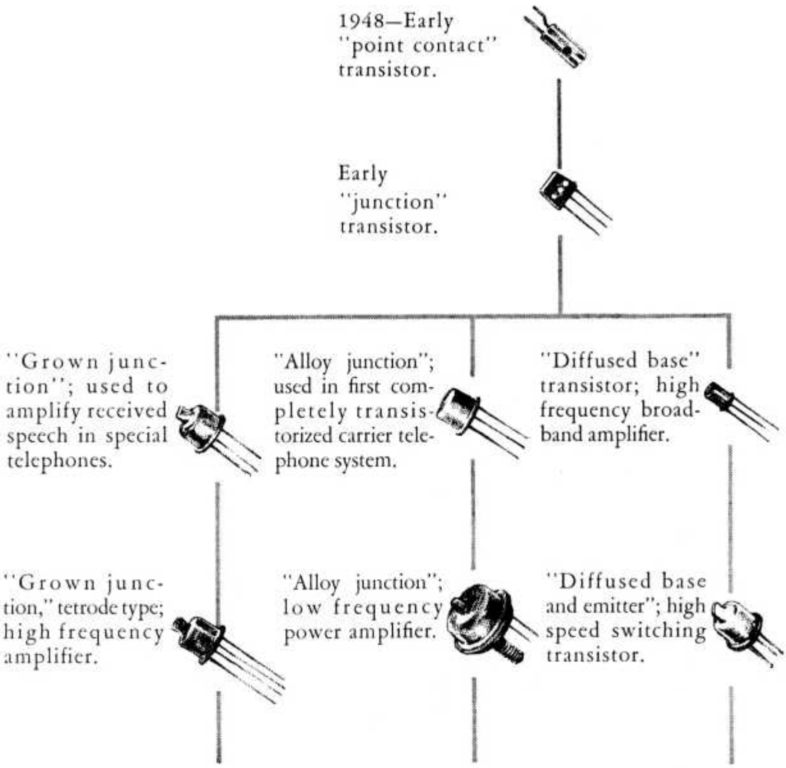
the story of the

TRANSISTOR

ten years of progress

BELL TELEPHONE LABORATORIES

THE TRANSISTOR FAMILY



THE STORY OF THE TRANSISTOR

"A tiny device that serves nearly all the functions of a conventional vacuum tube, and holds wide promise for radio, telephone and electronics, was demonstrated yesterday by Bell Telephone Laboratories scientists who developed it. Known as the transistor..."

-New York Herald Tribune, July 1, 1948

A SIMPLE AND UNPRETENTIOUS announcement stirred the scientific and technological world in mid-1948.

The news was the invention of the transistor at Bell Telephone Laboratories, and the achievement soon raised high hopes in the field of electronics.

The hopes were justified. In the decade since the announcement, the transistor scientists were awarded the Nobel Prize in Physics ... the device was recognized as the "giant of the electronic age" ... a new era in remote and automatic controls unfolded ... investigations into outer space became more practical ... medicine

found an electronic ally . . . the housewife's domain began to get the "new look" of transistorized electronics ... and the transistor kept your telephone system the best in the world.

The acclaim and attention belong to a tiny bit of solid material, plus three fine strands of wire, which serves as an amplifier or an oscillator. All together they make a device hardly the size of a dime.

Briefly, the transistor conducts, modulates and amplifies an electrical signal by means of a solid, rather than in the vacuum of a conventional electron tube, and without large inefficient expenditures of energy.

A NEW DEVICE FOR NEW METHODS

The invention came at a time when the reliability and power requirements of tubes placed a serious obstacle in the path of electronics. The transistor will do almost anything a vacuum tube will do, and there the resemblance ends. In addition, the transistor offers unique advantages not available in tubes.

The transistor meant new ways to build electronic circuits, offered a small but rugged substitute for tubes, pointed toward "packaged" and miniaturized components, and hurdled the barriers which had begun to limit the progress of electronics.

The impetus to further advances in electronics is owed to the curiosity of basic research, to a working alliance between fundamental science and engineering and to the facilities of the world's leading industrial research laboratories.

Most important of all, the transistor is a triumph of scientific research-"the challenge of untrodden territory now seen for the first time."

Our story will recount some of the probing into that "untrodden territory". . . explain how the transistor operates ... what it has meant in the first decade of its development ... and what the transistor may mean in the future.

THE BEGINNING - "A CHUNK OF SILICON"

". . . There was this man . . . and he had a little chunk of black stuff with a couple of contacts on it and when he shone a flashlight on it, he got a voltage ... 1 didn't believe it."
-Walter H. Brattain, *Co-inventor o f the transistor*

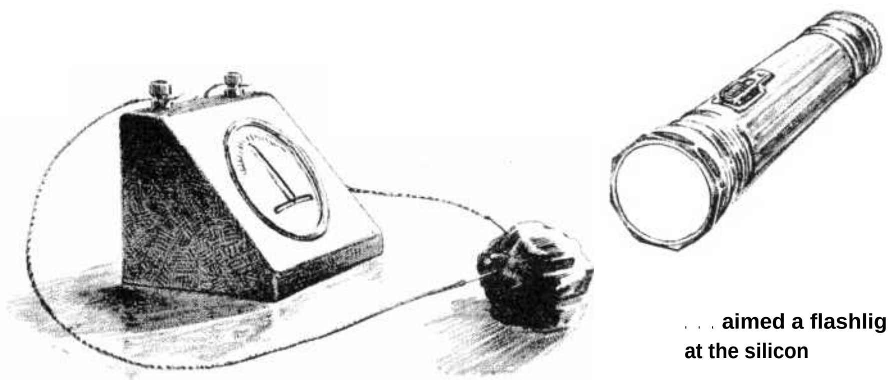
ALL SCIENTIFIC ACHIEVEMENT STANDS on the shoulders of the men who have gone before, and whose inquiries resulted in new steps toward other solutions. The transistor is the result of basic exploration at the frontier of human knowledge.

