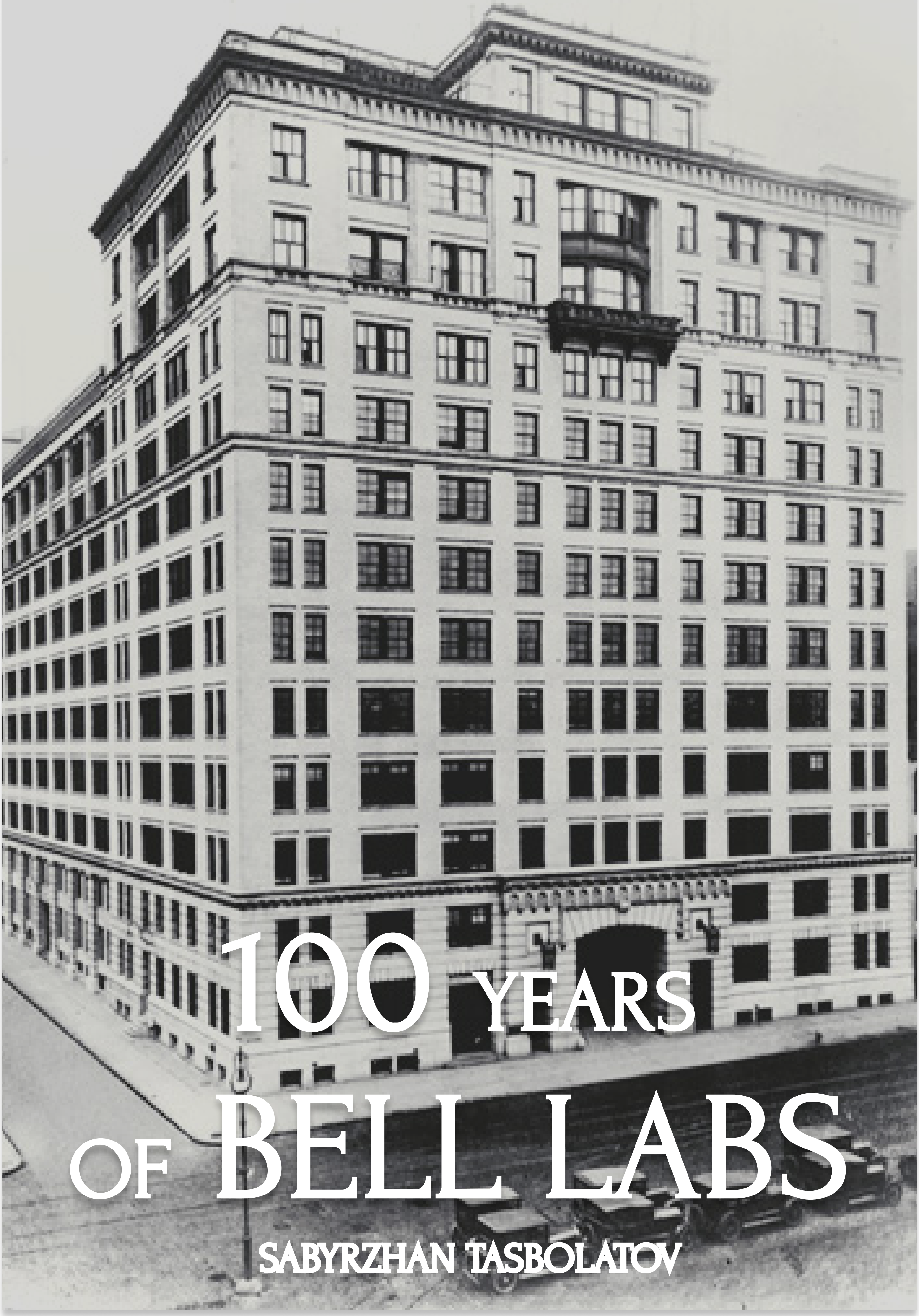
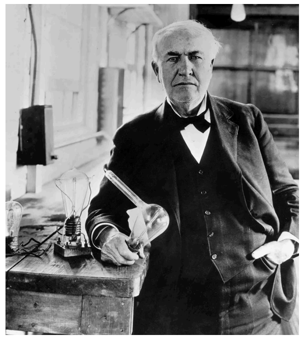


100 YEARS OF BELL LABS

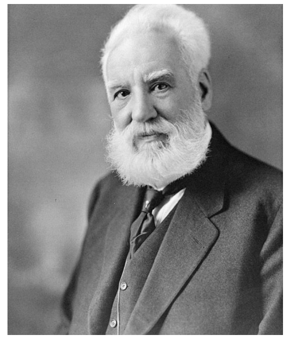
SABYRZHAN TASBOLATOV

AMIDST THE SECOND & THE THIRD INDUSTRIAL REVOLUTION

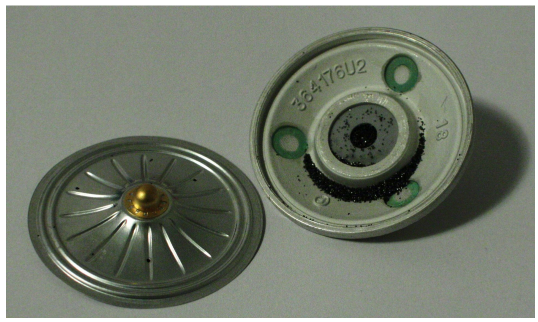
What is the best research & development organization of the last 100 years? If you search the Internet or ask an AI the question, Bell Labs will surely appear at the top of the list. This prestigious institution, founded in January 1925, shaped the course of worldwide technology after the dawn of the Second Industrial Revolution (1870–1914). Back in 1886, when Thomas Edison used roasted carbon granules after experimenting with various chemical compounds to improve the quality and voice power of telephone handsets, the American public was far more impressed by practical innovations rather than by theoretical knowledge. These carbon particles made long-distance communication practical, eliminating the need to shout to be heard on Bell Telephone Company devices. The Bell Telephone Company, founded by Alexander Graham Bell in 1877, was later restructured into the AT&T company in 1899, which eventually became a monopoly.



