# Bell Labs: More than 50 years of the Transistor

## What Is A Transistor?

Invented at Bell Laboratories in 1947, the transistor resulted from efforts to find a better amplifier and a replacement for mechanical relays. The vacuum tube had amplified music and voice during the first half of the 20th century, and it had made long-distance calling practical. But it consumed lots of power, operated hot and burned out rapidly. The telephone network required hundreds of thousands of relays to connect circuits together to complete calls. Network relays were mechanical devices, requiring regular maintenance to clean and adjust.

Cheaper to make than the vacuum tube and far more reliable, the transistor cut the cost and improved the quality of phone service and, seemingly overnight, spawned countless new products and whole new industries.

**How a Transistor Works**

The transistor has many applications, but only two basic functions: switching and modulation -- the latter often used to achieve amplification.

In the simplest sense, the transistor works like the dimmer in your living room. Push the knob of the dimmer, the light comes on; push it again, the light goes out. Voila! A switch. Rotate the knob back and forth, and the light grows brighter, dimmer, brighter, dimmer. Voila! A modulator. To understand amplification, think of this: a relatively effortless action by you to turn the knob from its low to high setting translates into a much more impressive reaction by the light – the whole room beams with light! Voila! An amplifier!

Both the dimmer and the transistor control current flow, be it through a lamp or a device to be activated. Both act as a switch--on/off--and as a modulator/amplifier--high/low. The important difference is that the “hand” operating the transistor is millions of times faster. And it’s attached to another electrical source--a radio signal in an antenna, for example, a voice in a microphone, or data signal in a computer system, or even another transistor.

Transistors are made of semi-conductors such as silicon and gallium arsenide. These materials carry electricity *moderately* well--not well enough to be called a conductor, like copper wires; not badly enough to be called an insulator, like a piece of glass.  Hence their name: semi-conductor.

The 'magic' a transistor performs is in its ability to control its own semi-conductance, namely acting like a conductor when needed, or as an insulator (non-conductor) when that is needed.

Semi-conductors differ in the way they act electrically.  Putting a thin piece of semi-conductor of one type between two slices of another type has startling results:  a little current in the central slice is able to control the flow of the current between the other two.  That little current in the middle slice is the juice that is supplied by an antenna or another transistor for example.  Even when the input current is weak, as from a radio signal that's traveled a great distance, the transistor can control a strong current from another circuit through itself.  In effect, the current through the 'output side' of the transistor mimics the behavior of the current through the 'input side'.  The result is a strong, amplified version of the weak radio signal.

**What Transistors Do**

In microchips today, which contain millions of transistors 'integrated' together in a particular pattern or 'design', the amplified output of one transistor drives other transistors that, in turn, drive others, and so on.  Build the sequence one way and the chip can be made to amplify weak antenna signals into rich quadraphonic hi-fidelity sound.  Build the chip differently, and the transistors interact to create timers to control watches or microwave oven, or sensors to monitor temperatures, detect intruders, or control car wheels from locking (ABS systems).  Arrange the transistors in a different array and create arithmetic and logic processors that drive calculators to calculate, computers to compute, 'process' words, search complex data bases for information, networks to 'talk' to each other, or systems that transmit voice, data, graphics and video to make our communications networks.

It may take a score of transistors, interconnected in teams called logic gates, to accomplish a task as simple as adding one and one.  But put enough transistors together in appropriate patterns and transistors end up knock off big jobs by working fast--switching on and off 100 million times per second or more--and by working in huge teams.

As discrete components as in the old days, a thousand transistors would occupy dozens of printed circuit boards the size of postcards.  But thanks to such techniques as photolithography and computer-aided design, millions of transistors and other electronic components, complete with wiring, can be compactly organized on an integrated circuit smaller than a cornflake.

At this scale, the cost of the transistor today is virtually free--about a hundred thousandth of a cent apiece.  And transistors in integrated circuits are extremely reliable.  If spared from electrical shocks and blows from blunt instruments, a working microchip will probably keep on working for a hundred years.

The way to make transistors still better, cheaper, and more efficient is to understand semiconductors even better.  And that's just what Bell Labs is up to.  Its scientists today know how to build semiconductor materials virtually atom by atom, from a wide selection of materials using sophisticated layering techniques that mother nature herself would be proud of.  It's almost like magic.

So, what is a transistor?  It's a marvelous, virtually invisible electronic device that has change our lives … forever.

