand higher temperatures compared with germanium, as far as anyone knew, no one had been able to grow silicon crystals with the characteristics needed for a workable transistor. No one, except for Teal and his research staff, who so far had kept mum.

As a result, speaker after speaker in the course of their discussions denied the near-term feasibility of the silicon transistor, until Teal, next to last on the agenda, took his turn. Jonsson recalls that Teal, "a quiet man," put everyone to sleep until, at the end of his speech, he calmly remarked, "Contrary to what my colleagues have told you about the bleak prospects for silicon transistors, I happen to have a few here in my pocket."

The audience woke up. When Teal concluded his speech by saying that someone from TI just happened to be standing at the back of the auditorium with literature on the new device, according to Jonsson, the assembly clamored to its feet en masse and stampeded to the door. "The poor last speaker was in trouble," Jonsson remembers. "He had no audience left, and to this day I don't know who he was."

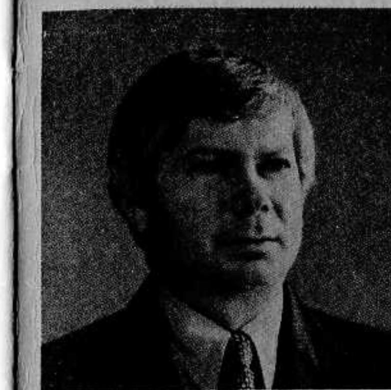
The first commercial line of silicon transistors included the 900, 901, 903, 904, 904A, 905 and the X-15, an experimental silicon power device. That line quickly grew to 15 devices, all of which were still in the Texas Instruments catalog 16 years later.

TI would have no competition in silicon transistors until 1958, when Fairchild Semiconductor was founded on the premise of producing the devices using the mesa technique patented by Bell Labs. Says Jonsson, "As far as the big companies were concerned that could have given us a run for the money, I think they were just fat and lazy. Back about Korea time, television was new, and they were as covered up with orders for TVs as we were for silicon transistors. The president of one of those companies once told me, with a slight smile, 'Don't get too egotistical about it, Jonsson; we'll take you on a little bit later when we have more time'. They haven't had enough time yet, I guess."

Jonsson admits that mass-producing silicon transistors was extraordinarily difficult in the beginning, but TI managed to fill its orders. "If you don't," he says, "your competitor will be breathing down your neck, and he'll fill 'em. We kept ahead, but it wasn't easy.

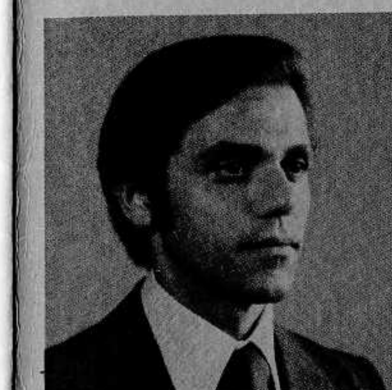
"The transistor was one more problem for us," he continues, "but we started out in the business of making instruments of great sensitivity, as well as ruggedness and dependability—first-class in every way. That was what our skill was. We also had an exceptional team that sort of gave up any thoughts of sleep. It also included Haggerty, an innovator and the best general manager I've ever known, and I've known a lot of them. So somehow, we always did what we said we would do, and that's probably why we're still around," Jonsson concludes.

EDITORIAL STAFF



Jerry Eimbinder, publisher, was formerly vice president of CMP Publications and publisher of both Electronic Engineering Times and Computer Systems News. Before being employed by CMP Publications in 1973, he was editorial director for United Technical Publications and editor of Electronic Products Magazine. He has also served as editorial director of EDN and Electro-Procurement (now Electronic Business). He holds an MBA from Fairleigh Dickinson University and a BSEE from Pratt Institute.

Dody Riggs, managing editor, joined the staff of Electronic Engineering Times in 1975 as new products editor. She was promoted to associate managing editor in December 1977. In October 1978, she left Times to join the founding editorial staff of Circuit News. She attended the University of Minnesota.



John Tsantes, editor, joined the staff of Electronic Engineering Times in May 1975 as engineering editor. He was promoted to managing editor in January 1976 and to editor in December 1977. He left Times to become editor of Circuit News in October 1978. Before joining Times, he worked for Raytheon, Potter Instrument and Mohawk Data Sciences as a design engineer. He has a BSEE and an MSEE from Polytechnic Institute of Brooklyn.

Mary Ann Murphy, news editor, was with EDN for two years prior to joining Electronic Engineering Times in 1977. She left Times in October 1978 to become a member of the founding editorial staff of Circuit News. She has a BA in English, Cum Laude, from Boston College, Chestnut Hill, MA.

Margie Stenzler, senior editor, worked as a reporter for a New York newspaper and as a manuscript editor for a book publisher before joining the staff of Electronic Engineering Times in 1974. She left Times to join the staff of Circuit News in October 1978. She holds a BS degree with a major in English/Journalism from the State University of New York at Plattsburgh and has completed most of the credits for an MBA degree at the State University in StonyBrook.

Elena Carelli, staff coordinator, after three years with Electronic Engineering Times, left in October 1978 to become a member of the team creating Circuit News. She is a graduate of Nassau College.

Circuit News, Published by Newsprint Inc., a Morgan-Grampian Company

Circuit News, 125 Jericho Turnpike, Jericho, NY 11753
(516) 333-9300