Magazine for the Science & Technology Innovation Center in Middletown, NJ • Premier Edition

AT&T

Science & Technology Innovation

Honoring the Past, Creating the Future

Innovation is in our DNA

Letter from our Editor

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Welcome to our Science & Technology Innovation Center of Middletown, New Jersey magazine premier edition. The new Innovation Center is a place of inspiration and learning from the history of AT&T and significant inventions that our company has created over the past 142+ years that contribute to the advancement of humanity. Over my years at AT&T, I have spoken to many people who never knew that AT&T had a history of innovation in so many areas beyond the creation of the telephone by Alexander Graham Bell.

Throughout the years, AT&T has been a key player in local and long-distance voice telephony, motion pictures, computers, the cable industry, wireless, and broadband. AT&T has served the nation's telecommunication needs and participated in many technology partnerships in every industry throughout the globe. The breadth of technology and innovation goes on and on, but a few of the innovations you might see at our new Innovation Center include: ground-to-air radio telephony, motion picture sound, the Telstar satellite, telephone switching, the facsimile machine, military radar systems, the transistor, undersea cable, fiber communications, Picturephone via T1's, coin phones, touch-tone dialing, AMPS cellular phones, UNIX™ and C language programming.

As a forward-thinking technology company, AT&T is continually re-inventing itself. Innovation has been alive in our corporate DNA for the past 142+ years. While this magazine is a tribute to the great people that give us such a rich history and future, it is my hope to inspire every person visiting the Innovation Center and reading this magazine to become a part of AT&T's legacy of innovation. With the opening of our new Center, it will be the first time people will see many of the artifacts on permanent display to inspire the current and all future generations of AT&T employees.

Finally, I would like to thank our leadership and the many individuals who made the Center and this magazine possible: our partners in this project, Hank Kafka, Scott Mair, Marachel Knight, Sihem Ben Saad, Middletown I2I; the AT&T Archivists — Sheldon Hochheiser, Bill Caughlin and Melissa Wasson; from Corporate Real Estate Jeff Onori and Chuck Ott; for help with Center media Barbara Laing and Dave Mahar; and the many volunteer authors, editors and other contributors who shared their spare time to produce the articles in this magazine.

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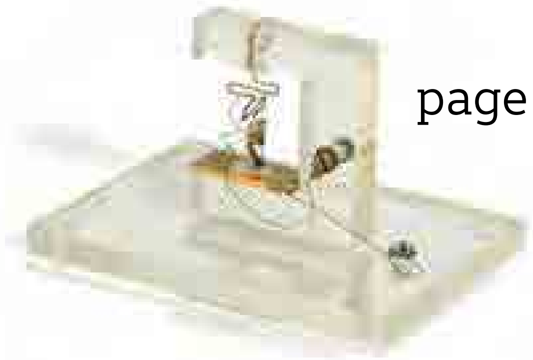

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The History of AT&T

A Company Grounded in Innovation

By Sheldon Hochheiser

Welcome to this exploration of AT&T's long history of innovation. AT&T was founded with an innovation — Alexander Graham Bell's invention of the telephone in 1876, and we have been innovating ever since in the interests of using technology — telecommunications — to bring people together.

The Birth of the Telephone

Bell was born in Edinburgh, Scotland in 1847. By the early 1870s, he was living in Boston and working as a teacher of the deaf, a profession he learned from his father. Like many young men with a technical bent, he turned to the cutting-edge technology of the day, the electrical telegraph, as an area where he could make his fortune by invention. Along with a few others, he thought of making the telegraph transmit speech rather than Morse code, but unlike the others he combined his newly acquired knowledge of electricity with an understanding of speech and hearing. In the summer of 1874, he had a key intellectual breakthrough—what was needed was not the digital on-and-off of Morse code, but what he called an "undulating current," a continuous electrical wave analogous in form to the sound wave. By June 1875, he had proven his idea by transmitting speech sounds (but not intelligible speech) down an electrical wire. This led Bell to file a patent application on February 14, 1876. The patent, #174765, was issued on March 7.

"Mr. Watson, come here; I want you!"

Three days later on March 10, using a newly designed instrument, the liquid transmitter, Bell succeeded in transmitting the first intelligible speech ever sent via electricity: "Mr. Watson, come here; I want you!" Thomas Watson, Bell's assistant, heard it down the hall on his reed receiver. Watson wrote this and several subsequent sentences down in his notebook, which is one of the treasures of the AT&T Archives and History Center. It is so fragile that a replica is on display at the AT&T Science and Technology Innovation Center. The following year, Bell applied for and received a second patent for a practical telephone.

Bell, however, was not interested in business, so he left the commercialization of his invention and the company founded to exploit it, the first Bell Telephone Company, in the hands of his chief financial backer and now father-in-law Gardiner Hubbard. Bell and his wife left for England on a long honeymoon. He was 31, and never had to work for a living again.

The Telephone in the 19th Century

Hubbard raised the capital to commercialize the telephone primarily by what we would call franchising — he licensed people in various cities to operate telephone businesses under Bell's patents. The first such franchisee, George Coy of New Haven, CT, invented the telephone switchboard, and with it opened the world's first telephone exchange in New Haven on January 28, 1878. The telephone caught on; by 1881 there were telephone exchanges licensed in almost every place in the United States with over 10,000 residents. By

Alexander Graham Bell (1876)
Photo courtesy AT&T Archives and History Center

then the parent company had been reorganized as the American Bell Telephone Company, and Hubbard and the other initial owners had lost control of the business to a group of wealthy Bostonians. American Bell and its franchisees continued to grow. In 1882, American Bell acquired a majority interest in the Western Electric Company, a leading manufacturer of electrical equipment. It became the sole supplier of telephone equipment to American Bell and its licensees. Engineers employed by Western Electric, such as Charles Scribner, made numerous inventions to improve the telephone system from multiple switchboards to underground cables.

And after the success of an 1884 long-distance line connecting New York and Boston, American Bell formed a subsidiary in 1885, the New York-based American Telephone and Telegraph Company, to build and operate a network of interstate long-distance lines connecting the local companies. AT&T reached its initial goal, connecting the nation's two largest cities, New York and Chicago, in October 1892. Alexander Graham Bell made the ceremonial call from New York to open the service. The line used an extremely thick copper wire to reduce the rate at which resistance weakened the signal so the call could travel the distance. Still, 1000 miles seemed the approximate limit for a call made with thick copper wires.

In an 1899 corporate reorganization, American Telephone and Telegraph acquired the assets of its parent American Bell and became the parent company of what soon began to be referred to collectively as the Bell System. Over the years, AT&T acquired a controlling interest, and then complete ownership of most of its licensees, which it combined into a smaller number of companies.

This followed the 1894 expiration of Bell's second patent at which time it became legal for others to open telephone exchanges. Within a decade, over 6,000 independent telephone companies had gone into business across the United States, but while Bell's market share dropped from 100 percent to 50 percent, its number of subscribers increased by 700 percent as the telephone became democratized.

Theodore Vail—One Policy, One System, Universal Service

In 1907, Theodore Vail became President of AT&T. He had previously been a senior manager of the business between 1878 and 1887, serving first as the general manager of American Bell, and later as the founding president of AT&T when it was the long-distance subsidiary. Vail was a visionary, a firm believer in systems and networks. He fought the independents by many means, including the nation's first public image advertising campaign. He used the slogan "One Policy, One System, Universal Service" to convince the American people and government that the United States would best be served by having a single national telephone system under AT&T control. He argued that the telephone, by the nature of its technology, was a natural monopoly where competition was inherently inefficient. Government regulation was the appropriate alternative.

He succeeded, but with limits, when AT&T Vice President Nathan Kingsbury negotiated an agreement with the U.S. Justice Department in 1913. In the agreement, regulation was accepted as substitute for competition. AT&T agreed to divest the controlling interest it had acquired in Western Union Telegraph Company, to bring the non-competing independents into the system by interconnecting them to AT&T's long-distance network, and not to acquire any independents without government consent. This agreement also served as the core of the settlement of an antitrust suit brought by the government earlier that year. The agreement, and Vail's organization of the business, provided the philosophy, strategy and structure under which the U.S. telephone system, both the dominant Bell System and the approximately 20 percent of the population served by independents, would operate into the 1980s. So, for much of the twentieth century, AT&T operated the Bell System as a regulated, government sanctioned national monopoly. And in doing so, with dedication and a strong service ethos, it by all accounts provided the people of the United States with the best telephone system in the world.

Advertising Brochure (1892)
Photo courtesy AT&T Archives and History Center

Theodore Vail (1915)
Photo courtesy AT&T Archives and History Center

To Vail, one of the several meanings of universal service was that all telephones should be connected in a single national network. In 1908, he made completing a transcontinental telephone line AT&T's top technical priority. Yet, as his Chief Engineer John J. Carty knew, the technology to do this did not exist. Signals weaken as they go down wires. Loading coils, placed according to a theory developed independently in 1899 by George Campbell at AT&T and Michael Pupin at Columbia University reduced attenuation, permitting circuits of up to around 2,000 miles, such as one AT&T opened between New York and Denver in 1911. What was needed was a way to amplify the signal. So, Carty hired a bright young physicist, Dr. Harold Arnold, in 1910 to work in the Western Electric Engineering Department on an electrical amplifier. In late 1912, independent inventor Lee de Forest brought his invention, the audion, the first three-element vacuum tube to AT&T. It would do a small amount of amplification but would break down, giving off a blue glow, at any attempt to do a practical amount. Arnold examined the tube and quickly figured it out. The blue glow was caused by residual gasses interacting with electrons. If he just increased the vacuum in the tube, it would work as an amplifier. AT&T bought the patent rights from de Forest, and by mid-1913 had successfully tested Arnold's high-vacuum tube amplifiers on existing lines. Now it became a construction project. One team built west from Denver, the other east from Sacramento.The two crews met and completed the line on June 17, 1914 at Wendover, Utah. The line opened for commercial service with great fanfare on January 25, 1915. Arnold's vacuum tubes were adapted to many other applications where electrical amplification was needed.

Arnold's success had one other consequence — it convinced Vail and his successors that bringing research

Completion of the First Transcontinental Line (1914)
Photo courtesy AT&T Archives and History Center

and development in-house was a good business strategy. And this led to the Western Electric Engineering Department being elevated in 1925 to a separate subsidiary — the famous Bell Telephone Laboratories. By the mid-1920s, under AT&T President Walter Gifford, universal service had come to be understood as meaning that AT&T and the government's agreed goal was that eventually everyone would have a telephone. This guided AT&T's mission into the 1970s.

Bell Telephone Laboratories' First Headquarters, 463 West St., New York (1927)
Photo courtesy AT&T Archives and History Center

The Bell System

Under the leadership of Gifford and Bell Telephone Laboratories' founding president, Dr. Frank Jewett, Bell Labs became the premier industrial research laboratory in the United States. It undertook far ranging and often basic research. The ultimate goal was improving the telecommunications system of the United States, but many innovations had far broader applications. Through the articles in this magazine, and the displays in the exhibit, you can learn about some of these major innovations and their applications.

With Bell Telephone Laboratories leading the way, AT&T was truly an innovative company. The absence of competition gave Bell Labs the luxury of taking a long view. The story of the transistor, the basis of all modern electronics, is a good example of how this worked out for AT&T, the nation and the world. It began in 1936 with Dr. Mervin Kelly, Vice President for Research. Kelly was thinking about the millions of moving electromechanical relays in the thousands of automatic telephone switches in the Bell System, and the many vacuum tubes amplifiers in the long-distance network. The relays required extensive maintenance, and eventually wore out; the vacuum tubes were fragile, gave off heat, and eventually burned out and needed to be replaced. Kelly thought that a research program in the emerging field of solid-state physics, if successful, might lead to solid-state replacements for both. So, in 1937, he hired Dr. William Shockley, a brilliant young solid-state theoretical physicist to lead the project. Two more solid-state physicists, theoretician Dr. John Barden, and experimentalist Dr. Walter Brattain soon followed. With the coming of World War II, normal Labs work gave way to projects for the war effort. The physicists resumed their prewar work as the war wound down. In December 1947, Bardeen and Brattain succeeded in amplifying an electrical signal with their invention, the point-contact transistor. There is a replica of this first transistor on display in the exhibit. In 1948, the project moved from research to development, where a team under Jack Morton spent three years turning a handmade laboratory device into something that could be produced in commercial quantities. The first applications for the transistor were for the U.S. military. Commercial applications by others, such as hearing aids and radios, followed over the next few years, as did the first applications within the Bell System. But AT&T never lost sight of the original goal, and in 1965, twenty nine years after Kelly decided to undertake solid-state physics research, AT&T installed the first solid-state electronic telephone switch, the #1 ESS, in a local office in Succasunna, New Jersey.

The First Transistor (1947)
Photo courtesy AT&T Archives and History Center

The Bell System developed a stable decentralized organizational structure that served the nation well. At the top were the AT&T General Departments, which provided overall coordination, and ran the system. Below that, AT&T Long Lines provided interstate long distance service, Western Electric manufacturing and supply, and Bell Labs research and development. But what most people knew were their local Bell Operating Companies. There were 21–24 such companies, depending on the year, which collectively provided service in the continental United States. With the exception of the Depression years of the 1930s, the percentage of households with telephone service steadily rose, reaching 40 percent in 1930, 62 percent in 1950, and 90 percent in 1969. Innovations such as the several generations of automatic switching played a major role in this expansion. Both AT&T and the country at large saw 90 percent as a sign that universal service had essentially been achieved.

Despite the success of AT&T and the Bell System in providing ever-improving telephone service in the United States, the company's monopoly status was a cause for periodic federal government inquiry and action. In general, monopolies were against American political philosophy and could violate the law. The Federal Communications Commission (FCC), as required by the statute that created it in 1934, undertook a massive multi-year investigation of AT&T. In 1949, the Justice Department filed an antitrust suit primarily seeking the divestiture of Western Electric. The suit was settled out of court in 1956 on terms widely perceived as favorable to AT&T. AT&T agreed to restrict its business to those things related to the national telephone system, and government projects. (AT&T, including Bell Labs, undertook many government projects during the Cold War.) AT&T also agreed to freely license its patents for uses outside of telecommunications.

The Fall of the Bell System

It was the third antitrust suit, filed in 1974, that transformed telecommunications in the United States. The nature of telecommunications had changed in many ways since 1956. Mainframe computers had become a major feature of the American economy, and an increasing portion of telephone traffic was actually computer data rather than conversations. Many predicted a future convergence of computing and communications. The rise of microwave relay technology for long-distance transmission, beginning in the 1940s, provided for the first time an economically feasible alternative to physical wires and cables, one that as MCI proved in the 1970s, made it possible to create an alternative long-distance network to AT&T's. AT&T sought a negotiated settlement as the case was actively being tried in court. The concept offered in 1981 by the Justice Department was simple: separate those parts of the AT&T-owned Bell System where the natural monopoly argument was still valid, namely local telephone service, from those parts where it was not; long distance, manufacturing, and research and development.

Ameritech Vice President Using a Cell Phone (1984)
Photo courtesy AT&T Archives and History Center

AT&T CEO Charles Brown accepted these terms to end the prospect of years of uncertainty. AT&T and the Justice Department announced the agreement on January 8, 1982. Federal judge Harold Greene approved the agreement after the incorporation of a variety of changes he required. The agreement took the legal form of a Modification of Final Judgement (MFJ). AT&T would divest all 22 of its local telephone operating subsidiaries. Seven independent Regional Bell Operating Companies (RBOCs), informally known as "Baby Bells," would inherit the 22 phone companies and retain the local monopolies. AT&T would keep the long-distance business, manufacturing (i.e., Western Electric) and Bell Labs. The RBOCs were barred from long distance and manufacturing, and would require a waiver from the court to enter other businesses. AT&T was barred from the local telephone business. Breaking up the Bell System was an enormously complex task, but it was done well and on January 1, 1984, the Bell System was no more. Southwestern Bell Corporation (SBC) was the smallest of the seven regional holding companies, but the one that would figure most prominently in subsequent AT&T history. SBC provided local service in Arkansas, Kansas, Missouri, Oklahoma and Texas. Among the assets that passed to the Baby Bells was cellular telephone service, which had just gotten started with the launch of the first commercial system in Chicago, in October 1983.

The Modern Era

Over the next few years, long distance became fiercely competitive as multiple companies competed for customers. Prices began a continuous decline, but the transition to fiber optics as the dominant transmission medium caused costs to decline even more quickly. With substantially lower prices, call volume exploded. The business remained very profitable for AT&T, as did AT&T's enterprise business of providing communications services to large corporations. AT&T gained entry to the growing wireless business in 1994 by purchasing McCaw Cellular Communications, which it soon renamed AT&T Wireless. Throughout the 1990s, data traffic grew even faster than voice, especially after the introduction of the public internet in mid-decade. In 2000, the volume of data transmitted on the AT&T network finally exceeded the volume of voice.

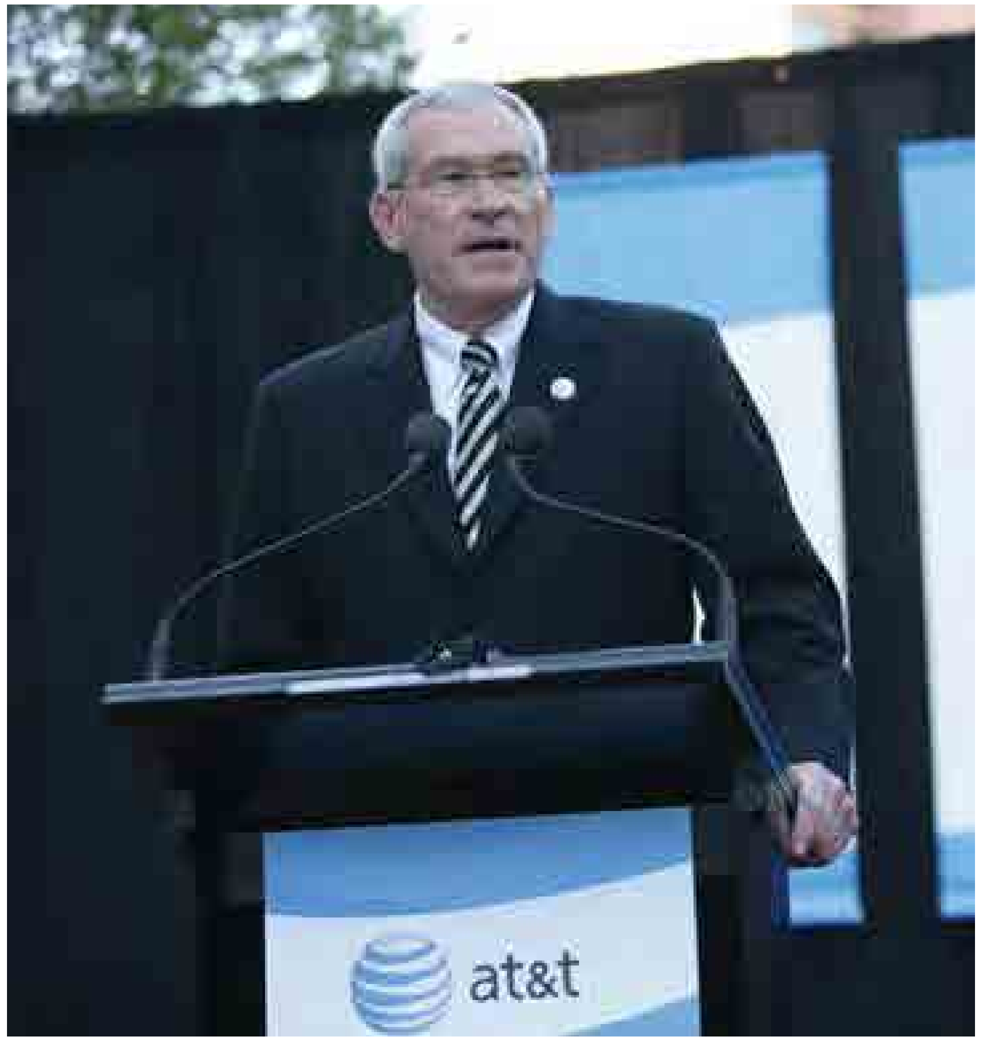
In the 1990s, AT&T came to realize that without the local companies, there were few synergies between its communications and manufacturing businesses. The RBOCs increasingly saw AT&T not so much as a preferred equipment supplier, but as potential competitor for the telecommunications services business. In 1995, AT&T announced that it was spinning off its manufacturing business into a separate company, which took the name Lucent Technologies. Since research and development served both the equipment and services businesses, it too split. The majority of the Bell Labs community supported the equipment business, and therefore went to Lucent, as did the famous Bell Laboratories name. The substantial part of the community that supported services stayed with AT&T, and continued its share of the Bell Labs heritage as AT&T Labs.

Fiber-Optic Strand, Bell Labs (1976)
Photo courtesy AT&T Archives and History Center

Throughout these years, the RBOCs found that the restrictions placed on their activities by the MFJ raised major obstacles to their attempts to grow their businesses. After several years of effort, Congress responded by enacting the Telecommunications Act of 1996, which President Clinton signed on February 8. The Act superseded the MFJ, and provided a new set of guidelines for the industry. It set up series of requirements which if met would allow the long-distance companies and the local telephone companies to enter each other's businesses. It removed other restrictions on RBOC activities.

The substantial part of the community that supported services stayed with AT&T, and continued its share of the Bell Labs heritage as AT&T Labs.

Edward Whitacre, the CEO of SBC, realized, even before the bill was passed, that there would now be no MFJ-related obstacles to one Baby Bell's acquisition of another. Whitacre acted quickly and on April



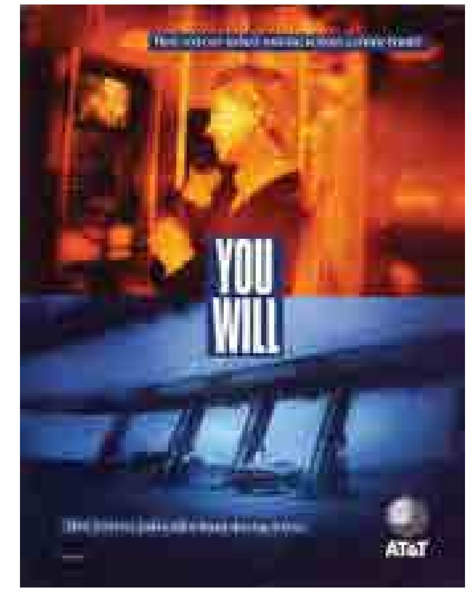
Ed Whitacre speaking at the birth of the new AT&T Inc. (2005)
Photo courtesy AT&T Archives and History Center

1, 1996 announced an agreement to acquire Pacific Telesis Group, the RBOC serving California and Nevada. Two years later, SBC reached agreement to acquire Ameritech Corporation, the Baby Bell serving Illinois, Indiana, Michigan, Ohio and Wisconsin. This deal closed in 1999. And then in 2000, in order to provide a national footprint to compete in the rapidly growing cellular telephone business, SBC combined its cellular business with that of fellow RBOC BellSouth Corporation in a joint venture, Cingular Wireless.

In late December 1999, Bell Atlantic Corporation became the first RBOC to satisfy the Telecommunications Act's requirements to offer long-distance service when the FCC approved its application for New York. The next June, SBC became the second RBOC to obtain such approval, for the state of Texas. Over the next several years, the RBOCs received these approvals across the country, and then aggressively and successfully marketed combined local and long-distance packages to their customers. AT&T's consumer long-distance business went into rapid decline. Its attempts to counter by offering its own combined packages were not successful, in large part because it did not have its own lines into people's homes, and had to rely on contentious procedures laid out in the law to lease lines from the RBOCs. As AT&T's profits plummeted, it responded with a variety of cost-cutting measures, including spinning off AT&T Wireless as a separate company in 2001. Cingular, the SBC-BellSouth joint venture, in turn acquired AT&T Wireless in 2004.

By this time, it had become apparent to many observers that AT&T's most likely future was acquisition by another healthier company. On January 31, 2005, SBC CEO Ed Whitacre and AT&T CEO David Dorman announced a definitive agreement for the two companies to merge, though it was clear that SBC would be acquiring AT&T. The transaction closed on November 18, 2005 once the companies had obtained all necessary regulatory approvals. SBC promptly changed its name to AT&T Inc. AT&T was a much better known and established brand. Besides the brand, the other major assets the new AT&T acquired was a large enterprise telecommunications business serving corporate and government customers, the premier global communications network, and a major R&D operation in AT&T Labs.

Whitacre was not finished using acquisitions to build his company. In 2006, AT&T acquired RBOC BellSouth, and with it complete ownership of Cingular Wireless. AT&T soon rebranded Cingular as AT&T. Whitacre over the course of a decade had merged four of the seven Baby Bells, legacy AT&T, and a national cellular carrier. With this achievement, Whitacre retired in 2007. Randall Stephenson succeeded him as AT&T CEO, a position he continues to hold as this article is being written.



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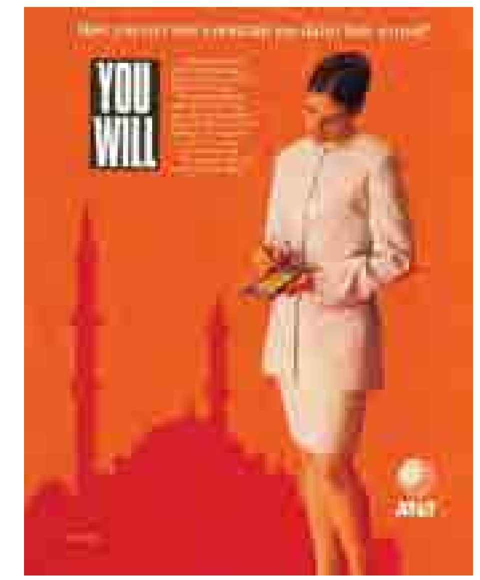
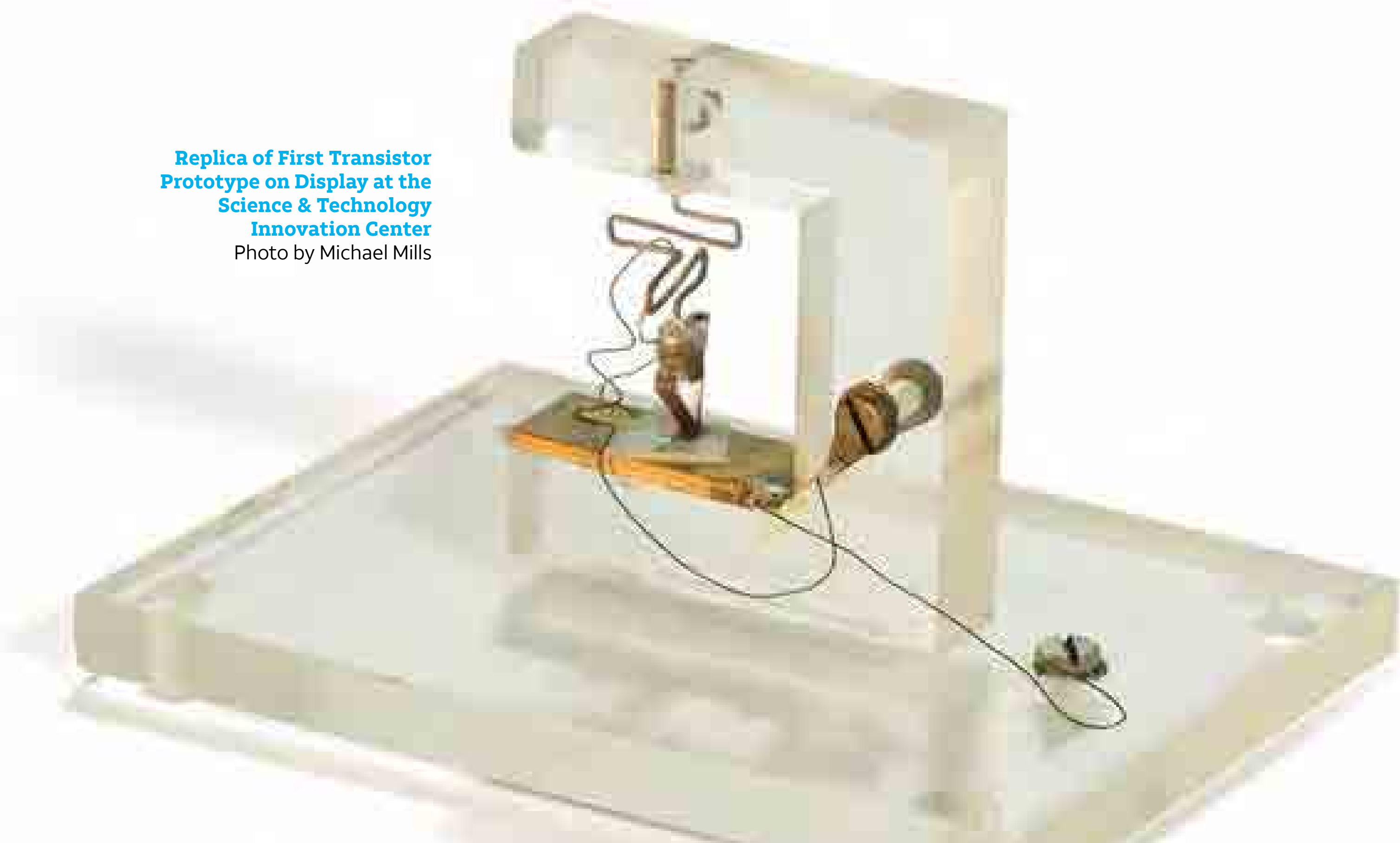


"You Will" was an AT&T advertising campaign from 1993–1994 that presented a future to be brought to you by AT&T.

The Transistor

The Invention that Started the Digital Age



Replica of First Transistor Prototype on Display at the Science & Technology Innovation Center
Photo by Michael Mills

By Daniel Gruspier

Each morning my alarm clock wakes me up by turning on the radio. I switch it off and get dressed after checking the weather on my smartphone. As I drive to work, I stream music from my phone through my car's speakers. Later when I get home, I raise the thermostat a few degrees to make the house warmer. None of these things would be possible without the transistor, the tiny devices that give us digital logic. Digital logic is the root of the modern digital age, and it is the only way of life that I have ever known. The transistor is the primary functional component of all modern electronics. At its simplest, it allows the flow of electricity between two point as controlled or switched by the supply of energy into another point. All modern electronics depend upon transistors. Although prototypes, in particular the field-effect device patented by Julius Edgar Lilienfeld, existed by the 1920s, it was not until the mid part of the twentieth century that practical transistors were developed.

The first functional transistor was produced in 1947 at AT&T's Bell Laboratories in Murray Hill, New Jersey by theoretical physicist John Bardeen, and experimental physicist Walter Brattain, working under department head William Shockley. Prior to this, Shockley had been working at Bell Labs for ten years on creating a transistor. In three years' time, Bardeen and Brattain completed the "point-contact" transistor, which was followed by Shockley's own bipolar junction transistor (BJT). The BJT ultimately replaced the point-contact model because of its superior performance. In 1956, the world honored their achievement, as they were awarded the Nobel Prize in Physics for discovering the transistor effect. This effect is comparable to the way that valves on a faucet control the flow of water.

Before the Transistor: The Vacuum Tube

The precursor to the transistor was the vacuum tube, which was originally used for demodulation of radio signals and for rectification of current. These tubes took the form of large glass bulbs containing two or more electrodes, an anode, a cathode, and a control grid surrounded by a vacuum. Energizing the cathodes allowed electrons to flow through the tube.

Vacuum tubes took communications and general electronic technology very far, for instance allowing World War II code-breaking computers to operate, but they soon became impractical. Although smaller and smaller ones were made, vacuum tubes are fragile, gave off heat, and could burn out, necessitating replacement. The practical transistor developed at Bell Laboratories solved all of these problems.

John Bardeen, William Shockley and Walter Brattain (1947)
Photo courtesy AT&T Archives and History Center

The number of transistors in constant use now exceeds the number of cells in the human body of every person in the state of California.