THOMAS EDISON
(1847 - 1931)



ALEXANDER G. BELL
(1847 - 1922)



MICROPHONE WITH CARBON GRANULES

There is a finite list of Bell Labs innovations compiled by A. Michael Noll in 2012. This list includes 213 discoveries made between 1925 and 1983. However, there are countless technologies and companies indirectly impacted by Bell Labs as derivatives. Here's another incomplete list (source):

Electric and electronic devices:
High-vacuum tube (developed but did not invent)
Silicon solar photovoltaic cell
Charge-coupled device (CCD)
CO_2 laser
Room-temperature semiconductor laser
Electret microphone
First videophone
Vocoder
Artificial larynx (both mechanical and digital)
Negative feedback amplifier

Telecommunications:
Coaxial cable
First black and white TV transmission in US
First color TV transmission
First fiber optic telephone cable
First active and passive communications satellites
First submarine telephone cable
First cellular phone network

Math/Computing:
Information Theory
Statistical Process Control
Nyquist Sampling Theorem
Pulse Code Modulation (developed but did not invent)
Linear predictive coding
Hamming codes
UNIX Operating System
C and C++ Programming languages

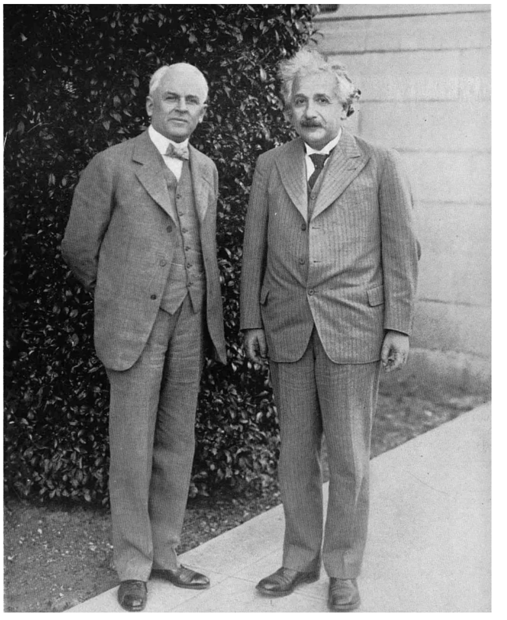
Transistor-related:
Point-contact transistor
Bipolar junction transistor
First silicon transistor
MOSFET
Crystal pulling (developed but did not invent)
Zone refining
Ion implantation
Gaseous diffusion
Photolithography
Molecular Beam Epitaxy (MBE)

Scientific discoveries/misc inventions:
Wave nature of electron (1937 Nobel Prize)
Radioastronomy
First motion picture with synchronized sound
Cosmic microwave background radiation (1978 Nobel Prize)
Fractional Quantum Hall Effect (1998 Nobel rize)
Laser cooling (1997 Nobel Prize)
Optical tweezers (2018 Nobel Prize)
Quantum dots (2023 Nobel Prize)
UV-stabilized polyethylene
Nb_3Sn high-temperature superconductor

The breakup of the Bell System in 1984 makes it difficult to fully trace its legacy. The fate of Bell Labs itself is also complex. In 1996, AT&T spun off Bell Labs' equipment manufacturing division, formerly known as Western Electric, into Lucent Technologies. Lucent was later acquired by Alcatel, which in turn was acquired by Nokia. Today, Nokia Bell Labs is actively involved in developing 6G wireless technologies and sub-THz frequencies, expected to begin rolling out in the early 2030s.

Before Bell Labs, also known as "The Idea Factory," was established in 1925—and before its invention of the transistor in 1947, marking the origin of the Third Industrial Revolution (the Information Age)—a series of important events unfolded in the early 1900s. In 1905, Albert Einstein's *Annus Mirabilis* papers were published in the German journal ***Annalen der Physik***. These papers became a source of inspiration for American scientists and engineers, including experimental physicist Robert Millikan (1868–1953), who studied the photoelectric effect. Although Millikan was not directly affiliated with Bell Labs, he served as the doctoral advisor to Mervin Kelly and Harvey Fletcher, who assisted him in the famous oil-drop experiment to measure the elementary charge ($e = 1.6 \times 10^{-19}$ C), earning Millikan the Nobel Prize in Physics.

Kelly and Fletcher would later play crucial roles in Bell Labs' future, alongside Frank Jewett, who was the best man at Millikan's wedding and later became Bell Labs' first president.



R. MILLIKAN, A. EINSTEIN, 1932

1902 - Millikan married to Greta, where Frank Jewett was his the best man.

1903 - Millikan worked on the photoelectric effect to replicate the results of J. J. Thomson who received the Nobel Prize in Physics for his discovery of electron.

1905 - A. Einstein published the famous papers including about the photoelectric effect.