**A tiny invention … a huge revolution … another Bell Labs innovation.**

# # #

# The Invention of Radio

Guglielmo Marconi

In 1895, Guglielmo Marconi, an electrical engineer and inventor from Italy, demonstrated a new technology invented by Nikola Tesla by sending a radio signal more than a mile. Thus was born the beginning of wireless communication, but there were plenty of technical barriers to surmount before the technology was practical.

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# The Problem of Detection

First and foremost was the problem of detection-- radio waves carrying information could be transmitted without wires but the difficulty was developing receivers that could detect the signal carrying the information.

An earlier discovery by Ferdinand Braun, a German Physicist, became instrumental in solving this problem. In 1874, Braun discovered that crystals can conduct current in one direction under certain conditions. This phenomena is called rectification.

Braun and others later applied the discovery to introduce the use of crystal detectors in radio receivers. Acting as a rectifier, the crystal is able to separate the carrier wave from the part of the signal carrying the information.

Russian boy tinkering with crystal set

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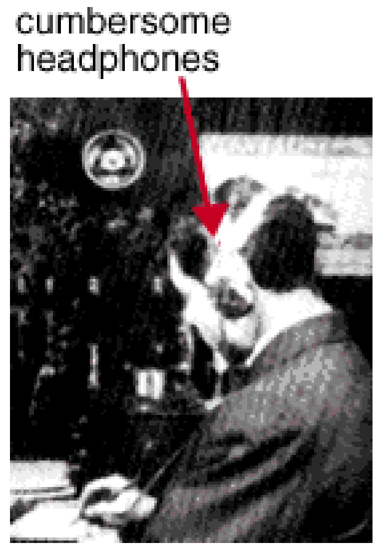
# Amplification




Crystal sets only worked if the radio wave was strong enough to detect. But, the radio signal is weakened by distance and terrestrial obstructions. And, even if the signal was detected, early radio operators had to listen closely with their headsets to hear the broadcasted information.

Amplification was needed to boost the weakened signals to make the technology practical over long distances, as well as make it loud enough to hear.

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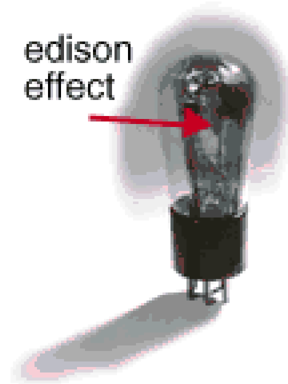
# The Rectifying Vacuum Tube




The first step toward a solution was developed by John Ambrose Fleming, an English physicist, who was attempting to improve the reception of wireless radio signals. Building upon his research into the "Edison effect" (the tendency for dark particles to smudge the inner surface of glass lightbulbs as current flows through in a single direction), Fleming attached a lightbulb outfitted with two electrodes to a radio receiving system.

In his rectifying vacuum tube, electrons flow from the negatively charged cathode to the positively charged anode. As the current within the tube is moving from negative to positive, the oscillations of incoming signal are rectified into detectable direct current.

next ▶

# The Amplifying Vacuum Tube


Lee De Forest

The next step was an invention by an American, Lee De Forest, who added an innovation component to Fleming's vacuum tube. It was a third electrode, called a grid, a network of small wires surrounding the cathode.

The grid's negative potential controlled the flow of electrons from the cathode to the anode. The lower the negative potential of the grid, the more electrons it allowed to flow through the tube, thus producing an amplified current. The amplifying vacuum tube was born.

next

# Impracticalities

The vacuum tube was not only an essential component in the development of radio, but also early telephone equipment, television, and computers. But the problem was the technology that it initially helped to advance came to require a more compact and reliable device.

vacuum tube from the early 1900's

For example, the University of Pennsylvania's ENIAC computer, due to its incorporation of thousands of vacuum tubes, filled several large rooms and consumed enough power to light ten homes. The vacuum tube's cathode required a good amount of heat in order to boil out electrons and often burned out. Also, the actual glass tube was fragile and bulky.

man changing one of 18,000 tubes

**"Nature abhors the vacuum tube."**

-J.R. Pierce, Bell Labs engineer who coined the term 'transistor'

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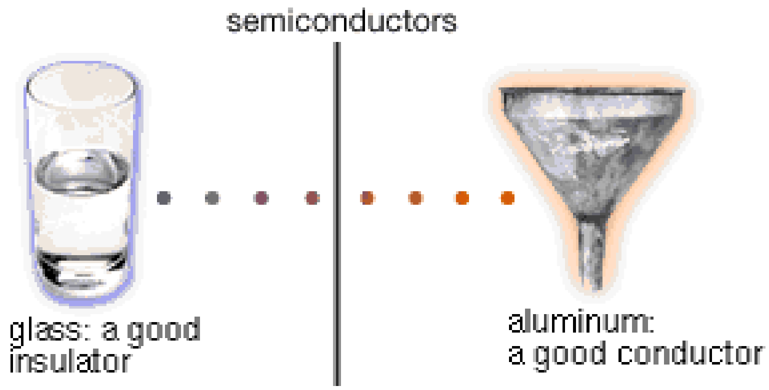
# Strange Properties of Crystals