The Transistor

The first practical transistor was, perhaps, 4 by 4 cm in size. Even this first prototype (a replica of which is on display at the Science & Technology Innovation Center in Middletown, NJ) achieved significant scale reduction in size, power consumption and heat generation. Today's transistors are microscopic and consolidated into integrated circuits. More complicated electronics, such as smartphones and laptops contain the equivalent of billions of individual standalone transistors. Other simpler devices, such as hair dryers, need a way to manage the "on" and "off" switch and their electronics contain at least a few transistors. Every year, billions upon billions are produced and incorporated into electronic devices. The number of transistors in constant use now exceeds the number of cells in the human body of every person in the state of California. And each of these are expanding our digital world. The initial device created by Bardeen, Brattain and Shockley shifted the course of humanity by launching the modern digital age.

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Megabit Chip with Pen Point for Comparison (1985)
Photo courtesy AT&T Archives and History Center

Quick Look

Inventors: Daryl Chapin, Gerald Pearson, and Calvin Fuller (1954)
Photo courtesy AT&T Archives and History Center

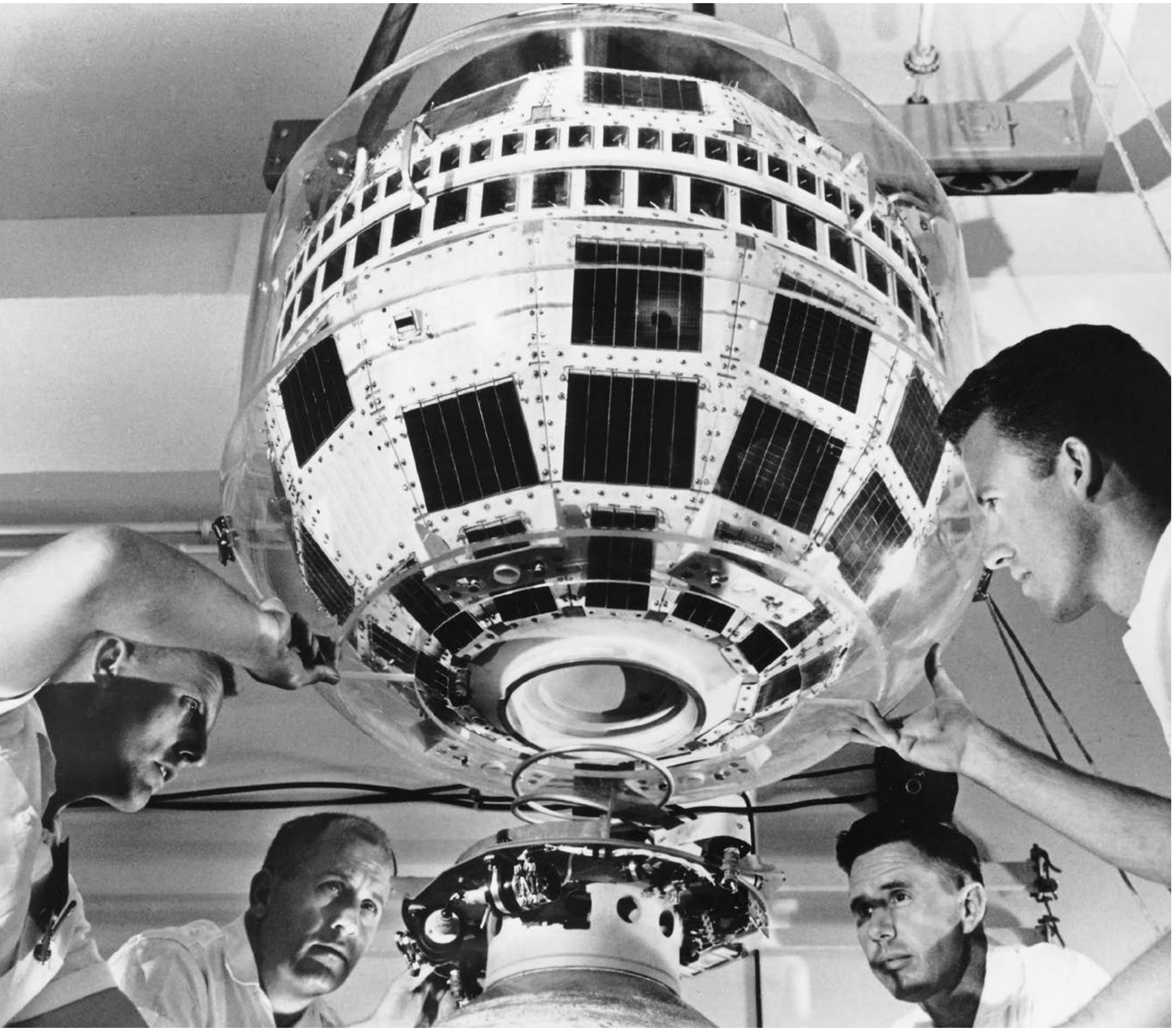
Bell Solar Cell

In 1954, researchers designed the first practical solar cell, a solid-state device capable of converting sunlight into electricity at a useful efficiency of six percent. The unit on display at the Science and Technology Innovation Center in Middletown, NJ, is an early solar battery containing eight individual cells. AT&T later used solar cells to provide power for its 1962 Telstar satellite.

Solar Battery: Comprised of 8 Solar Cells
Photo by Michael Mills

Launching Satellite Communications: The Telstar Project

By Leon Lubranski



Telstar Satellite Being Placed atop a Rocket (1962)
Photo courtesy AT&T Archives and History Center

On July 10, 1962, a Thor-Delta rocket was launched from Cape Canaveral, Florida and successfully inserted the first active communications satellite, AT&T's Telstar, into orbit around the earth. By day's end the satellite had proven that it could successfully relay both voice and television signals. In doing so it demonstrated that it could achieve one of its prime objectives. AT&T received numerous laudatory messages. For example:

> *"Congratulations on your Telstar accomplishment. It was one of the truly great technical accomplishments of all time."*

> *"Our congratulations to you and your associates on the magnificent Telstar success. The conception of the satellite communication system and its perfect execution on the first shot certainly makes the whole world well aware of your fine capabilities and capacity for such an enormous undertaking."*

> *"Warmest congratulations on your distinguished achievement. It promises world consequences far beyond the boundaries of science and technology."*

The Meeting of Great Minds

The relatively short but very difficult and challenging journey from idea to concept to realization began in 1955. Dr. John R. Pierce, Research Director for Bell Laboratories (BL), published a highly technical article entitled, "Orbital Radio Relays", in *Jet Propulsion*, a journal of the American Rocket Society. In it he proposed the use of orbiting satellites for the purpose of delivering transoceanic communications. These satellites would effectively play the role of microwave towers in space. However, 1955 was pre-Sputnik and the United States didn't have a rocket capable of orbiting a satellite. Nevertheless, Dr. Pierce and his colleagues decided to start research and development on technology that could potentially play a role in a satellite communications system.

> AT&T's entry into satellite communications came about completely by chance.

AT&T's entry into satellite communications came about completely by chance. At a technical meeting, W. H. Pickering of JPL (Jet Propulsion Laboratories) described to Dr. Pierce and Rudy Kompfner, his colleague, an experiment they were planning for NASA (National Aeronautics and Space Administration). A 100-foot sphere of metallized plastic film would be placed in a circular orbit around the earth. Its purpose was to measure the density of the upper atmosphere. Pierce and Kompfner recognized that the sphere would reflect radio waves, i.e., behave as a passive system. A proposal was written for JPL, which led to a joint experiment involving Bell Laboratories, NASA, and JPL. BL decided to deploy the infrastructure – receiver and transmitter – for the experiment in Holmdel, NJ. The receiving system consisted of a horn-reflector antenna and the associated radio signal amplification equipment. Echo I was launched in August of 1960. During one of its

Project Echo — Horn Antenna Holmdel, NJ (1960)
Photo courtesy AT&T Archives and History Center

passes JPL transmitted a message from President Eisenhower via Echo which was successfully received in Holmdel. Numerous experiments proved that it was practical to use man-made satellites to reflect two-way telephone conversations. The lessons learned from the Echo experiment would have direct applications to active satellite technology.

From Proposal to Proof-of-Concept

In August 1959, Leroy C. Tillotson, head of BL's Radio Systems Research Department proposed that AT&T should build and launch an experimental active repeater satellite. This type of system receives a radio signal and amplifies it before beaming it back to earth. He made the proposal partly because he realized that AT&T already possessed "most of the tools to do the job." BL had developed a number of new electronic devices, many of which had direct application to satellite technology.

As early as May 1960, even before the launch of Echo, R.W. Kompfer wrote Leonard Jaffe, NASA's Director of Communications Systems, describing research toward an active satellite already under way in BL. It became apparent that a major AT&T project was materializing. Development personnel, numbering about 500, were recruited from almost every part of BL. The first system proposal was issued on August 30, 1960, less than three weeks after Echo had been launched. It called for the orbiting of an active communications satellite system, called Telstar, by mid-1962. The success of Echo created some excitement about the potential of communications satellites. There was a realization by NASA, the Department of Defense, communications carriers, and satellite hardware manufacturers that the time of satellite based communications had arrived. AT&T decided that its satellite development program should lead to a fully operational commercial system. It envisioned the deployment of 50 satellites that would support worldwide delivery of voice, data, and television communications. These systems could replace undersea transmission cables. Subsea technology, at the time, was very expensive to deploy and offered a relatively small number of communications channels. Capacity could not keep up with demands, especially for TV broadcasts.

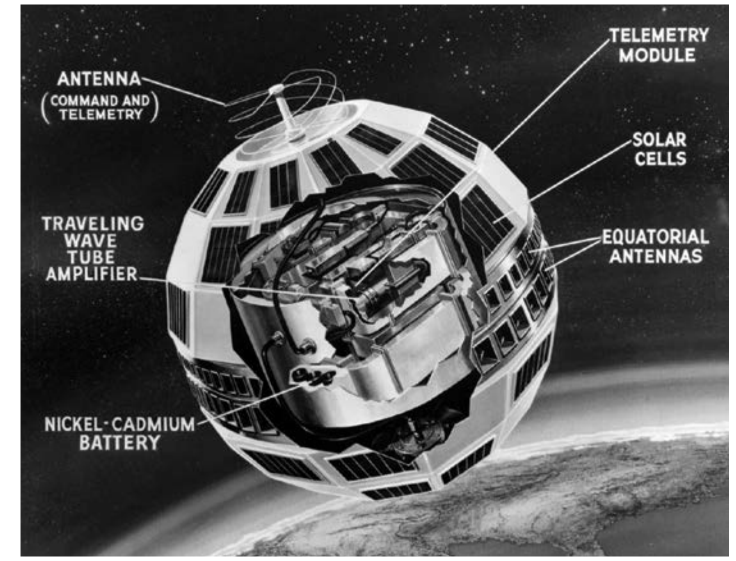


Diagram Depicting Telstar Interior and External Features (1962)
Photo courtesy AT&T Archives and History Center

Productization of an AT&T Satellite and a New Industry

On October 21, 1960, AT&T Long Lines requested approval from the FCC for the deployment of an experimental space communications system. Authorization was granted on January 27, 1961. However, just as Telstar development was gathering momentum, NASA told BL on November 4, 1960 that they were planning four launches of communication satellites (known as Relay) of their own, and they expected BL to bid. Basically, BL had no choice since NASA had the launch vehicles. The NASA RFP (Request for Proposal) was issued on January 4, 1961 and In May the contract was awarded to RCA. AT&T's proposal was ranked fourth primarily due to the fact that it had no prior experience in satellite construction. Shortly afterwards, NASA indicated that it was willing to discuss the launch of Telstar. After six months of negotiations NASA agreed to supply AT&T with a three-stage Thor-Delta rocket. AT&T had to cover all costs related to the development and construction of the satellite and had to pay NASA $3 million for all costs associated with the rocket, the launch and ground support. NASA also got worldwide rights to any patents that AT&T might develop from the satellite, and it could license these patents royalty-free to any third party.

Telstar 1 Launched from Cape Canaveral (1962)
Photo courtesy AT&T Archives and History Center

Telstar Electronic Component Housing (1962)
Photo courtesy AT&T Archives and History Center

The Telstar Project was extraordinarily demanding considering its 21-month interval. During this period, BL had to design and produce a complicated satellite, design and construct a large high performance earth station in the US, and reach agreement with European carriers for construction of similar facilities in a number of countries. The key objectives for the project were:

- Prove that a broadband communications satellite could transmit telephone messages, data, and television across the Atlantic
- Test, under the stresses of an actual launch and the hazards of space, some of the electronic equipment that had been developed for satellite communications
- Measure the radiation that a satellite would encounter in space (Telstar's orbit passed through the Van Allen belts, a region of energetic charged particles which were captured by the Earth's magnetic field)
- Find the best ways to track a moving satellite accurately

Within BL the project was viewed as the "Telstar Experiment" since many of functions went beyond proving that a satellite could effectively support communications services. NASA was very concerned about the impact of radiation on satellite components. The surface of Telstar was equipped with sensors to measure this phenomenon.

The success of the project would hinge on the use of numerous BL inventions, capabilities, processes and skills, including:

a. Maser microwave amplifiers (very low noise, required to maintain usability of a signal)
b. Travelling-wave-tube amplifiers (amplifies very faint signals)
c. Transistors
d. Solar cells (provides power to the satellite)
e. Microwave technology (used extensively by AT&T for its long distance network)
f. Design and construction of horn-reflector antennas (supported the Echo experiment)
g. Design and construction of high reliability electronic systems for undersea cable applications
h. Frequency modulation feedback circuits (invented in 1930, a tuning device that keeps out background noise)
i. Experience with the Echo project
j. The use of polyurethane foam to form a firm structure highly immune to the effects of shock and vibration. The technique was developed previously by BL in missile-guidance work for the military.

Another key success factor was the Bell Labs environment which encouraged the exploration of new areas of research and supported collaboration across different departments with a minimum level of formality.
The design of the satellite was driven by the objectives discussed above. The Delta-Thor launch vehicle imposed restrictions on satellite size, weight, and orbital parameters. The weight was limited to a maximum of 170 pounds and it was determined that a sphere with a 34.5 inch diameter was the best geometry. This meant that microwave functions that would normally require hundreds of square feet of floor space would have to be compressed to fit into a very small volume.

The Telstar Satellite

Telstar's exterior consisted of 72 flat facets, a double row of antennas around its equator – one row for receiving and another for transmitting. Sixty of the facets were used for solar cells (power source) and others were utilized to support radiation measurements, tracking, and the determination of satellite orientation. The telemetry, command, and beacon antenna was located at the top. The structure of Telstar consisted of a magnesium frame that was covered by aluminum panels. The satellite's various electronic circuits contained more than 1000 transistors and numerous other components. A critical function was provided by a single electron tube – a traveling-wave tube – used for communications amplification. All electronic components were housed inside a 20-inch diameter aluminum canister.The canister was filled with a liquid foam that when hardened served to protect the equipment from damage and vibration. It was hermetically sealed before its installation in the satellite. Thirty watts of power would be required to support a fully operational (meaning all functions powered up) system. Only half of this requirement could be met by solar cells. The rest would be provided by 19 batteries which would be recharged during those periods of the orbit that weren't used for communications experiments.

The satellite consisted of three primary systems. The communications system supported 600 one-way voice channels or one TV channel. The very faint signals received from the earth stations were amplified by a factor of 10 billion by the combination of transistors and the traveling wave tube. The amplified signal was then transmitted to its destination. The telemetry system was responsible for collecting 115 different measurements related to satellite performance factors such as critical temperatures, pressure, solar cell power output, and data from the radiation damage experiments. These would then be transmitted to Earth every minute. The command system provided the means for power management. Commands would be issued by the earth station to turn on or off various satellite systems. The communications system, which consumed 50% of the satellite's peak power, was only turned on when needed for testing purposes.

Thermo Vacuum Chamber Test to Determine Thermal Effects of Sunlight (1962)
Photo courtesy AT&T Archives and History Center

Telstar engineers developed a number of techniques that would be useful in building future satellites. They found a way to mount 3600 solar cells on the outside so that they could provide about 15 watts of power. The cells were coated with a layer of artificial sapphire to protect them against the effects of radiation and impacts of micrometeorites.

The first phone call via Telstar occurred at 7:30 pm EDT. It was between F. R. Kappel, Chairman of the Board of AT&T, and Lyndon Baines Johnson.

The satellite was assembled at Western Electric's Hillside, NJ shop. This facility's clean rooms had been used to assemble submarine cable repeaters. Processes were already in place to support high standards for electronic system assembly. This included strict inspection requirements and detailed record keeping. The Bell System had considerable experience in designing equipment for reliability. This included procedures that addressed the testing and selection of system components for undersea cables. The vast majority of components used for Tel-

Television Image of American Flag Waving in Front of the Andover Radome (1962)
Photo courtesy AT&T Archives and History Center

This was the first TV image sent to space and back.

star were off-the-shelf and were designed to operate in a controlled environment. There was insufficient time to design custom components and to execute lengthy tests to assess their reliability. Widely fluctuating temperatures, such as those occurring in orbit, could seriously limit their performance and even shorten their life. A decision was made to implement a thermal control mechanism that would insure a near room temperature environment for the batteries and electronic components for a satellite functioning in outer space. The satellite weight limitation meant that the number of redundant components had to be kept to a minimum. Once completed the satellite was subjected to a series of tests meant to simulate the vibrations and shock of launch and the environment of space.

Andover, Maine, Telstar Earth Station (1962)
Photo courtesy AT&T Archives and History Center

The Ground Station

The design and construction of the earth-based support infrastructure was in many ways just as complex and challenging as the satellite itself. The site for this facility was a 1000-acre piece of land in Andover, Maine. The major elements of the ground station included:

- A horn-reflector antenna and associated amplifiers
- Various acquisition and tracking antennas
- Computer systems used for orbital predictions
- Highly sensitive receivers
- Powerful transmitters
- Equipment associated with the sending and receiving of command and telemetry signals
- A massive radome (161-feet high) designed to cover the horn-reflector antenna structure and prevent damage and physical distortions that would impact antenna performance due to weather conditions

AT&T anticipated that the site could support additional antennas if needed for a network of satellites.

The power of the broadband communications signal radiated from the satellite is about 2.25 watts. The Andover horn antenna was modeled after the one in Holmdel that supported Echo. However, it was considerably larger since it had to capture very weak transmissions – about a billionth of a watt – from a satellite that could be situated approximately 3500 miles above Earth. A maser (microwave amplifier) was employed to amplify this signal without introducing any perceptible noise which could make the signal unusable. A critical function of the Andover facility was the rapid acquisition and accurate tracking of the satellite. This was important since Telstar was "visible" to the site for approximately 20 minutes of each orbital pass. Bell Labs had long term relationships with carriers in France, England, and Germany. They readily agreed to deploy (at their own expense) ground stations to support the project.

Success

Telstar I was successfully launched from Cape Canaveral on the morning of July 10, 1962. A number of communications transmissions were scheduled for late in the day. The first phone call via Telstar occurred at 7:30 pm EDT. It was between F. R. Kappel, Chairman of the Board of AT&T, and Lyndon Baines Johnson. Afterwards, the first television transmission via Telstar was initiated. Viewers saw a picture of the American flag waving in front of the Andover radome. That was followed by a question-and-answer period between a Washington audience and AT&T executives in Andover that was relayed "live" via Telstar. At 7:47 pm the French reported that they were also seeing the broadcast.

Hundreds of additional tests were conducted during the next few months. They covered TV broadcasts (color and black and white), voice, data, and facsimiles. Satellite telemetry revealed that thermal and electrical performance aligned extremely well with design targets. However, in mid-November 1962, Telstar starting to experience problems with its command system. As a result, all communications related tests had to be halted. BL initiated an effort to determine the origins of the failure. They concluded that it was due to the impact of excessive radiation exposure that exceeded the design target by a factor of 100. This level of radiation may have been a direct result of the Starfish Prime high-altitude nuclear bomb test that occurred on the day before the Telstar launch. A fix was implemented and Telstar began to function normally during the beginning of January 1963. The command system failed again and on February 21, 1963, Telstar ceased to function.

AT&T's plans for deploying a network of communications satellites was never realized. The political environment had changed in late 1961. The Department of Justice took the position that a space communications system was too important to be turned over to any group that might be dominated by any one company, particularly AT&T. The Communications Satellite Act was signed into law on August 31, 1962. It placed all American satellite communications under control of a federally managed, privately owned corporate monopoly, COMSAT. In hindsight, the RCA win of the NASA communications satellite bid in May of 1961 may have been the turning point for AT&T's vision of a privately owned global satellite system. Telstar project management concluded that Telstar was going to be a "one-shot experiment" and that AT&T should focus on reaping the public relations benefits.

The success of the Telstar Project was critical to proving in the feasibility and value of broadband communications via active repeater satellites. To date, approximately 2000 civilian and military communications satellites have been launched. AT&T BL demonstrated how a complex idea could be turned into reality through ingenuity, scientific research, engineering, collaboration, intelligent management, and of course, will power. The Telstar Project is just one example of how AT&T Bell Laboratories innovation has proven to be beneficial for AT&T and the world resulting in transformative and historical changes to societies, commerce, and global relations.

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Coaxial Cable in Long Distance Transmission

By Doug Olsen

Most of us are familiar with Cable TV and the coaxial copper cable or "coax" in use in millions of homes across the United States today. However, AT&T's role in the development of the coaxial cable, as well as the history of the cables' use in AT&T's long distance network may not be as obvious. Coaxial cable had its commercial origins in AT&T's Bell Labs and AT&T's network. The initial applications of coaxial cable systems were in long distance telephony, early long distance television transmission, and transmission of a technology ahead of its time — the Picturephone.™

Lloyd Espenschied and Herman Affel (c. 1949)
Photo courtesy AT&T Archives and History Center

Bell Labs Innovation in Transmission

In the 1920s, while the decade "roared" and time and technology advanced, ambitious innovators grappled with a fresh set of communications challenges. Novel experiments and increased pressures on the transmission capacity of the long distance open-wire communications networks pushed researchers to develop a transmission medium that could meet the growing bandwidth and capacity demands of the 20th century. In 1928, British inventor C. S. Franklin patented a coaxial cable for limited use as an antenna feeder. A year later, Lloyd Espenschied and Herman Affel of Bell Labs (AT&T's R&D subsidiary) enhanced earlier models to develop the first modern high capacity coaxial cable transmission system, which was patented in 1931 (U.S. Patent 1,835,031). Espenschied and Affel's cable was comprised of a central conducting wire centered in a conducting tube that could carry an enormous signal bandwidth as compared to the existing open wire and twisted pair cables in use at that time. The transmission signals were contained between the outer surface of the central core, and the inner surface of the tube. The system also included terminal multiplexing equipment at each end of the line along with repeaters at regular intervals designed to boost the signal along the line.

Why Coaxial Cable?

During the early 20th century the method Bell System engineers employed to increase long haul circuit capacity was accomplished with analog carrier systems (C, J, and K) on open wire and copper cable. These systems were limited to transmission bandwidths in the KHz range (4-12 voice circuits per channel) and were subject to external electromagnetic interference. As capacity needs in long distance communications grew, it became obvious to the engineers that the existing low frequency analog carrier systems would be unable to fulfill the need. Espenschied and Affel's coaxial cable system was able to handle the increasing capacity demands. These systems would eventually carry 13,200 voice circuits per channel. Key advantages of coaxial based transmission systems are listed below:

- Less channel noise and elimination of crosstalk interference
- Higher frequencies vs. open wire and copper cable carrier systems
- Electronics at terminals could be upgraded along existing cable routes, allowing for future-proofing the deployment
- Simultaneous High Capacity Voice, Television, and Data Transmission

The era's analog carrier systems included terminal multiplexer equipment and line and repeater equipment. Espenschied and Affel's coaxial cable is the transmission medium

Coaxial Cable (1936)
Photo by Michael Mills

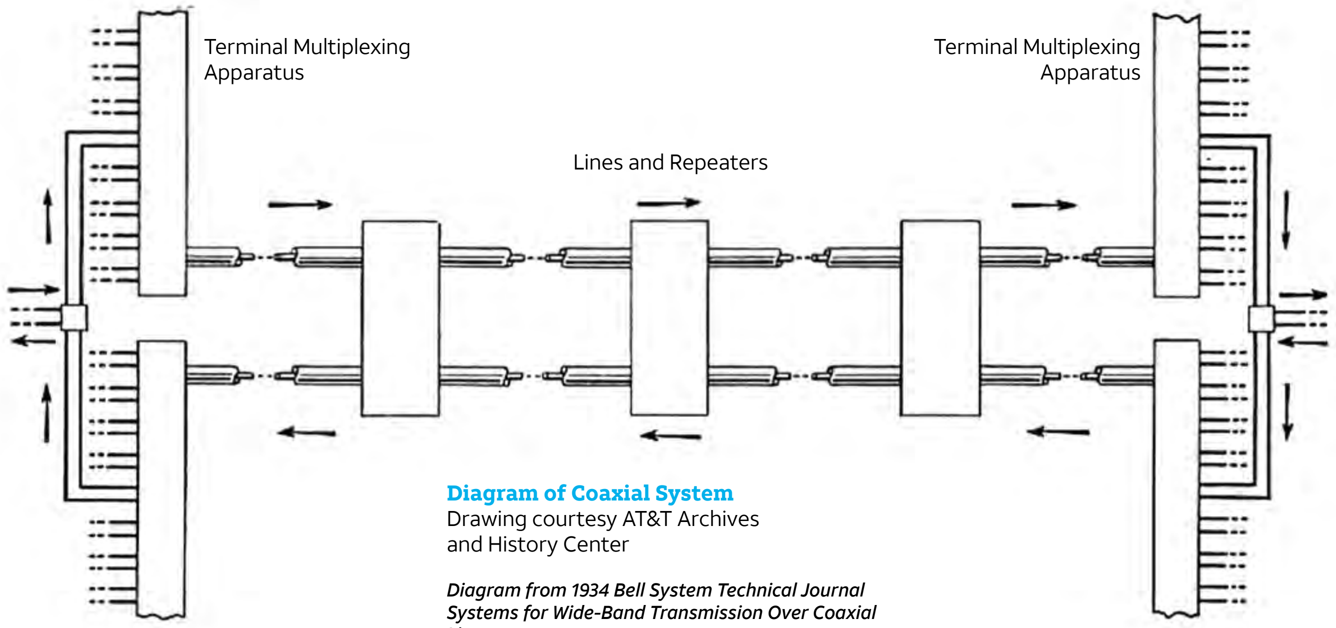

Diagram of Coaxial System
Drawing courtesy AT&T Archives and History Center

Diagram from 1934 Bell System Technical Journal Systems for Wide-Band Transmission Over Coaxial Lines.

which creates the "line" component of the system. Single Sideband Modulation (SSB) was the signal processing used to maximize the bandwidth per transmitted signal on the line. The terminal equipment used Frequency Division Multiplexing (FDM) which allows many channels to share a wide bandwidth whereby each channel is assigned a portion of the frequency spectrum. The photo shows a cross section of a 20 tube coaxial cable.

The following sections provide a deeper understanding of a sampling of the historical milestones listed above. The focus will be on the evolution of the L-Carrier system, an integral component in AT&T's long distance core for almost half a century.

L-Carrier Systems Evolution

AT&T deployed L-Carrier systems manufactured by Western Electric from 1941 through the 1970s. These coaxial systems carried a significant portion of AT&T's long distance voice communication for over 50 years. These systems were typically deployed over long distance spans ranging from 250–4,000 miles. Coaxial system design changed drastically over 34 years to handle ever increasing long-distance call volumes. The number of conductors per cable increased from 4 to 22, while the voice circuit carrying capacity improved from 600 circuits to 13,200 circuits, a 2200% increase per tube. The voice circuits per system similarly saw a vast improvement with voice circuits increasing from L1 at 600 voice circuits per system to L5E at 132,000 voice circuits per system. In addition to cable and multiplexing improvements, repeater technology also took advantage of another Bell Labs innovation, the transistor. Invented in 1947 by innovators Shockley, Brattain, and Bardeen, the transistor supplanted the vacuum tube, increasing the performance, scale, and reliability of repeater equipment.

AT&T's L-1 Coaxial System

In 1941, AT&T deployed the first commercial field application of a L-1 Coaxial System, consisting of two hundred miles of coaxial cable between Stevens Point, Wisconsin, and Minneapolis, Minnesota. The L-1 Carrier system was capable of transmitting 480 simultaneous voice conversations and one 4 MHz Television signal over this span. The system used 4 coaxial tubes in a single cable sheath comprised of a working pair (TX, RX) and a backup pair in case of failure. The overall route was approximately 200 miles end to end, broken into four 50 mile segments. At the end points in Stevens Point and Minneapolis, terminal modulators transformed the carrier circuits to voice circuits and vice versa. The end terminal also included power supply equipment, testing and alarm equipment, amplifiers and regulating equipment. The cable was attached to aerial pole lines for part of the route, and buried underground at an average depth of about 30" for the remainder. As mentioned previously, this cable was capable of transmitting a television signal in addition to the voice channels. In May of 1941 an 800 mile circuit was created by connecting the four 200 mile conductors in series; this was the longest successful test of television transmission over coaxial cable at the time.

AT&T's L-5 Coaxial System

In 1970 an L-5 Coaxial Cable Carrier system was trialed by AT&T between Cedarbrook NJ and Netcong NJ and was expected to carry 90,000 voice calls and 420 Picturephone™ calls, or 30 color TV programs, or high-speed data. Full blown deployments of the L-5 Coaxial System began in 1972. The diagram depicts the Western Electric L-5 Coaxial Cable Carrier system deployed in the AT&T long distance network. These systems were typically used in high traffic routes terminating in large metropolitan areas. The L-5 system was eventually capable of transmitting 108,000 two way voice calls over 20 coaxial tubes (0.375" in diameter each tube) with 10 transmit tubes and 10 receive tubes in a cable providing the two way communication. The system had a spare pair of coaxial cables in case one of the 10 pairs failed. Upon failure, the built in line protection switching system would switch the traffic to the spare pair until the failed pair could be repaired. The system required solid state repeaters which were placed at varying intervals based on the repeater function employed. Basic repeaters were spaced at 1 mile intervals, regulating repeaters were spaced at 7 miles max intervals, and equalizing repeaters were spaced at 38 miles max intervals.

Interestingly, these systems were also designed for future trunks to carry AT&T's Picturephone™ service, the late 1960's precursor to today's video calling applications such as Skype™ and Facetime.™

Sample Length of 20 Coaxial Cable with Bob Robertson in Baltimore, Maryland (1964)
Photo courtesy AT&T Archives and History Center

Undersea Coaxial Cable TAT-1

In 1956, a joint U.S.-British-Canadian effort led to the application of coaxial technology for the first transatlantic telephone cable, TAT-1 (Transatlantic No. 1). TAT-1 was designed to connect London to NY and London to Montreal, the key interexchange points to reach further into North America and Europe. The London–NY circuit was 4,078 miles and the London-Montreal circuit was 4,157 miles. The deep sea submarine coaxial connection from Clarenville, Newfoundland to Oban, Scotland was 2,240 miles with a range of depth from a few fathoms on the continental shelves to a maximum depth of 2,300 fathoms. TAT-1 was one of a number of SB undersea carrier systems deployed from 1956-1960 which used (2) 0.62" diameter coaxial cables run in parallel. The system was able to carry 36 working voice circuits along with maintenance circuits.

In September of 1957 the TAT-1 cable opened at 11:00AM EST with a three way call between AT&T Board Chairman Cleo F. Craig and FCC Chairman George C. McConnaughey in NY, British Postmaster General Charles Hill in London, and Minister of Transport George Carlyle Marler in Ottawa. The ceremony was viewed and heard by thousands that gathered at the Bell Systems headquarters building. On its first full day of operation TAT-1 completed 588 US-UK calls. This capped a unique collaboration between the engineering and management teams on both sides of the Atlantic. Each contributing their unique talents and expertise to the project, ensuring its success for the mutual benefit of North America and Europe.

Transtlantic TAT 1- Pulling the cable onto shore (c. 1954)
Photo courtesy AT&T Archives and History Center

The TAT-1 undersea coaxial system was in service for a total of 22 years and was retired from service in 1978.