No one suspected when the research first began that there existed such a thing as a "transistor effect." Indeed there was not a great deal of well-organized knowledge about "semiconductors," materials such as germanium and silicon and other solids which do not readily transmit (or conduct) an electric current.

Early in 1940, Dr. Mervin J. Kelly, then Director of Research for Bell Telephone Laboratories, called into his office several members of his staff who had begun some work on semiconductors. They included Walter H. Brattain, a young physicist.

The purpose of the meeting was to watch a demonstration by Russell S. Ohl, a member of the staff who was then studying silicon. Ohl showed his fellow scientists a "little chunk of black stuff," silicon, to which were attached wires leading to a volt meter.

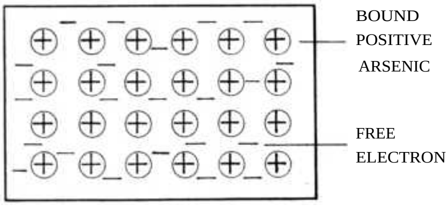
He aimed a flashlight at the silicon, and the meter registered a voltage across the wires. The silicon had converted light into electrical energy as any photoelectric cell might do. There were important differences.



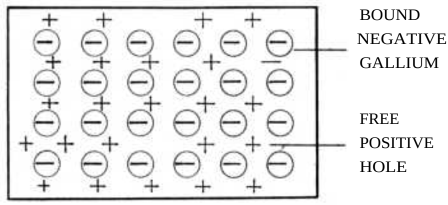
. . . aimed a flashlight at the silicon

WHAT IS A P-N JUNCTION?

n-type

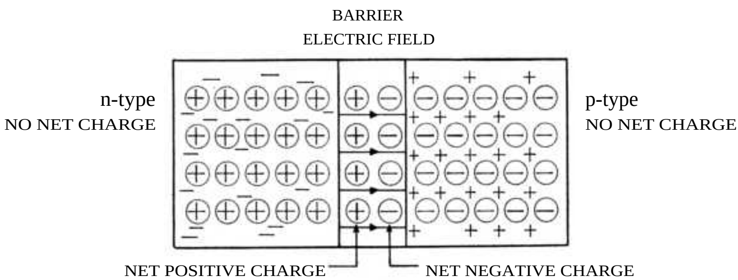


p-type



N-type, or electron rich silicon, is made by adding minute traces of an element such as arsenic. From each arsenic atom that is added, one electron (negative charge) detaches itself, thus becoming free to move, and leaves behind the arsenic atom with unit positive charge bound into the crystal structure. Thus n-type silicon consists of silicon to which is added equal numbers of free electrons and bound positive charges, so that there is no net charge.

P-type, or hole rich silicon, is made by adding minute traces of an element such as gallium. For each gallium atom that is added, one hole (positive charge) detaches itself, thus becoming free to move, and leaves behind the gallium atom with unit negative charge bound into the crystal structure. Thus p-type silicon consists of silicon to which is added equal numbers of free positive holes and bound negative charges so that there is no net charge.



When p-type and n-type silicon meet at a junction, the free holes and free electrons try to intermix like gases. However, the holes which enter the n-type material disappear and leave behind negatively charged gallium atoms. The electrons which enter the p-type material disappear and leave behind positively charged arsenic atoms. These fixed charges constitute an electrical barrier, or field, which prevents the rest of the holes on the p-side and electrons on the n-side from intermixing.

The usual photoelectric material registered a voltage when light was shone on a section of a carefully prepared surface. The silicon made the conversion without careful treatment of the surface. But the silicon nonetheless showed a voltage of more than ten times that usually received from the ordinary photoelectric cell.

Ohl had demonstrated what has come to be known as a "p-n junction" (see chart on page 4), and it was the first finding of the junction in an elemental material. Some eighteen years later, Brattain still recalled the excitement and curiosity at witnessing the demonstration. Although he knew his colleagues were not playing parlor tricks, Brattain was eager to test the silicon in his own laboratory.

A SEARCH FOR UNDERSTANDING

Between the first demonstration of the "p-n junction" and the eventual use of the junction as part of the transistor action came eight years of intermittent study, analysis, experimentation, theorizing-and a world war. At the end of World War II, the scientists at Bell Laboratories decided to seek a fundamental understanding of semiconductors rather than aim toward solution of a technological problem.

In January, 1946, active work was resumed, this time under the joint supervision of William Shockley and S. O. Morgan. Shockley, as a theoretical physicist, worked as part of the research team. John Bardeen, another theoretical physicist, also joined the group.

Brattain, an experimental physicist, conducted the laboratory work on surface properties of semiconductors, and G. L. Pearson the experiments on bulk properties of the materials. A physical chemist, R. B. Gibney, and a circuit expert, H. R. Moore, also were members of the group and made important contributions.