## Bell Labs Innovations

Founded in 1925, Bell Laboratories brought together worldclass scientists pursuing research in electronics, chemistry, physics, communications technology, and many other disciplines. Their research picked up on early discoveries by Braun and others about the strange properties of crystals. These materials became known as semiconductors-because they have properties that place them somewhere between conductors and insulators.

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# 1930's Radio Research

**Bell Labs Innovations**

It began with a group of Bell Labs scientists who were trying to use ultrahigh frequency waves for telephone communications. They needed a reliable method of detecting such waves, but the now conventional electron tube detector proved incapable of picking up rapid vibrations.

an antique crystal detector

Seeking a new method of detection, the scientists reverted to the antiquated "cat's whiskers" detector, which was based on a crystal. Not only did it work effectively, it also set them on the path of exploring the particular properties of the most reliable semiconductor material: silicon.

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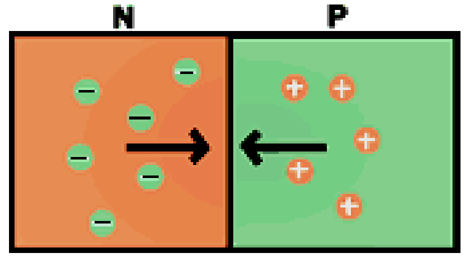
# The PN Junction

## Bell Labs Innovations




What the Bell Labs scientists discovered was that silicon was comprised of two distinct regions differentiated by the way in which they favored current flow. The area that favored positive current flow they named "p" and the area that favored negative current flow they named "n." More importantly, they determined the impurities that caused these tendencies in the "p" and "n" regions and could reproduce them at will. With the discovery of the P-N junction and the ability to control its properties, the fundamental ground work was laid for the invention of the transistor. This Bell Labs discovery was instrumental in the development of all semiconductor devices to come.

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# Drive Toward Solid State

## Bell Labs Innovations

silicon is found in quartz

In 1945, Bell Labs' executive director, Mervin Kelly, boosted Bell Labs semiconductor research by putting together a worldclass team of solid-state physicists. Realizing that the vacuum tube had surpassed its potential as a practical amplifying device, this team of Bell Labs scientists went to work on developing a new means of amplification. As Lee De Forest saw the potential of attaching a third electrode to John Ambrose Fleming's vacuum tube rectifier, the Bell Labs scientists speculated that by adding a third electrode to the semiconductor detector, they would be able to control the amount of current flowing through the silicon. If their theories proved correct, the resulting device would amplify in the same way as the vacuum tube with much less power consumption and in a fraction of the space.

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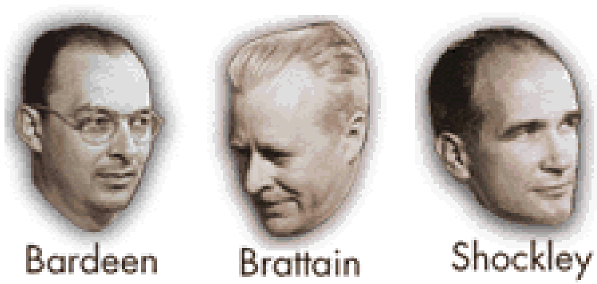
# The Invention!

**Bell Labs Innovations**

During one experiment, Brattain observed that a germanium crystal that was set in contact with two wires two-thousandths of an inch apart was amplifying. After exclaiming, "Eureka! This thing's got current gain!", he informed his colleagues that many years of research by many Bell Labs scientists finally paid off. They had invented the first semiconductor device that could do the work of a vacuum tube: the transistor.

# The Team

## Bell Labs Innovations




Three of the physicists working on the investigation team were John Bardeen and Walter Brattain, both of whom had been researching the properties of semiconductors, and William Shockley, whose specialty was solid state physics.


Combining their expertise, they conducted experiments with another type of semiconductor-- germanium-- a grayish white element with brilliant metallic luster and a crystalline structure with a diamond pattern.