Future of Coaxial Cable

The advent of fiber optic transmission systems in the late 1970s and early 1980s rendered copper coaxial cable transmission systems obsolete for all long haul carrier service. Coaxial cable continues to be used today predominantly for intra-building CATV transmission, and in the “coax” part of hybrid fiber-coax systems in MSO networks. The “coax” is the distribution plant in the last mile into the CATV subscriber’s home. However, the field of use for coaxial cable will continue to diminish over time as fiber optics moves closer to the end user’s equipment and fiber to the home services, such as AT&T Fiber,™ penetrate more homes. In addition, WIFI, 4G-LTE cellular, and eventually 5G cellular will provide high speed substitutes for coaxial cable especially in the last mile and home network. The future of coaxial cable, the transmission medium that carried long distance communications for thousands of miles over land and undersea for over half a century, is tenuous at best.

Historical Milestones of Coaxial Cable Systems

- **1929** Broadband coaxial cable invented by Lloyd Espenschied and Herman Affel.
- **1929** Proof of concept coaxial line near Phoenixville, PA (2) 2600 foot coaxial sections tested.
- **1936** First Field Trial coaxial system, New York to Philadelphia, capable of carrying 240 conversations or a single television channel.
- **1936** First Bell System coaxial cable for TV use in NYC. A 1.5 mile span from NBC studio to the transmitter on the Empire State Building.
- **1937** Experimental transmission of motion pictures over the NY-Philly coaxial system.
- **1941** First U.S. commercial L-1 coaxial cable installation, Minneapolis, MN to Stevens Point, WI.
- **1947** World Series baseball games were televised through coaxial cable, NY-Philly-Baltimore-DC
- **1947** Transistor invented by Shockley, Brattain, and Bardeen all affiliated with Bell Labs.
- **1950** First undersea coaxial system, Florida to Cuba.
- **1956** First transatlantic telephone cable opens, Newfoundland-Scotland. TAT-1 Coaxial.
- **1964** First transpacific telephone cable opens, California-Hawaii-Japan, TPC-1 and HAW-1
- **1970** L-5 Coaxial Cable Carrier system trialed between Cedarbrook NJ and Netcong NJ expected to carry 90,000 voice calls and 420 Picturephone™ calls, or 30 color TV programs, or high-speed data.
- **1983** Last Coaxial Undersea transatlantic telephone cable opens, New Jersey-England, TAT-7

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Fiber Optics in the AT&T Network

By Kathy Tse

Domestic fiber deployments and the advancements of fiber systems technology have uniquely enabled the high bandwidth required today to drive our need for video and beyond. Earlier coaxial cable system and radio technology had extremely limited bandwidth, and the advent of fiber optic cabling opened up new possibilities, with AT&T leading the way.

Starting in 1977, ATT used the first fiber optic cable in a commercial communications system for local service in central Chicago (the loop). Other local installations followed. AT&T's first long distance commercial fiber optic installation, between New York and Washington opened in February 1983. The fiber AT&T deployed was from their Network Cable Systems division, and was multi-mode fiber. This limited the distance and bit rate that could be reached, due to the large core diameter that allows multiple modes of the light to be propagated. Multi-mode fiber is still used today for applications inside buildings, due to the low cost for short reach connectivity and the enablement of lower cost optics.

In order to support the longer distances required for coast-to-coast transmission, the modal dispersion present in the multi-mode fiber had to be overcome to keep the pulses from spreading. The next generation of fiber cable, using single mode fiber, was first introduced into the network in early 1985. This fiber was fabricated by AT&T in Atlanta, Georgia

An optical fiber is a thin, flexible strand of silica glass that can guide light over distances of up to several thousands of kilometers. Optical fibers are made by drawing (i.e. pulling while heating) a glass rod, called a preform, to a diameter slightly thicker than a human hair (125 micrometers).

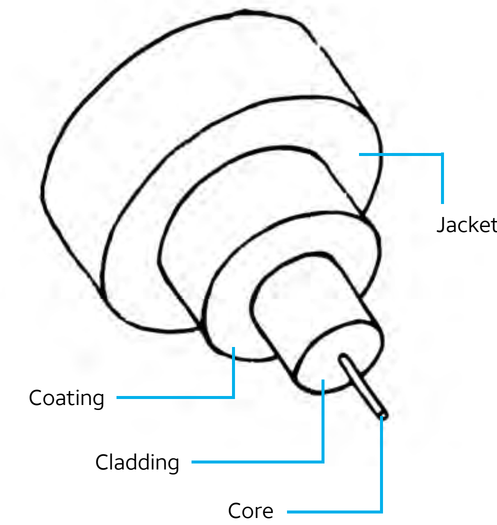
Fiber-Optic Cable
Photo by Michael Mills

The basic structure of a standard single-mode fiber (SSMF) consists of a high purity glass core of ~10um diameter that guides light, and a cladding comprised of glass of a slightly different chemical composition and having 125um (0.125mm) diameter. For mechanical and chemical protection, the optical fiber has a polymer coating applied in two or more different layers and may also have a PVC jacket for additional protection.

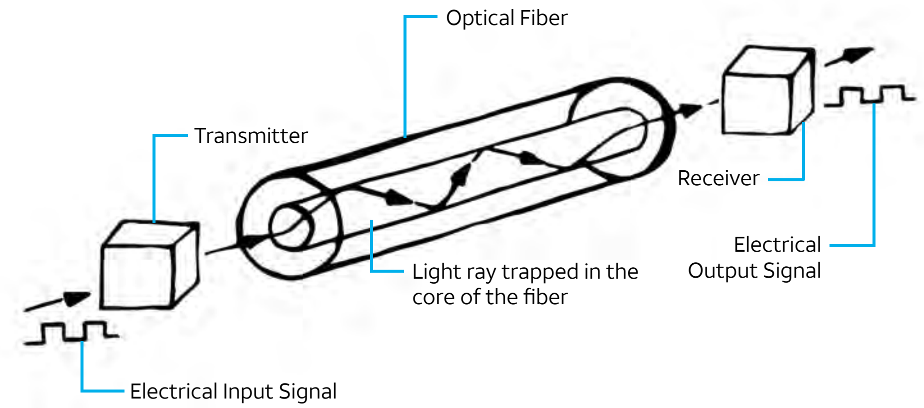
Light is guided in the core of an optical fiber by a phenomenon called total internal reflection. Total internal reflection occurs when a light beam traveling in one medium hits the interface with a medium of lower refractive index at a sufficiently large angle, such that the light is refracted back into the first medium, thus "trapping" the light beam. This phenomenon guides light in the fiber. Using this single mode fiber and an FT Series G system developed by the Network Systems division, AT&T's first single mode fiber system was deployed between Wayne and Harrisburg, Pennsylvania carrying a 417 Mb/s signal with single channel repeaters spaced every 50 km. There was skepticism about the ability of the fiber systems to operate at that rate with the same quality as the deployed radio systems, but after a month without a single error it was clear that the single mode fiber systems were here to stay.

Soon the race was on to put more bandwidth across the fiber and to build out a larger fiber footprint across the US map. Through the first use of WDM (Wavelength Division Multiplexing), AT&T was able to increase the capacity on a fiber up to 1.7 Gb/s through multiple carriers spread across the fiber spectrum.

The fiber deployed in the 1980s and early 1990s served AT&T well, but the quality of the deployed fiber was surpassed by new fiber that was being produced using better processes and with a variety of compositions met different transmission needs advantages. When AT&T looked at options to build a new fiber backbone composed of the most modern fiber, different options for the

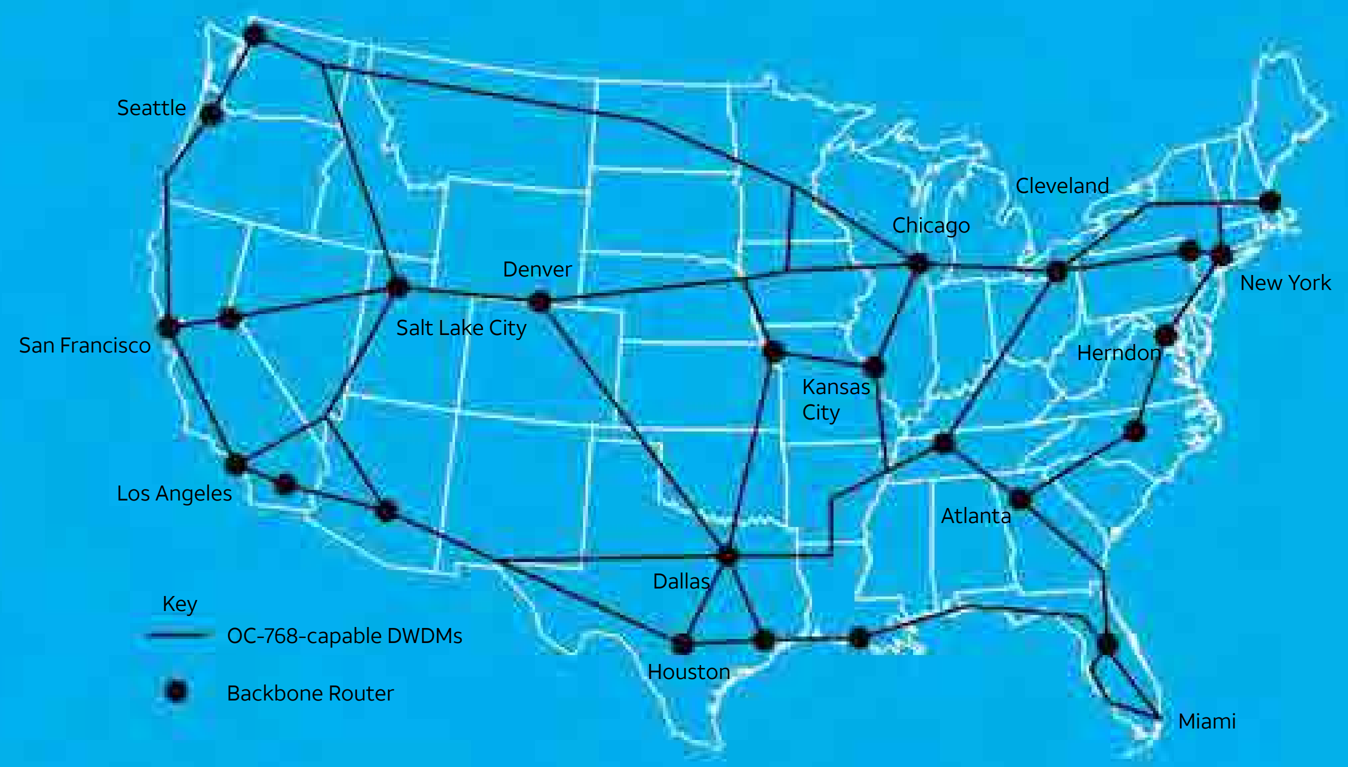


Optical Fiber Structure and Light Propagation
Illustration by Jacqueline Bogdan



Light is guided in the core of an optical fiber by a phenomenon called total internal reflection.

AT&T's NexGen Fiber Backbone Connecting Major US Cities



best way to accomplish this build were looked at, including outsourcing our entire backbone to a competitor, buying already deployed

Today AT&T has a great fiber network, the envy of our competitors.

fiber from a competitor, or building our own fiber backbone with partners. After a business analysis the decision was made that AT&T should have their own fiber backbone as a competitive advantage, and that it would be built together with partners sharing the cost. The NexGen Fiber Network construction started in the late 1990s, with a major buildout to all the critical cities. This massive effort used a hut spacing that was optimized to the long distance fiber systems that were available, overcoming many of the issues of the early fiber builds that had long distances between amplifiers limiting the total distance possible before electrical signal regeneration.

Today AT&T has a great fiber network, the envy of our competitors. Between the Nexgen backbone that forms an express "highway" between large cities, and the regional fiber that terminates at hundreds of smaller cities, we blanket the US with fiber cabling. This fiber allows us to get the best optical distance, reducing the need for costly electrical regeneration, and provides for multiple diverse paths between cities. As the fiber has evolved, so have the systems, with the modern systems allowing 96 channels with 100Gb/s of data per wavelength, and distances of thousands of kilometers between regeneration points. Digital signal processing has avoided the need for coils of dispersion-compensating fiber at each amplifier site by digitally "erasing" chromatic dispersion at the wavelength termination. In 2017, AT&T has demonstrated 400G wavelength transmission on a deployed system, proving the fiber is ready as the transmission systems support increasingly higher bandwidth into the future.

AT&T Access Network Field Trial to Offer Multi-Gigabit Internet Speeds

AT&T will be field testing 10 gigabit per second symmetrical passive optical network technology later this year. We call this (XGS-PON) and this new technology can deliver up to 10Gbps on the downlink of a broadband connection.

"Software-defined networks and XGS-PON are a natural step along the evolutionary path of PON technology... This is another way we're enhancing our network and staying ahead of changing consumer and business needs."

Eddy Barker,
Asst. Vice President of Access Architecture and Design, AT&T

AT&T's goal is to support the merging of all services on a single network, including 5G wireless infrastructure. AT&T's vision is to put XGS-PON in the cloud using software. Open hardware and software designs speed innovation. This innovative application can save time needed to manage, deliver, monitor, troubleshoot and provide care services to customers.

Customers are requiring faster internet speeds because of bandwidth-heavy applications like virtual and augmented reality and artificial intelligence. XGS-PON helps networks handle the bandwidth from these cutting-edge technologies.

Interoperability is key to our "Open Access" strategy. It's necessary for the Software-Defined Network (SDN) and Network Function Virtualization(NFV).

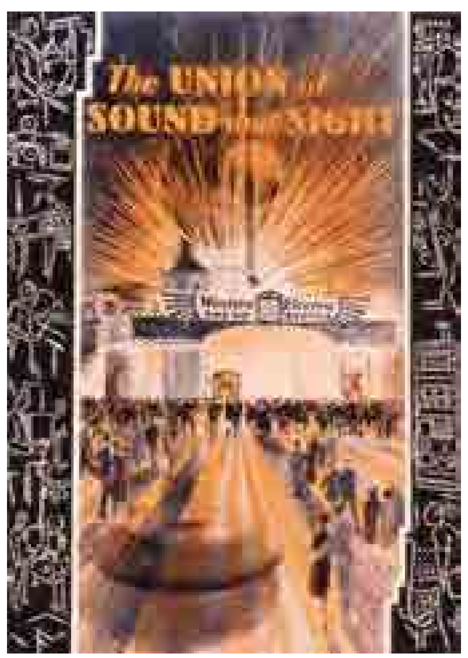
Vitaphone and Western Electric Recording

Bringing Sound to Film

By Zoe Goodman-Frost

The technology that successfully brought sound to motion pictures in the 1920's was developed at AT&T's Bell Laboratories and its predecessor, the Western Electric Engineering Department. AT&T initially had no corporate goal to introduce sound to motion pictures – its goal was to improve the national telephone network. Credit is given to AT&T R&D executive E.B. Craft, who, in 1922, recognized that telephone and transmission research and development provided all the piece-parts (i.e., amplifiers, loudspeakers, microphones, and electrical recording) for the addition of sound to movies, except for the means to synchronize sound and picture in both recording and playback. By 1924, this was developed which completed the working system.

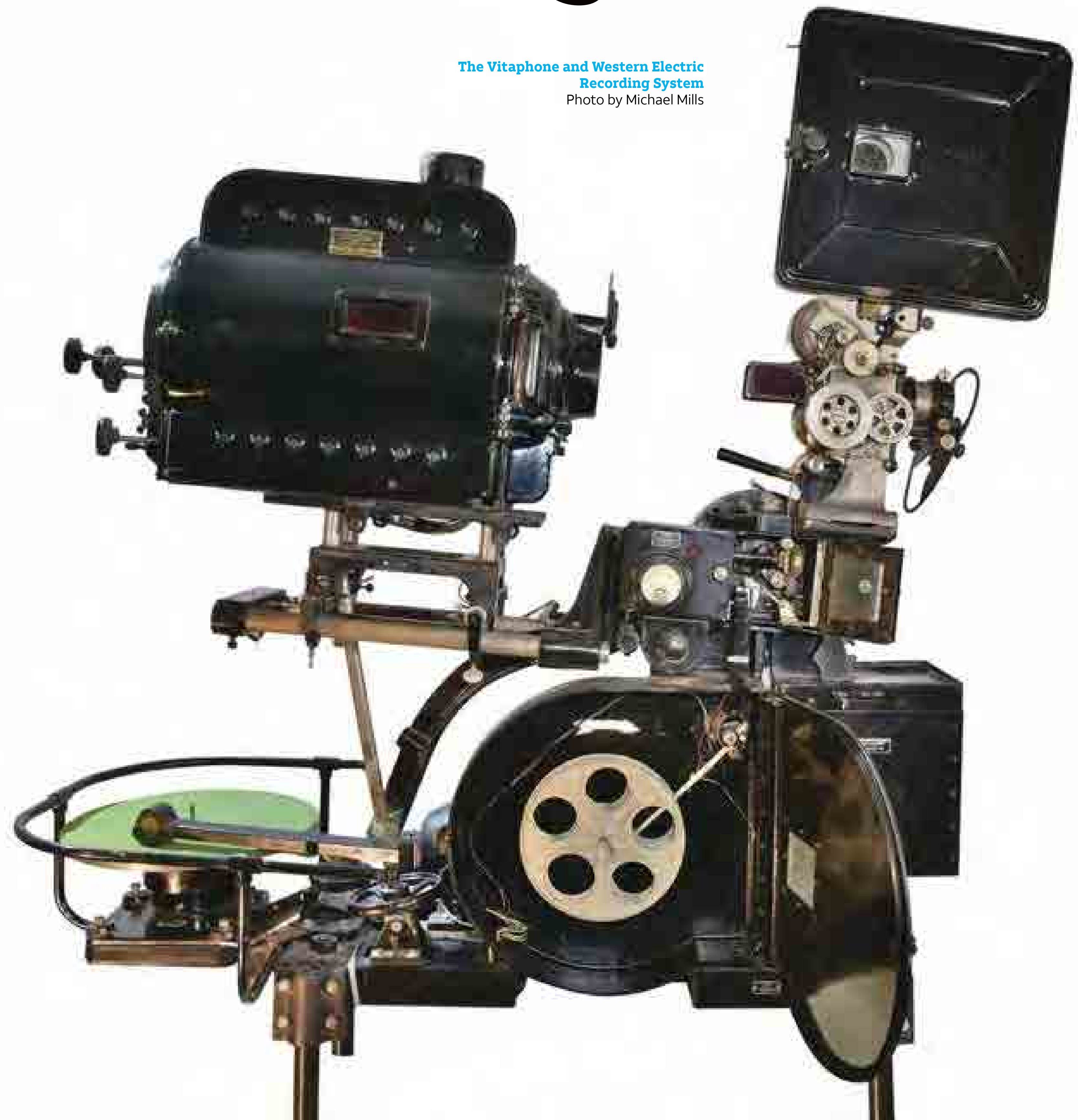
Interestingly, the movie industry initially also had no interest in talking pictures. They had a tremendous investment in the thriving silent film industry and there were no business drivers to risk this by investing in movies in which the characters spoke. Previous attempts were found to have poor synchronization, inadequate sound volume, and had been described as expensive failures. The movie industry was concerned, however, in creating a more consistent movie-going experience. Movie-goers in the larger cities had the benefit of orchestras providing musical accompaniment, while those in small towns often had a single pianist, sometimes of dubious ability. The reproduction of sound for background to silent movies would give a consistent quality to the musical accompaniment. The movie *Don Juan* (1926), the first film made with Vitaphone technology by Warner Brothers, was essentially a silent movie with background score performed by the New York Philharmonic. Only one scene contained ground-breaking sound effects – a sword fight included the clanging of sword against sword.



Cover Western Electric Sound Systems brochure (c. 1929)
Photo courtesy AT&T Archives and History Center

The movie industry was presented with two methods to record sound – one in which sound is recorded on a disc resembling a phonograph record which is played while a projector displays the film, and the second in which sound is recorded on the film itself. The Vitaphone – from the Latin and Greek words for "living" and "sound" – was the only sound-on-disc method which was commercially successful. It was developed by Bell Telephone Laboratories and Western Electric.

The system was first embraced by Warner Brothers and both feature films and short subjects were produced at the Warner Brothers-First National Studios between 1926 and



The Vitaphone and Western Electric Recording System
Photo by Michael Mills

Edward C. Wente of Bell Laboratories with a Condenser Microphone (1931)
Photo courtesy AT&T Archives and History Center

1931. Ultimately, however, the sound-on-film technique prevailed and is the method used today.

Making a Better Microphone

In 1911, the single most important problem in the national telephone network was the limited distance over which a telephone conversation could be transmitted. Long-distance service had just been established between New York and Denver, but this was the limit possible with then-current technology. Bell and Western Electric research had been working on technologies for long-distance telephone transmission to span the US. A device was needed to amplify the electric current that carried conversations.

Lee de Forest, in 1906, developed the *audion* tube, the first three-element vacuum tube, which amplified electrical signals, and demonstrated it to Western Electric in 1912. Western Electric purchased the rights in 1913. The tube was then improved in 1913 by Harold D. Arnold, making it a practical amplifier. This amplifier had low distortion and good linear amplification and made transcontinental telephone communication possible. Telephone service was expanded from NY to San Francisco. Western Electric engineers soon applied the amplifier to loudspeakers, making it possible for many people to hear simultaneously what only one could hear through a conventional telephone receiver. By 1922, Western Electric public address systems were widely used.

In addition to amplification, the existing device to convert sound energy into electrical signals needed to be improved. Since the earliest days of Bell's telephone, the carbon microphone had been used. It consisted of two metal plates separated by granules of carbon. The plate facing the speaker was very thin and flexible, and acted as a diaphragm. Sound waves striking the diaphragm caused it to vibrate, exerting varying pressure on the granules, which in turn changed the electrical resistance between the plates. Higher pressure lowered the resistance as the granules were pushed closer together. A direct current was passed between the plates through the granules. The varying resistance resulted in a modulation of the current, creating a varying electric current that reproduced the varying pressure of the sound wave. In telephony, this modulated current was directly passed through the telephone wires to the central office. However, the carbon microphone was not well suited for sound research. The frequency response of the carbon microphone was too uneven and was limited to a narrow range, and even well-engineered carbon microphones produced a low level hissing or sizzling background sound from the vibration of the carbon granules.

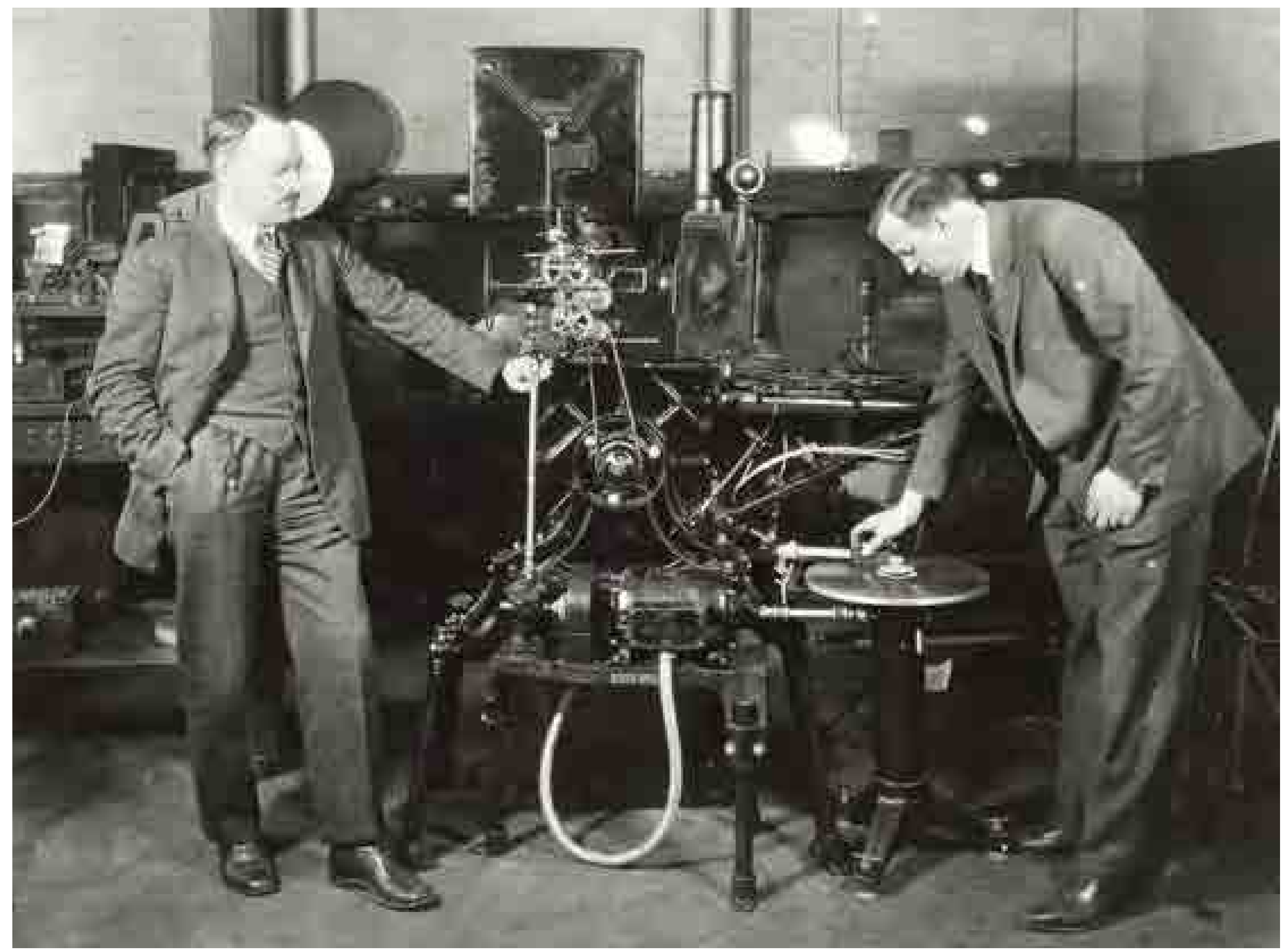
Using Arnold's amplifier to augment the extremely weak signals, Edward Christopher "E.C." Wente in 1916 turned a previously unusable device known as an electrostatic transmitter into the first flat frequency response microphone or, as Wente called it, the condenser microphone. This design also consisted of two conducting plates with one plate serving as a diaphragm. A voltage was applied to the plates. The diaphragm vibrated when struck by sound waves, changing the distance between the two plates and therefore changing its capacitance. This allowed a change in current flow in the circuit connected to the microphone. [Specifically, when the plates are closer together, capacitance increases and a charge current occurs. When the plates are further apart, capacitance decreases and a discharge current occurs.] The amplifier circuit then amplified this low-level signal to a useable level. The condenser microphone connected to an amplifier was found to produce strong signals capable of transcontinental transmission. It was also found to have remarkable acoustic performance. The larger frequency range, lower harmonic distortion, and the fact that it did not suffer from the background noise inherent in the carbon microphone, made the condenser microphone a key component for Western Electric sound and telephony systems.

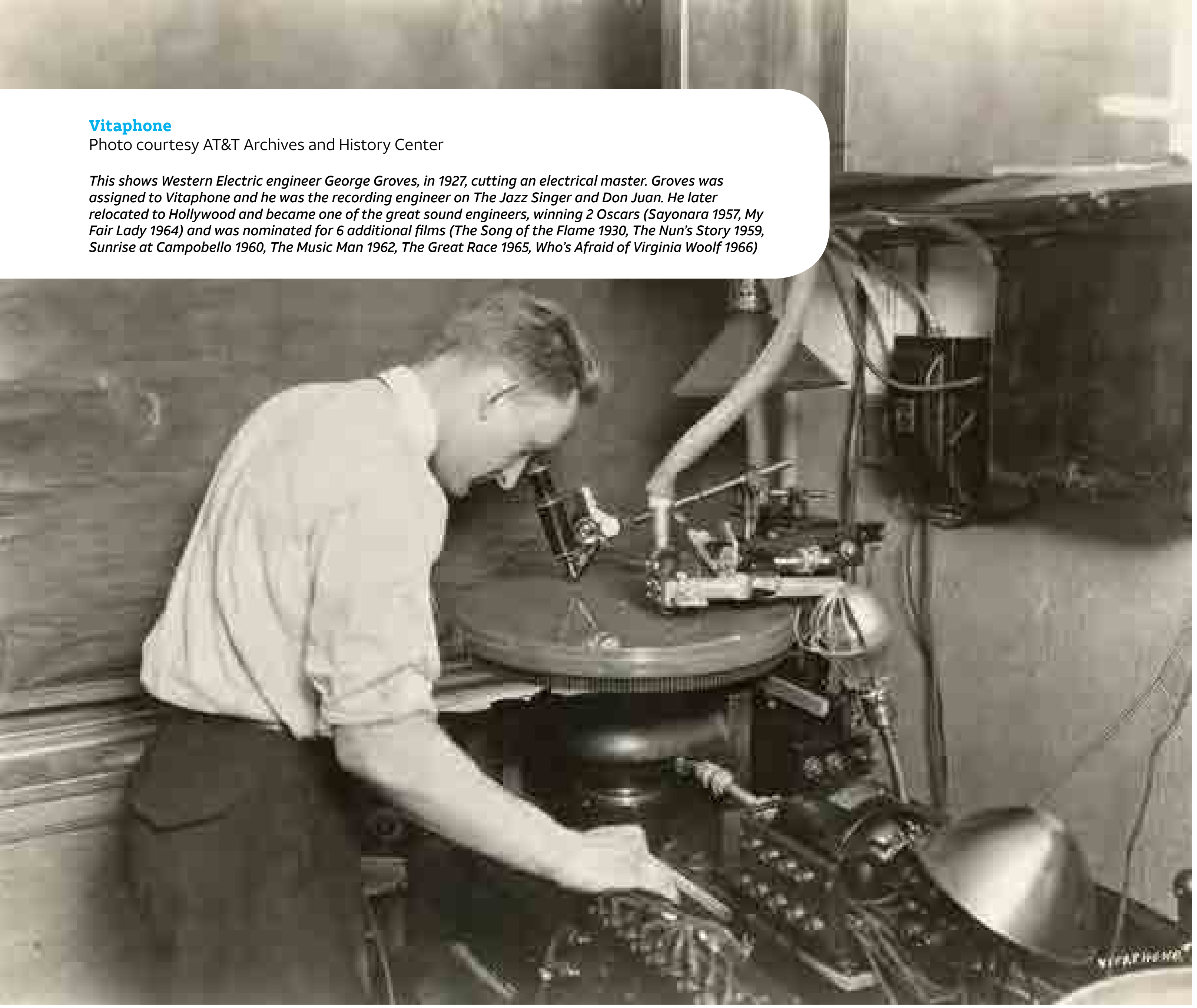
Making a Better Way to Record Sound

The researchers also needed to record and reproduce sound electrically. There seemed to be two likely paths to electrical recording. Either the existing phonograph could be re-engineered or sound could be translated into patterns recordable on photographic film. Recording would need to be done electrically with both methods. The voice or music to be recorded would be picked up by a microphone which generated a small electric current whose variations correspond to the sound waves. These would then be captured on either disc or film. Two teams at Bell Laboratories were created in 1920 to pursue electrical recording. Joseph P. Maxfield and Henry C. Harrison were charged with developing a phonograph recording system, or more specifically, an electromagnetic version of the existing acoustic disc phonograph. The second group, E.C. Wente, Irving Crandall, and Donald MacKenzie, was assigned to develop a sound-on-film recording technique.