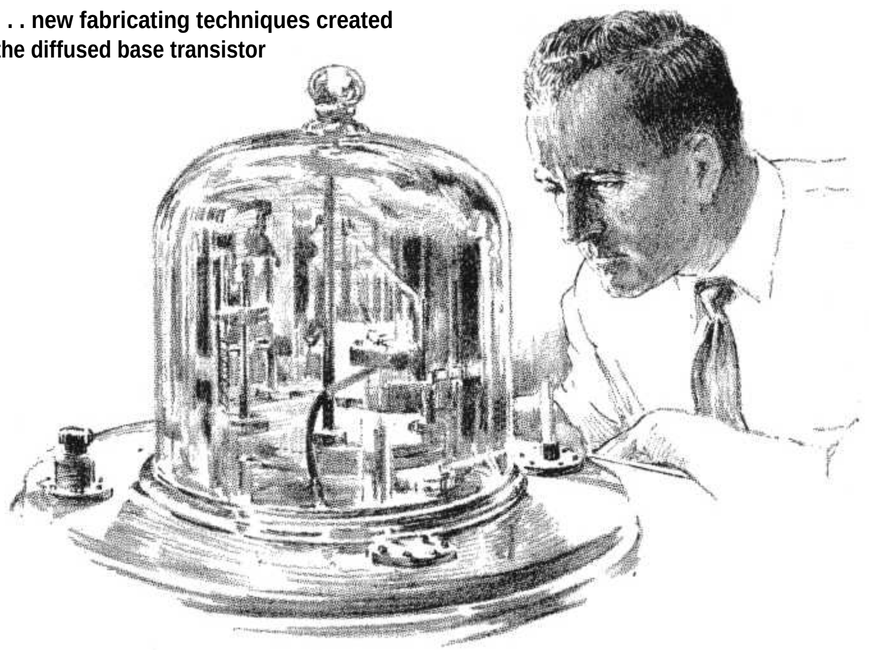
Of the team, Brattain and Pearson had considerable experience in the field prior to World War II, but none had worked on semiconductors during the war. Considerable help was obtained from other groups in Bell Laboratories which were more concerned with wartime developments in semiconductors, and particularly from the early work of J. H. Scaff and H. C. Theuerer, who supplied all the experimental silicon and germanium, and from Ohl, who did the early work on silicon.

THE NEED FOR A BETTER THEORY

The work undertaken in 1946 proceeded from a theoretical and experimental foundation laid by many others. The first satisfactory model of a semiconductor, for example, came from application of developments by A. H. Wilson of England in quantum theory, the highly abstract basis for a great deal of modern physics.

Shockley predicted that it should be possible to control the movable electrons inside a semiconductor by influencing them with an electric field imposed from outside and without contacting the material.

. . . new fabricating techniques created the diffused base transistor



But the results of various laboratory experiments, including those based on Shockley's prediction, disagreed with known theory of how electricity flows across the surface of a semiconductor. The need for a better theory was solved by Bardeen. He believed that electrons are trapped in the surface layers of semiconductors such as germanium and silicon.

This concept, the "surface state theory," led to the idea of one sign of charge in the surface traps and an equal and opposite space charge extending into the semiconductor. In other words, a "space-charge layer" may exist at the free surface of a semiconductor, independent of a metal contact.

Bardeen's theory opened up ways of investigating the electronic behavior at the surface. The next steps were verification and measurement. Experiments to test further predictions of the surface state theory were suggested by Bardeen, Shockley and Brattain.

An experiment which indicated the presence of the space-charge layer was carried out by Brattain, and further proof was obtained in experiments by Gibney and Brattain. From their experiments, Gibney and Brattain pointed out that an electrolyte - a solution which will conduct electricity - in contact with a semiconductor could be used to produce the "field effect" predicted by Shockley, and thus make a device which could amplify.

Bardeen suggested a convenient means for accomplishing this, and on the same day of his suggestion in November, 1947, he and Brattain produced a very low frequency amplifier using silicon and an electrolyte.

At Bardeen's suggestion, the semiconductor material was then switched from silicon to germanium. Bardeen and Brattain worked together on the experiments and the arrangement speeded interpretation and discussion and enabled the ideas of both men to be tried with a minimum of delay.

In his laboratory notes in mid-December, 1947, Brattain recorded observing for the first time what has come to be known as the "transistor effect." From their experiments, Brattain and Bardeen invented the semiconductor amplifier. Shockley went on to explain the "p-n junction" and that a "p-n-p junction" could be used to make a transistor.

The accomplishments of Bardeen, Brattain and Shockley earned for them the individual honors which they subsequently received, yet they have been among the first to point out that the research involved skills, instruments and materials which were available, almost uniquely, at Bell Telephone Laboratories.

For within one organization at Bell Laboratories are gathered the facilities for physical research and for the developments of practical importance. To the organization fell the task of developing the semiconductor amplifier. Physicists, chemists, metallurgists, engineers, laboratory and shop technicians, auxiliary and office personnel and staff executives played a part in furthering the scientific breakthrough.

. . . zone refining assures ultra-pure germanium

A member of the Bell Laboratories staff, J. R. Pierce, contributed the name for the semiconductor amplifier. He called it a "transistor," from one of its important properties, transfer resistance.

On June 22, 1948, the point contact transistor-the invention of Bardeen and Brattain-was demonstrated to the technical staff of Bell Laboratories, and almost immediately thereafter to U.S. military authorities. Eight days later, news of the invention was announced to the press.

The electronic revolution had begun, but it was far from complete. Whether the transistor could be improved and be mass produced were problems which would require technological skills of many people, and more time.

A GROWING ART

The landmarks in making better transistors and in simplifying production were these:

1951 -Further research led to making the junction transistor, constructed by M. Sparks from the theory Shockley had advanced in 1949.

1953-The "phototransistor" went to work as an electric eye.

1954-Announcement of "zone refining," a new technique which reduces impurities in a semiconductor to one part in ten billion, thus assuring ultra-pure germanium for transistors. The technique was developed by W. G. Pfann of Bell Laboratories.

1956-New fabricating techniques created the diffused base transistor. The new transistor opened the way to the broad application of high frequency transistors in telephony, FM, TV, guided missiles and electronic computers.