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# The Inventors

Dr. John Bardeen, Dr. Walter Brattain, and Dr. William Shockley discovered the transistor effect and developed the first device in December, 1947, while the three were members of the technical staff at Bell Laboratories in Murray Hill, NJ. They were awarded the Nobel Prize in physics in 1956.

next ▶

# John Bardeen (1908-1987)

"I had known Walter since my graduate student days at Princeton. Although at that time 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."
- John Bardeen

A brilliant theorist, Dr. Bardeen brought his keen understanding to the transistor team by explaining effects found in early transistor experiments. Born and raised in Madison, Wisconsin, he obtained his Ph.D. in mathematics and physics from Princeton University in 1936. A staff member of the University of Minnesota, Minneapolis, from 1938 to 1941, he served as principal physicist at the US Naval Ordinance Laboratory in Washington, DC, during World War II, after which he joined Bell Telephone Laboratories, Inc. There he conducted research on the electron-conducting properties of semiconductors. This work led to the invention of the transistor. Dr. Bardeen won the Nobel prize in 1956 as co-inventor of the transistor, and again in 1972 as co-developer of the theory of superconductivity at low temperatures. Dr. Bardeen left Bell Labs in 1951 to join the faculty at University of Illinois, where he dedicated himself to research superconductivity.

next ▶

# Walter Brattain (1902-1987)

"This has made it possible for even the most underprivileged people to listen. Nomads in Asia, Indians in the Andes, and natives in Haiti have these radios, and at night they can gather together and listen."
- Walter H. Brattain

Dr. Walter H. Brattain's creativity and persistence enabled the transistor team to triumph over difficult technical obstacles. Born in Amoy, China and raised in Washington State, he received a Ph.D. in physics from University of Minnesota. He was a distinguished member of technical staff at Bell Labs from 1929 to 1962. From 1962 to 1972 he was a professor and visiting lecturer at his alma mater, Whitman College in Walla Walla, Washington. He was also a visiting lecturer at Harvard University, The University of Minnesota, and the University of Washington.

Brattain's chief field of research involved investigations into the surface properties of solids. Dr. Brattain also discovered the photo effect at the free surface of a semiconductor and was instrumental in work leading to a better understanding of the surface properties of germanium.

next

# William Shockley (1910-1989)

"Exploiting [the transistor's] potential caused many headaches. A colleague called it a 'persistor', because persistence was what it took to make it."
- William Shockley

Born in London and raised in Palo Alto, Shockley received his Ph.D. in solid-state physics from the Massachusetts Institute of Technology in 1932 and joined the staff of Bell Laboratories in Murray Hill, NJ, in 1936. During World War II, he served as director of research for the Antisubmarine Warfare Operations Research Group of the US Navy. After the war, he returned to Bell Labs as director of transistor physics research.

Dr. Shockley left Bell Labs in 1955 to establish Shockley Semiconductor Laboratory (part of Beckman Instruments, Inc.), an effort that was instrumental in the birth of Silicon Valley and the electronics industry. His former employees later invented the integrated circuit and founded Intel, the most successful microprocessor company in the world. Dr. Shockley later became a distinguished professor of electrical engineering at Stanford University.

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"My introduction to semiconductors came just after the war, in late 1945, when I joined the Bell Laboratories research group on solid-state physics, which was being formed under the leadership of Stanley Morgan and William Shockley," Dr. Bardeen once related. "Following a Ph.D. under Eugene Wigner at Princeton and post-doctoral years with John H. Van Vleck at Harvard, I had been interested in the theory of metals before the war and was anxious to go back to solid-state physics after five years at the Naval Ordnance Laboratory in Washington."

While at Harvard, Dr. Bardeen had become friends with James B. Fisk, who in 1945 was director of research at Bell Labs. Bardeen also knew Shockley when he was a graduate student at M.I.T.

"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."

There he conducted research on the electron-conducting properties of semiconductors. This work led to the invention of the transistor.

"Conditions were rather crowded when I arrived at the Murray Hill, NJ, laboratory. The wind-up of World War II research was still going on." He said a new building was under construction, so he was asked to share an office with Walter Brattain and Gerald Pearson.

“I had known Walter since my graduate student days at Princeton.  Although at that time 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.”

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He died at age 78.

## Walter H. Brattain (1902-1987)

An ingenious experimenter, Dr. Walter H. Brattain's creativity and persistence enabled the team to triumph over difficult technical obstacles to demonstrate the transistor effect.

Dr. Brattain, born in Amoy, China and raised in Washington State, received his Ph.D. from University of Minnesota in physics. He was a distinguished member of technical staff at Bell Labs from 1929 to his retirement in 1962. From 1962 to 1972 he was a professor and visiting lecturer at his alma mater, Whitman College in Walla Walla, Washington. He was also a visiting lecturer at Harvard University, the University of Minnesota, and the University of Washington.