The phonographs of the era were acoustic-mechanical devices that were limited and uneven in frequency response, and could not be coupled directly to telephone lines. Prior to the Bell Laboratories research, attempts had been made to develop an electrical recording process that involved microphones and electrical disk cutting which did not produce a good enough sound quality. But by mid-1922, Maxfield's group produced an experimental prototype system for electrical disc recording using Wente's condenser microphone and Arnold's amplifiers. In the new system, a condenser microphone converted the musician's sound energy into electrical energy, which was then amplified before being converted into mechanical energy at the recording stylus. The stylus scratched a groove

Stoller and Pfannenstiehl with Vitaphone Projector (1926)
Photo courtesy AT&T Archives and History Center





Vitaphone
Photo courtesy AT&T Archives and History Center

This shows Western Electric engineer George Groves, in 1927, cutting an electrical master. Groves was assigned to Vitaphone and he was the recording engineer on The Jazz Singer and Don Juan. He later relocated to Hollywood and became one of the great sound engineers, winning 2 Oscars (Sayonara 1957, My Fair Lady 1964) and was nominated for 6 additional films (The Song of the Flame 1930, The Nun's Story 1959, Sunrise at Campobello 1960, The Music Man 1962, The Great Race 1965, Who's Afraid of Virginia Woolf 1966)

in a spinning wax disk. While the existing acoustic device picked up only the sounds aimed directly at the sound-collecting horn, the microphone was sensitive to more distant sounds. This allowed an orchestra to sit normally, but it also meant that room acoustics became important. Since the microphone and amplifier had a broader frequency range and less harmonic distortion, the recording cut into the wax was dramatically better. Maxfield's group went on to develop the system further for use in consumer phonographs. By 1925, the phonograph was re-engineered. The two major record companies, Victor and Columbia, took licenses from Western Electric and switched to this new technology.

At the same time, Wente's team had succeeded in developing a prototype for translating electrical impulses from a microphone into variable-density light patterns on photographic film. They developed the *light valve,* a light-emitting vacuum tube with a shutter of metallic ribbon. In their design, the width of the slit formed by the ribbon varied with an applied electric current. During film recording, the exposure received by a moving film varied with the fluctuations of the microphone current, creating a photographic record of these fluctuations, and therefore the voice or music. After the film was developed, the film was played back between a constant light source and a photoelectric cell. The cell output corresponded to the patterns of exposure which was then amplified.

Wente was granted a patent on this technology in 1923, and it was the basis for Western Electric's sound-on-film process. However, in the view of the AT&T engineers of the mid-1920's, optical recording was an experimental system not yet ready for commercial use. In addition, initially the sound quality and fidelity of the sound-on-disc system surpassed the optical sound track.

The company's developments in amplifiers, loudspeakers, microphones, and electrical recording had been undertaken as part of AT&T's efforts to improve the telephone network. In 1922-1923, Research Administrator E. B. Craft proposed to apply the company's developments towards a commercial system for sound motion pictures. As he wrote to Western Electric Vice President in charge of research Frank Jewett, "It seems obvious that we are in the best position of anyone to develop and manufacture the best apparatus and systems for use in this field." Management agreed.

Putting Sound and Moving Pictures Together

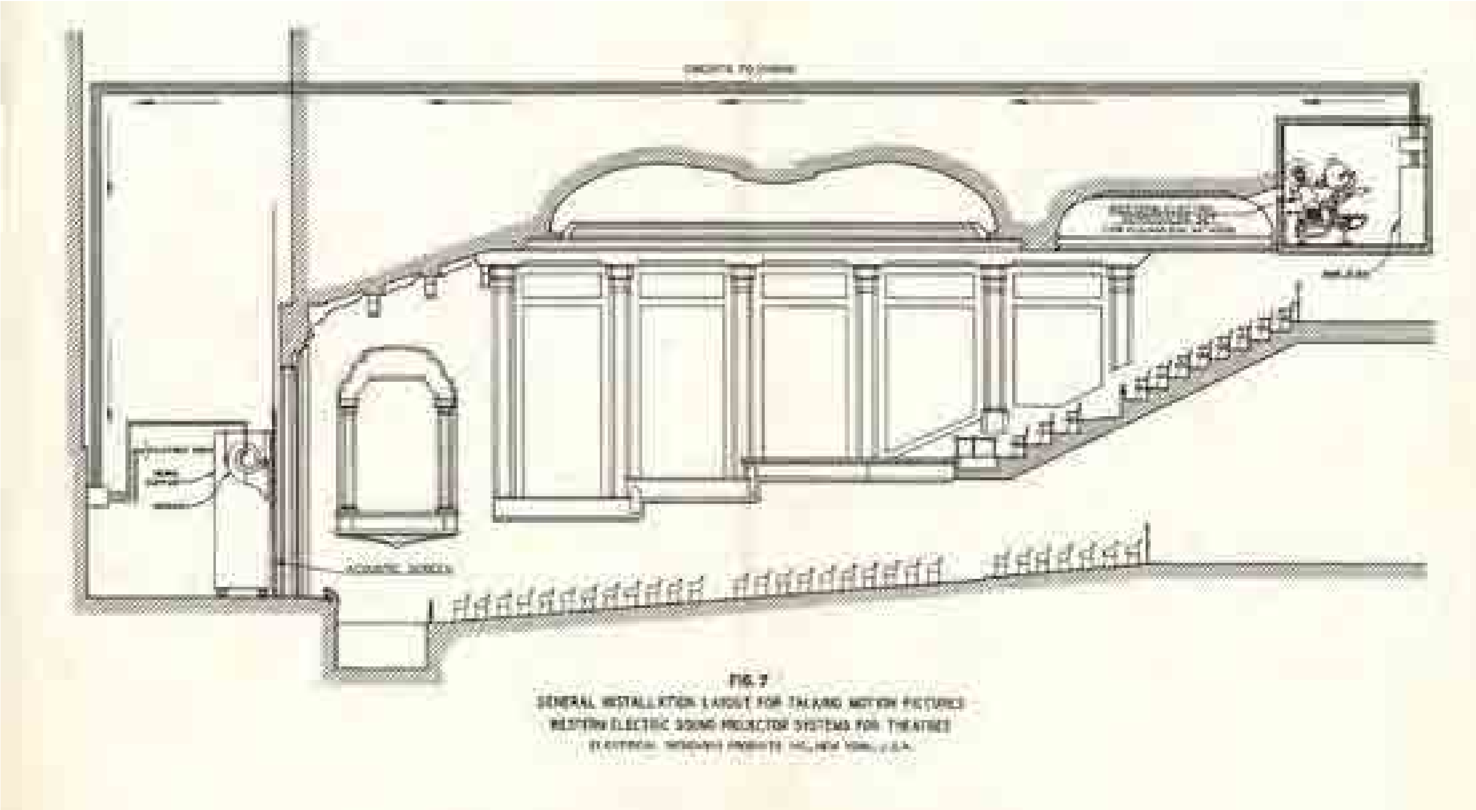
Two related problems remained – synchronized recording and playback. Playback was the more straightforward. The problem was solved by running both projector and turntable from a single motor with a mechanical filter in place to screen out vibrations. Synchronized recording was more difficult, because it was necessary to keep the recording equipment stationary to prevent vibrations while allowing the camera motion for filming. This was solved in studio design. The recording machines were usually located in a separate building to completely isolate them from sound stage floor vibrations and other background noise. Synchronization was maintained by driving all the cameras and recorders with synchronous electric motors powered from a common source. When music and sound effects were being recorded to accompany existing film footage, the film was projected so that the conductor could watch the recently completed film and synchronize the music with the visual cues. In this way, it was the projector, rather than the camera, that was in sync with the recording machine.

The end product – the Vitaphone – was not just the single piece of sound-on-disc equipment, but rather a system of interdependent parts. A Vitaphone-equipped theater used special projectors, sound amplification, and speakers. The projectors operated the same way that a conventional motorized silent projector would, but there was also an attached phonograph turntable. When the film was threaded into the projector, the projectionist aligned a start mark on the film with the picture gate on the projector, and would at the same time place a phonograph record on the turntable, aligning the phonograph needle with an arrow on the record's label. The projector motor would also drive the phonograph turntable, and played sound synchronized with the film passing the picture gate. The discs themselves were slightly different from typical phonograph discs. The needle on Vitaphone records moved from the inside of the disc to the outside. In addition, unlike the prevailing speed of 78 revolutions per minute for phonograph records, Vitaphone discs – typically 16 inches in diameter – were played at 33-1/3 rpm to increase the playing time to match the running time of a reel of film.

A section of sound film showing the photographic recording. The arrow points to the sound track.

Photo courtesy AT&T Archives and History Center

Except for the unusual disc size and speed, the physical record-making process was the same one used by record companies to make records for home use. The recording lathe cut an audio-signal-modulated spiral groove into the polished surface of a slab of wax-like material rotating on a turntable. Since the wax was much too soft to be played in the usual way, a specially supported and guided pickup was used to play it back immediately to detect any sound problems that might have gone unnoticed during the filming. If problems were found, the scene could then be re-shot while everything was still in place. Even the lightest playback caused some damage to the wax master, so it was customary to employ two recorders and simultaneously record two waxes, one to play and the other to be sent for processing if that "take" of the scene was approved. At the processing



Western Electric—Sound Projector Systems for Theatres (1929)
Drawing courtesy AT&T Archives and History Center

plant, a metal mold was produced with a ridge instead of a groove, and this was used to press discs. It is interesting to note that, because of the desirability of an immediate playback capability, later on even studios using sound-on-film systems used a wax disc "playback machine" together with their film recorders. Film was preferred for editing and final release, but disc could be played back immediately for the director to see if the sound take was satisfactory. Without the disc recordings, production crews needed to wait until the optical recording returned from the film processing laboratory.

The Other Innovation Path – Sound on Film

In contrast, in the sound-on-film method under development by Wente's team, the fact that the sound record is on the same film with the picture made synchronization inherent. The sound record consisted of a band about 1/8 inch wide, called the sound track, which ran down one side of the film. Such a film was called a sound film, and was otherwise similar to an ordinary film. After leaving the projector head, the sound film entered the reproducing unit, where it passed over a sprocket that moved it along at constant speed. A narrow bright beam of light from a high-intensity lamp was focused on the sound track of the film through a system of lenses and an aperture plate. The light passing through the moving film would then vary in intensity according to the variations recorded on the sound track. This light fell on a photoelectric cell, causing variations in an electric current passing through it; these variations corresponded to the light, and therefore to the sound which was recorded. The current was then amplified.

The New Movie Theater Experience

For both sound-on-disc and the later sound-on-film techniques, the amplified current was then converted into sound. The number and size of the speaker horns in the theater would depend on the room's acoustic properties. Horns were placed behind the screen so that a perfect illusion that the voice or music is coming from the screen was obtained.

The microphone plus amplifier combined with the electromechanical disk cutting mechanism was the new Western Electric electrical recording system, commercialized as the "Westrex" system. It was an integrated system for recording, reproducing, and filling a theater with synchronized sound. By May of 1924, Western Electric was ready to demonstrate its system to the movie industry.

When the Western Electric Sales Department approached the motion picture industry, the largest companies and several minor companies expressed their complete lack of interest. In 1925, Warner Bros – then a minor company – saw the Western Electric sound motion picture system as a means to become a major player in the business.

Vitaphone — *Don Juan* Premiere (1926)
Photo courtesy AT&T Archives and History Center

The Vitaphone Corporation was set up as a joint venture to experiment with the production and exhibition of sound motion pictures. Warner Brothers provided the picture production skill and Western Electric provided the sound skill. In 1926, Vitaphone Corporation was given exclusive license to produce sound pictures using the Western Electric system and to equip theaters with Western Electric sound systems. Warner Brothers announced it would use "Vitaphone", as the new technology was now called, to provide synchronized musical accompaniment for all its films.

Don Juan Premiere in 1926

Vitaphone debuted with the opening of the silent movie *Don Juan,* starring John Barrymore, at the Warner's Theater in New York City on August 6, 1926. The movie featured the first synchronized musical soundtrack with sound effects – no spoken dialogue – accompanied by several short subjects featuring comedians and singers, and a greeting from motion picture industry spokesman Will Hays. As for the main feature, an electrical sound system – carrying the recorded strains of the New York Philharmonic – replaced accompaniment by live musicians. The system was a hit.

The following year (October 6, 1927), Warner Brothers released its second Vitaphone feature, *The Jazz Singer,* which included classical and popular music, as well as about 350 words of dialogue. Human voice was now added to film. The film broke box-office records and established Warner

Cast of Don Juan (1926)
Drawing courtesy AT&T Archives and History Center

The film broke box-office records and established Warner Brothers as a major player in the film industry.

Brothers as a major player in the film industry.

In 1927, Western Electric established a subsidiary, Electrical Research Products Inc. (ERPI) to work with the motion picture industry to develop commercial sound film production, and also to work with theater owners to equip theaters to show sound films. Following this, Vitaphone Corporation and Warner Bros became a nonexclusive licensee of ERPI for sound motion picture recording technology. Later in 1927, Warner Brothers moved production from New York to the West Coast, where it had constructed the first studio designed for sound pictures. Bell Laboratories constructed a new building in New York exclusively for sound picture development.

The Next Generation of Technologies

By this time, two sound-on-film technologies emerged to compete with Western Electric's sound systems. The first was *Phonofilm,* which later evolved into *Movietone.* The variable-density track was created by the audio modulating the intensity of a recording lamp which exposed the sound track, similar to the technique developed by Western Electric, but used an invention by Theodore Case called the *AEOlight.* William Fox of the Fox Film Corporation acquired the *AEOlight* from Theodore Case. Since the new Fox-Case Corporation had no amplifiers nor a public address system to show its Movietone films, they acquired a license to use Western Electric equipment. Bell Labs engineers developed a layout for theaters that could play both sound-on-disc or sound-on-film, the latter with either the Fox-Case *AEOlight* or the Wente light valve for variable-density sound recording. By 1927, producer William Fox introduced sound-on-film with the feature film *Sunrise.*

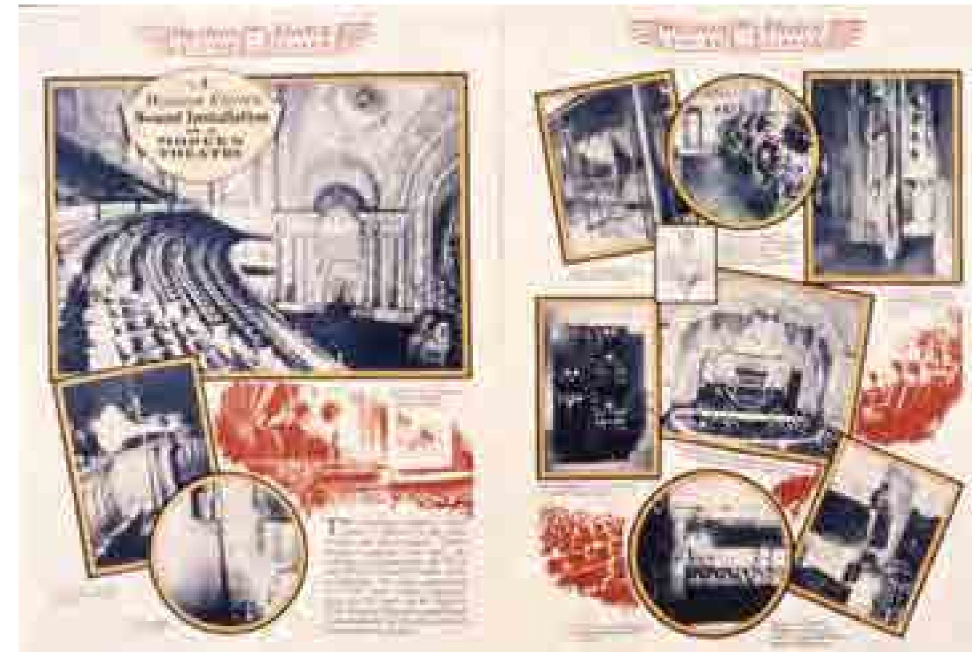
The second sound-on-film technology to emerge was *Photophone,* a "variable-area" sound-on-film system developed by RCA and its part-owner General Electric between 1925 and 1927. This system used a fast-acting mirror galvanometer to create the variable-area film exposure, in which the modulated area (width) corresponded to the waveform of the audio signal. The first public screening with this system was a sound version – music plus sound effects only – of the silent film *Wings* which was shown in around a dozen specially equipped theaters during 1927. RCA then changed the width of its Photophone variable-area sound track to that used by ERPI. This made it possible to show films recorded by either technique through the same equipment. All the projectionist had to do was change a single part.

Ultimately, the sound-on-film technique dominated the industry. The sound-on-disc system was already known to have drawbacks. First, there were distribution problems. Vitaphone records containing the film's sound track had to be distributed along with film prints, and shipping the records required an infrastructure apart from the already-existing film distribution system. Second, there were synchronization problems. If a record was improperly cued up or if a record skipped, it would be out of sync with the picture and the projectionist would have to try to manually acquire sync. If the wrong record had been cued up there was no option but to pause the show for a few minutes while swapping in the correct disc and starting that reel again. If the film print became damaged and was not precisely repaired, the relationship between the record and the print would be thrown off, also causing a loss of sync. Third, there were editing problems. A phonograph record can't be edited directly, and this created a nightmare for the sound editor. Editors and directors vastly preferred sound on film technology.

Vitaphone's disadvantages ultimately led to its retirement early in the sound era. All but Warner Brothers had settled on sound-on-film by the end of 1929. It was simply easier to work with and to edit. By 1931 Warner Brothers-First National was also recording and editing optical sound on film – primarily using RCA's Photophone rather than Western Electric's – and then dubbing the completed soundtrack to discs for use with the Vitaphone projection system. There were many theaters that had invested in the earlier technology and could not immediately afford to switch from their sound-on-disc only equipment. To make new film titles backward-compatible with Vitaphone equipped theaters, films produced with sound-on-film processes were released by Warner Brothers and the other Hollywood studios simultaneously in Vitaphone versions as late as 1937. Warner Brothers kept the "Vitaphone" name alive as the name of its short subjects division, The Vitaphone Corporation, most famous for releasing Leon Schlesinger's Looney Tunes and Merrie Melodies (Leon Schlesinger Studios later became the Warner Brothers Cartoons Studio).

For nearly half a century, motion picture sound systems were licensed, with two major licensors in North America – RCA and Western Electric (Northern Electric, in Canada) – which licensed their principal sound element recording systems on a non-exclusive basis. In general, motion picture producers elected to license one or the other. In a few cases where mergers had occurred, a producer might be licensed for both. For many years, it was customary to brand a film with its sound system, as "RCA Sound Recording," "Western Electric Recording," or similar brands, often including the corporate logo of the licensor. This branding for the most part ended by about 1976, as by that time nearly all optical sound recording had been converted to a stereo variable-area system.

Western Electric Sound Installation in a Modern Theatre (c. 1926)
Drawing courtesy AT&T Archives and History Center



1929 was the year that the talkies conquered Hollywood and the silents died. The transition to sound was rewarding for the entire industry, but most especially to the companies that had taken the initial risks. Warner Brothers used its profits from sound to acquire First National, and along with Fox and RKO, joined Paramount and MGM as the leading companies in Hollywood.

By January 1932, the job of wiring existing theaters for sound was complete. Only 2% of isolated theaters in the country were still showing silent pictures. In 1937, ERPI left the motion picture theater business. Wiring the nation's theaters had been lucrative. AT&T remained active in providing sound equipment to movie studios for another twenty years, leaving thousands of films with the credit line "Sound by Western Electric."

Acknowledgements

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Bell Laboratories and The Development of Electrical Recording

A Service Decades Too Early Picturephone

By Elisabeth Patterson

Visitors to the 1964 World's Fair were offered a wide choice of attractions. Some amused, some celebrated the past, and some presented futuristic technologies and possibilities. One astonishing technology on display was a device like a small television set, 5x5 ½ inches, that offered a video display to accompany a phone conversation. This was the general public's first introduction to Picturephone. Bell Labs scientists presented the system to the fair-going public, and surveyed human factors analysis to refine an offering they hoped to make public in the 1970's.

Picturephone was conceived in part as a humanizing element to telephone service

Picturephone was conceived in part as a humanizing element to telephone service, improving communications by adding sight to voice, for a more satisfying exchange. Picturephone could also be used to transmit graphical material, like drawings and photographs, as well as images of physical objects. Moreover, the equipment could be used for rudimentary remote communication with a computer, via Touch-Tone keypad, and display on the Picturephone screen.

Infrastructure

Picturephone technology was designed to work with existing telecommunications infrastructure. Picturephone was supported at first by No.5 crossbar switching machines, with the expectation that the capability would be added to 1ESS switches over time,

Picturephone
Photo by Michael Mills

Picturephone at Bell System Exhibit, NY World's Fair (1964)
Photo courtesy AT&T Archives and History Center

broadening the geographic base for the service. The voice component of a Picturephone call was carried on the existing two-wire loops, as was typical for voice traffic. For the Picturephone signals, two additional pairs were added, one pair for transmission in each direction. The voice pair was connected to the central office as usual, however the video pairs were connected to a separate four-wire video switch, under the control of the existing switching equipment.

The Picturephone picture signal was transmitted as analog between central offices within a distance of six miles. Beyond six miles the picture, voice and signaling information were encoded as a digital signal, which remained encoded to within six miles of the central office destination. (The single encoding protected the signal from degradation during transmission.) It was expected that the projected T-2 digital carrier system would be used for the transmission of Picturephone signals. The T-2 system was understood to be a single network that could transmit all services.

Video Telephone Equipment

The essential component of video telephony was the Picturephone itself. The equipment was designed to meet stringent requirements in technology and human factor engineering.

The camera requirements included a great image that could stay sharp automatically, and adapt to a variety of subjects, backgrounds and conditions. It had to be versatile enough to show objects and sketches, change the field of view for additional persons in a single setting. And naturally it had to offer the user the option not to be seen.

The Picturephone was designed with close attention to human factors, to simulate as closely as possible the free and natural communication of face-to-face conversations. The integrated camera was situated to control the eye contact angle, to replicate normal conversational facial expressions in the video subject. Camera placement supported the most natural, least distorted view of the subject, permitting natural movement and the use of ambient light.

In addition to the camera, the display unit contained a speaker, with a volume control knob on the control unit. The control unit allowed a speaker to mute his microphone, and monitor and disable the broadcast image.

The control unit included capabilities to support document and image transmission, to automatically focus the camera unit to the correct angle to a physical desktop. The resolution offered was imperfect for typed and printed text, but sufficient for sketches and photographs. In a parallel development, the same small monitor could be used to retrieve and display data, and even be the gateway to controlling a computer in a remote location.

These requirements were embodied in the Picturephone MOD II set.

The Mod II set consisted of a picture display unit, containing the camera, picture tube, and loudspeaker. Video was displayed on a 5x5 ½ inch black and white monitor. The display unit contained all the video circuits, camera and picture tubes, and the speaker. Presenting 30 frames per second with an odd-even line interface to give 60 fields per second, the display unit yielded a satisfactory image. Sound was provided by a touch-tone speaker phone. Users could view the video display, monitor their own image, or turn the video of.

Western Electric Picturephone Ad (1969)
Photo courtesy AT&T Archives and History Center

Commercial History

Picturephone was introduced in Pittsburgh PA in July 1970, targeted towards large business customers. Service was soon expanded to Chicago. But Picturephone service never really developed a following of enthusiastic early adopters, and the number of installations remained static. In 1973 AT&T eliminated the Picturephone offering.

What Happened?

Picturephone technology offered a human face to telephone conversations on a small black-and white desk monitor. Picturephone never achieved wide success, for a variety of reasons. The equipment was never widely deployed among customers, so its use never became routine. The service was extremely expensive. Although so much attention was paid to the ergonomics of the system, many people were uncomfortable to be "seen" on the telephone. An enthusiastic customer base never really coalesced around the video capability.

Still, Picturephone represents as early attempt to transmit image and data over the wired telephone network. It was an ambitious attempt to expand telephone capability, and the technical ancestor of applications and services that we now take for granted in daily communication.

Picturephone Birth to Death

- **1956** Bell Labs Video Telephone systems in development. Prototype transmitted and received pictures over ordinary telephone wires.
- **1957** Experiments produce a feasible system, establishing standards for picture resolution, contrast and other features.
- **1963** Experimental Picturephone system: station set included the camera-receiver-loudspeaker unit, and separate combination telephone set-video control unit.
- **1964** Public debut of Picturephone service at the New York World's Fair. Selected individuals tried the system for ten minutes or so, and shared their reactions with Bell Lab Researchers. Limited Picturephone service was established between New York, Chicago and Washington DC.
- **1965** Equipment and operational changes improve Picturephone capability. Experimental trials begin at certain corporate locations, expanding to include three Bell Labs locations. The trial integrated Picturephone service with normal telephone service, and explored further uses, such as an interface to a computer.
- **1968** The Picturephone "see-while-you-talk" set incorporates improvements and new features. MOD II Picturephone set is created.
- **1970** Picturephone service introduced in Pittsburgh, but does not find a wide market.
- **1973** Picturephone is withdrawn from the market.

Theseus

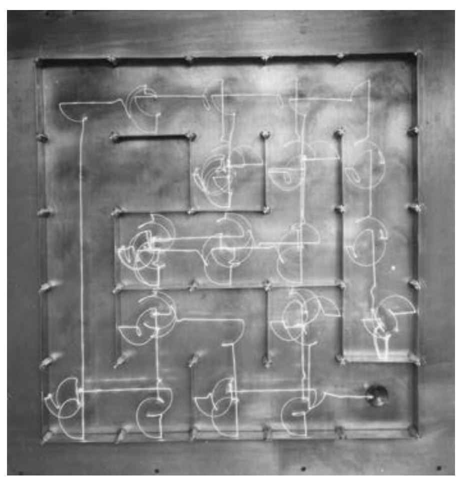
A Mouse with Artificial Intelligence

By Byoung-Jo Kim

It has a simpler brain than a microscopic worm in the soil of your backyard, but the size of its brain is that of a small reading desk. It does not eat, it does not tire, although it constantly seeks its inedible metal “cheese.” Most importantly, it learns from its experience. It is this ability to learn and change its behavior that makes Theseus one of the very first ancestors of Siri or Alexa, the AI (Artificial Intelligence) assistants in your smartphones and many other AI innovations of late.

Theseus
Photo by Michael Mills

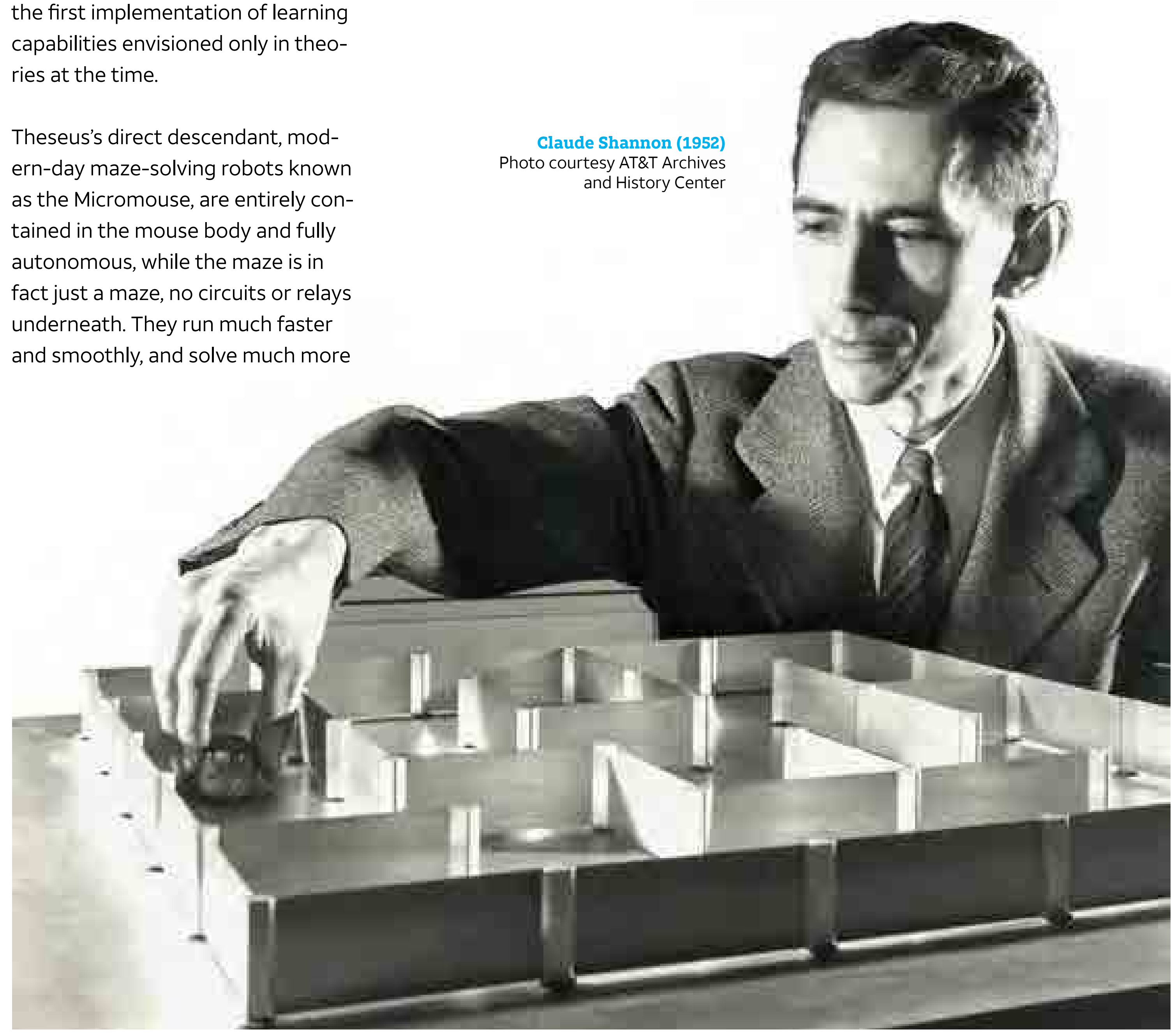
As the inventor and builder of Theseus, Claude Shannon, surmised, it is “a demonstration device to make vivid the ability of a machine to solve, by trial and error, a problem, and remember the solution.” Shannon's fame as the ‘father of information theory’ (the foundation of all digital communication technologies) afforded him nearly unfettered freedom to pursue whatever intellectual interest that fancied him. This was even more so for him than other research scientists at the Bell Labs who already enjoyed substantial freedom that resulted in much of modern innovations that we take for granted now. One of such pursuits was to build various robots that perform specific tasks such as juggling, playing chess, riding a unicycle, and playing a flame-throwing trumpet.



Theseus' Path through a Maze (1952)
Photo courtesy AT&T Archives and History Center

Theseus is perhaps the most well known of his such inventions: a mouse with memory and the ability to learn. The mouse that moves in the maze is a mere wooden carving with a magnet underneath and whiskers made of copper wires.
All the moving, remembering, and learning is in fact housed under the maze along with the 90 electrical telephone communication relays whose logic and memory decide how the mouse moves by way of magnets and actuators. The circuits hidden under the maze remember the layout of the maze as the wooden mouse explores and calculates where to explore next so as not to go where it already learned was a dead end. It is this learning, however primitive at the time, places it at the very beginning of the AI history as the first implementation of learning capabilities envisioned only in theories at the time.

Theseus's direct descendant, modern-day maze-solving robots known as the Micromouse, are entirely contained in the mouse body and fully autonomous, while the maze is in fact just a maze, no circuits or relays underneath. They run much faster and smoothly, and solve much more complex mazes, but fundamentally, are not much different from Theseus from nearly 70 years ago. The true legacy of Theseus, however, is not faster and smaller autonomous mice, but the vastly improved learning capabilities of modern AI systems, enabled by unimaginably faster and power-efficient semiconductor digital circuits than Shannon's relays and switches, and the availability of more or less curated and structured data through the expansion of the Internet with which to teach new AI systems to perform seemingly impossible tasks.