Within ten years, the transistor-benefiting in part from vacuum tube technology - has reached a point of development which had taken almost half a century for the vacuum tube. The transistor has fulfilled its initial promise ... with more to come.

UNDERSTANDING THE TRANSISTOR

"Most of the early developments of *solid state devices ... were based on empiricism. Progress in the physicists' knowledge of the structure of matter in solids is making a profound change.... It is this fundamental approach that is bringing the new era in electronics."*

-Dr. M. J. Kelly, *Former President*
Bell Telephone Laboratories

THE TRANSISTOR BEGAN ITS industrial life after long gestation in the research laboratories; and on the day the device was disclosed to the public, scientists knew why the transistor worked, had a good idea of how well it would perform, and a clear view of the paths to further developments.

So, in our understanding of the transistor we have the advantage of being able to look at a scientific explanation of the transistor, as well as to examine a functional device.

One way to understand the transistor is as an "active circuit element." Transistors and vacuum tubes both are what electronic engineers call active circuit elements.

To explain such circuit elements, we must distinguish between the *intelligence* and the *power* of a signal.

For example, a spoken word has the same meaning whether it is spoken or shouted. If the word can be heard above the background noise, the *intelligence* has been transmitted. The intelligence in speech comes from the brain.

The *power* in the speech comes from the muscles in the lungs, throat and mouth. To transmit the intelligence over long distances the speaker has to shout. The intelligence could be transmitted even further than the power of any person to shout by having repeaters properly spaced, people who could listen to the sound and then repeat it.

The repeater's function is not intelligent. His work is to repeat exactly the intelligence he hears. However, he does add new power to the signal. This addition of power comes from his own body and not from the signal he heard.

The control of local power to augment the power of an intelligent signal is just what an active circuit element does.

In the electrical case, the intelligence has been converted from mechanical power (sound) to electrical power, or fluctuating electrical currents. These electrical signals can be transmitted over wires, by telephony or telegraphy, or be broadcast as fluctuating electrical waves as in radio or television.

The signal on the receiving end, as long as it is strong enough to be detected (heard) above the random electrical noise, contains the intelligence, but usually is too weak to run a loud speaker or to make a picture on the television screen. The signal is, however, strong enough to control the receiver's local power-supplied by a battery or the power mains-to increase or amplify the signal to the point where it can actuate the speaker or light the screen.

Thus, the *intelligence* comes from the signal, and the *power* from a local source of electricity.

The electrical device that makes it possible to control intelligently a non-intelligent source of power is an active circuit element.

TWO ACTIVE CIRCUIT ELEMENTS

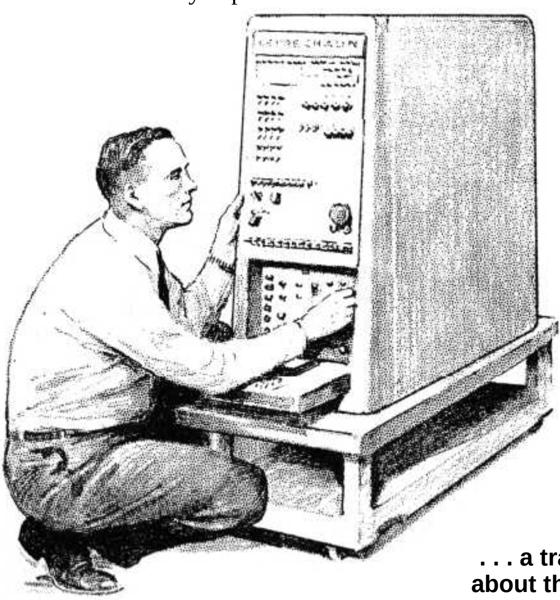
An example of an active circuit element is the vacuum tube. In the device is a hot filament or a cathode in a vacuum, and electrons boil out of this filament. The plate of the tube, if positively charged, attracts the negatively charged electrons so that they flow to the plate. The power necessary to do this comes either from batteries or the power mains.

A vacuum tube also has a grid. By placing a controlled charge, negative or positive, on the grid, the flow of current between the filament and the plate can be controlled. It takes very little power to do this since little, if any, current flows to or from the grid. The weak, intelligent signal can control the flow of current between the filament and the plate. Thus, the vacuum tube amplifies; i.e., it controls local electrical power intelligently so that it augments the intelligent signal.

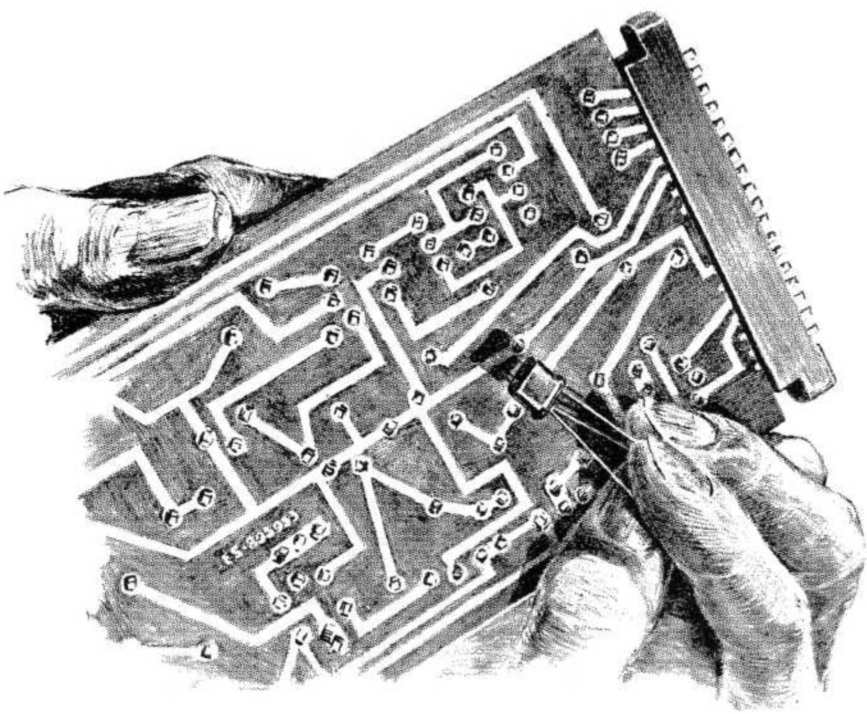
The transistor also is an active circuit element. In a transistor we have a solid, a semiconductor in which both negative and positive charge carriers-electrons and holes, respectively-can exist. The ability of the semiconductor solids to conduct electricity depends on the number of these holes and electrons.