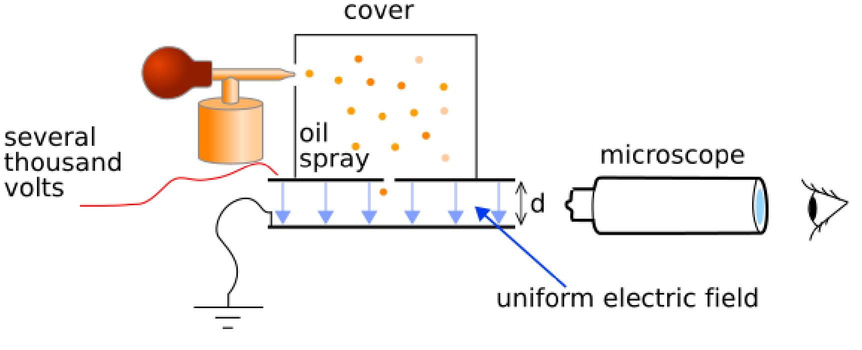
1906 - San Francisco earthquake.

1909-10 - Millikan with Harvey Fletcher performed the oil-drop experiment to measure *e* electric charge.

1909-15 - Jewett led the project of the first transcontinental phone service (New York - San Francisco). Millikan's student Harold Arnold joined the Western Electric where he improved the audion, later would be known as the vacuum tubes, the predecessor of the transistor.

1915 - Kelly was an assistant to Millikan and participated in the oil-drop experiment.

1915 - Pacific-Panama Exposition in San Francisco. The first transcontinental telephone call.



SIMPLIFIED SCHEME OF OIL-DROP EXPERIMENT
TO MEASURE ELECTRON CHARGE

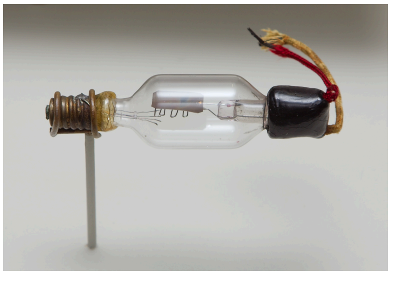
H. FLETCHER (1884 - 1981)

Millikan claimed sole credit for the oil-drop work, while Fletcher agreed to claim full authorship of a related result in his dissertation. Fletcher's contributions were primarily focused on meticulous details. Millikan later won the 1923 Nobel Prize in Physics, partly for this work, and Fletcher upheld their agreement in secrecy until his death.

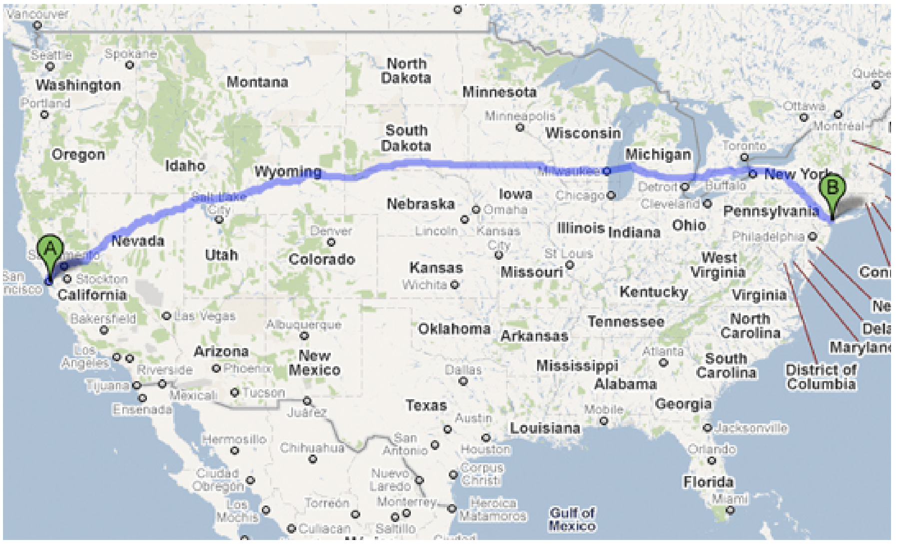
Jewett was a senior manager at the phone company in 1909 when he and his boss John J. Carty, AT&T's chief engineer, traveled to San Francisco, still recovering from the devastating 1906 earthquake. Their mission was to repair the local phone system, but they also began planning the first transcontinental telephone service, connecting New York to San Francisco in time for the Panama-Pacific International Exposition of 1915.

"The crux of the problem was a satisfactory telephone repeater or amplifier," Jewett later wrote about his conversations with Carty. Jewett was appointed head of the operation and traveled back to the East Coast to consult with Millikan, hoping his scientific expertise could help create an amplifier capable of transmitting voice signals over such a long distance. Millikan suggested the task to Harvey Fletcher, who had previously proposed replacing evaporated water with oil mist during the electron charge measurement. However, Fletcher declined, and Harold Arnold, a skilled experimentalist, took over the project to improve the existing amplifier—a device resembling a small light bulb known as the audion, invented by Lee De Forest. Arnold hypothesized that a high vacuum would significantly enhance the audion's efficiency. After testing this hypothesis with Jewett and Millikan, Arnold developed what became known as the **vacuum tube — the predecessor of the transistor.**

FRANK JEWETT (1879 - 1949)