Claude Shannon (1952)
Photo courtesy AT&T Archives and History Center

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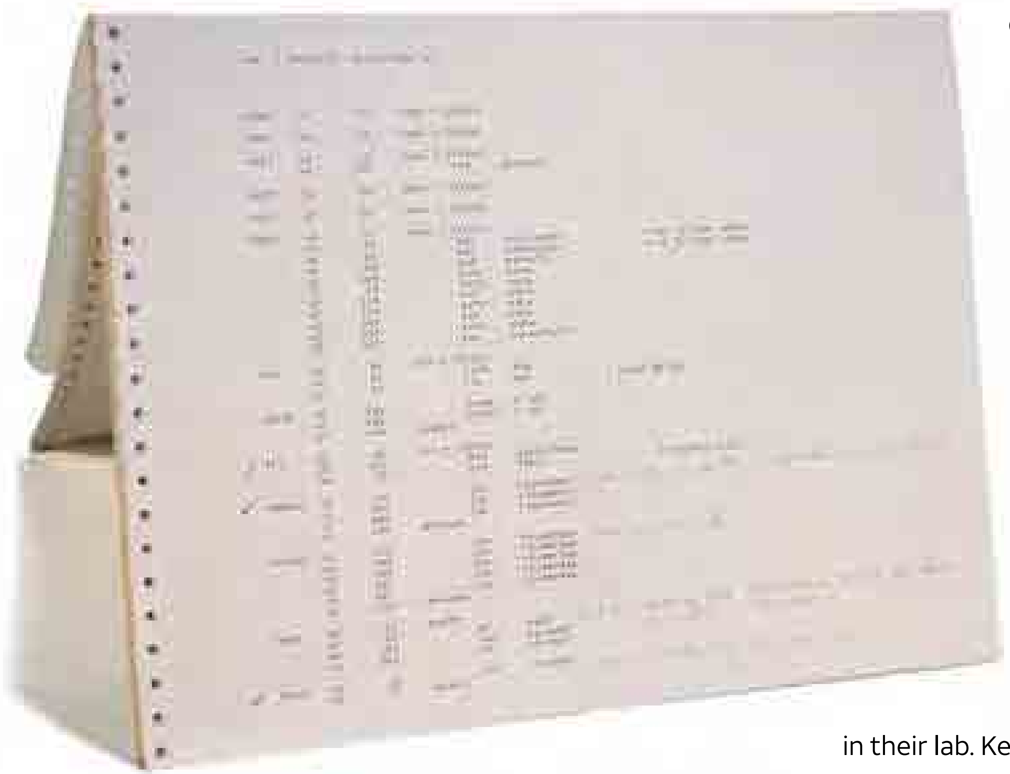
A Short History of UNIX™

Printout of UNIX™ Version 3 or 4
Photo by Michael Mills



By Tony Hansen

What do billions of cell phones have in common with billions of Internet of Things devices, millions of computers sitting on desktops, and the largest supercomputers?

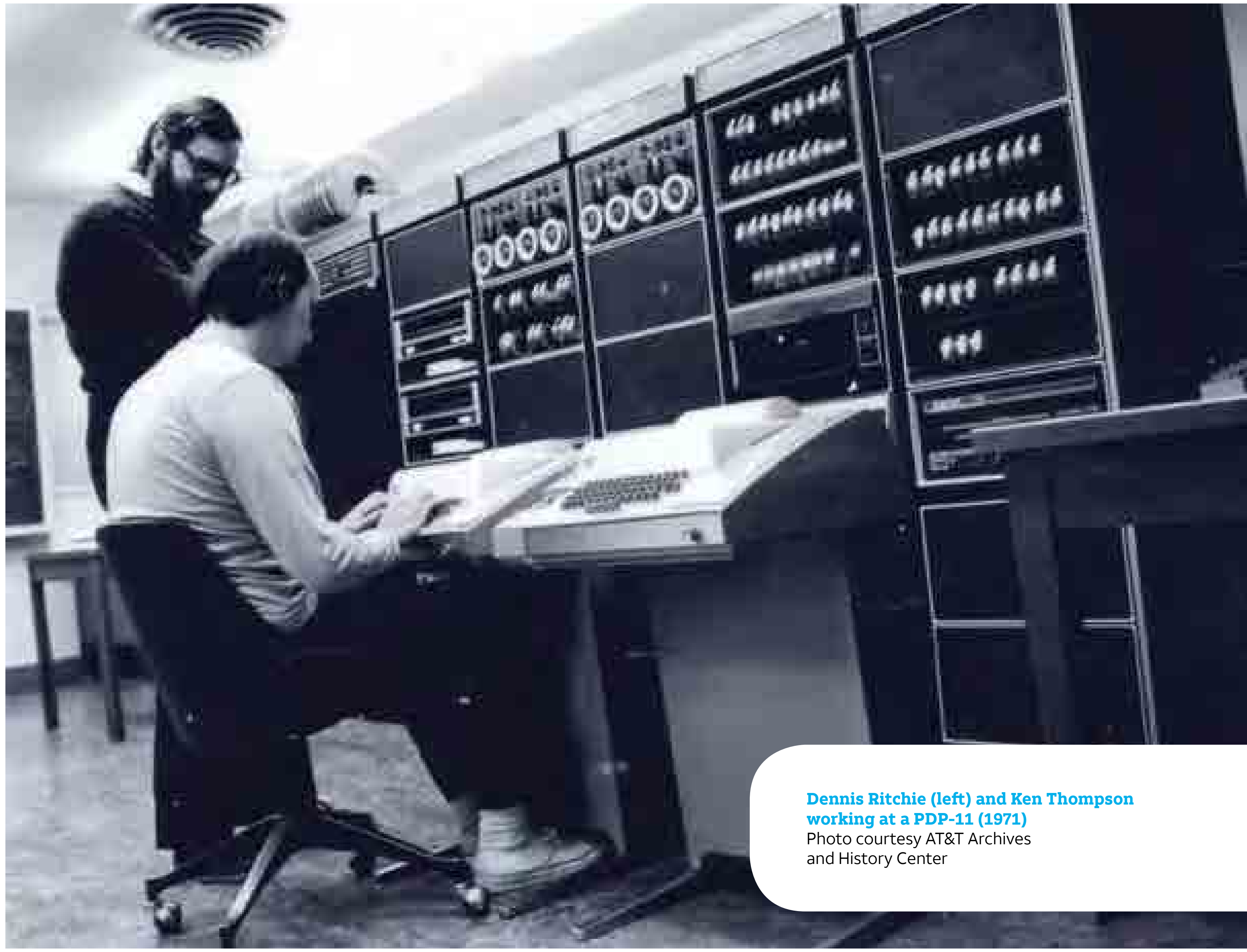
Go on, take a guess. (Hint: look at the title of this article.)

Got it yet? They all are using UNIX™ or a UNIX™ - like operating system. Yes, the operating system running in the smart phone in your hands, microcomputers such as Raspberry Pis, the Apple Macs, and the largest supercomputers in the world all share a common heritage with each other.

A New Operating System Is Created and Evolves

Back in the late 1960s and early 1970s, a group of scientists from Bell Laboratories created a new operating system for the Digital Equipment Corporation's PDP-7 computer that they had sitting in their lab. Ken Thompson, Dennis Ritchie and others at Bell Laboratories had been working on a multiple-user timesharing project known as Multics, but the PDP-7 ran a single-user operating system (DECsys). After Bell Laboratories pulled out of the Multics project, Ken decided to write a new operating system for the PDP-7, which he wrote in assembler in 1969. This operating system went through several revisions and subsequently ported to a PDP-9, and then different versions of a PDP-11. During that time, Dennis Ritchie developed the language C (based on the B language that Ken had previously created). Brian Kernighan suggested the name UNIX™ as a pun on Multics, and the first public article was published in The Communications of the ACM (Ritchie & Thompson, 1974) in July 1974

The most important characteristics of the system are its simplicity, elegance, and ease of use.



Dennis Ritchie (left) and Ken Thompson working at a PDP-11 (1971)
Photo courtesy AT&T Archives and History Center

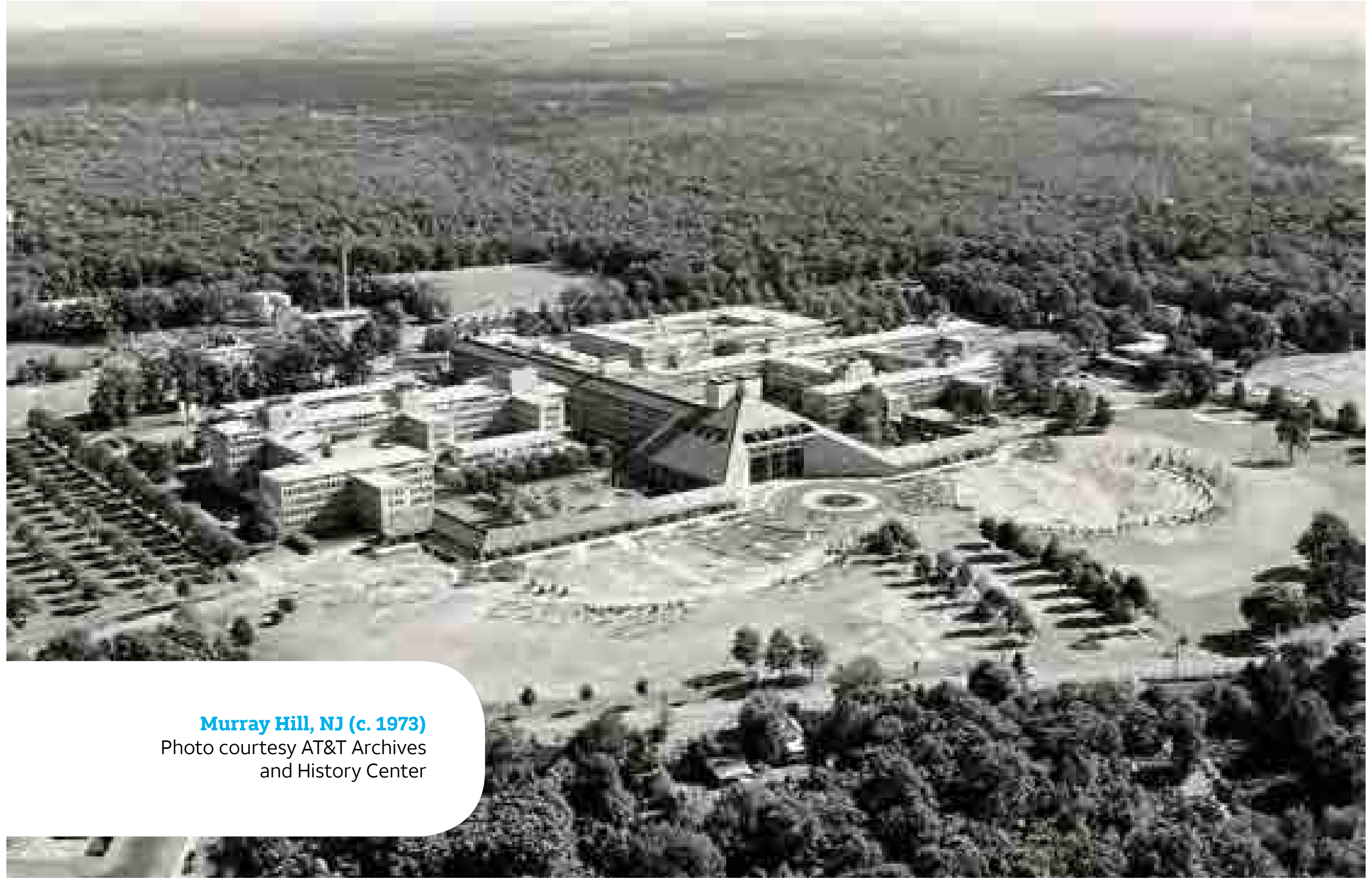
by Dennis Ritchie and Ken Thompson. Its abstract says:

> UNIX™ is a general-purpose, multi-user, interactive operating system for the Digital Equipment Corporation PDP-11/40 and 11/45 computers. It offers a number of features seldom found even in larger operating systems, including: (1) a hierarchical file system incorporating demountable volumes; (2) compatible file, device, and inter-process I/O; (3) the ability to initiate asynchronous processes; (4) system command language selectable on a per-user basis; and (5) over 100 subsystems including a dozen languages. This paper discusses the nature and implementation of the file system and of the user command interface.

In their article they state a goal achieved through the widespread use of UNIX™ and its derivatives:

> It is hoped, however, the users of UNIX™ will find that the most important characteristics of the system are its simplicity, elegance, and ease of use.

In addition to the basic operating system kernel, end users were also provided basic commands for compiling and linking executable programs, a rudimentary command language interpreter (the Thompson shell), and a set of small general-purpose tools. All of this allowed end users to write complex programs in a multitude of languages.[1] Another innovation supported in this early shell was the notion of many small programs tied together in a command pipeline, whereby the output of one program could be automatically passed as the input to another program. Note, to most people the term UNIX™ covered not only the kernel code but also all of (or only) the tools that commonly came with a particular version. Thus, you had the UNIX™ mail program, the UNIX™ shell, etc.



Murray Hill, NJ (c. 1973)
Photo courtesy AT&T Archives and History Center

Other innovations include the I/O, file structure and file system. Other operating systems often supported a variety of file types, such as fixed-length 80-character card-image files or indexed access files; in UNIX™, all files appear as a series of bytes. Special files might be associated with physical devices, such as a "punch paper tape" device, /dev/ppt; the user reads from or writes bytes to it and the device file does the translation.

As Thompson and Ritchie put it in their ACM article:

> The success of UNIX™ lies not so much in new inventions but rather in the full exploitation of a carefully selected set of fertile ideas, and especially in showing that they can be keys to the implementation of a small yet powerful operating system.

By the time UNIX™ Version 5 came out, most of the operating system kernel was written in C with only some assembler. When UNIX™ Version 6 came out in May 1975, the operating system was completely written in C. This drastically improved the portability of the code, and moving to new hardware platforms became much easier.

Because of the 1956 Consent Decree, AT&T could not sell UNIX™. The UNIX™ Version 5 and 6 code was made available to various universities under an educational license for little more than the cost of the media and shipping; Version 6 was also available with a commercial license for $20,000. Although the source code was considered to be a "trade secret", the early UNIX™ license did not forbid teaching classes on the code base. The University of Illinois was the first to receive such a license, and the University of New South Wales and the University of California, Berkeley were some of the many schools that taught classes on UNIX™.

John Lions (UNSW) wrote a series of class notes that annotated the entire Version 6 kernel source code. With the blessing of Western Electric, the class notes (Lions, 1976) and the kernel code (Bell Laboratories, 1976) were made available to UNIX™ licensees in March 1977; in 1978 they were published as books by Bell Laboratories. The two books are each about a quarter inch thick. There are exactly 9,073 lines of C code, including comments, in the kernel book. (Original copies of these two volumes are rare and hard to come by.) Because of his work, Professor Lions was later invited to join the Bell Labs technical staff in Murray Hill during a sabbatical.

UNIX™ As a Commercial Product

It was about this time that variations of the UNIX Operating System began spawning new versions and related software, both within Bell Laboratories and externally. Internally, the UNIX™ Support Group was created and the Programmer's Workbench series was put together to support a department of 1000 programmers, with a number of new tools added for document preparation and compilation/cross-compilation support. PWB/UNIX™ 1.0 was based on UNIX™ Version 6, and PWB/UNIX™ 2.0 was based on UNIX™ Version 7. Tools added to one system were quickly added to the other as well.

AT&T decided that UNIX™ might actually be a valuable commodity, and UNIX™ Version 7 (announced in June 1979) had a drastically different license. Commercial licenses to other companies were $20,000. Automatic permission to use it in a classroom was removed, so most universities stopped teaching courses based on the UNIX™ kernel code. The Lions books also were no longer published, although multiple-generation Xerox copies were still sometimes studied "on the side." (The Lions books were officially republished in 1996 by SCO.)

UCB continued teaching courses based on UNIX™, subsequently creating the Berkeley Software Distribution (BSD) and bundling the UNIX™ kernel and tool set with additional programs, many of which were extensions of the V6 or V7 code. UCB students and staff started adding their own innovations to the kernel, particularly in the areas of networking, compilers and visual interfaces. The 3rd and 4th Berkeley Software Distributions gained significant popularity outside of UCB.

Advertisement for UNIX™ (1980)
Photo courtesy AT&T Archives and History Center

The UNIX™ kernel was ported to a number of other systems during this time. Of particular note were the DEC VAX-11 series; the VAX-11/780 and later the VAX-11/750 were popular machines to run UNIX™ on both within universities and Bell Laboratories. UNIX™/32V was a direct port of v7 to the 32-bit Vax architecture, done by a separate organization within Bell Labs. The 3rd Berkeley Software Distributions was based on UNIX™/32V.

Back within AT&T, UNIX™ System III built from PWB/UNIX™ 2.0 and UNIX™/32V; UNIX™ 4.0 and UNIX™ System V later came from that.

The Research organization continued work on operating system research, eventually creating UNIX™ versions 8, 9 and 10, and subsequently a derivative known as Plan 9. Some ideas from v8 and v9 eventually made it into other UNIX™ flavors.

The Apple Mac OS X has its roots in BSD UNIX™, as does iOS.

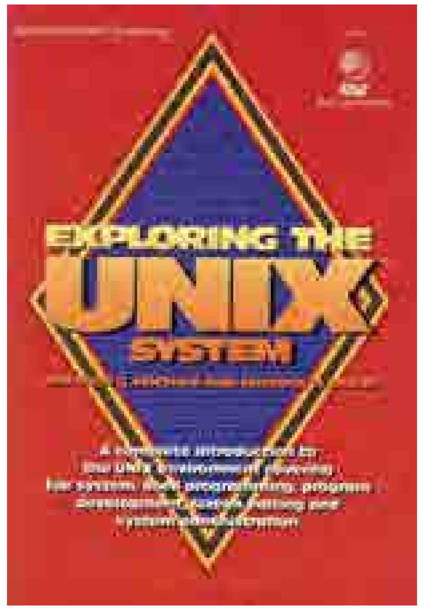
UNIX™ System Laboratories

The changes in the consent decree in the early 1980s allowed AT&T to officially sell copies of UNIX™ to individuals and not just companies, and they decided to do so with System V as the base.

Around this time, AT&T became very protective over the word UNIX™, making certain that everyone knew that it should ALWAYS be used as an adjective for the words Operating System and that the ™ symbol would always be used with it. Nevertheless, most people continued to use just "UNIX™" in everyday speech. Many people also spelled it "Unix" instead of "UNIX™."

The term "System V" itself became a branded term, so from System V came System V release 2, System V release 3 and eventually System V release 4.

In 1989, AT&T coalesced all of the UNIX™ development into a separate organization, UNIX™ System Laboratories, and eventually spun USL off into a separate compa-



Exploring the UNIX™ System by Stephen G. Kochan and Patrick H. Wood (1984)
Photo courtesy AT&T Archives and History Center

ny. Novell purchased USL in 1993, along with all rights to AT&T's UNIX™ copyrights. Novell subsequently sold part of its UNIX™ business to The Santa Cruz Operation (SCO), but maintained certain rights. The following twenty years have been a licensing mess, with suits and counter suits between SCO, Novell, and various other organizations that had licensed UNIX and created their own variations.

Opensource Versions

Because UNIX™ was licensed software, and many people were unwilling or unable to pay the licensing fees, open-source versions sprang up in the 1980s. Although they may not have direct code lineage to UNIX™ they are considered to be UNIX™ - like, leveraging all of the most important characteristics of the system: simplicity, elegance, and ease of use that Ritchie and Thompson strove for in 1974. These often used a name that ended with the letter X, as in Minix and Linux. The GNU project has both a kernel part and tool part, but the kernel part (Hurd) was never finished. The most popular UNIX™ - like distributions use the Linux kernel combined with the GNU toolset, plus many other free software programs.

FreeBSD was created from 4BSD by reimplementing from scratch the Berkeley Software Distributions kernel portions whose code was derived from AT&T code. It is licensed under a rather permissive license, different from GPL. MacOS uses some FreeBSD code, as does the PlayStation 3 and 4, and the Nintendo Switch.

The Android OS is based on a Linux kernel. Many computer systems, from the smallest Raspberry Pi micro-computer to large super computers, use a Linux+GNU distribution.

As with UNIX™, Linux has gone through a number of flavors starting with the original Linux Kernel, then Debina and now the most recent being Unbuntu Linux.

Standardizing UNIX™ and UNIX™-Like Operating Systems

There's a saying that the wonderful thing about Standards is that there are so many to choose from. Many companies wanted to make products that ran on UNIX™, but it was difficult because of the numerous versions of UNIX™, IEEE, X/Open, Unix International, Open Software Foundation, and were all various groups involved in or created to "standardize" on different aspects of UNIX™. Some were formed to directly compete with others.

IEEE created the Portable Operating System Interface (POSIX), which formed the basis for most further standardization. The Common Open Software Environment formed another part. Novell assigned the UNIX™ trademark to X/Open in 1993.

X/Open and OSF merged in 1996 to form The Open Group. It became THE certifying body for the UNIX™ trademark and publishes the Single UNIX™ Specification technical standard, based on POSIX and the earlier efforts.

Even though Linux is not derived from UNIX™ source code, the Linux distributions generally aim for POSIX compliance, so a high amount of compatibility has been maintained between UNIX™ and Linux.

Enabling Software Anywhere

So there you have it. From many IoT devices to your smartphone, from your video game system to the Apple laptops and desktops, from the systems your web browser attaches to the largest weather-data-crunching super computers, the odds are extremely high that you are using some embodiment of UNIX™ vision.

Thank you, Ken and Dennis, for your wonderful legacy.

References

[1] Later versions of the shell (the Mashey shell, the Bourne shell, the C shell, the Korn shell, and the Bourne-Again shell) still use many of the syntax elements first created in the Thompson shell.

ECOMP & ONAP

SDN and ECOMP: SDN allows us to move to a software-centric network running on a cloud environment. Think of our network as a giant computer and ECOMP is the brain, the operating system that manages it.

- SDN stands for software-defined network. This software-centric cloud environment creates a better, more secure, faster, and more cost-effective network where resources and functions are controlled dynamically.
- ECOMP stands for Enhanced Control, Orchestration, Management and Policy. ECOMP is the brain, the operating system that manages the network. It helps us to automate network functions and size the network instantly to enable the best customer experience.
- ONAP stands for Open Network Automation Platform and will allow end users to automate, design, orchestrate, and manage services and virtual functions.

"Opening up ECOMP" means making it available for others to use

- Our AT&T ECOMP software code and the Open Orchestrator Project (OPEN-O) are merging to create the new Open Network Automation Platform (ONAP) Project at the Linux Foundation. AT&T is opening up not just the software code for third-party operators, developers and other groups, but also information like documentation and educational videos. Making two sample use cases (one on virtual security firewall and one on virtual dynamic networks) that will be placed on a public cloud for users to access.

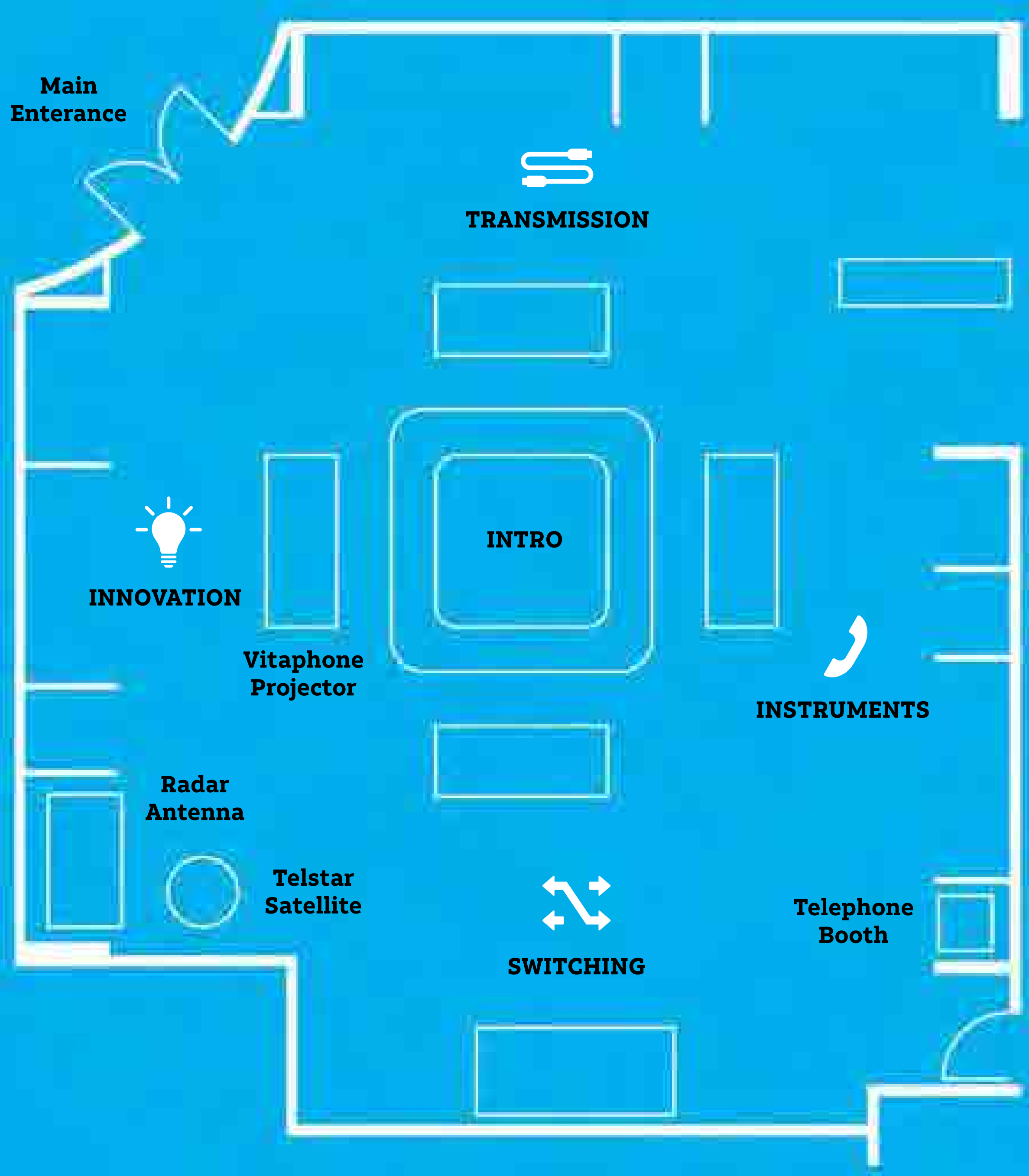
Opening up ECOMP is a game-changer & benefits the entire ecosystem.

- Opening up ECOMP is a game-changer. It seeks to create a common platform for building communications services within a software based network cloud.
- The initiative invites a global communications ecosystem to explore, contribute to, test, integrate and deploy the code. By providing a common, open source, standards-based platform, it promotes a global standard for these kinds of technologies.
- Everyone wins from standards. For example, cars and planes are built based on standards. With standards, we and others in the ecosystem can offer customers the best experience when interacting with each other on any device, anytime, anywhere.

Museum

Science & Technology Innovation Center

Middletown, New Jersey



INNOVATION

AT&T's strong history of innovation is represented in this section of the Science & Technology Innovation Center. The Telstar satellite, a U.S. Navy radar dish, the Vitaphone movie projector, Shannon's mouse, and the transistor, as well as a host of other innovations, are represented in this section of the Center.

INSTRUMENTS

From the wall-mounted, hand-crank phone to the classic candlestick to the Trimline and smartphone, the Science & Technology Innovation Center has an expansive collection of end user devices. Although the phone booth in the Center proper is for display purposes only, a second working model will be located just outside the center so visitors can see what it was like to make a public call in quiet privacy.

SWITCHING

The switching section contains two manual switchboards from an earlier era when a local operator was necessary to connect a call. On the opposite end of the time scale, the 4ESS switch, AT&T's largest, is represented by its control panel.

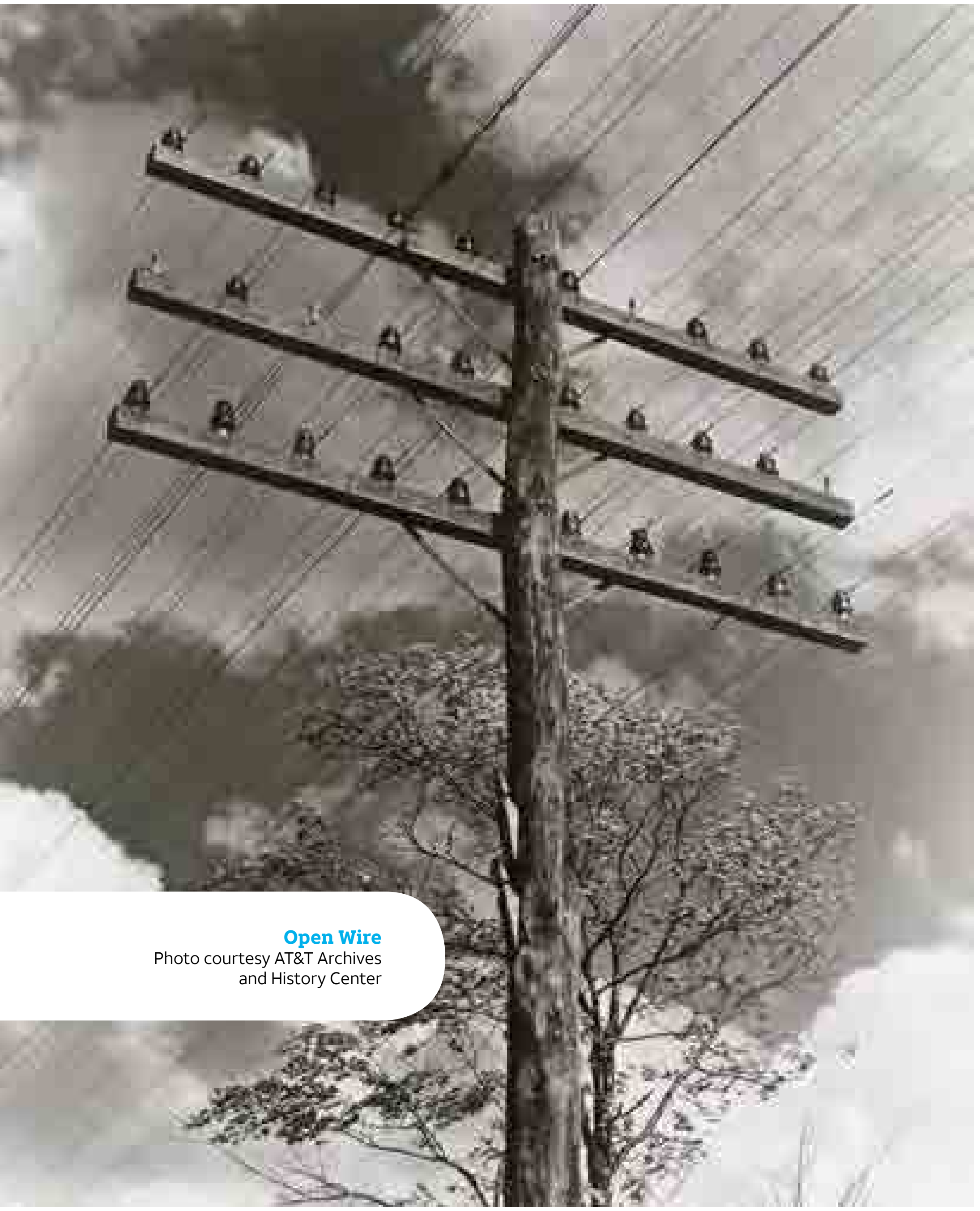
TRANSMISSION

The large wall photo in the Transmission section depicts the completion of the first transcontinental telephone line. The evolution of AT&T's transmission is also represented by cable, undersea cable, microwave radio, fixed waveguide, and fiber artifacts, as the company sought to deploy longer lines at greater capacities.

Renderings by Blumlein Associates, Inc.

Transmission Media Evolution

Open Wire through Coaxial Cable and a Glimpse of the Future



Open Wire
Photo courtesy AT&T Archives and History Center

by Doug Olsen, Kathy Tse

The evolution of metallic wired[1] transmission media covers a period of 100 years (1875 to 1975), beginning with the first telephone calls over existing iron telegraph wire and concluding with L-5 coaxial cable systems. These first 100 years saw tremendous innovations in transmission media that expanded system capacity, improved voice quality, and introduced new services.

The innovation timeline leading up to the first transcontinental telephone call was approximately 40 years, starting with the first one way call transmitted a distance of eight miles over telegraph wire in 1876, through to the first transcontinental call over 2 wire circuit with amplifiers transmitted a distance of 3000 miles from NYC to San Francisco in 1915.