During his long distinguished career, Dr. Brattain's chief field of research involved investigations into the surface properties of solids, particularly the atomic structure of a material at the surface, which usually differs from its atomic structure in the interior. Dr. Brattain also discovered the photo effect at the free surface of a semiconductor and was instrumental in work leading to a better understanding of the surface properties of germanium.

"Since I am the oldest of the three Nobel Prize winners, I can say that it all happened in my lifetime," he once said. Indeed, when he joined Bell Labs the organization was only four years old.

He said that after he and a fellow worker, J. A. Becker had looked at using a copper oxide rectifier as the basis of 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." Dr. Brattain tried, but he admitted, "This attempt was not successful."

He noted, "The research work to understand what was really going on in the simplest semiconductors, silicon and germanium, finally resulted in the breakthrough," and perhaps not a minute too soon, since he admitted, "after fourteen years of work I was beginning to lose faith.  But I never felt any pressure from management to discontinue work or to change fields."

In 1937, when it was announced that another Bell Labs researcher, C. J. Davisson, won the Nobel Prize, Dr. Brattain was watching as the news services took pictures and movies of him.  During a break, Davisson walked over to him and said, 'Don't worry, Walter, you'll win one someday.'  Little did I know that the day would come when he'd be one of the people to nominate us for the prize."

He came very close, however, to not being around when the semiconductor research team was being put together.  During the depression, he was next on a list of people to be let go if conditions got any worse, and later he had to convince his research vice president that he preferred research to supervising others.

One of the applications of the transistor that Dr. Brattain was most proud of was the development of the transistor radio.  “This has made it possible for even the most underprivileged people to listen.  Nomads in Asia, Indians in the Andes, and natives in Haiti have these radios, and at night they can gather together and listen.”  He added, “All peoples can now, within limits, listen to what they wish, independent of what dictatorial leaders might want them to hear.”  He did admit he wasn’t particularly pleased to listen to very loud rock and roll.

He died when he was 85.

## William Shockley (1910-1989)

The brilliant director of the transistor effort, Dr. William Shockley's research in the behavior of electronics in crystals introduced him to Bardeen and Brattain, who aided him in his experimentation to build working models of transistor mechanisms.  Spurned on by their demonstration of a working point-contact transistor, Dr. Shockley created the junction transistor, which became the fundamental structure of transistor developments to come.

Dr. Shockley, born in London and raised in Palo Alto, received his Ph.D. in solid-state physics from the Massachusetts Institute of Technology in 1932 and joined the staff of Bell Laboratories in Murray Hill, NJ, in 1936.  Mervin Kelly, then director of research and later to be vice president, lured Shockley to Bell Labs by promising him he could work with C. J. Davisson, who in 1937 won the Nobel Prize for his work in physics.  He didn't start working for Davisson, but wound up in Kelly's old vacuum tube department instead.

Within a year, however, Dr. Shockley pressed to resume his research on the behavior of electrons in crystals, "and the management policy was flexible enough to allow me to make the change.  This research introduced me to Walter Brattain."

During World War II, he served as director of research for the Antisubmarine Warfare Operations Research Group of the US Navy.  After the war, he returned to Bell Telephone Laboratories as co-head of a solid-state research group, "and I set as one important goal of the group the making of solid-state amplifier structures that would work."

"I suggested devices using principles like my pre-war idea," rectification mechanisms in copper oxide.  "They failed," Dr. Shockley declared.  "But this time the failure was creative."  From the work, he said, "Bardeen explained the failure in terms of the surface states that produced the Schottky barrier at the free surface."

"Our [earlier] failure to make a transistor was creative," he said."  It led to research on the scientific aspects of Bardeen's surface states."  He noted, "The managerial art of optimizing the interaction between pure and applied research is what makes Bell Labs so eminent a leader in innovation."

His work led to the invention of the junction transistor. “Exploiting its potential caused many headaches,” he said. “A colleague called 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, the first microwatt junction transistors were what really inaugurated the transistor era.”

Dr. Shockley left Bell Labs in 1955 to establish Shockley Semiconductor Laboratory (part of Beckman Instruments, Inc.), an effort that was instrumental in the birth of Silicon Valley and the electronics industry. Several of his former employees left his company to found what later became Intel, the most successful microprocessor company in the world.

Dr. Shockley later became a distinguished professor of electrical engineering at Stanford University.