Power from a local power source can be used to make a steady current flow through such a solid. If the character of the solid is such that most of the flow is due to electrons, then it turns out that a properly made third contact to it will add positive carriers (holes) and these will make it easier for current to flow.

This process is called "conductivity modulation." It is the transistor effect. The process is accomplished by



. . . a transistorized computer about the size of a file cabinet



... a complete electrical circuit printed on a thin sheet of insulated board

very little power. A weak, intelligent signal can do this. The transistor can amplify; it is an active circuit element.

Semiconductors such as germanium and silicon are ideal as active circuit elements because the number of electrons they contain is not too large. A few added positive carriers will make a significant difference. Actually, the added positive carriers result also in added electrons since a conductor cannot become charged. In a metal there are already so many electrons that it is almost impossible to change the numbers.

From this discussion, we see the transistor differs from the vacuum tube. The differences add to the importance of the transistor and make feasible new things in electronics. The transistor is especially useful in handling, processing and controlling intelligence at very low power levels.

The best device yet known for handling and processing information is the brain. The active circuit element in the brain is the neuron. The transistor is almost as efficient as a neuron.

The transistor and the vacuum tube each have particular advantages. The transistor operates "cold," eliminating the need for "warm-up" time; it has low power requirements, operates at low voltage and is considerably smaller in size than a tube.

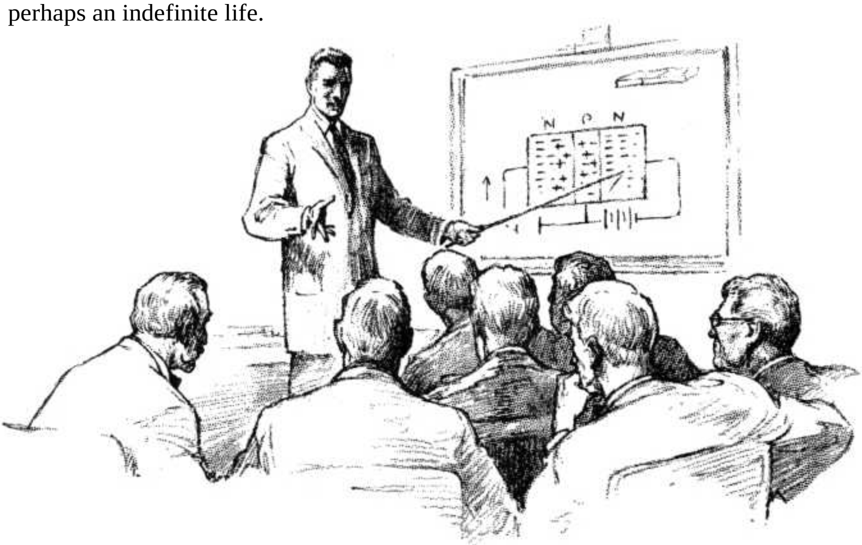
The transistor's power needs are comparatively meager. It requires as little as one-millionth of a watt for a transistor to carry a signal without waste. A conventional vacuum tube requires at least a full watt of power and considerably higher voltage than does a transistor.

There is also the matter of size. The transistor is tiny in comparison to a tube, and the transistor makes worthwhile the miniaturization of other apparatus-resistors, capacitors, transformers, inductors, etc.

The results in terms of size are dramatic. In 1957, Bell Laboratories announced a transistorized computer which even in preliminary models was only about the size of a file cabinet. A similar electronic brain built with vacuum tubes would have required several rooms of equipment and air conditioning and added complex maintenance problems.

The transistor also permits "packaged units." A complete electrical circuit can be printed on a thin sheet of insulated board with pre-punched holes. The transistor leads are bent into the holes and the amplifying package is ready for use. Substitution in the event of faulty circuits can be made in minutes.

In addition there is the advantage of the reliability of transistors in performance. When properly manufactured and operated within the energy and voltage limits of its design, the transistor will have a trouble-free life measured in tens of years - perhaps an indefinite life.



. . . numerous speakers on the new art

THE IMPACT OF THE TRANSISTOR

"In the rust-born electronics age it is not easy to assay the part the transistor will play. But at a conservative guess, it should have a major revolutionary role rivaling that of the development of the vacuum tube...."
-The Magazine of Wall Street, October 3, 1953

THE ADEQUATE ASSESSMENT of an invention requires a perspective of time, so that its worth may be measured by its achievements. In terms of time, the transistor is still in its infancy. Yet it is not too soon to say that the impact of the transistor has been felt over a wide range of science and industry.

A large part of that development is due to a wide sharing of information on the transistor. Bell Laboratories has published numerous papers and books on transistor theory and technology, sent speakers all over the country to lecture on the new art, and conducted a transistor school for university professors.