[1] This report does not include wireless transmission such as microwave radio which was also in use during this time.

Enabling innovations of transmission media in the first 40 years on open wire systems included

- Hard Drawn Copper Wire
- 2 Wire Copper Line
- Line Transposition
- Phantom Circuits
- Loading Coils (induction)
- Amplifiers (Repeaters)

We will explore each of the innovations and provide a summary of how they enabled the growth of the Bell Systems long distance transmission lines over the first 100 years.

Cable (Non-Coax)
Photo by Michael Mills

Open Wire Lines

The open wire type lines were the first commercial telephone lines installed for telephony use only. Initial applications used telegraph lines with a ground return which turned out to be very noisy and made clear communication difficult. Pole lines on rooftops became overcrowded with lines in the late 1800s which drove engineers to work on underground cable solutions especially in cities where the growth of telephone lines was exponential.

The telephone lines in the late 1800s were made of iron or steel No. 12 gauge and No. 14 gauge respectively. These lines would easily corrode and rust which led to noisy connections. In addition the relatively high resistance of these materials led to increased attenuation. This attenuation was a major obstacle to long distance telephone transmission. Innovators would need to solve the attenuation and noise problems associated with these early open wire lines.

The eventual solution had two components. One was changing the wire material to a lower resistance metal (copper), and second was adding a second wire to the line instead of using a ground return which was the state of the art to this point.

Two Wire Copper Circuit

Thomas B. Doolittle implemented the first hard-drawn copper wire, it was strung at Ansonia Brass Co. in Ansonia, CT, in 1877, intended to overcome the resistance inherent in the iron and steel lines. During the same period the conversion of a single wire line to a two-wire line was first introduced into the commercial network by future AT&T Chief Engineer John J. Carty in 1881 on a

NY-Boston Line Open Wire (c. 1899)
Photo courtesy AT&T Archives and History Center

line between Boston and Providence. Doolittle's hard drawn copper and Carty's two wire circuit innovations were combined and by 1884 the first long distance two-way conversation was completed between Boston and NYC. The Boston–NYC line was sponsored by the American Bell Telephone Company and 500 miles of copper wire were produced by the Bridgeport Brass Company, resulting in a two wire #12 copper line that

Early Loading Coil
Photo by Michael Mills

was able to carry a call over 250 miles from Boston to NYC.

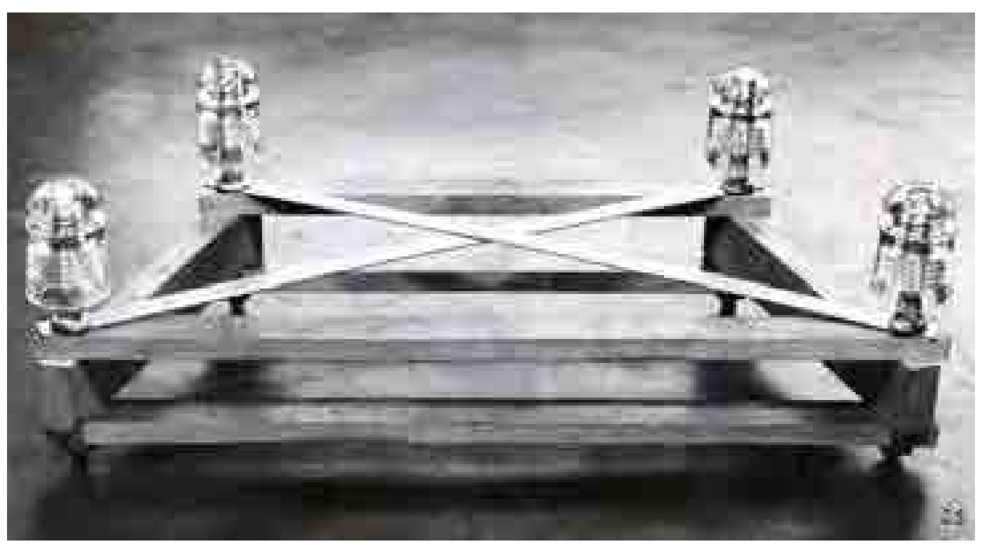
Line Transposition

The two wire copper line reduced the noise and attenuation associated with the ground return lines; however, crosstalk was still a problem on these early lines. Between 1885 and 1904 a series of innovations were made with a line balancing technique called transposition. Transposition cancelled out the crosstalk by transposing the position of the copper conductors along the length of the line at regular intervals. Three innovators are credited with developing the method of transposition. John A. Barret patented transposition in 1885, J.J. Carty developed the theory around transposition in 1891 and finally in 1904 E.H Colpitts developed modern transposition design.

The combination of two wire copper line and transposition lead to long distance transmission that reached from NYC to Omaha NE, a distance of over 1300 miles. However, the cost and the quality of the service at these distances was subpar. Additional innovations would need to be discovered if coast to coast telephone service was going to be possible.

Loading Coils

The attenuation problem on long distance lines was still not remedied; however, a significant improvement was introduced to the network around 1900 by way of the loading coil. A loading coil is a magnet in a toroidal shape that is inserted into a telephone circuit to increase its inductance. Loading coils in long haul telephone transmission were placed at intervals of approximately 8 miles and reduced the attenuation of the line by a factor of 2 over a non-loaded open wire line. The concept of loading coils was discovered by Oliver Heaviside 1860s in England while studying undersea telegraph cables. The actual design for loading coils was developed around 1899, by George Campbell at AT&T and Michael Pupin at Columbia University independently. Pupin actually received two United States patents for loading coils in 1900. AT&T purchased the rights from Pupin and eventually deployed millions of loading coils in both its local and long distance networks.



Transposition Frame for Insulators
Photo courtesy AT&T Archives and History Center

Phantom Circuits — Early Multiplexing

As the long distance network expanded, so did the demand for long distance calls. The problem with the open wire lines was only a single voice call could be transmitted over the two wire circuit. As the cost of adding additional circuits and space on the pole lines was at a premium, more innovation was required. An early form of multiplexing, the phantom circuit, allowed three telephone conversations to be carried simultaneously over two pairs of wires. The phantom circuit uses the side circuits, side circuit 1 and side circuit 2 as its four wire transmission media. Phantom circuits did not really provide the gain that the next promising technology, vacuum tube amplifiers would provide, and as a consequence had a short lifespan as compared to other technologies.

Vacuum Tube Amplifiers

The final innovation that would eventually enable the transcontinental long distance line was the vacuum tube amplifier[2]. The vacuum tube amplifier was developed over a period of years starting in 1906 when Dr. Lee de Forest invented the three element tube; however, it was nine years before the first transcontinental long distance line from NYC to San Francisco was completed using both loading coils and amplifiers. At a distance of over 3000 miles, this line took advantage of the amplification made possible by the vacuum tube amplifier. Over time, the NYC to San Francisco line was improved by adding additional amplifiers. Eventually in 1920, all the loading coils were removed and 12 improved amplifiers were added which cut the line loss in half and increased the propagation velocity by a factor of 3.5. These additional amplifiers greatly improved the voice transmission quality. Vacuum tube amplifiers would also play an integral role in the next breakthrough in long distance transmission, the carrier system.

Carrier Systems

With the attenuation problem solved by amplifiers, the long distance network continued to expand across the country, along with the demand for long distance calls. Carrier systems were invented to solve the capacity problem.

There were three types of analog carrier systems deployed over a period of approximately 50 years from 1924 through 1975. Three types of transmission media were leveraged for carrier systems, including open wire pair, two cable pairs, and coaxial cable. While there were many significant technical innovations in this period the primary challenge that Bell Systems engineers faced was capacity growth, in particular growth on the busiest existing routes.

[2] Amplifier and repeater are used interchangeably in telephony parlance.

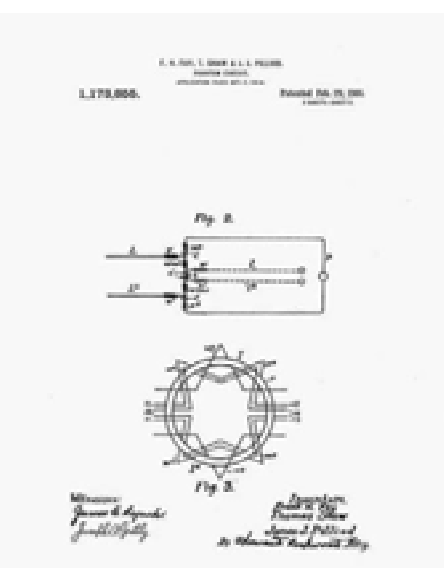
[3] Type D carrier was two voice circuits per channel for shorter haul of ~200 miles

Audion and High Vacuum Tube Amplifier (1913)
Photo courtesy AT&T Archives and History Center

Cross-section of Coax Cable
Photo by Michael Mills

As capacity needs in long distance communications grew, it became obvious to the engineers that the existing low frequency analog carrier systems would be unable to fulfill the need.

C-Carrier was the first widely deployed multiplexing system that increased the capacity on open wire from one to four voice circuits, and by 1950 there were 1.5 million voice-circuit miles installed on C-Carrier. J-Carrier was the next advance in open wire carrier systems, J-Carrier was capable of transmitting 12 voice circuits over an open wire pair. The J-Carrier system operated in frequency above that of C-Carrier and was superposed on the same copper conductors as the C-Carrier system. The figure below shows phantom circuits, side circuits, C-Carrier, J-Carrier, and D-Carrier[3] all on the same physical pole line.



Phantom Circuit Patent Drawing
Photo courtesy AT&T Archives and History Center

During the early 20th century, the method Bell System engineers employed to increase long haul circuit capacity was accomplished with analog carrier systems (C, J, and K) on open wire and copper cable discussed previously. These systems were limited to transmission bandwidths in the KHz range (4–12 voice circuits per channel) and were subject to external electromagnetic interference. As capacity needs in long distance communications grew, it became obvious to the engineers that the existing low frequency analog carrier systems would be unable to fulfill the need. The next innovation would be in 1928, when British inventor C. S. Franklin patented a coaxial cable for limited use as an antenna feeder. A year later, Lloyd Espenschied and Herman Affel of Bell Labs (AT&T's R&D subsidiary) enhanced earlier models to develop the first modern high capacity coaxial cable transmission system, which was patented in 1931 (U.S. Patent 1,835,031). Espenschied and Affel's coaxial cable system was able to handle the increasing capacity demands. These systems would eventually carry 13,200 voice circuits per channel. However another innovation was right around the corner that would ignite the revolution we are still in today. The advent of fiber optic transmission systems in the late 1970s and early 1980s rendered copper coaxial cable transmission systems obsolete for all long haul carrier service.

A Glimpse of the Future

Fiber optic transmission has evolved from a single wavelength of 45 Mb/s on a fiber with regeneration every 80 miles, to 96 wavelengths of 100Gb/s that can go thousands of miles without the need for electrical regeneration. In addition, the capability to switch individual wavelengths of light between fibers using WSS (Wavelength Selective Switch) devices the size of a paperback novel allow for ROADMs (Reconfigurable Optical Add/Drop Multiplexers) that can route wavelengths in a node between many directions or drop the appropriate wavelengths needed for service. These advances have allowed high bandwidth, low cost optical connectivity between customers or routers, but are still limited in the need to manually set up the wavelengths requiring multiple truck rolls. In order to overcome this limitation, two advances were required. The on/off ramps to the optical highway needed to be flexible, allowing each wavelength to be connected to any "color" in any direction using software. AT&T has been the leader in deploying these C/D ROADMS (Colorless/Directionless), first in our Ultra-long Haul Backbone and now spreading into our regional and metro nodes. In addition, we have led the work to develop optical controllers that can use SDN control to turn up, down and reroute the optical wavelengths on demand to serve our Common BackBone and customer needs.

Legacy ROADMs allow wavelengths to be expressed or add/dropped at a node, however the devices used to add or drop wavelengths had ports that required a specific "color" of light and were connected to a single direction. Even though the lasers could be tuned to any wavelength, as soon as they were cabled to a port they were fixed in terms of the color and direction associated with that add/drop. By deploying C/D ROADMs, AT&T can now change both the color and direction of the wavelength using software, allowing reconfiguration on the fly to a new path or connection. This allows the application of optical bandwidth on demand, where wavelengths can be turned up or down as needed by the application and the equipment returned to the pool for future demands.

AT&T has taken this a step further, by spearheading an effort called Open ROADM (details at Open-ROADM.org).

For Legacy ROADM systems there was no interoperability at the optical layer, so a single vendor's system had to be used in a Metro or Long Haul area. Open ROADM defines optical "pieces" such as a ROADM, Amplifier and Transponder, and defines interoperability between the devices across different vendors. In addition, a set of common APIs are defined, allowing interchangeability between devices and connectivity across a flexible network regardless of deployed equipment. The final advancement of Open ROADM is a set of Yang models that describe the devices and hide their complexity, a network model that describes the optical layer, and a service model that further abstracts the network to a multi-layer controller.

Using SDN control and Open ROADM, AT&T is deploying a multi-vendor SDN controlled network that can be used to meet the future needs of our customers for bandwidth when and where they need it. It is also being used for a coordinated Packet/Optical layer that has improved reliability and efficiency.

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By deploying C/D ROADMs, AT&T can now change both the color and direction of the wavelength using software — this allows the application of optical bandwidth on demand.

Millimeter Waveguide

The Technology that Nearly Changed the World of Telecommunications

by Thomas Willis III

Metal electromagnetic waveguides (hollow metal pipes of various cross-sectional shape) can carry different configurations of radio signals, known as modes, provided the frequency of operation is high enough. As long ago as the 1930s, George C. Southworth and other researchers at Bell Laboratories were aware of the large theoretical usable bandwidth within the millimeter wave spectrum that could be carried by circular waveguide. The resistive (heat) losses of Transverse Electric (TE) modes in circular waveguide actually decrease with frequency. Compared to coaxial cable systems, where resistive losses increase with frequency and thereby limit their usable bandwidth, circular waveguide transmission systems held the great promise of extremely large capacities.

History

In 1959 Bell Laboratories began an exploratory development program on a system utilizing a 51 mm inner- diameter circular waveguide. At that time the best device available to generate and amplify the millimeter wave signals needed was the Travelling Wave Tube (TWT). However the project was abandoned in 1962 due to TWT cost and reliability issues, along with the fact that the Bell System did not yet need the capacity provided by the waveguide system. However in the mid-1960s solid-state devices such as the IMPATT diode were developed that could also generate millimeter wave signals. By 1968 additional capacity growth in the long-haul network along with the availability of solid-state millimeter wave devices, sparked renewed interest into developing a waveguide transmission system at Bell Laboratories. The ultimate result of the joint development program between Bell Laboratories, AT&T Long Lines and the Western Electric Engineering Research Center was the WT4/WT4A millimeter waveguide system. By the mid-1970s use of millimeter waveguide systems for telecommunications was also being investigated in the United Kingdom, France, Italy, West Germany, Japan and the U.S.S.R.

> As long ago as the 1930s, researchers were aware of the large theoretical usable bandwidth within the millimeter wave spectrum that could be carried by circular waveguides.

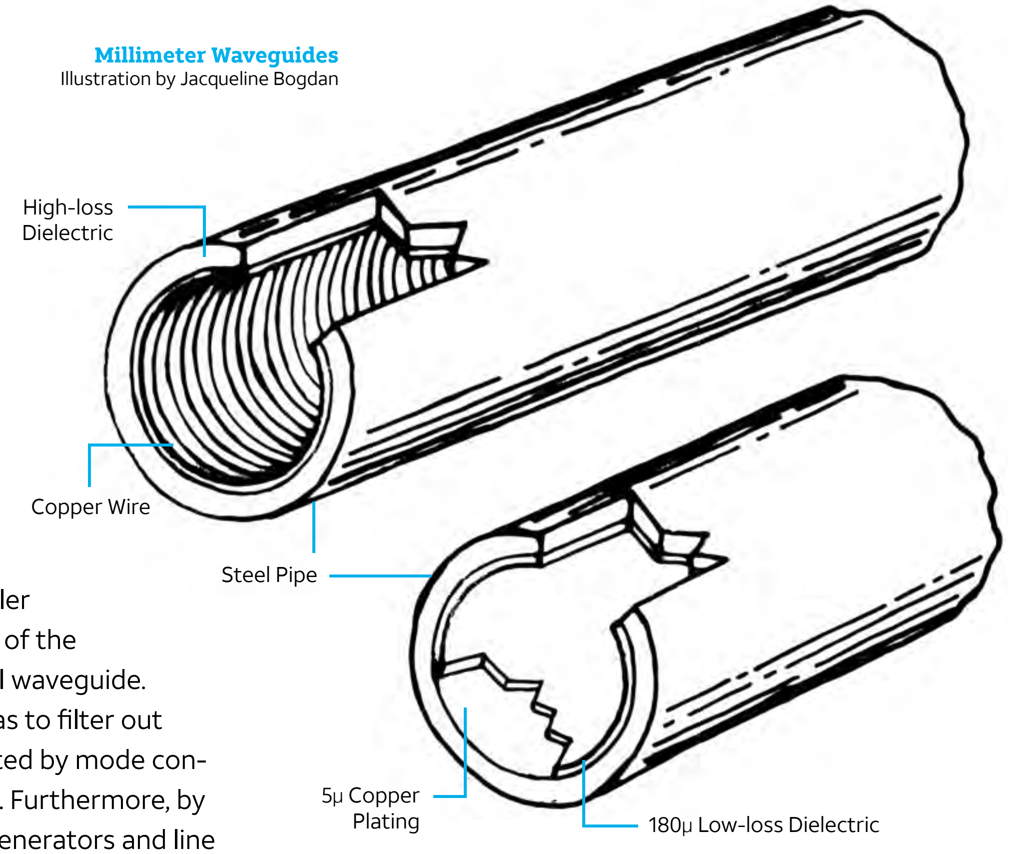
A WT4 system could provide just over 16.1 Gbps of throughput capacity in each direction (nearly 238,000 voice circuits) transmitting signals in the millimeter wave spectrum from 38 GHz to 104.5 GHz down a 60 mm inner-diameter circular waveguide. Regenerators would be needed every 50 Km to 60 Km depending on the required

Millimeter Waveguide (1970s)
Photo by Michael Mills

The ever increasing traffic on the AT&T network led Bell Labs to a search for a higher capacity transmission medium. By the early 1970s, the Labs had developed a prototype system using millimeter frequency radio waves transmitted inside highly polished metal tubes, such as this one. Before the system was commercially released, however, something better came along — fiber-optics.

bends along the route of the waveguide line. The waveguide line itself was made from two different types of circular waveguide sections: 9 meter sections of interior dielectric coated waveguide and 4.4 meter sections of helical waveguide. The helical waveguide had a tightly wound coil of insulated copper wire bonded to the inside surface of the waveguide. A helical waveguide section was used in roughly one out of every 50 sections while the rest were the simpler dielectric lined variety; so that about 1% of the length of the line consisted of the helical waveguide. The purpose of the helical waveguide was to filter out undesired modes, which may be generated by mode conversion, from propagating down the line. Furthermore, by upgrading just the electronics in the regenerators and line terminating equipment to the WT4A system, the modulation could be changed from BPSK to QPSK thereby doubling the capacity to over 32.3 Gbps.

Millimeter Waveguides
Illustration by Jacqueline Bogdan



These data rates were carried on a number of radio channels over the millimeter waveguide. The WT4 system could carry up to 124 radio channels grouped into seven subbands. Channels within the same subband were spaced at 500 MHz. Each channel occupied 475 MHz of spectrum and carried a DS4 (274 Mbps) signal. In the WT4A system, using QPSK modulation, each channel carried two DS4 signals. The 62 channels in the upper three subbands above 75 GHz carried traffic in one direction down the millimeter waveguide, while those in the lower four subbands below 75 GHz were used for traffic in the other direction. Of the 62 channels for each direction, two were reserved for automatic protection and one as a manual patch channel. This left 59 working channels for each direction of transmission in a fully equipped system.

Field Evaluation Test

From 1974 to 1976 a Field Evaluation Test (FET) of the WT4 system was conducting in New Jersey from the AT&T Metropolitan Junction Station in Netcong to a test equipment shelter 14 Km away in Long Valley. A great many engineering and operations challenges had to be overcome to conduct this trial. The Western Electric Forsgate pilot plant in Cranbury, NJ had to manufacture the millimeter waveguide for the FET to very exacting mechanical tolerances and material properties. Regenerators, line equalizers, channelizing networks and digital multiplexing equipment all had to be designed, built, tested and along with 14 Km of millimeter waveguide installed in the field. The FET included all the elements of a complete operating system such as protection switching, span terminating, fault locating, auxiliary communications and maintenance.

Waveguide Insertion Process (1974)
Photo courtesy AT&T Archives and History Center

Special construction equipment was developed for trenching and installing the waveguide. During the installation process, first a 140 mm outer-diameter protective sheath steel pipe was deployed using techniques similar to a conventional pipeline. Then the millimeter waveguide sections were fusion welded together in the field at their end flanges and pushed into the outer sheath pipe at selected insertion sites. Spring loaded roller supports were placed approximately every 50 cm around the waveguide to accommodate its insertion into the pipe. A special waveguide insertion machine that could apply up to 10,000 lbs of insertion force was used in this process.

During the FET a maximum length of approximately 2.4 Km of waveguide was inserted into a section of the sheath pipe requiring about 2000 lbs of insertion force, although longer runs were theoretically possible. Once the waveguide was completely installed, the air inside it was evacuated and replaced with dry nitrogen. This was done to eliminate any attenuation that could be caused by moisture or oxygen absorption around 60 GHz.

Microwave Good, Fiber Better

After the successful completion of the FET, managers at AT&T had planned to start deploying millimeter waveguide across the nation for commercial services during the 1980s. However this vision was never realized. By the late 1970s, another technology that promised even greater potential capacity with easier, lower cost deployments loomed on the horizon. Fiber optics would bring an end to millimeter waveguide at AT&T. In fact after the dissolution of the project, discarded sections of millimeter waveguide were sawed down and reduced to garden stakes to support sapling trees by the grounds keeping crew at the Holmdel Bell Labs facility. Although this seems an ignominious end to millimeter waveguide, it should be remembered that new technologies often grow out of the ashes of those discarded. Much of the high speed digital multiplexing work done for the millimeter waveguide project was re-used with fiber optics. Furthermore low loss circular waveguide has been used by the National Radio Astronomy Observatory at their Very Large Array facility located outside of Socorro, NM. Hence the quintessential waveguide research that made the WT4 system possible lives on there.

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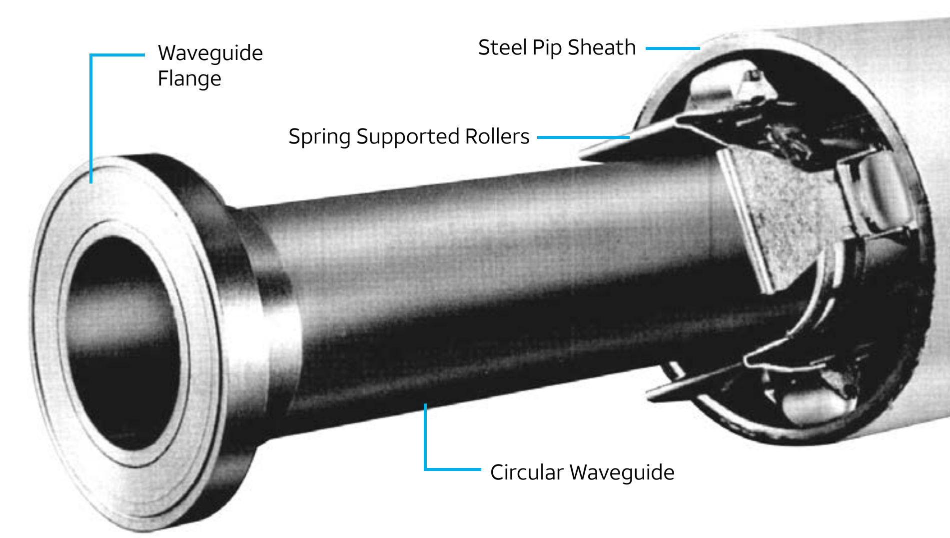

Components of WT4 Sheathed Waveguide Medium
Photo courtesy AT&T Archives and History Center

Connecting the World —

Undersea Transmission

by Mike Neubelt, Ken Reichmann, Beatriz Ugrinovic

Over 150 year ago the world as we know it changed forever with the laying of the first transatlantic telegraph cable, establishing a communication link between Europe with America for the very first time. Until this time the only way messages could be sent across the Atlantic was via mail carried by ships, taking up to 10 days to deliver.

The 1850's ushered in several attempts to lay a telegraph cable across the Atlantic, however these first attempts were plagued by repeated failures.

First transatlantic telegraph cable to successfully be laid was the 1858 Atlantic cable. This feat was accomplished by cable laying ships HMS Agamemnon and the USS Niagara. While transmission quality began to deteriorate immediately and it failed within a few weeks of being laid it proved that it was possible to build a telegraph link that connected Europe with America. Even with a transmission rate of only a few words per hour it proved to be a financial success, and more transatlantic cables were soon to follow.

Upon the successful laying of the cable a congratulatory message from Queen Victoria was received by the President of the United States, James Buchanan. This first official exchange over the newly laid transatlantic telegraph cable led to a great celebration in New York City including a parade featuring a replica of the ship that completed the final leg of the cable laying operation Unfortunately, poor attention to the engineering of the cable led to its early failure. However, many lessons were learned from this initial cable laying experience and future cable designs proved to be much more robust.

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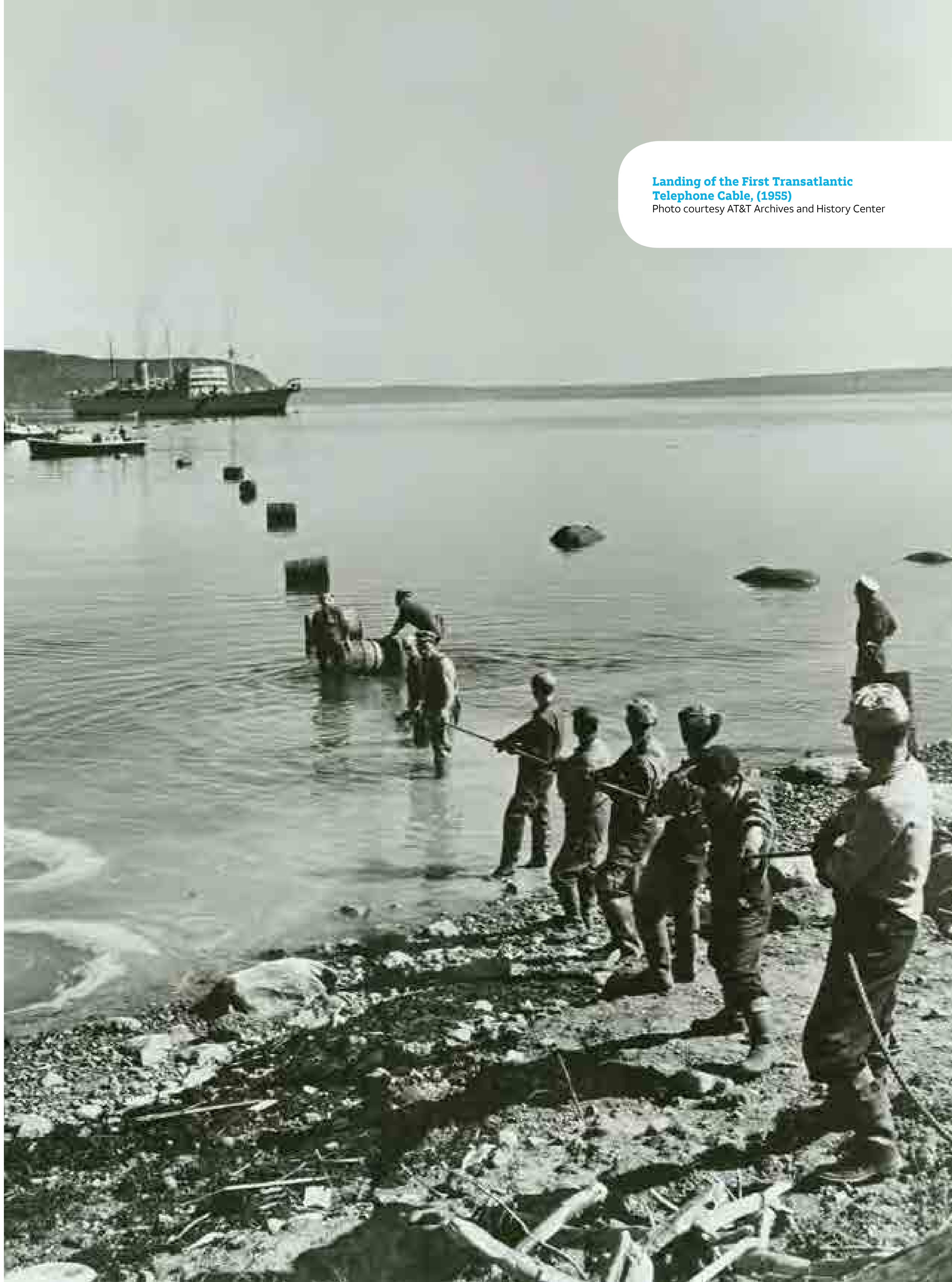


Landing of the First Transatlantic Telephone Cable, (1955)
Photo courtesy AT&T Archives and History Center

Several more attempts were made to connect the continents and in July, 1866 Europe and America were once again connected and this time the cable did not fail. This new cable could transmit up to eight words per minute which represented a great leap in speed from the first transatlantic cable laid less than seven years earlier. The cost to send a message was $10 per word with a 10 word minimum so needless to say most of the traffic was sent by large companies.

First Bell System Repeatered Cable – SA System Design

Driven by the desire to transmit voice, rather than messages using Morse Code, and with the advance in electronic technology during the 1930's it became feasible to build an undersea repeater using high reliability vacuum tubes. After 18 years of reliability testing the technology was ready to be used on a brand-new repeatered coaxial cable design.

This type of repeatered coaxial cable system had been developed in the late 1940s by Bell Labs and Simplex, and was first used commercially for the 1950 Key West - Havana cable. The cable demonstrated the viability of a repeatered system design and was designated the SA System. This was a trial run for the design, and would form the foundation for new cable designs to follow.

> Based upon the success of the Florida – Cuba cable system a new cable design was developed capable of spanning the Atlantic Ocean.

The SA cable design could carry 24 voice channels but could carry voice traffic in only one direction, hence two cables had to be laid to support bi-directional communication.

The two cables were 120 nautical miles long and had three repeaters on each cable that were laid at depths of 950 fathoms.

The SA cable design was like that used on early telegraph cables, however polyethylene was used as the insulator instead of gutta-percha, the gum of a tree native to the Malay Peninsula and an ideal insulator for submarine cables. In addition, an outer conductor was added to create a complete coaxial cable structure.

Based upon the success of the Florida – Cuba cable system a new cable design was developed capable of spanning the Atlantic Ocean and was called the SB system.

TAT-1 – The First Transatlantic Coaxial Repeatered Cable – SB system design

In 1952 the British Post Office began negotiations with AT&T for a transatlantic cable based on the SB System that would connect Oban, Scotland and Clarenville, Newfoundland and this cable was called TAT-1 (the first transatlantic telephone cable).

TAT-1 went into service in September of 1956 and operated for 22 years without a single tube failure. The cable was taken out of service in 1979, exceeding its 20-year design life.

Based upon this success the SB design was also used for the 1956 Washington-Alaska telephone cable, and in 1957 for the California-Hawaii cable, HAW-1.

The TAT-1 repeater was based upon a flexible outer housing design with articulated sections not much larger than the cable itself. This section was about 8 feet long while the overall length with the cable tails measured approximately 70 feet long.

The flexible repeater, due to its interior volume, had a limited bandwidth which could support only 36 4-kHz spaced voice channels and transmit signals in just one direction. Bi-directional communication required two cables, one for each direction of transmission. The length of each uni-directional cable on TAT-1 was 1950 nautical miles with 51 repeaters spaced every 37.5 nautical miles.