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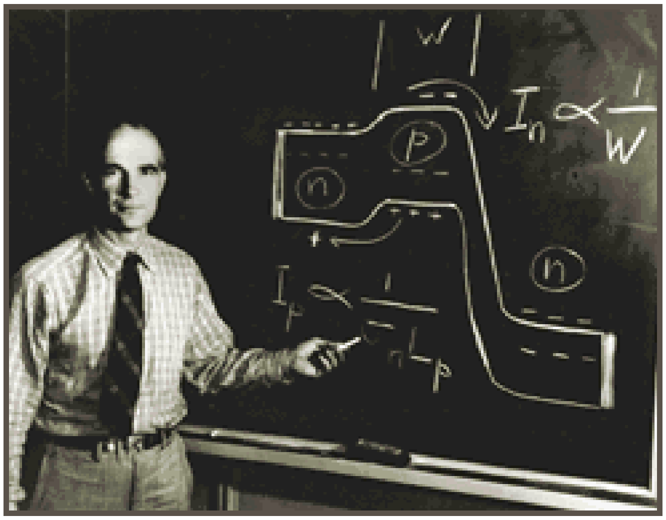
# What is it?




In order to grasp the transistor effect, you need to understand how a transistor can function both as an insulator and a conductor. It is the transistor's ability to fluctuate between these two states that enables it to switch or amplify.

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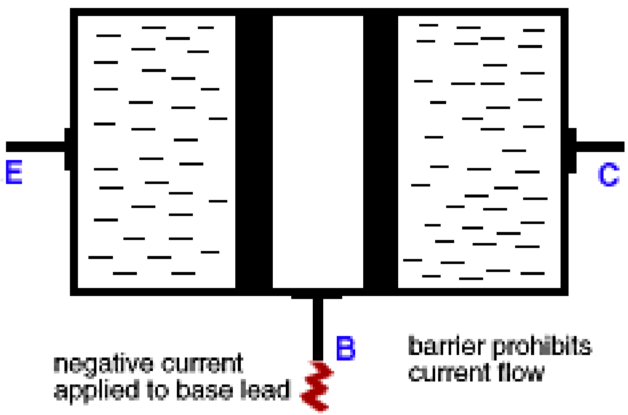
# Insulation

Restart Animation




This shows the transistor effect as the transistor is made to alter its state from a starting condition of conductivity (switched 'on', full current flow) to a final condition of insulation (switched 'off', no current flow).

The animation begins with current flowing through the transistor from the emitter (point E) to the collector (point C). When a negative voltage is applied to the base (point B), electrons in the base region are pushed ('like' charges repel, in this case both negative) back creating insulation boundaries. The current flow from point E to point C stops. The transistor's state has been changed from a conductor to an insulator.

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# Conductivity

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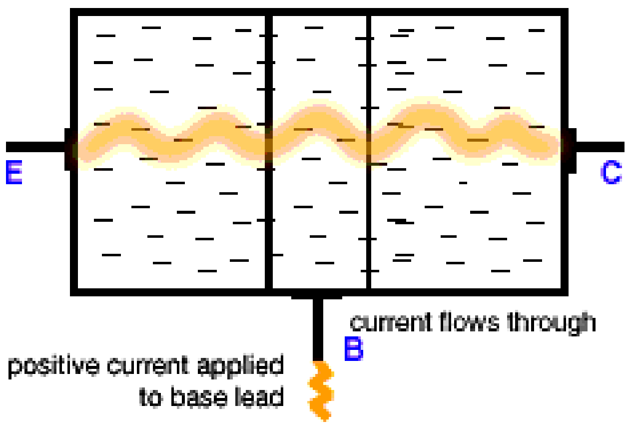


This animation shows the transistor effect as the transistor is made to alter its state from a starting condition of insulation (switched 'off', no current flow) to a final condition of conductivity (switched 'on', full current flow).

The animation begins with the transistor acting as an insulator. In order to have it conduct, positive voltage must be applied to the base (point B). As opposite charges attract (in this case, positive and negative), electrons are 'pulled' out of the insulation boundaries and flow out of the base region at point B. The barriers that once restricted flow of electrons from the emitter to the collector are diminished. Electrons begin to flow in at the emitter (point E), through the base to the collector (point C). The transistor's state has been changed from an insulator to a conductor.