TRIODE AUDION VACUUM TUBE, 1908



THE FIRST TRANSCONTINENTAL CALL
FROM NEW YORK BY A. G. BELL
TO T. WATSON IN SAN FRANCISCO IN JANUARY 25, 1915

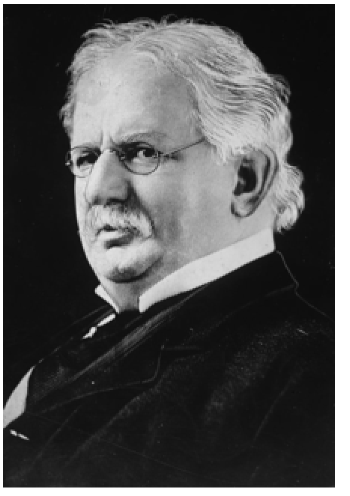
TELEPHONES USED ON
THE FIRST TRANSCONTINENTAL CALL

Despite his relatively short life of 50 years, H. Arnold is regarded as a pioneer in vacuum-tube electronics, making significant contributions to radio communication and telephony. He also served as the ***first research director of Bell Labs*** *from 1925 until his death from a heart attack. An intriguing article, "Radio Telephone Equipment for Caribbean Service," provides a detailed technical account of Arnold's contributions.*

H. ARNOLD (1883 - 1933)

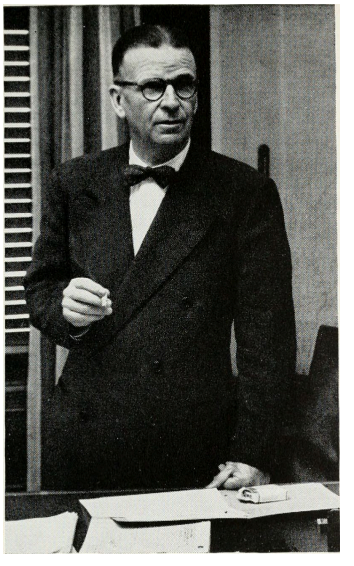
DE FACTO NATIONAL TREASURE

The first transcontinental call was a pivotal milestone for AT&T and its subsidiary, Western Electric, laying the groundwork for the establishment of Bell Labs in 1925. Engineers, researchers, and the Bell System demonstrated remarkable resilience during challenging periods such as World War I (1914–1918), U.S. Prohibition (1920–1933), and the Great Depression (1929–1939). Bell Labs later contributed groundbreaking innovations, including radar and sonar technologies, which played a critical role in Allied defense efforts during World War II (1939–1945). This resilience and innovation were made possible by the stability provided through AT&T's monopoly, its protected R&D budget, and its de facto status as a vital American asset.



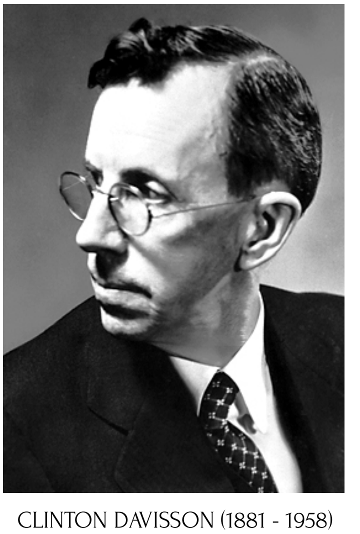
THEODORE VAIL (1845 - 1920)

At the helm of AT&T, Theodore Vail, who became its president in 1907, is widely regarded as the company's savior due to his visionary management principles and bold strategies like firing 12000 employees. Under his leadership, AT&T consolidated its operations, including the engineering departments, into the New York office, where F. B. Jewett later worked. Vail is credited with shaping AT&T's approach to achieving a monopoly by advocating for regulated cooperation with the government rather than brute force. Recognizing that the telephone was becoming a "necessity of life" in public and private spheres, he foresaw that AT&T's monopoly could be sustained through political oversight rather than aggressive acquisitions. Instead of indiscriminately buying out smaller telephone companies, which often required government approval, Vail introduced a system where independent companies could pay AT&T fees to connect to its long-distance network.



MERVIN KELLY (1894 - 1971)

Kelly grew up in a poor family in Missouri, where he worked various odd jobs during the summers. He kept the books for his father's store and had a newspaper delivery route. By the time he was 16, he had saved just enough money for tuition at the Missouri School of Mines and Metallurgy in Rolla. His ambitions propelled him to career excellence, starting as Millikan's assistant and ultimately becoming the president of Bell Labs. Kelly was robust, energetic, and an avid smoker. He had tremendous energy, often running up and down staircases at the Bell Labs office. While working as a research physicist in the engineering department led by H. Arnold at Western Electric, Kelly met Clinton Davisson, another Midwestern protégé of Millikan. Davisson, in contrast to Kelly, had a reserved temperament, speaking slowly or sometimes not at all. Despite their differences, Kelly and Davisson became close friends. After World War I ended, during the Prohibition era in the United States, and with the founding of Bell Labs in 1925, both Kelly and Davisson were transferred to the newly established organization, where they worked on vacuum tube technology.



CLINTON DAVISSON (1881 - 1958)

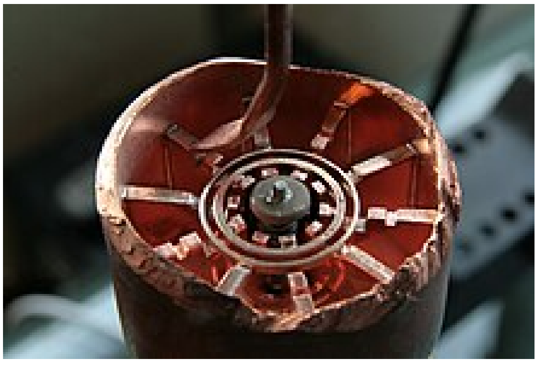
Davisson would later win the Nobel Prize in Physics in 1937 for his discovery of electron diffraction in the Davisson-Germer experiment. In this experiment, electrons scattered by the surface of a nickel crystal displayed a diffraction pattern, confirming the hypothesis of wave-particle duality and supporting the wave mechanics approach described by Schrödinger's equation. This achievement was a pivotal experimental milestone in the development of quantum mechanics.