Time-assignment speech interpolation (TASI) was used to upgrade the TAT-1 cable in June 1960 and effectively increased the cable's capacity to 72 voice channels.

Over 8000 nautical miles of cable based upon the SB cable design was deployed.

Following the success of TAT-1 numerous improvements of repeatered coaxial cable designs would follow, culminating in TAT-7.

An example of the important role TAT-1 played was when it was used to carry the Moscow–Washington hotline between the American and Soviet heads of state, although using a teleprinter rather than voice calls as written communications were regarded as less likely to be misinterpreted. The link became operational on 13 July 1963, and was principally motivated as a result of the Cuban Missile Crisis where it took the US nearly 12 hours to receive and decode the initial settlement message that contained approx. 3,000 words. By the time the message was decoded and interpreted, and an answer had been prepared, another more aggressive message had been received.

TAT-3 – A second generation SD system design

This new cable design was based upon a rigid repeater housing, though much larger than the flexible repeater used on TAT-1 it had space for more electronics, thus enabling a much wider bandwidth system capable of transmitting 138 3kHz voice channels in both directions simultaneously on a single cable.

This new rigid repeater design required the design of new shipboard handling equipment for the cable and repeaters as well as the design of a brand-new cable laying ship, the C.S. *Long Lines*.

Manufacturing an Undersea Repeater, Clark, NJ Plant (1962)
Photo courtesy AT&T Archives and History Center

Based upon these new cable handling designs the C.S. *Long Lines* would now be able to deploy the repeatered cable continuously, without having to stop the cable payout and manually handling the repeater each time a repeater was launched over the stern of the ship.

TAT-5 – SF system

Following upon the success of improved electronics used on the TAT-3 system design, in 1963 development began on a new system design called SF.

In 1970 the TAT-5 cable based upon the SF design was installed between the Green Hill, Rhode Island, USA and Conil, Spain. An extension from Spain to Italy was also built and was called MAT-1.

While the SF design shared many of the characteristics of the SD design it did introduced a major technical

AT&T Cable Ship *Long Lines*, Launched in 1961
Photo courtesy AT&T Archives and History Center

advancement with the use of germanium transistors in place of vacuum tubes. Future SF systems were upgraded to silicon transistors. This new design was capable of transmitting 845 3kHz voice channels. TAT-5 was 3461 nautical miles long and used 361 repeaters with a repeater spacing of 12 nautical miles. MAT-1 was 990 nautical miles long with 93 repeaters.

By 1983 over 17,000 nautical miles of SF design cable had been installed.

TAT-6 – SG system

The demand for the ability to carry yet more voice channels continued and early development began 1966 on a higher bandwidth repeater design capable of carrying 4000 3kHz voice channels.

In 1976 the first system based upon the SG design was installed between Green Hill, Rhode Island and St. Hilaire, France.

New Link to Europe – TAT 5 Route Map
Photo courtesy AT&T Archives and History Center

TAT-8 – the first generation of fiber optic cables

With the development of low loss optical fiber, it was now possible to replace the coaxial cable with a fiber optic cable, however a new repeater design was needed to support the optical transmission along the optical fiber. With this advanced design, TAT-8 was initially able to carry 40,000 voice circuits. By 1993 over 125 km of TAT-8 systems had been installed. It remained in use until retired in 2002.

When you visit the Science & Technology Innovation Center in Middletown New Jersey, you will see an example of a TAT-8 repeater. Since all transmission signals, even optical transmission suffer loss, repeaters are installed periodically in order to cover the span for both TAT-8 and all undersea systems. These repeaters receive digital light signals, re-time, re-shape and regenerate them and subsequently transmit them to the next repeater downstream. In the case of TAT-8, the repeaters would be spaced every 40 km (24 miles) over its entire length of 5066 km (3148 miles) and would lie on the ocean floor at depths reaching 5,486 meters (17,998 feet or 3.4 miles). The repeater was based on an optical regenerator operating at a wavelength of 1310 nm with a transmission rate of 280 Mbit/s on each of its two active pairs of optical fiber. Presently, most long-haul systems operate near 1550 nm and at much higher transmission rates. These wavelengths are located just past visible light in the infrared region of the electromagnetic spectrum and are invisible to the naked eye. The copper cladding applied over the steel reinforcing strands for the fiber cable serves as the conductor to power the repeater electronics.

TAT-8 Repeater
Photo by Michael Mills

Given their location, the repeaters needed to be manufactured to perform flawlessly and reliably for upwards of 20 years as the cost to recover and repair them was nearly prohibitive. As a result, unprecedented diligence, testing and inspection was required in order to insure the operating life of the devices. As part of the quality control, many of the critical electronic components, including the transmitters and receivers were manufactured in the Western Electric facility in Reading, Pennsylvania under ultra-clean conditions. Further assembly, precision tooling and extensive testing, including exposing the repeater to high pressures, was performed in the Western Electric facility in Clark, NJ. Final repeater assembly occurred at Bell Laboratories in Holmdel, NJ. As part of the rigor, the electronic circuitry was encased in a hardened housing, sealed and insulated to prevent penetration of seawater and corrosion.

Some of the repeater features include; integrated circuits as opposed to discrete transistors, independent digital regeneration for each direction of transmission, and of course it is an optical fiber-based solution exploiting all the benefits of fiber.

Fine-tuning the First Generation of Undersea Fiber-Optic Cable Design

The first TAT-8 deployment was the 72-mile prototype laid by AT&T in the Canary Islands in 1983 (between Gran Canaria and Tenerife), in partnership with the Compañía Telefónica Nacional de España (CTNE). A month after its installation, AT&T learned that the cable had a "Shark Attraction Problem." Since it was an optical cable not a coaxial cable, the electrical interference shield for

Fish Bite Protected Deep Sea Fiber-Optic Cable
Photo by Michael Mills

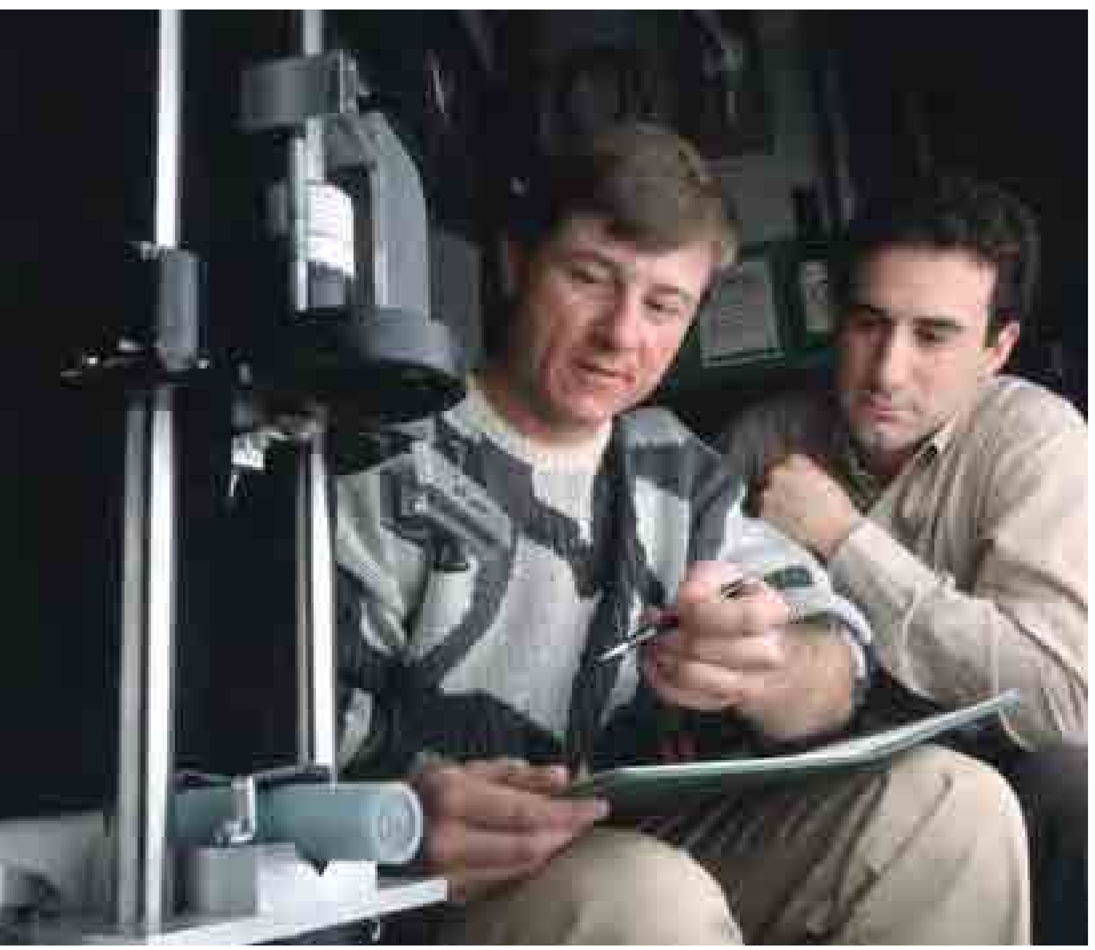
AT&T SCARAB, Remote Controlled Cable Repair Submarine (1986)
Photo courtesy AT&T Archives and History Center

the power supply lines was considered unnecessary for this cable and therefore removed from the original design. After analyzing recovered pieces of the damaged sections of the cable, it was discovered that the sharks that swam nearby were compelled to "attack" the cable with bites deep enough to puncture the cable allowing salt water to reach and short-circuit the power lines serving the repeaters.

Using the recovered shark teeth, Bell Labs scientists teamed up with members of NYU School of Dentistry to create "Jaws" to evaluate physically new cable designs and select the most appropriate one. The new design included a "shark shield" that prevented the sharp teeth from reaching and damaging the fiber and the power lines in the cable, although it did not prevent the sharks from biting the cable. The new "FBP" (Fish Bite Protected) Cable was designed with a dual layer of helical steel tape over the original cable with an outer shell of polyethylene wrapping.

Studies conducted by Bell Labs engineers concluded that the habitat of shark species that "attack" the cable is at ocean depths between 1300 to 2600 m (~4300 to ~8500 feet); based on the Atlantic Ocean Floor Profile, for TAT-8 this habitat is limited to a portion of the slopes between the continental shelves and the deep ocean floor. Only 130 Km (81 miles) of TAT-8[1] required the FBP cable design, since the remaining cable is either buried or installed in ultra-deep waters.

There are many theories regarding the stimuli that cause the deep-water sharks to attack the undersea Fiber-Optic cable; the most accepted one points to the strong electric fields around the cable – created by the power supply line running along the optic fiber to feed the repeaters, regenerators, and branching unit.



Ralph Rue and Mike Notarfrancesco Test Submarine Cable Against Their Jaws (1989)
Photo courtesy AT&T Archives and History Center

[1] The entire length of TAT-8 was about 5800 km (3600 miles); it lied on the ocean floor at depths reaching 5,486 meters (17,998 feet or 3.4 miles).

TAT-9 – the second generation of fiber optic cables

This cable went into service in 1992 and remained in use until 2004. It was owned by a consortium of AT&T, British Telecom and France Telecom and was initially able to carry 80,000 voice circuits. It was a two fiber pair cable transmitting at 560 Mb/s per fiber pair.

Subsequent cables, TAT-10 and TAT-11, shared a similar design and represented the last transatlantic cables based upon repeaters that had to perform an optical-electrical-optical regeneration of the optical signal along the way.

TAT-12/13 – First transatlantic fiber optic with optical amplifier

By the 1990's the erbium doped optical amplifier had been developed and enabled a huge leap in transmission rate along the optical fiber. Now the optical signals did not need to be converted to an electrical signal at each repeater and regenerated. This meant transmission speeds were no longer limited by the speed of the electronics inside the repeater.

TAT 14 and beyond

This first all-optical transmission cable was able to transmit at 5 Gb/s on each of the two fiber pairs. TAT-14 increased the capacity by carrying 16 optical wavelengths operating at 10 Gb/s on each of four fiber pairs for a total cable capacity of 640 Gb/s. This is equivalent to 9,700,000 voice circuits.

Today undersea cables have evolved dramatically and as of 2016 the AE Connect (AEC) cable can carry 130 wavelengths operating at 100Gb/s per fiber pair for a current system capacity of 52 Tb/s.

The World Is a Much Smaller Place

With the rapid advance in undersea cable transmission rates it has dramatically changed the way we interact globally. These undersea systems were critical to the launch of the global Internet and the communications between the Continents. Where once we could only transmit a few words per hour now it is possible to stream live video on your phone with friends around the globe. News travels instantaneously, doctors can interact with patients remotely, and financial markets can react to global news immediately just to name a few ways instantaneous communication has affected the way we interact. We live in a very connected world and all of it is due to the long history of pioneering research and development of undersea communication systems.

Bell Labs Innovations for TAT-8

Optimized Fiber-Optic Cable: in two versions: Deep water with no protection for fish bites and the special FBP (Fish Bite Protected) cable for the slopes where the sharks live. The glass fibers were manufactured by AT&T at its Norcross, Georgia facility and converted to undersea cable by Simplex Wire and Cable Company in Newington, New Hampshire.

Terminal Equipment: Undersea cable system terminal equipment was similar to the terminal equipment that was developed by AT&T Bell Labs for Optical terrestrial Transport Systems; with the added requirement that it had to conform to the agreed International Digital Interworking Hierarchy, per ITU G.704, and it also had to provide the power feed to the regenerators, repeaters, and branching unit to be installed underwater.

Underwater Regenerators and Repeaters: Same as the Terminal Equipment, the Regenerators and Repeaters to be used in TAT-8 were similar to the ones used in terrestrial systems, but had to be designed and built with a special housing suitable for underwater conditions, and using a power feed embedded in the Undersea Fiber-Optic Cable.

Branching Unit: An innovative undersea branching unit was developed to enable the TAT-8 System to serve three countries (US, UK, and France) with a single transatlantic crossing. This Branching Unit was deployed underwater on the continental shelf off the coast of Great Britain.

The Evolution of Switching

By Magda Nassar

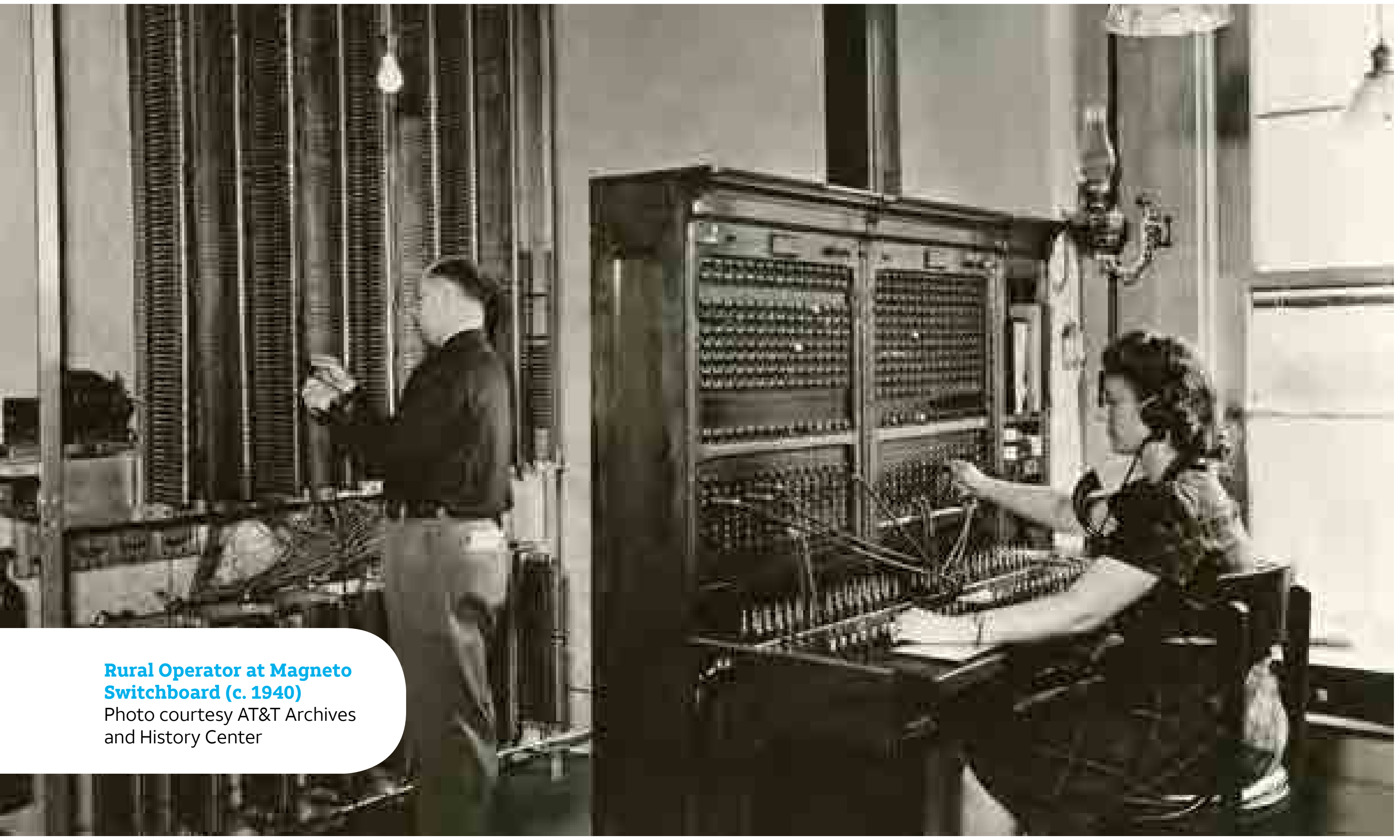
The story of switching is the story of innovation in America. It illustrates that creative minds are always in motion, and that necessity is the mother of Invention. Furthermore, good Inventions lead to the realization of a vision through leveraging teamwork and cooperation among those sharing the vision. Less than two years after Alexander Graham Bell received his first patent for the telephone, the world's first telephone exchange service became operational in New Haven, Connecticut. The exchange provided service to only twenty subscribers who had to first call the exchange operator, and then be manually connected to one of the other twenty subscribers using a central switchboard. Within a decade, switchboards, with many innovations for automation and scale, were operational in nearly every city in the United States. As late as the 1950s, the U.S. lead the technology evolution and had more than half of the world's telephones. Shortly after, Telephony service, with many advanced features, became not only an affordable and reliable service in every household, but also an essential component of every successful business.

Telephony service, with many advanced features, became not only an affordable and reliable service in every household, but also an essential component of every successful business.

Telecommunication Networks

To understand the role switching systems played in the telecommunications network, we must first start with a basic explanation of a Network. In a broad sense, a Network is a group of interconnected elements needed to provide service to a large number of widely dispersed customers. The two most basic network elements in a simple telecommunication network are links and nodes. Graphically the links are the lines and the nodes are the points where the lines interconnect. Within AT&T's network, the nodes could be Switching Offices, while the links are transmission facilities such as fiber cables. The primary function of a Switching office in a telecommunications network is to provide a central point that can economically connect telephones or other devices amongst a wide array of customers. This connectivity can vary across many different types of network elements depending on the type of service being provided.

Bell Opening New York–Chicago Telephone Line (1892)
Photo courtesy AT&T Archives and History Center



Rural Operator at Magneto Switchboard (c. 1940)
Photo courtesy AT&T Archives and History Center

It is easy to illustrate the tremendous value of centralized switching. First, start with a highly over simplified telecommunication network In this first model there are no switching systems. Each telephone is directly interconnected by transmission links. For networks supporting millions of end users, who are geographically dispersed, it is not hard to realize how extremely complex and prohibitively expensive this solution becomes.

This initial model can be significantly improved with the introduction of a switching function in a central location to interconnect transmission paths to every endpoint. All end points are connected to the Switching System, which in turn facilitates the connectivity between 2 or more end points in the network. It is easy to see how valuable a central switching point can become as the numbers of end points grow.

Switching Systems (often referred to as Telephone Exchanges) are typically located at Service Provider centers or large enterprise locations and serve to interconnect end user telephone lines and establish communication between subscribers. These Switching Systems make it possible for subscribers to connect to each other across a variety of locations (homes, businesses, or public spaces) without the need for dedicated direct connections between each of these end points.

It is interesting to note that Telephones were invented before switching systems. However the invention and introduction of Switching technology, along with its continued evolution provided the key elements that made telephony a viable communications tool that was scalable, affordable, and widely used. This evolution has seen many remarkable technologies including electromechanical, complete electronic, and most recently Programmed Software based Solutions. Many of these innovations have interesting stories of their own that drove various needs and solutions and the basis for much of the technology still used today.

Manually Operated Switching Systems

The first form of a switching system was a manually operated switch, where an operator was required for each call and completed the connection by plugging cords into jacks on switchboards. Initially, these systems could only handle a limited number of end points. However, at the time, this was a fascinating advancement in the capability of personal communications.

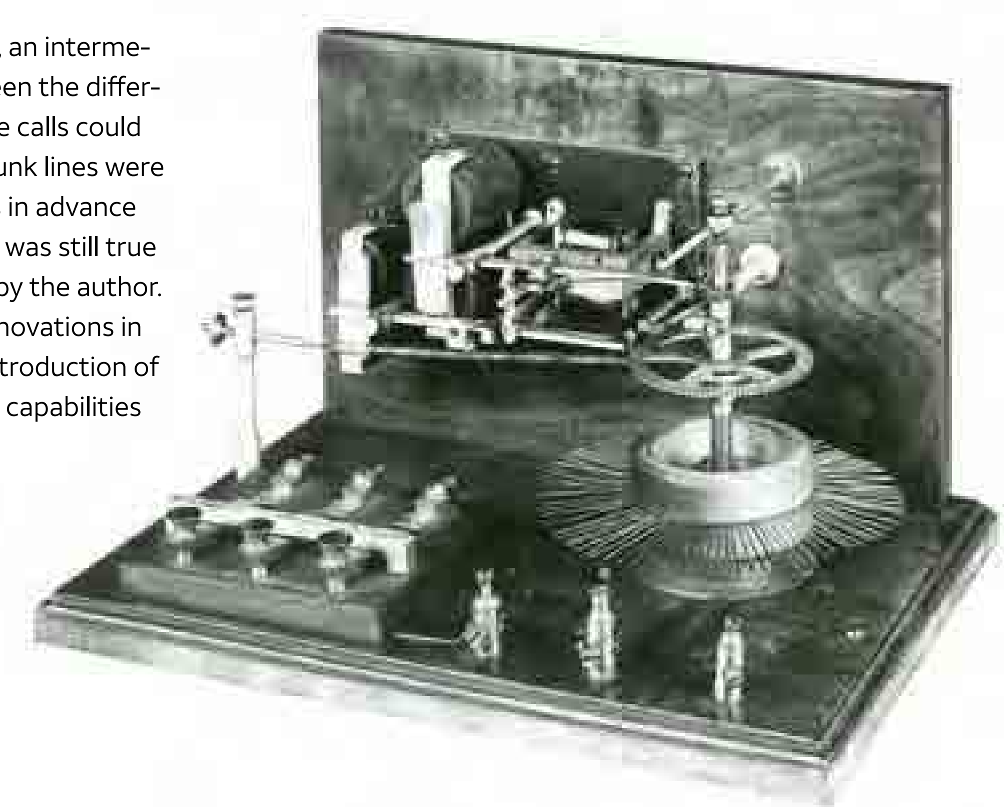
Later these exchanges grew to support hundreds of subscribers and many staffed switchboard operators. Many advanced capabilities and tools began to emerge to support larger and larger numbers of subscribers. Each operator was provided access to a vertical bank of jacks, each of which was a local termination of a subscriber telephone line. The operators would manually connect the calling and called party. When the caller initiating a call lifted their telephone receiver, a signal lamp or a buzzer was activated at the switchboard to signal the operator. The operator then responded by inserting the answering cord into that subscriber's designated jack and the operator would ask for the number that they wished to call. The operator would then connect the two jacks as long as both parties were on the same switchboard.

In the case of long distance call, or a connection to a subscriber on a different switchboard, the operator would connect into a " Trunk Circuit" that connected to another Operator sitting at another switchboard. In 1918, the average time to complete the connection for a long-distance call was 5 minutes.

For Calls to be completed across the country, an intermediate operator and intermediate trunk between the different operators were needed at all times. These calls could only be completed when the intermediate trunk lines were available. Calls needed to be scheduled hours in advance to get the needed trunks between cities, this was still true in 1976 for International calls as experienced by the author. Starting in the 1920s, the next key wave of innovations in this operator based environment were the introduction of the dialed number, listening keys, and ringing capabilities to reduce some of the manual operations and improve call set up time. These manual switch boards required the operator to operate listening keys and ringing keys to answer the calling party and ring the called party. These innovations allowed the initiated call to be answered automatically by the operator inserting the cord into the subscriber's switchboard jack. Subsequently, the ringing cord was plugged into the subscriber's jack being called and the call completed "automatically". The key point here is that operators were still needed to connect the calling party to called party, even though their level of manual involvement was reduced to allow them to handle much larger volumes of calls.

Electromechanical Switches

As the demand for calls increased, the need for a faster and more efficient method to meet the demand arose. This led to the invention of the next generation of switches. Until 1889 a human operator was needed to complete a call. In 1891, Almon Strowger was granted a US Patent for what would be the basis for the first practical automatic telephone switch. In the Strowger switch, pulses generated at a subscriber's telephone directly moved electromagnetic contacts in a two-way motion in a stack of rotary contacts, thus selecting a telephone number, one digit at a time, without operator intervention. His original device was crude and impractical, but achieved the main purpose of eliminating the operator.



Strowger Switch Patent Model (1890)
Photo courtesy AT&T Archives and History Center

A commonly told story explained that Strowger, an undertaker in Kansas City, was driven to his invention by learning that the funeral of a friend was being handled by a competitor. Strowger was convinced that his friend's family had been led to another undertaker by an unscrupulous telephone operator. Strowger and his backers formed a company, eventually known as the Automatic Electric Company, to develop the patent into a practical switch and eliminated the dependency on humans to direct and complete a call.

In a Strowger switch, the subscriber's rotary telephone dial directly controlled the movement of the switch contacts that established the circuit. The earliest switch could only handle a very limited number of customers. However, the invention continued to be refined and eventually increased the switch capacity to 10,000 telephones. But the direct control of the switch by the subscriber remained the key innovation.

The Strowger, or step-by-step switch as it also became known, remained the most widespread switch in use until the 1960s, and was particularly common in non-urban exchanges.

AT&T's Panel Switch

The AT&T Bell System did not adapt the Step-by Step automatic switches because they needed a larger capacity switch to serve large urban cities. Additionally, a large percentage of calls required routing between exchanges within a city. The Strowger switches seemed to be slower than AT&T's improved manual switches. In addition, by this time there were many subscribers connected to the manual exchanges and changes needed to be compatible with this existing network.

In 1905 an AT&T engineer, Edward C. Molina, invented a design breakthrough that was better suited to meet urban needs. This invention introduced the concept of indirect control. The pulses from the telephone dial would be translated into an electromechanical code. This code allowed for a subscriber's telephone to select from a larger number of possible circuits, and for the separation of the circuits used to set up calls from those used for the call itself. This in turn led to the development of the Panel Switch which was more suitable for large cities and large volumes of interoffice calls. It was this technology that was chosen by Western Electric for continued development in the United States.

The Panel Switch was a complex device equipped with tall panels that were covered with 500 rows of terminals. Each panel had an electric motor to drive its selectors by electromagnetically controlled clutches. The selector moved continuously rather than in steps, and the selectors establishing contact points could move a considerable distance. Separate frames were used for the several parts of the telephone-calling process.

The Bell System's initial plan was for semiautomatic operation, where subscribers would still call operators, who in turn would enter the subscriber's desired number. However, the Bell System soon moved to fully automatic switching, partly because of continued growth in the number of telephones that further complicated manual interoffice trunking, and partly because of changing labor conditions.

For the operation of smaller, non-urban exchanges, AT&T acquired a license in 1916 to manufacture Strowger step-by-step switches, and also reached an agreement to purchase such switches. The first step-by-step switch in the Bell System entered service in Norfolk, Virginia in 1919.

The crossbar switch achieved its goal of reducing costs for manufacturing and maintenance, and it had many innovative features that gave it a more flexible and adaptable design than panel or Strowger switches.

AT&T's Crossbar Switch

Due to the high cost, complexity, and demanding maintenance requirements, it became critical to work on alternative solutions to the complex panel switches. By the 1920's, AT&T's W.R. Mathies from the research and development division and other researchers had been working to produced a more cost effective design to solve the issues of the panel switch for urban use. It was not until 1930 when Mathies visited Sweden and saw the crossbar selectors in use in rural exchanges, that he decided to combine innovations to create something even more effective

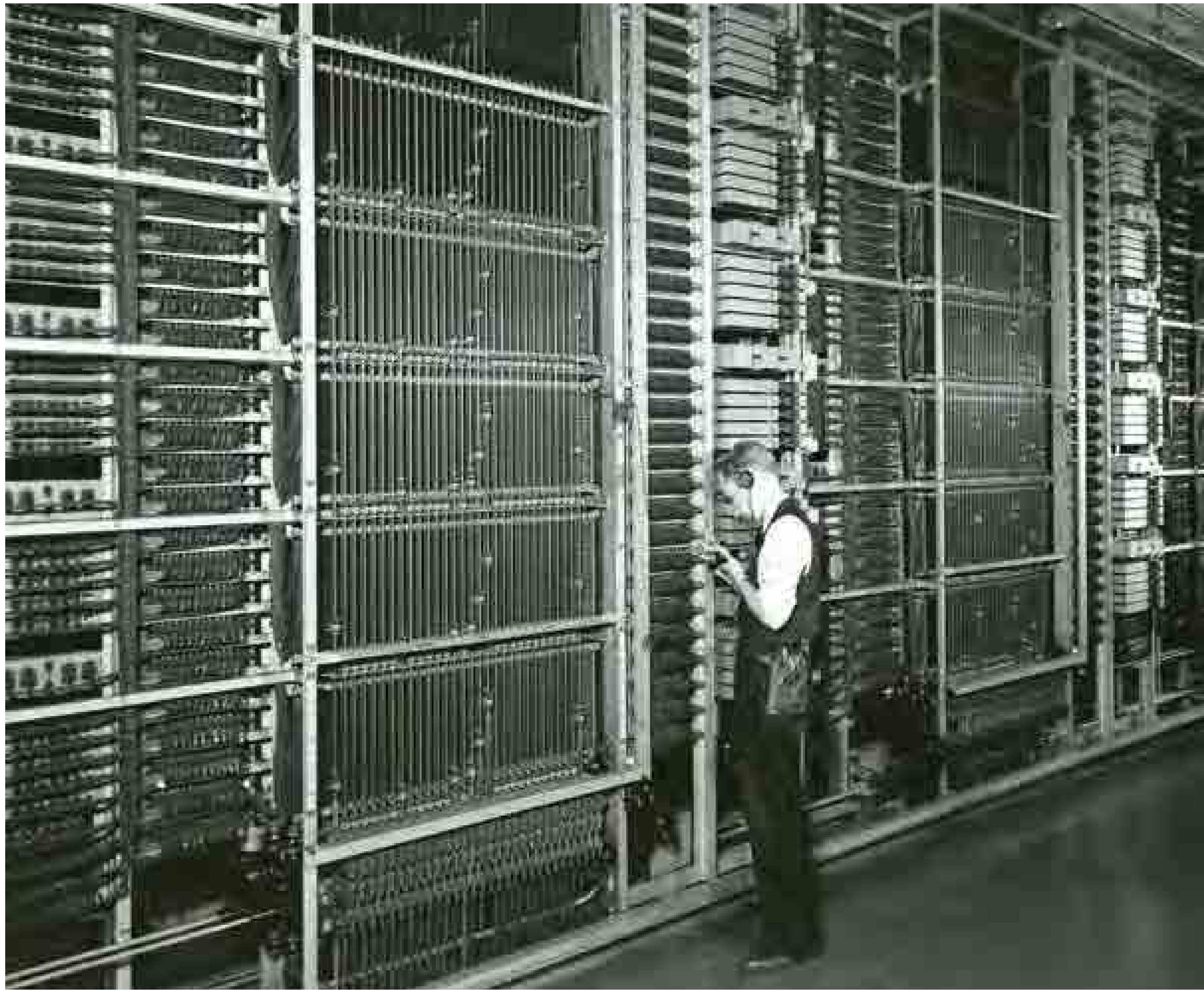
Convinced that the crossbar selectors could be adapted to large switches, Mathies had his group build on this idea in combination with work they had done earlier. They rejected the idea of simply replacing the selectors on the existing panel design, and instead they developed, beginning in 1934, an entirely new switch for urban use.