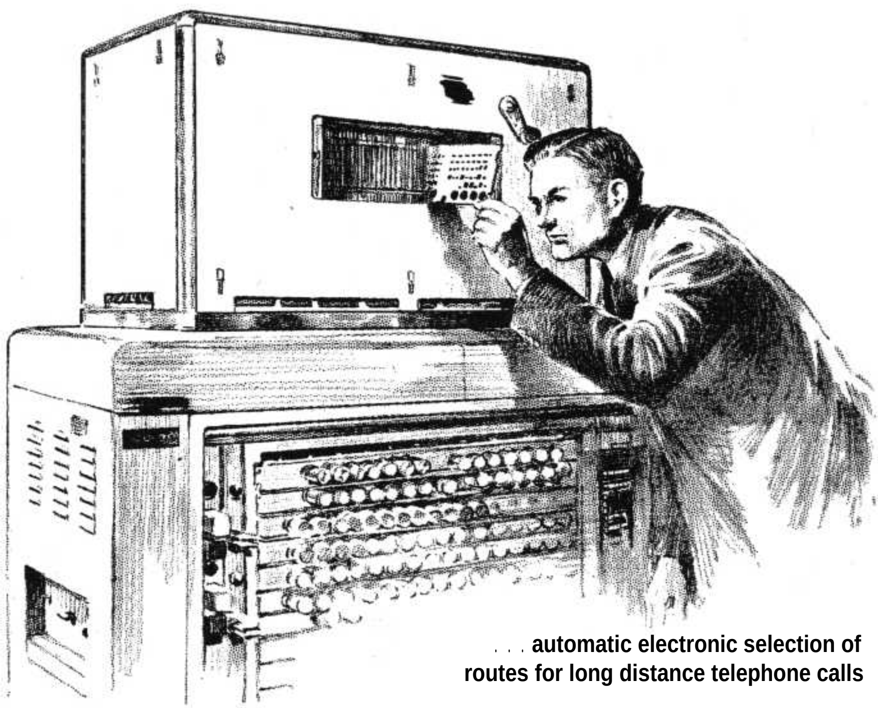
Bell Laboratories also offered intensive courses to representatives of firms licensed by the Western Electric Company to manufacture transistors. By 1958 seventy-six firms throughout the world were licensed to make and sell transistors.

One of the first commercial uses of the transistor was in hearing aids. In a kind of living memorial to Alexander Graham Bell, the inventor of the telephone and a teacher of the deaf, manufacturers of hearing aids were granted licenses without charge to utilize transistors. By the end of 1952, the first over-the-counter sales of transistorized hearing devices had begun.

A WIDE VARIETY OF APPLICATION

Since then, commercial transistors have sprouted into a staggering variety of equipment. Transistorized devices also include: radios, phonographs, tape recorders, remote amplifiers, toys, a duck decoy, measuring equipment, electrical test sets, photographic and direct-writing recording instruments, tool controls, voltage regulators, servo systems, sensing devices, fire and burglar alarms, controls for windows and doors, lights and appliances.

Also, fuel injection systems, ignition systems, fuel gauges, power generators, beacons for aviation, direction finders, private switchboards, personal paging systems, selective mobile telephone equipment, public address and intercom systems, video amplifiers, guidance systems, radar, instrumentation controls, computers, data



. . . automatic electronic selection of routes for long distance telephone calls

processing, and even a guidance system for a chicken-feeding cart.

For the military, the urgent needs of national security overrode the somewhat high cost considerations in the early transistors. Almost immediately upon disclosure of the invention, Bell Laboratories and the military initiated a joint program to develop transistors and circuits for military uses.

Military systems such as computers, digital data transmission, guidance and servo systems, radar and communications systems relied entirely or in part on transistors for their successful development.

Transistors designed by Bell Laboratories were part of America's first space satellite, "The Explorer." The transistors used in the satellite transmitter were of the diffused base design, manufactured by the Western Electric Company and other firms.

In the Bell Telephone System, the transistor is entering almost every area-telephone apparatus, power systems, switching, transmission and the new field of data processing.

The first application of transistors in the Bell System was in 1952 when point contact transistors went to work in a system which permits a telephone operator to reach another point by tones sent on various channels and thus limits the amount of information that need be sent.

Another early device was the "card translator," which permits automatic electronic selection of routes for long distance telephone calls and is helping to open the way to direct distance dialing.

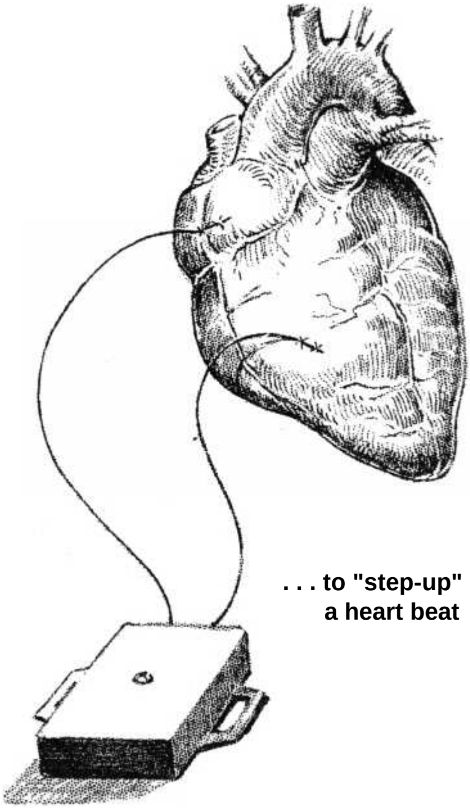
Transistorized telephone sets, with amplification controls, have been offered to the hard-of-hearing and for use in noisy locations. The low power needs of the transistor offered new methods to improve rural telephone service, and the opportunity was quickly utilized.