As director of vacuum tube development, Kelly improved the lifetime of vacuum tubes from 1,000 to 80,000 hours. He later became the director of research at Bell Labs in 1936, succeeding H. Arnold, who had passed away in 1933.

The U.S. government's investments in radar development during WWII were greater than those in the infamous Manhattan Project. The $2 billion (roughly $36 billion in today's dollars) allocated for nuclear weapon development under the Manhattan Project, led by J. Robert Oppenheimer, contrasts with the $3 billion investment (around $50 billion in today's dollars) for radar development. Bell Labs played a crucial role in advancing radar technology, particularly in the field of microwave radar, which became central to detecting enemy aircraft and ships. Several significant radar systems were developed or improved at Bell Labs, contributing significantly to the Allied victory in WWII. Notably, Bell Labs was involved in the development of radar systems like the AN/TPS-1, which became a key component of the post-war radar network.

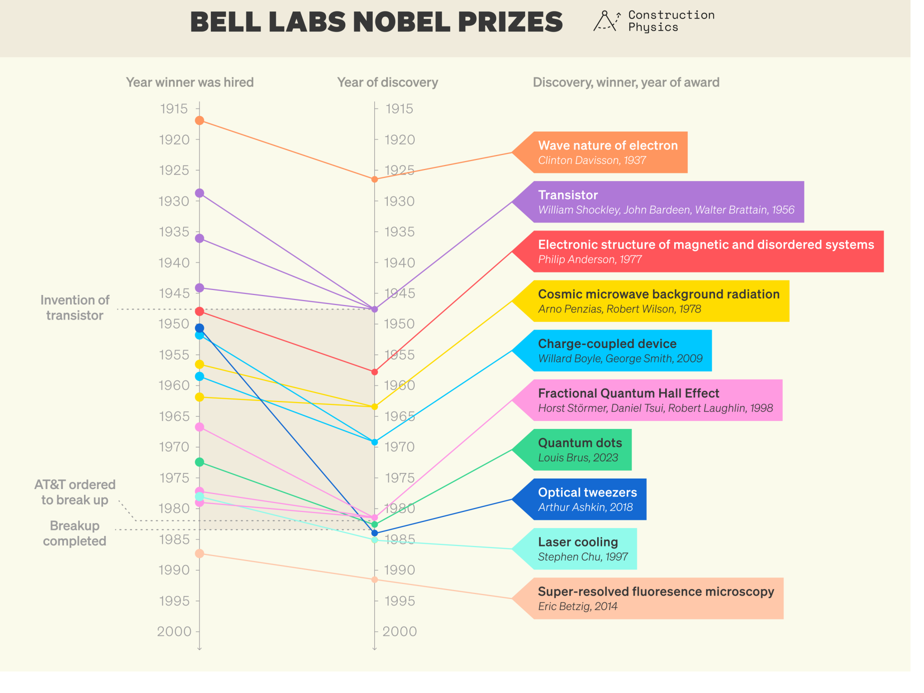
AN/TPS-1B SEARCH RADAR DURING WWII

Cavity magnetron developed in 1940 in the UK at the University of Birmingham. Allowed radar systems to emit shorter, more focused signal. Now used in the microwave ovens and communications. Bell labs received the samples of magnetrons to improve and adapt them in the US Airforce.



Mervin Kelly was in charge of all military work of Bell Labs and remarked: "Progress has been made in some fields of technology in a four-year interval that, under normal conditions of peace, would have required from 10 to 20 years". As WWII came to an end, Kelly formed a new solid-state group where William (Bill) Shockley whom Kelly recruited in 1936, led the team of replacing unreliable, expensive and fragile vacuum-tube with something innovative. Kelly made sure that in order to solve the complex problem, the solid state group should include physicists, experimentalists, theorists, chemists and metallurgist, electrical engineers and circuitry experts to solve the problem of switches.

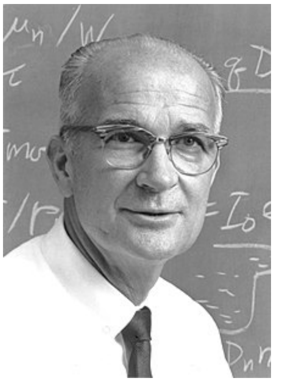
Kelly was acknowledged in the 1956 Nobel Prize acceptance speeches of Shockley, Bardeen, and Brattain when they were awarded "for the researches on semiconductors and their discovery of the transistor effect".