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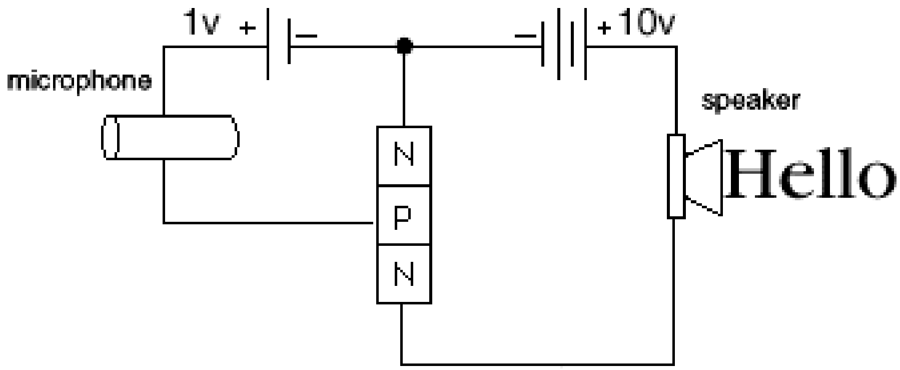
# Amplification

Restart Animation




This animation demonstrates how a transistor functions in a circuit. As it begins, the transistor is acting as an insulator-- that is when there are no sound waves activating the transistor, it simply blocks the flow of current through the circuit. But as the microphone converts incoming sound waves into waves of positive electrical current, the current travels along the left side of the circuit to the transistor and pumps electrons out of the base region. A large surge of electrons rushes through the transistor and transforms the weak incoming current into a stronger copy of itself. This stronger current then travels along the right side of the circuit to the speaker where it exits as amplified sound.

# It's Everywhere

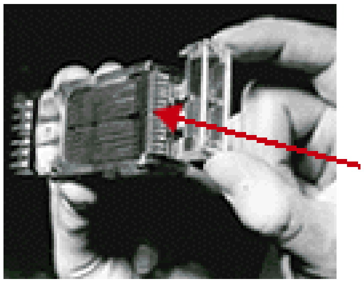
Transistors have become an invisible technology that is part of virtually any electronic device. Every major information age innovation was made possible by the transistor. Without it we would not have:

... and thousands more ...

next ▶

# First Uses

A prime motivation of the Bell Labs team that invented the transistor was to devise a way to pull unreliable mechanical relays out of telephone exchanges and make the connections electronically. So, it makes sense that the first commercial use of the transistor was telephone equipment in the early 1950's.



a telephone relay
from the early 50's

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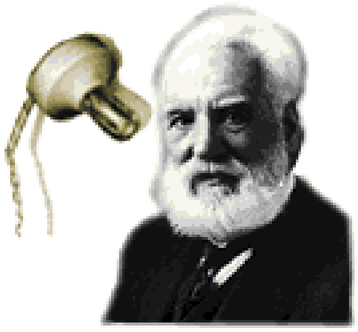
## Early Applications



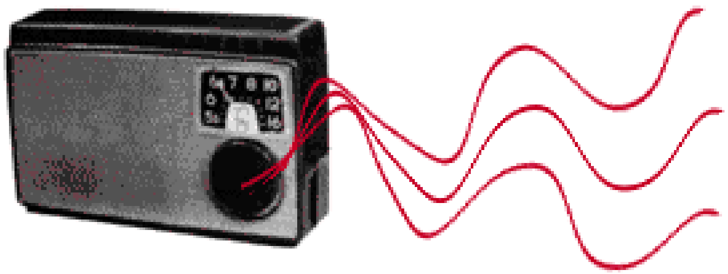
Alexander Graham Bell

The first applications were rural telephone carrier amplifiers and headset amplifiers for operators. Another early amplification was the transistorized hearing aid. In honor of their namesake, Alexander Graham Bell, a lifelong advocate for the hearing impaired, Bell Labs waived the patent royalties for the hearing aids. In 1954, IBM announced they would no longer use vacuum tubes in their computer designs by announcing their first fully transistorized computer. That machine had 2000 transistors.

next ▶

# Transistorized

In 1954, the transistor became part of popular culture with the sale of the first transistor radio. By the late 1950's, the transistor became an integral part of the electronic telephone switching system, but also a key component of other important products and services, such as portable radios, computers, and radar.



Dr. Brattain was most proud of the development of the transistor radio. (But he did admit that he wasn't particularly pleased to listen to very loud rock and roll.

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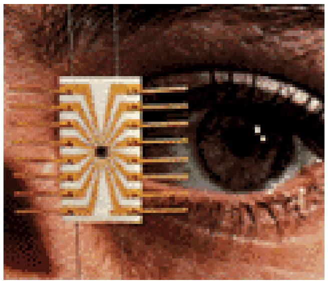
# Integrated Circuits

As the semiconductor technology improved, the transistor became faster, cheaper, and reliable. In 1959, a huge breakthrough took place with the invention of the integrated circuit--the ability to organize numerous transistors and other electronic components on a silicon wafer--complete with wiring. These microchips took the transistor innovation to an exciting new level and spurred the evolution of the Information Age.