The transistor will make an electronic telephone switching system practical. Electronic switching systems will occupy substantially less floor space than comparable elect ro-mechanical systems. The transistorized system will increase the speed of switching a thousand-fold, eliminate switching equipment in private exchanges (office switchboards), and permit automatic dialing from a "memory" system in the switching center.

In transmission, transistors allow multiple calls on a single, short-haul telephone line. Transistor technology also has made possible improved performance of radio relay systems through a lowering of the noise figure of modulators and up-converters.

Rectifiers, voltage regulators and lightning protectors using techniques evolved from transistor manufacture have become standard in telephone apparatus and power systems. In the new field of data processing-where business machines "talk" to their counterparts across the continent-transistorized devices have an important function.

...the urgent needs of national security



. . . to "step-up"
a heart beat

While the uses of the transistor in communications, the military and industry have vast implications, other fields also have made some interesting uses of the device, particularly medicine.

A tiny transistor amplifier, weighing less than two ounces, has been designed to "step-up" a heart beat when there is muscular damage impeding the impulse between the upper and lower chambers of the heart.

In another medical use, a photoelectric cell and a transistorized amplifier were linked together to leads implanted in the brain of a blind woman. The cell converted light into an electrical charge which was amplified, and the woman reported seeing "flashes of light." It would be inaccurate to say the transistor enables the blind to see, but the experiment opened interesting avenues for further research.

In the sciences, the field of pure physics probably was most affected by the discovery of the transistor effect. The years from 1947 - 1951 saw a rapid rise in semiconductor research by scientists all over the world. Physicists came more to realize that to understand the materials with which they worked required cooperation among themselves, and among chemists, metallurgists, and other scientists.

OPENING DOORS TO NEW TECHNIQUES

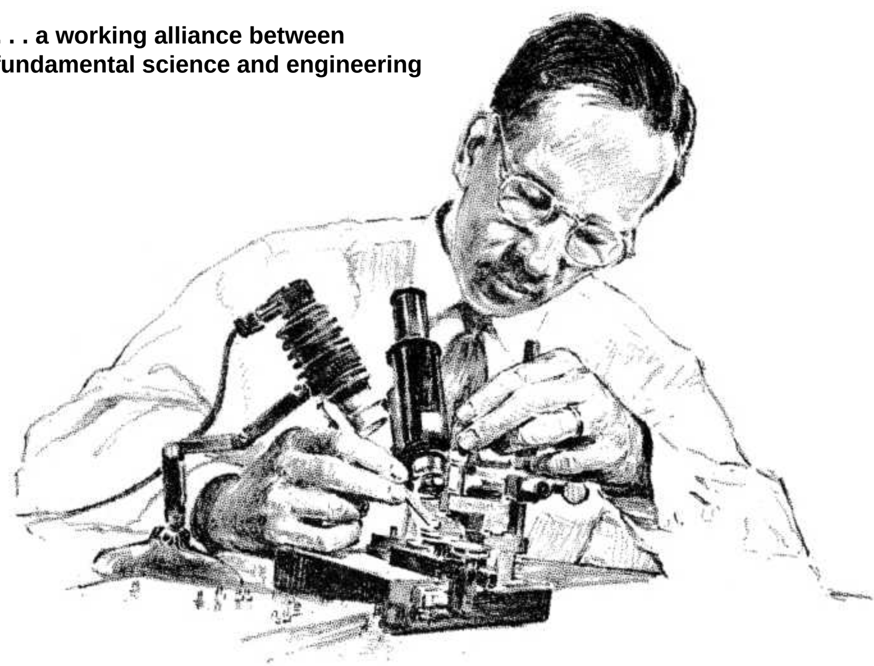
An example is the growth of single crystals of germanium and silicon, essential to ensure that electrical properties can be reproduced. The impetus for that development came from transistor needs, and the growth was accomplished through the efforts of G. K. Teal and his associates in the Chemical Physics Department of Bell Laboratories.

The availability of such pure and perfect crystals contributed greatly to a more thorough understanding of the electrical, chemical and mechanical properties of solids. This understanding has had a tremendous impact on the entire field of solid state physics.

Transistor technology has led to new and more direct ways of measuring many of the most important physical properties of semiconductors, and various applications can now be made of the understandings of the p-n junction. Since the transistor, study of the properties of surfaces has become an extremely active subject for research in many nations.

The world of science has not missed the lesson to be learned from the discovery of the transistor, and its swift translation into production. A physicist has commented that the transistor experience highlights the fact that pure science does not work in a lonely attic, and that its relations to applied science are increasingly of a two-way nature.

. . . a working alliance between fundamental science and engineering



LOOKING FORWARD

"The answers begin with research but they don't end there. . . . Western Electric, the manufacturing organization, works very closely with the Laboratories so that we can get promptly the most ... efficient ways to produce.... Finally, the operating telephone companies... help get each new development into practical use.... This is very much a team job."

-Frederick R. Kappel, *President*
American Telephone and Telegraph Co.