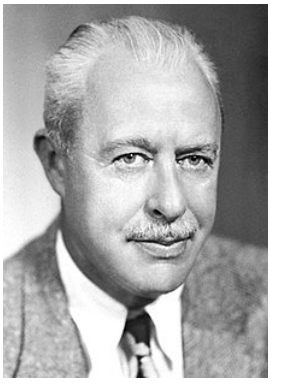
SOURCE

The early point-contact version of the transistor, where **germanium** was used as the semiconductor, was invented on December 23, 1947, by John Bardeen and Walter Brattain, without Shockley at that day, who led the solid-state group. Although Shockley publicly took the majority of the credit for the invention, this led to a deterioration in his relationship with Bardeen. Despite this, Bell Labs management consistently presented all three inventors as a team. Shockley's actions eventually angered and alienated Bardeen and Brattain, effectively blocking them from working on the junction transistor. Bardeen left Bell Labs in 1951 to pursue a theory on superconductivity, and in 1972, he was awarded a second Nobel Prize in Physics, shared with L. N. Cooper and J. R. Schrieffer. He remains the only individual to have received the Nobel Prize in Physics twice. Brattain, unwilling to continue working with Shockley, was reassigned to another group. After the first year following the transistor's invention, neither Bardeen nor Brattain was significantly involved in its further development.

JOHN BARDEEN (1908 - 1991)



WILLIAM SHOCKLEY (1910 - 1989)



WALTER BRATTAIN (1902 - 1987)

1953 - Shockley left the Bell Labs.
1955 - Shockley founded the Shockley Semiconductor Lab at the West Coast, Mountain View, CA. The first high-tech company to work on **silicon-based** semiconductor devices and the place to be later known as "Silicon Valley".
1956 - Shockley hired young PHd students.
1957 - 8 PHd students left Shockley Lab and founded Fairchild Semiconductor. Shockely called them "The traitorous eight". Shockley Semiconductor Lab never recovered from this and was later acquired by another company.

Intel was co-founded by Robert Noyce, Gordon Moore, and Andy Grove, all of whom were associated with Fairchild.

AMD was created by early employees and the former executive of Fairchild, Jerry Sanders.

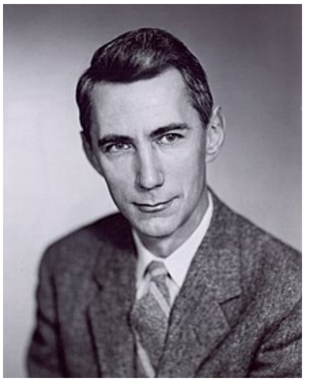
NXP emerged as a spin-off from Philips in 2006. Philips had acquired Signetics in 1961, a company founded by one of the "traitorous eight."

Kleiner Perkins, a venture capital firm established in 1972, has funded many major tech companies, including Amazon and Google, during their early rounds of investment.

THE TRAITOROUS EIGHT, 1960:
GORDON MOORE, C. SHELDON ROBERTS, EUGENE KLEINER, ROBERT NOYCE, VICTOR GRINICH, JULIUS BLANK, JEAN HOERNI, JAY LAST

ESPRIT DE CORPS

Fostering an unparalleled environment of collaboration, innovation, and excellence. Scientists, engineers, and visionaries from diverse disciplines worked together, driven by a shared mission to push the boundaries of technology and knowledge. This culture of mutual respect and intellectual curiosity was bolstered by Bell Labs' unique blend of academic freedom and industrial focus, enabling breakthroughs like the transistor, laser, and information theory.



CLAUDE SHANNON (1916 - 2001)

Claude Shannon and Harold Nyquist were two monumental figures in the field of information theory and telecommunications, both leaving indelible marks during their time at Bell Labs. Nyquist is best known for the Nyquist-Shannon sampling theorem, a cornerstone of digital signal processing, which established the foundation for converting analog signals to digital form without loss of information. He also contributed significantly to the understanding of thermal noise in communication systems, formulating the Nyquist noise equation that became critical for designing efficient telecommunication systems. Claude Shannon, often called the "Father of Information Theory," revolutionized the field with his groundbreaking 1948 paper **"A Mathematical Theory of Communication"**. Shannon introduced the concept of the "bit" as a unit of information and developed methods to quantify and optimize data transmission.

HARRY NYQUIST (1889 - 1976)

An interesting historical note is Shannon's playful personality—he built quirky inventions, including a machine that solves Rubik's cubes, and famously juggled on a unicycle. Together, these two luminaries laid the foundation for the modern digital and communication age. For example, the latest Xilinx RFSoC frequently references Nyquist zones in various contexts, such as RF ADCs, DACs, and other signal processing applications, to describe how input frequencies are mapped to specific frequency ranges based on sampling rates.

The charge-coupled device (CCD), invented by George E. Smith and Willard Boyle at Bell Labs in 1969, is a revolutionary technology that transformed fields such as astronomy, medicine, and photography. Initially conceived as a memory device, the CCD's ability to capture and store images was soon realized, making it the first digital imaging sensor. This innovation paved the way for digital cameras, video cameras, and advanced telescopes like the Hubble Space Telescope, which rely on CCDs for capturing detailed images of the universe. Boyle and Smith's work earned them the Nobel Prize in Physics in 2009, recognizing the profound impact of their invention.

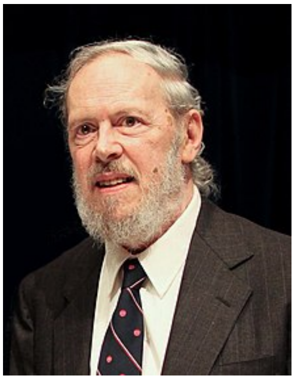
Interestingly, their initial brainstorming session for the CCD lasted just an hour, showcasing the creative brilliance and collaborative culture at Bell Labs.