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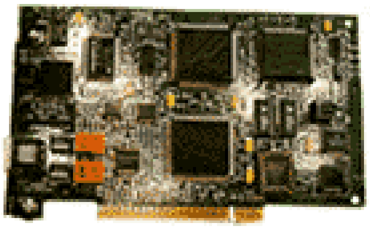
# Microprocessors

Now microprocessors are comprised of millions of transistors--a popular PC chip, for example, has 3.5 million transistors.

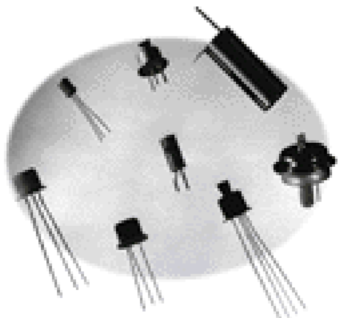


faq

# What is a transistor?

A transistor a small electronic component that is found in virtually every electronic device. It has two basic applications. The first, modulation of an electronic current, came first in the form of an amplification of an electric signal in a radio. The second application, switching, is of utmost importance in computer operations which are based on millions of lightning fast on-off decisions. The transistor is an integral component of an integrated circuit, the brains of a computer.

What is it? (tech.pdf)



next ▶

faq

# Why don't you hear much about them anymore?

In the early 1950's, a few years after the transistor was invented, it captured the world's imagination. Here was an amazing new invention that affected the lives of ordinary people. The transistorized radio was the fastest selling retail object of all time. Using the term 'transistorized' was a selling point! But now, years after the invention of the microchip, the transistor has become virtually invisible. It's everywhere, so people take them for granted. Its the one true sign of a technology's overall success!

next ▶

faq

# How much does a transistor cost?

In the early 50's, a transistor cost between $5 and $45 dollars to make. Now the transistors on a microchip cost less than a hundred thousandth of a cent. For all practical purposes, they are free.


next ▶

faq

# What's a semiconductor?

germanium

A semiconductor is a unique material with physical properties somewhere in between a conductor like aluminum and an insulator like glass. Examples include germanium, the semiconductor used for the first transistors, and silicon, the basic material in the integrated circuit. Researchers exploited the unique properties of a semiconductor to create the transistor effect--that is, the ability to change its conductivity properties using an electric current.

next

faq

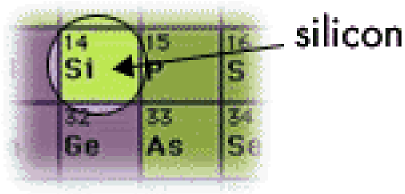
# What's a vacuum tube?

A vacuum tube was an integral device in electronic components before the transistor was invented. Indeed, it was used for the same tasks--switching and modulation (amplification)--but was expensive, unreliable, hot, and bulky. The first computers were made with vacuum tubes, but the vacuum tubes burned out frequently, so something better was needed. Also, the lights attracted moths which short-circuited the computer. Ever since, fixing computer problems has been called 'debugging.'

next ▶

faq

# What is silicon?

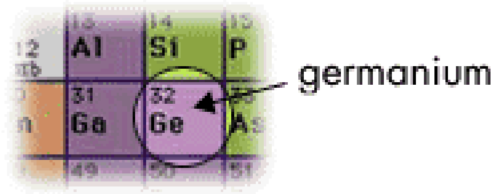



Silicon is the most popular semiconductor material in the world. It is a gray, crystalline element. It has four electrons, thus possessing the material characteristics of a semiconductor. It is never found as a free element in nature, but its dioxide and other compounds constitute nearly 9/10ths of the earth's crust. Its most common form is sand or sandstone. Initially, it was very hard to use to create transistors due to its high melting point, brittleness, and other difficult characteristics. But, with advanced silicon processing techniques developed in the 1950's (many developed at Bell Labs) silicon eventually became the semiconductor material of choice over germanium, in no small part due to its abundance and durability.

next

faq

# What is germanium?




Germanium is the semiconductor material that the Bell Labs team used to create the first transistor. It was used in the first years of transistor development until techniques were invented to utilize the much more abundant semiconductor material, silicon. Germanium is a grayish white element with brilliant metallic luster and a crystalline structure with a diamond pattern.