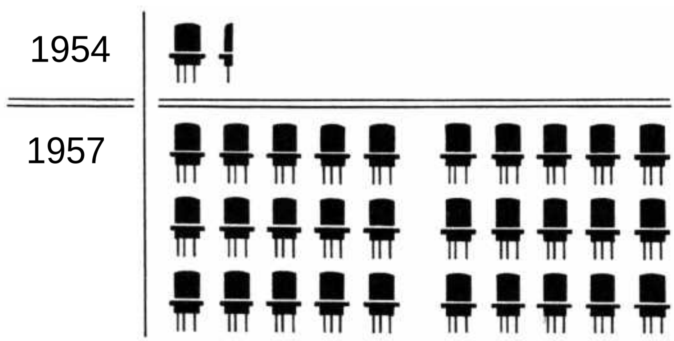
A COMMERCIALLY MANUFACTURED transistor of a specific type sold in 1953 at $21. Five years later, that same type of transistor could be purchased for $1.50. The difference in cost illustrates the maturity of production which the transistor achieved by its tenth birthday.

The costs point up the contrast between a "custom crafted" device and the mass produced item which the transistor has become.

Production techniques established by Bell Laboratories and Western Electric have paced transistor output since the initial point contact transistor was designed, even though the problems faced in mass production were formidable.

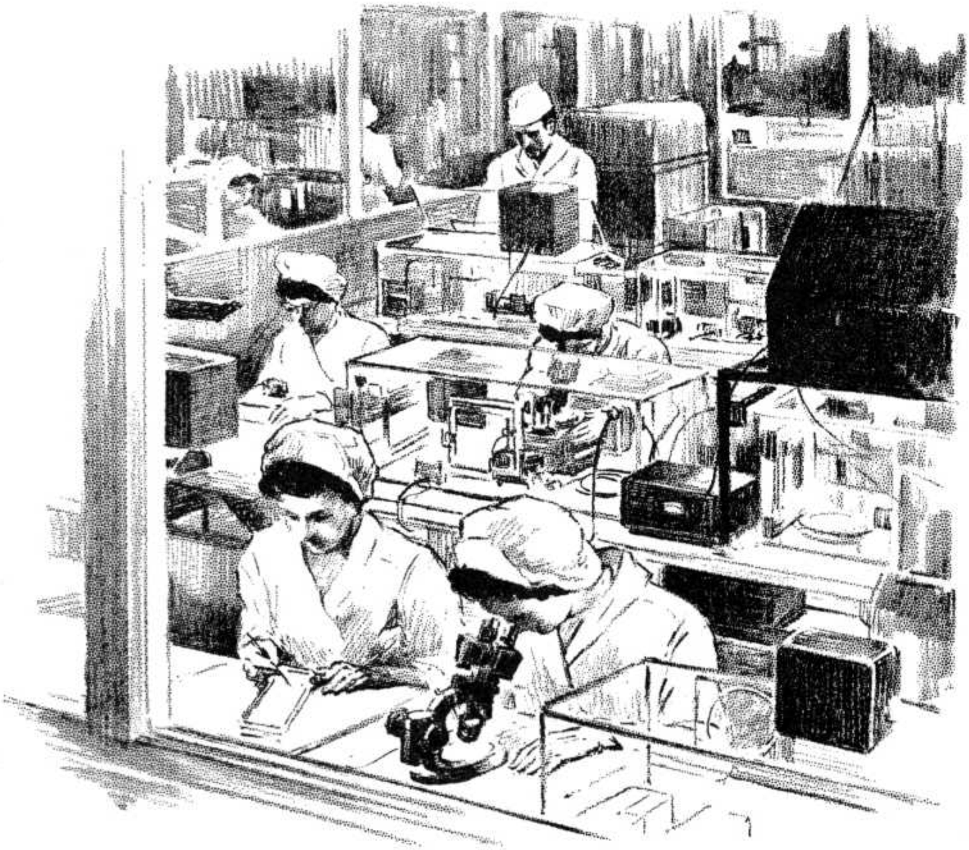
Typical production first involves refining the semiconductor, such as germanium, to an extremely high degree of purity, with not more than one part of foreign matter to 100-million parts of germanium.

GROWTH IN PRODUCTION OF TRANSISTORS



EACH SYMBOL REPRESENTS ONE MILLION UNITS

. . . further advances in electronics owed to curiosity of basic research



. . . production in super-clean, air conditioned rooms

The next step is to distribute the proper type of atoms throughout a single crystal of semiconductor, which is large enough to form several thousand transistors. The ingot of "doped" germanium is sliced into wafers less than 1/100th of an inch thick and then diced into 1/16-inch squares.

Western Electric employees peer through microscopes and use fine mechanical and sensitive electronic instruments to aid them in assembling transistors. Many steps of production are carried out in super-clean, air conditioned rooms.

Even with these standards of purity and cleanliness, transistor production for commercial use has jumped from 1.3 million units in 1954 to about 30 million units in 1957. The output is expected to climb to 300 million by 1965, with unit prices less than those of vacuum tubes.

As transistor technology and production techniques have matured, more and more industrial applications have been found for which electron tubes would not be economical because of power efficiency and reliability.

Transistor designs still in the early laboratory stages indicate the devices will extend the frequency range of transistors ten times beyond present levels. Other types are being designed which, even at high frequencies, will supply sufficient power for output stages of radio transmitters.

AN EVEN BETTER TELEPHONE SYSTEM

Within the next ten years the Bell System will depend heavily upon this new solid state device for a vastly improved and highly reliable telephone service.

The new electronics, born with the transistor, will make large contributions to cost reduction in equipment, installation, operation and maintenance. These lower costs will expand the use of communication services and make many new services feasible. New designs will make possible complex, high speed computers, all-electronic telephone central offices, and many other systems where speed and accuracy are paramount.

The evolution of "an amazingly simple device" is revolutionizing the world around us, creating new arts and new industries, opening the doors to new explorations of the secrets of nature, giving us new understanding of how men and machines may better communicate with each other.

BELL TELEPHONE LABORATORIES

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