GEORGE E. SMITH
(BORN 1930)

WILLIARD BOYLE (1924 - 2011)

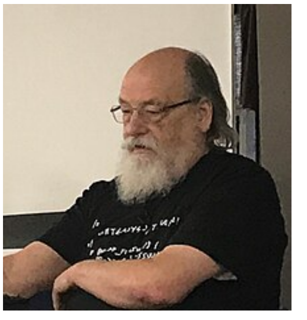
CCD CAMERA AND CCD SENSOR WHICH IS
DOMINATED BY CMOS SENSORS USED IN DIGITAL IMAGING

Dennis Ritchie and Ken Thompson, renowned computer scientists at Bell Labs, revolutionized the world of computing with their groundbreaking contributions. Together, they created the UNIX operating system in 1969, a multitasking, multi-user system that became the foundation for countless modern operating systems, including Linux and macOS. Ritchie also developed the C programming language, which provided the structural framework for UNIX and remains one of the most influential programming languages in history. Thompson, a visionary in system design, contributed significantly to early computing innovations, including his work on the B programming language and the development of early text editors and utilities. Their partnership at Bell Labs exemplified the lab's ethos of innovation, where interdisciplinary collaboration drove transformative technologies that shaped the digital age.



DENNIS RITCHIE (1941 - 2011)

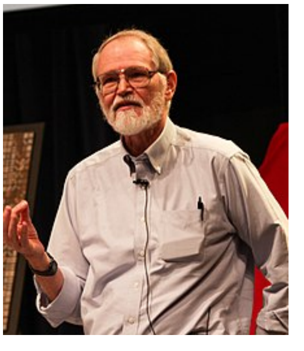
Bjarne Stroustrup, another luminary at Bell Labs, extended Ritchie's work on C by developing C++ in the early 1980s. Stroustrup designed C++ to add object-oriented programming features while maintaining C's efficiency, making it a versatile and powerful tool for software development. Stroustrup often credited Ritchie and Thompson's work as an essential foundation for his innovations, and their collaborative and innovative environment at Bell Labs was instrumental in fostering his achievements. Together, these individuals epitomized Bell Labs' legacy of shaping the modern computing landscape.



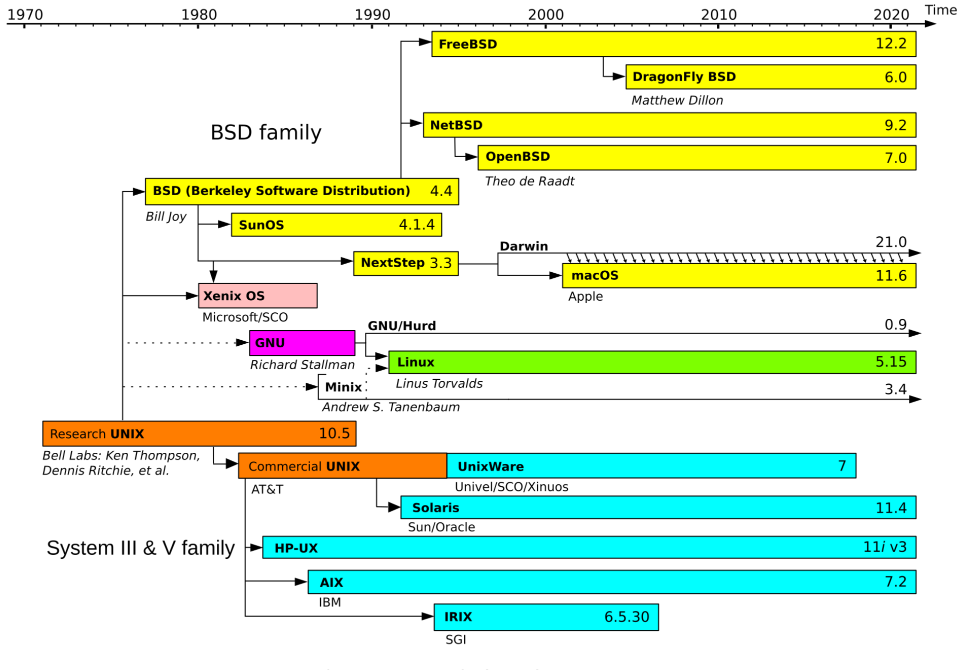
KEN THOMPSON (BORN 1943)

Douglas McIlroy and Brian Kernighan were key figures in the collaborative and innovative environment at Bell Labs, both contributing to its legendary esprit de corps. McIlroy, a pioneer in software engineering, is best known for his development of the Unix pipeline, a concept that allowed multiple software tools to be connected in series to process data efficiently. His work on the design of Unix utilities and his emphasis on composability and modularity helped shape modern programming practices. Kernighan, often referred to as one of the "founding fathers" of Unix, made significant contributions to the development of the C programming language and the Unix operating system. Along with Ritchie, he co-authored the influential book "The C Programming Language", which became the definitive guide for learning C and had a lasting impact on generations of programmers. Both McIlroy and Kernighan, through their technical accomplishments and commitment to collaboration, embodied Bell Labs' culture of intellectual curiosity, teamwork, and excellence, which fostered transformative innovations in computing.

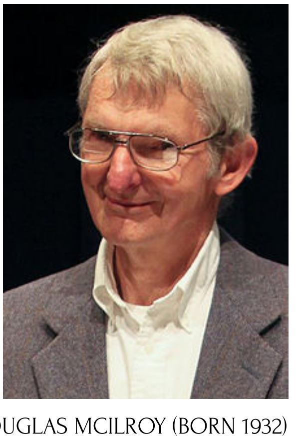
BJARNE STROUSTRUP (BORN 1950)



BRIAN KERNIGHAN (BORN 1942)



SIMPLIFIED HISTORY OF UNIX-LIKE OPERATING SYSTEMS (SOURCE)



DOUGLAS MCILROY (BORN 1932)

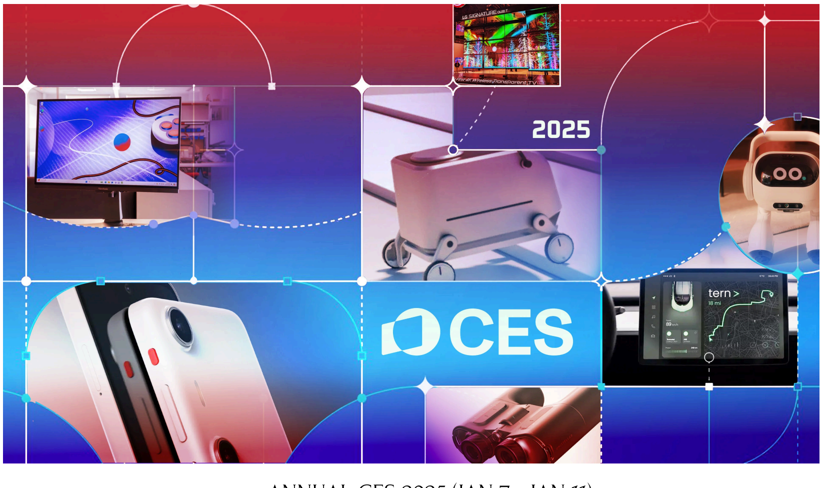
INDUSTRY 4.0 AND 2025

Bell Labs, renowned for its groundbreaking innovations like the transistor, UNIX, and the laser, continues to shape the future of technology in 2024-2025 by driving advancements in Industry 4.0. Now a hub for cutting-edge research in artificial intelligence, 5G/6G communications, and quantum computing, Bell Labs collaborates with industry leaders to redefine the boundaries of connectivity and automation. At IEEE conferences, Bell Labs showcases its latest breakthroughs, influencing global standards and inspiring the next wave of engineers. Meanwhile, at the annual CES events, its innovations feature prominently, from AI-driven network solutions to smart manufacturing systems that epitomize Industry 4.0. By blending its rich legacy of innovation with modern technological imperatives, Bell Labs remains a cornerstone of progress, fostering intelligent, connected, and sustainable systems that resonate across industries and transform lives globally.

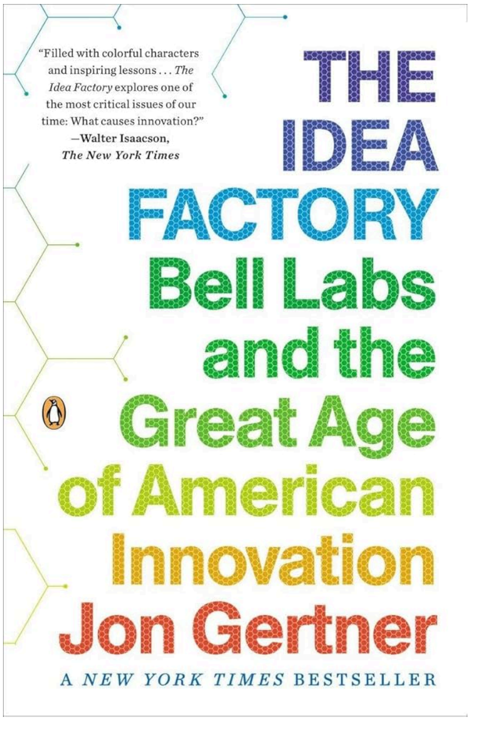
As the world celebrates 100 years of Bell Labs in 2025, its legacy as a beacon of human ingenuity and discovery remains unparalleled. From inventing the technologies that defined the 20th century to propelling advancements in Industry 4.0, Bell Labs symbolizes the power of human creativity and collaborative spirit. Yet, in an era dominated by AI, where U.S. President Donald Trump's historic $500 billion investment plan in OpenAI has set the stage for unprecedented innovation, questions arise about the future of human-driven discovery.

Could AI supplant the unique innovation culture of Bell Labs, where ideas grew organically through serendipity and collaboration? Perhaps, as machines increasingly lead the charge, there will never be another Bell Labs. But its century-long journey serves as a reminder that while AI may automate processes and optimize creativity, the human spirit of curiosity and the magic of collective breakthroughs remain irreplaceable. Bell Labs' story is not just about innovation—it's a testament to the enduring potential of humanity itself.

NOKIA IS THE PARENT COMPANY
SINCE 2016
OF THE HISTORIC BELL LABS



ANNUAL CES 2025 (JAN 7 - JAN 11).
THE MOST TECH EVENT
IN THE WORLD



THE MAIN SOURCE AND THE INSPIRATION
OF THIS MATERIAL

AUTHOR

My name is Sabyrzhan Tasbolatov. I was inspired by Jon Gertner's book about Bell Labs and decided to create a brief summary of this institution, which has an amazing history of significant achievements, in honor of its 100th anniversary on January 1, 2025.

There are many other accomplishments and notable figures that I have not included in this material, such as innovations in laser technology and astronomy. However, my intention was to inspire and commemorate the 100th anniversary in some way.

Please feel free to reach out to me for editing or corrections. All pictures were sourced from the Internet, mostly from Wikipedia.

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