By combining these inventions from Western Electric by Reynold's, and the Swedish Postal Telegraph and Telephone Administration by Betulander, the cross bar switch was invented. In this design there were small mechanical motions and none of the large sliding movements required in the panel and Strowger switches.

The first two crossbar switches went into service in 1938 in New York City. The crossbar switch achieved its goal of reducing costs for manufacturing and maintenance, and it had many innovative features that gave it a more flexible and adaptable design than panel or Strowger switches.

The units used to establish calls were not only separate from those used for the actual call paths, as they had been in the panel, but there were also common control units. This meant that all selector frames were accessible to all of the phones, and after a call they were released for use on other calls. These "markers" as they became known, were fast, thus reducing connection times.

Panel Switch at Chicago 'Franklin' CO (1938)
Photo courtesy AT&T Archives and History Center



Also significant, was that the crossbar was the first switch where both the originating and terminating traffic were combined on the same set of line switches. This made connections from telephones to the switches much simpler, and also allowed the crossbar to be adapted, as it soon was, for use in tandem switches. Tandem switches were used specifically to route calls between multiple urban exchanges. Crossbar tandems also allowed, for the first time, automatic alternative routing when the direct route between exchanges was not available. Crossbar switches were wired to allow for the separation of the two directions of transmission. These highly innovative features made the switch very adaptable and provided for easy modification for both applications as well as and new peripheral additions and features.

Thus, it proved easy for Bell Labs to adapt the crossbar switch for use as the first automatic switch in the long distance network. Previously all long-distance calls required one or more operators at manual long distance switchboards. The first long distance crossbar switch, the #4 crossbar, was installed in Philadelphia, Pennsylvania in 1943. Four additional #4 crossbars were installed in other metropolitan areas in the next five years. Thus the evolution to the long distance capabilities and communications that we know today was underway.

Electronic Switching System

AT&T Bell Labs continued to improve the switching system to meet a growing demand for telephone services. The electronic switching, made possible with the invention of the transistor, used an electronic data processor, operating under the direction of stored program control, and a high-speed switching network. The stored program control had the software containing the logical steps involved in making a telephone connection.

First TSPS Operators, Morristown, NJ (1969)
Photo courtesy AT&T Archives and History Center

No. 4 ESS Installation, Chicago, IL (1975 - 1976)
Photo courtesy AT&T Archives and History Center

In electromechanical switching, changes to the operations or services required extensive circuit redesign and, frequently, labor-intensive rewiring in the field. In an electronic switching system, new services can frequently be implemented by making changes to the stored program control. This makes it available to the customers sooner after the software has been centrally developed and distributed to the systems.

The processors used in a switching system are input/output driven and are designed for real time processing. They respond promptly to signal and data transmitted by customers and other switching systems. In addition, these processors must be highly reliable and provide continuous operation 99.999 percent of the time (approximately 5 minutes of allowable planned/unplanned downtime per year).

The first trial of electronic switching was in 1960 after 6 years of development. The trial proved the viability of the Stored Program Control concept. The first application was the 1ESS switch in 1965 in NJ. It was used in areas with heavy business customers. The ease and flexibility of the 1ESS made it a natural fit for city applications where demand for new sophisticated business and residential services is high.

The need for smaller local switches was met with the 2ESS. It was oriented toward residential services rather than business. The processor was smaller and less expensive. It was used in areas that were previously served with Step-by-Step switches. The Rural areas were served with 3ESS switching equipment, yet a smaller and more economical implementation than the 2ESS design.

No. 4 Electronic Switching System (4ESS)

The next crucial step in the evolution of electronic switching was the introduction of the 4ESS. In 1976, the first electronic toll switching system to operate a Digital Time Division Switching network under Stored Program Control, the 4ESS system, was placed in service.

On January 17, 1976, the first 4ESS™ switch was placed into service, culminating the single largest switch development effort ever undertaken in the Bell System, until that time. When it was introduced, the 4ESS switch was the largest high-capacity digital switch in existence. The 4ESS switch played a pivotal role in enabling the emerging U.S. long distance market to grow into today's multibillion $ industry. The hallmark reliability and capacity of the 4ESS switch set the standard for digital switching. Although the classic digital switch architecture pioneered by the 4ESS switch has passed the test of time, every major subsystem within the switch has gone through one or more technology upgrades to offer new features and reduce costs.

Key Dates in the Switching Technology Evolution:

- **1878** The first manual telephone exchange opens in New Haven, Connecticut.
- **1889** Almon Strowger invents the first automatic telephone switch.
- **1891** Strowger receives US Patent 447918 for his invention.
- **1891** The Automatic Electric Co. is formed to develop a practical Strowger system.
- **1896** The first prototype of a dial telephone system operates.
- **1912** Gotthief A. Betulander invents the first all-relay telephone switch.
- **1913** John Reynolds invents the crossbar selector.
- **1921** AT&T introduces the panel switch, designed for use in large cities.
- **1938** AT&T installs the first #1 crossbar switch in New York City.
- **1943** AT&T introduces the #4 crossbar switch, designed for long distance calls.
- **1948** AT&T introduces the #5 crossbar switch, designed for suburban exchanges.
- **1951** Customer dialing of long distance calls begins in the United States.
- **1965** AT&T installs the first all-electronic telephone switch.
- **1975 - 1976** AT&T installs the first 4ESS.™
- **1982** AT&T installs the first 5ESS.™

The Architecture of the 4E includes three main building blocks: The Switching Processor Platform, the Switching Fabrics Platform, the Customer Interface Platform.

The Switching Processor Platform provided the central intelligence of the system and overall call control, call signaling processing, operation, Administration and Maintenance support and Overall system integrity. The starting point of the processor evolution was the 1A Processor, a high-capacity, custom designed uniprocessor. The rising call traffic growth, new call features, and growing sophistication of end customer service/features created the need for a higher processing capacity and Intelligence in the 4ESS Switch. To meet that need, the 1B processor was introduced to replace the 1A. The 1B processor more than doubled the call handling capacity of the 4ESS switch while achieving the same extraordinary reliability objectives as the 1A.

The Switch Fabric Platform is managed by commands from the Processor Platform. Real Time routing routines were developed to optimize the call routing in real time to manage cost and increase call completion. The 4ESS first implemented a Dynamic Non-Hierarchical Routing (DNHR) and then evolved to a more advanced Real Time Routing (RTNR) scheme for optimal call completion.

In a sheer physical size and cost, the switching fabric platform dominated the switch. Work continued upgrading 4ESS Switch fabric in 1980's and 1990's. From a physical size perspective, generally a single deployed 4ESS switch would take up at least an entire floor in a Central office. The development of the expanded Time Slot Interchange offered the most significant innovation in the 4ESS switch fabric evolution. It provided a high speed transmission, higher capacity, and reduced cost, power, and floor space. It also provided an integrated echo cancellers to eliminate a significant capital investment in associated transmission equipment.

During a call the Customer Interface Platform enables the switching processor Platform to interact with the end customers using touchtone reception, announcements and speech recognition capabilities enabling more advanced service features.

No. 5 ESS, Seneca, IL (1982)
Photo courtesy AT&T Archives and History Center

No. 5ESS Switching System (5ESS)

AT&T supplemented the 4ESS toll tandem switches with 5ESS switches featuring an advanced design, and are used as edge switches in the network. The 5ESS was also a Digital switching system. It was designed to replace smaller offices in rural, suburban and urban areas.

The 5ESS switch was deployed in 1982, initiating the global presence of AT&T digital switching equipment around the world. It was destined to replace the Number 1 ESS and 1AESS. The 5ESS was also used as a class 4 switch or as a hybrid class 4/5 switch in markets too small for the 4ESS. The 5ESS 2000 version, introduced in 1990's, increased the capacity of the switching module and provided more enhanced features. A major design goal of the 5ESS was the use of equipment modularity to achieve an economically competitive system over wide range of line sizes. The 5ESS switching equipment uses distributed processing and modular software and hardware to provide a flexible architecture and simplify the addition of new features. The 5ESS switch has three main modules: The Administrative Module (AM) contains the central computers for Routing Control and Administrative Maintenance; the Communications Module (CM) is the central time multiplex switch of the system; and the Switching Module (SM) which makes up most of the equipment in most exchanges.

The SM performs multiplexing, analog and digital coding, and other work to interface with external equipment. Each has a controller, a small computer with duplicated CPUs and memories, like most common equipment of the exchange, for redundancy.

The 4ESS and the 5ESS technology, along with their predecessors, were transferred to the AT&T Network Systems division upon the breakup of the Bell System. The division was divested by AT&T as Lucent Technologies, and after becoming Alcatel-Lucent, it was acquired by Nokia.

Mobile Calls Before the Cell Phone

The Phone Booth

By Samantha Lelah

From near ubiquitous deployment in every town and city to an almost non-existent phenomenon in the United States, the telephone booth has had a significant impact on America's ever-evolving culture. Whether one considers this invention as a practical enabler to make a private call in a public place or simply as a now-famous icon in pop culture, it is important to acknowledge this innovation and its evolution over time.

Like most innovations its story has various paths and key moments of notoriety.

The Beginnings of the Phone Booth and the Payphone

Like most innovations its story has various paths and key moments of notoriety. Therefore, the telephone booth that we know today has come a long way since 1878. In this year, Thomas Doolittle, a notable inventor, repurposed an old telegraph wire and stretched it from Bridgeport to Black Rock, Connecticut — a distance of just over two miles. On each end of the line, he placed a wooden booth where people could pay 15 cents (about $3.60 today) to make a phone call to the other town. The telephone booth is a combination of two major functions: the payphone and a privacy space. William Gray is responsible for the invention of the first commercial payphone, which he created in the late 1880s. It was operated by a "post-pay" honor system where the user would put in their coins *after* they completed their phone call. At the Science and Technology Museum in Middletown, N.J., we pick up the story of the phone booth in 1939 with a Western Electric #2 model. Built around 1939, the main material used for this phone booth construction was wood. Inside the booth is a three-slot rotary pay phone where users could place a local call for a nickel.

A Constant Evolution and Spread of Phone Booths

The need for phone booths was mainly for convenience reasons when traveling away from home or work. In cities, where it seemed like they were situated in nearly every corner store, decorated with a sign that read "Telephone." Sometimes accompanied by a phone book that was secured by a chain, users would be able to talk on the phone in complete privacy while encircled by the hectic city life.

As the years went on, there was continued development and refinement of the phone booth to accommodate the public's basic need for them. To create more of a soundproof booth, double walls, curtains and even rugs were added to the interior. In the early 1900s, the telephone started to become less of rarity so the booths were installed in more constricted quarters. The hinged door became dangerous to unaware individuals who were walking right in front of the booth. Maurice Turner, who was an employee of the New York Telephone Company, patented his idea in 1910 of a door that folded inside the booth. The folding door was supported on hinges so the user could easily pull the door open and shut. Turner's invention lasted the test of time, as this innovation can be found on the few telephone booths that are still around today.

There were other changes throughout the early to mid-1900s but what is important to note about this part of the telephone booth's history is that household phone penetration rate was increasing. Between 1910 and 1920, the rate was only 15% but by the end of the 1920s, almost 40% of all household in America had landlines. Then, the rate declined to 30% during the Great Depression and then increased after WWII to 50%. However, telephone booths were still a significant aspect in American culture. So much so that in October

First Los Angeles Pay Station (1899)
Photo courtesy AT&T Archives and History Center

Indoor Telephone Booths in NYC (1940)
Photo courtesy AT&T Archives and History Center

of 1949, an article was published by the *Western Electric Company* that presented a new telephone booth designed by Bell Laboratories. 13,000 booths were being made for distribution that year and they would add to the 300,000 Bell System telephone booths already in operation around the country. The demand of the product increased exponentially because of "population growth and the faster tempo of modern life." Bell Laboratories' new design called for major improvements in aesthetic and practicality. The most noteworthy item that was added was a ventilator, which changed the air three to four times a minute so the space would be less polluted and more refreshing. The outer lining on the inside of the booth was now made of steel that had a "hammered effect," so notes and other random doodles could be easily erased. As for the floor, it was made out of an impermeable, perbunan rubber that eliminated any possibility of fading. As for the payphone itself, the cost of a phone call increased to a dime. However, if the user didn't have exact change, the phone had a coin return (invented in 1908 by an electrical engineer of Western Electric). Later the booth portion was no longer part of the full deployment of pay phones.

The Telephone Booth's Demise

The phone booths nowadays are comprised of steel and glass; however, they have drastically dwindled in numbers. Currently, there are only *four* spread out in the Manhattan area; a huge change from when they were located on every street corner in every major city. These four are only preserved for historical curiosity reasons instead of practical ones. The gradual extinction stemmed from the increasing cost of maintenance and stricter regulations of the actual telephone booth. In the 1960s, new phone booths were no longer the primary deployment method for payphones. While the number of fully-enclosed telephone booths began to give way to these smaller enclosures, the number of payphones continued to grow until 2001. By the late 1960s, the household phone penetration rate was almost 90% of homes across America. However, the overall blame for the booth and payphone's demise goes to the invention of the commercial cellular system in 1983. With this mobile phone, people no longer needed to stop and find a booth because they could now talk anywhere at any time.

Telephone Booth, Peoria, IL (1956)
Photo courtesy AT&T Archives and History Center

The Nostalgic Imprint

America's culture was becoming enamored with mobile telecommunications and the personal freedom of communications anywhere. One by one, telephone booths were removed from the corners, stores and hotels, only to remain as a faint memory in society's brain. With this demise, telephone booths became more of an icon and used in song and films to invoke feelings of nostalgia. Clark Kent relied on them as a place for a quick change into Superman. However, in the 1978 "Superman" there is an iconic scene where Lois Lane is in trouble and Clark Kent needs to change. He finds a pay phone but it is only surrounded by small glass panels. He looks it up and down briefly and runs to find another dressing room. Additionally, in the film "Phone Booth," released in 2002, Stu Shepard is confined in a — you guessed it — phone booth in fear for his life. He is forced to stay on the line or a sniper that is apparently aimed right at him might kill him. Booths even made it into songs in the 2000s when the lead singer of Maroon 5, Adam Levine, released the song "Pay Phone." Levine sings, "I'm at a pay phone trying to call home. All of my change I spent on you." As you visit the Science & Technology Innovation Center in Middletown, NJ we hope that as you look at the telephone booth you are transported back to simpler times where society wasn't always on the go.

Public Telephone — Walk-up, Drive-up (c. 1959)
Photo courtesy AT&T Archives and History Center

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Sharing the Conversation

142 Years of Talking on the Phone

by Elisabeth Patterson

Telephones are familiar and indispensable devices. But the familiar appearance has changed a lot over the years, and the changes represent enormous advances in capability and service to customers.

Telephone infrastructure begins in parallel to telegraphy, with the attempt to adapt that infrastructure to the transmission of the human voice. In 1875 Alexander Graham Bell filed a patent for an "Improvement in Telegraphy" that could transmit sounds, and by 1876 he had famously transmitted a voice message to his assistant, Thomas Watson.

Commercial telephones for the earliest exchanges were available to the public by 1878.

By 1882 the Western Electric Company introduced a telephone model that remained in production for most of a decade, and in use well beyond that. This was a large wooden wall set with three separate boxes attached to a backboard. The top box contained a ringer, a switch hook on the left, and a magneto with a crank to generate the current necessary to signal the telephone operator. The middle box contained variable-resistance transmitter and an induction coil, and the bottom box two wet-cell batteries. The batteries powered the talk circuit.
It's worth noting that a telephone is only one element of the telephone network. The other components are transmission and switching, and each of the elements affects all the others. Advances in switching and networking proceeded rapidly, if in the background for most users. Changes in the network led to changes in the telephone design as well.

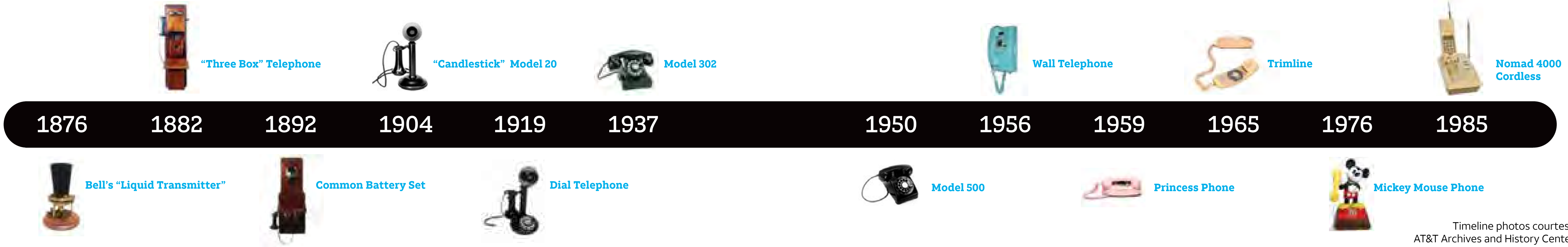
A key network change was the introduction of the common battery system. In this system, a low dc current was sent down the transmission wire from the telephone exchange to all subscribers. That eliminated the need for a magneto and batteries in the individual telephone unit, allowing for a new, smaller and simplified design to the telephone set. Common battery systems were installed one exchange at a time, and for many years were not suitable for the long circuits found in rural areas. A recent editorial by an author, born in small-town Minnesota in 1942, casually mentions memories of the use of a magneto phone and the need to turn the crank to summon an operator. Innovation and improvement were constant, though implementation was spread out over time, depending on local needs and local geography.

Woman Using Candlestick Phone
All photos courtesy AT&T Archives and History Center

Common battery systems also enabled the development and introduction of desk sets. The Model 20 was introduced in 1904, and with minor modifications remained the most widely used telephone model for over 25 years. The phone itself was a desktop unit, while the ringer and induction coil, collectively known as the network, resided in a separate box on the wall. This box, the "subscriber set" or subset, later included additional components for service improvement.

It's worth remembering that at this time, the Phone Company owned the transmission network, the telephone wiring in the subscriber's home, and the telephone unit itself, which was rented from the company at a monthly cost. This allowed the phone system stringent control over service and device quality while

A Timeline of Telephone Instruments



Timeline photos courtesy AT&T Archives and History Center and Michael Mills

500 Series Wall Phone (1957)
Photo courtesy AT&T Archives and History Center

making advancements in telephone technology.

For instance, dial telephones were tied to the introduction of automatic telephone switching. Automatic switching required that the subscriber send signals to operate the switch from his or her telephone, since a human operator would no longer routinely handle the call. The numbered telephone dial was created for this purpose. Each rotation of the dial sent electrical pulses to the switch to indicate the digits of the telephone number. The dial also included letters, since early telephone exchanges were known by name as well as number. In 1919, the Bell System installed its first dial telephones in Norfolk, Virginia, and then undertook the enormous task of converting its exchanges from manual telephones and switches to dial telephones and automatic switches, one exchange at a time. Complete implementation took decades.

Telephony in the United States was operated as a regulated monopoly. Telephones were designed for reliability and ease of maintenance, and were not subject to consumer fashion. Still, subscribers pressed for certain stylistic changes, including the development of a combined handset. Western Electric engineers experimented with combined handsets as early as the 1890s, however, it wasn't until the late 1920's that a combined handset was produced for use by Bell subscribers. But the initial offering aged poorly and had performance problems.

In 1937 Bell Laboratories produced a completely new telephone design, the Model 302. It was a complete desk telephone, with all components reduced in size and contained in the device. For the first time, the Labs engaged an industrial designer to explicitly consider the aesthetics of a phone. The result was efficient, durable and popular, and remained in production into the 1950's.

In 1951, the Bell System introduced a new standard telephone, the Western Electric 500, developed again at Bell Labs. The case, again designed for aesthetics, was more streamlined and rounded in design. Numbers and letters were place outside the dial for easier readability and reduced wear.

Technically the handset contained an improved transmitter and receiver, supporting a stronger signal on the subscriber's wire. The new phone was also easier to maintain and repair, benefitting the company and the subscribers. The phone was extremely durable. The author and contemporaries may well recall having a Model 500 in the home of their families and friends, with the typed phone number including letters for the exchange, well into the late 1970's.

The phone was introduced in black only. However, the plastic housing could be manufactured in almost any color. Beginning in 1954, telephones were introduced and advertised in a range of colors for an added monthly charge. Wall set versions, particularly popular in kitchens, were introduced in 1956.

For business customers, the telephone set was enhanced to include ability to accommodate multiple phone lines, and pick up or hold calls, using a series on buttons on the phone set.

The 1958 Rogers and Hammerstein musical "Flower Drum Song" features the song "I Enjoy Being a Girl," with an actress singing that she "talks on the telephone for hours." In 1959 AT&T introduced a very different phone that played into that sensibility, to be marketed for its style. The Princess phone featured a wide, low, oval shape, and was marketed with the slogan, "it's little, it's lovely, it lights." The feminine name and profile became very popular as an extension phone for the bedroom.

The last major design innovation from Bell Labs was the redesign of a dial-in handset, the Trimline, introduced in 1965. The ringer, receiver and dial were all reduced in size, a major engineering effort driven by considerations of style. In the same time period, considerable research continued in the transmission technology.

Digital telephone transmission came into use in the early sixties, supporting data and improved voice communication. Touch tone service was introduced in 1963, initially only in 2 towns in Pennsylvania. The availability spread one exchange at a time into the 1970s. Touch-tone service transmitted tones at a unique pair of frequencies for each key to indicate the digits of the number that the subscriber wished to reach. These tones, working in conjunction with new equipment added to existing switches, could travel through the entire network rather than just as far as the local switch, and thus had the potential for a variety of additional uses. Phone designs were modified to include the Touch-tone keypad. During all these innovations, the Bell System maintained a strict policy of supporting compatibility with old equipment. A candlestick phone in working order could be wired for a phone jack, and plugged into the network, and that device would still provide phone service.

Until 1975, the Bell System had complete control over consumer telephony, owning the telephones that were rented to consumers. In 1975 the United States Supreme Court ruled that subscribers could own their telephone units. In some areas the Bell System opened Phone Stores, and made a variety of practical and whimsical designs available for sale, for instance the Mickey Mouse phone.

Mother and Child with Princess Phone (1967)
Photo courtesy AT&T Archives and History Center

The production and sale of telephones naturally became a competitive and consumer-driven market. Telephones were no longer designed to work without fail for years, and became more disposable. The degradation in quality may have come as a surprise to consumers who took the reliability of the standard equipment for granted. On the positive side, competition in telephone sets led to innovations, such as the widespread adoption of cordless phones. The change in the nature of service represented the end of an era in telephony.

"it's little, it's lovely, it lights."

A Brief History of Data Transmission over the Phone Network

By Dave Hayward, Al Morton, Sal Talamo

Starting in World War II, the emergence of electronics and computer systems led to the desire to share digital information between locations. The ubiquity of the telephone network made it an obvious choice for making these connections. However the copper wires of the phone network were designed to carry the human voice, not the "ones and zeros" used by digital devices. So devices were needed to transform the binary digits ("bits") into a more voice-like signal. This led to the invention of the "modem" which uses the information bits to control ("modulate") a signal suitable for the telephone network at the source of the data, and turn that signal back into bits ("demodulate") at the destination. In true geek fashion, engineers soon shortened the name of this device to "modem."

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Early Drivers of Modem Development

As with many technologies, military applications drove initial modem developments. Perhaps the first modern modem was used to transport voice, not computer data. During the second world war, a secure telephone was invented which prevented enemy agents from listening to classified phone calls. This "SIGSALY" system, whose development was led by AT&T Bell Labs, turned human voice into digital bits which were encrypted before being fed to a modem and transported over the network. At the receiving end, the signal was turned back to bits, unscrambled, and converted back to voice. A SIGSALY system ran over special connections, used 40 racks of electronic equipment, weighed over 50 tons, and consumed about 30 kW of power! Later versions of "secure (voice) terminal units," such as STU-III (1987) which used echo cancellation based modems to provide high speed connections over ordinary phone lines, were about the size of a phone answering machine, weighted a couple of pounds, and plugged into ordinary electrical outlets. Digitizing voice for encryption / transmission is now the standard operation of ordinary cell phones.

In the early 1950's, the need to defend against enemy bombers and missiles led to creation of radar "warning lines" across Canada and the U.S. coast lines. Data from these radar installations were digitized and transmitted using modems to central "SAGE" ("Semi-Automatic Ground Environment") computing sites where they were processed into a unified view of the airspace. The first generation of SAGE modems used vacuum tubes and transmitted at 750 bits per second (bps). By the late 1950's, vacuum tubes gave way to discrete transistors and transmission rates reached 1300 to 1600 bps.

Commercial Data Applications

Military applications covered much of the research and development costs, and led to modems being manufactured in large numbers. This pushed modems down the technology cost curve and made them more attractive to business customers. Some modems were developed for specific applications while others could be used for any type of digital information.

Examples of modems for specialized commercial applications include:

- Evolving from telegraph-based systems, the teletypewriter took text entered by a typewriter-like keyboard at one location and reprinted it out at another. Classic uses included news distribution, speeding sales orders to manufacturing plants or warehouses, and hotel / airline reservation systems. Starting in the late 1950's, AT&T developed a progression of modems such as models 28, 101, 402 A/B/C/D for teletypewriters with transmission speeds of 300 bps. While most of these units worked over "private line" connections, dial-up connections using a special private switch were also supported.

DEW Line, Canadian Arctic (1956)
Photo courtesy AT&T Archives and History Center

Modem Terminology

Simplex A transmission mode where data is sent in only one direction.

Half-Duplex A transmission mode where data is sent in both directions but only in one direction at a time.

Full Duplex A transmission mode where data is sent in both directions simultaneously.

Bit Rate The number of bits per second that are being sent/received at a point in time.

Baud Rate The number of times the modem signal changes per second. Each signal change is called a symbol. Depending on the modulation technique being used, a symbol can represent one or more one bits. For example, if a signal can take on one of four states, each signal state (symbol) represents two bits (00, 01, 10, 11). The bit rate is equal to the symbol rate multiplied by the number of bits per symbol.

Error Rate The rate at which a demodulating modem incorrectly identifies the received signal. Errors can be caused by various kinds of electrical "noise." The most common error measure is the "bit error rate" which is calculated by dividing the number of bits received in error by the total number of bits sent. When transmitted data are segmented into groups of bits (blocks), the "block error rate" may better reflect the efficiency of the transmission. The block error rate is calculated by dividing the number of blocks containing errors (which requires the entire block to be retransmitted) by the total number of blocks sent.

Dial Up Line A connection made over the standard telephone network where the destination endpoint is specified by the number dialed at the originating site. Modem signals made on dial up lines go through telephone switches which can add noise and other impairments which ca limit the bit rate.

Point-to-Point Connections made between exactly two endpoints.

Private Line Private lines were hard-wired connections between (or among) fixed endpoints. They can be thought of as a pair of wires from one location to another. They are not sent through telephone voice switches which may add noise to the signal. It was possible to lease "conditioned" private lines which were guaranteed to meet specific transmission quality standards.

Multipoint Connections made between one fixed endpoint (the "central site") and more than one other fixed endpoints (the "remotes"). Multipoint connections were often set up between a bank's computer center and a number of remote branches.

Signal-to-Noise Ratio The "SNR" is a measure of the quality of the connection. It is measured at the receiving (demodulating) modem. It is calculated by dividing the energy level associated with the signal transmitted by the sending modem by the level of any other energy seen at the receiving modem. A higher SNR indicates a better transmission path which results in a lower error rate and a more efficient data transfer.

- Starting in the early 1960's, AT&T developed a series of "Touch-Tone" transmitters and receivers. These were used for signaling between customer phones and a telephone switch as well as between switches within the network. An expanded Touch-Tone product, with 16 keys instead of the typical 12, was used for certain military and network control functions.
- In 1965 AT&T introduced the model 603 modem which was used to send electrocardiogram information over dial-up connections from hospitals or doctor offices to specialists.
- The transmission of images (pictures or text) over distances, today known as a fax (facsimile) began in the mid-1800's. Until the mid-1900's fax machines were large, expensive, and slow. AT&T introduced the model 602A fax modem in 1963; that system took 6 minutes to transfer one page over dial-up connections! The coming of inexpensive large scale integrated circuits enabled faster page scanning, compression of images and faster modem speeds, all of which shortened page transmission times to a few 10's of seconds by the mid-1980's.

Dataphone 608D Portable, Acoustic Coupled Modem (1966)
Photo by Michael Mills

Voiceband modems for general commercial applications originated in the late 1950's and advanced in speed and capabilities over the next 40 years. Some of the notable models include:

- Developed in 1959, the Bell 101 modem ran at 110 bps – about 10 characters a second.
- Introduced in 1961, the 201A/B transmitted at 2400 bps in one direction on private lines.
- In 1962, the Bell 103A modem provided 300 bps over dial-up connections.
- The invention of adaptive equalization in 1968 allowed the Bell 203A modem to operation at 4800 to 9600 bps over private lines.
- By 1976, the Bell 212A modem provided 1200 bps simultaneously in both directions over dial-up connections.
- In the late 1970's, AT&T introduced a new line of "diagnostic" private line modems named "Dataphone II." The initial 3 models ran at 2400, 4800, and 9600 bps in both directions simultaneously; they also included a 110 bps subchannel which was used for testing and configuring remote modems. These were AT&T's first microprocessor-based modems which made extensive use of integrated circuits. Later models running at 14,400 and 19,200 bps were introduced.

Consumer Data Applications

The availability of reasonably priced personal computers and the spread of the Internet led to the general public's desire for data connections. In the late 1980's many homes added a second standard phone line for internet access. Initially the only method of getting to the internet used relatively inexpensive but slow (300 to 1200 bps) modems. Advances in integrated circuit and manufacturing technologies quickly lowered the cost and raised the speed of dial-up connections. AT&T's Dataphone II line of switched network modems included the 2224 (1988; 2400 bps), the 2248 (1988; 4800 bps) and the 2296 (1989; 9600 bps). These modems used echo cancellation to provide high-speed data transfer in both directions simultaneously. Additional advances in modulation techniques, specialized signal processing chips, and data compression methods quickly led to ever higher speeds: 14,400 bps (14.4 kbps) in 1991, 28.8 kbps in 1994, 33.6 kbps in 1996, and 56 kbps in 1998. Advances in integrated circuit technologies eventually led to these modems becoming just a card inside a personal computer and, later, just a chip or two on the main computer board.

Fax Transmission and International Standards

In the time before wide-spread e-mail, fax machines provided an efficient and timely alternative to overnight envelope shipping and the postal services. The name "fax" is the nickname for facsimile transmission, where text pages and some types of images are transmitted over phone lines with sufficient fidelity to fulfill their purpose (a "reasonable facsimile" of the original). Court rulings that a signature received by fax remains legally binding encouraged widespread adoption in the business sector, and this aspect (combined with near immediate delivery) is a key reason why fax transmission is a feature still found in many devices. But how did we reach the point where all the operations required to send a page work seamlessly between any two fax machines? The answer is International Standards for facsimile transmission, first agreed in the mid-1980's. The standards included protocols for machine identification and capability negotiation, modem selection and control, and methods to select page scanning

Dataphone Facsimile (c. 1966)
Photo courtesy AT&T Archives and History Center

resolution and perform image compression, in addition to the standards for data modems.

With world-wide fax adoption brought a series of improvements. The first wave of the so-called “Group 3” fax machines was susceptible to modem transmission errors which could cause a line of text to become un-readable. This fostered standards for page quality evaluation and various forms of transmission error-correction in enhanced standards. Other enhancements included support for color images, page transmission times of just a few seconds, and printer-quality resolution, eventually reaching the point where fax machines were like remote printers.

Modems Today

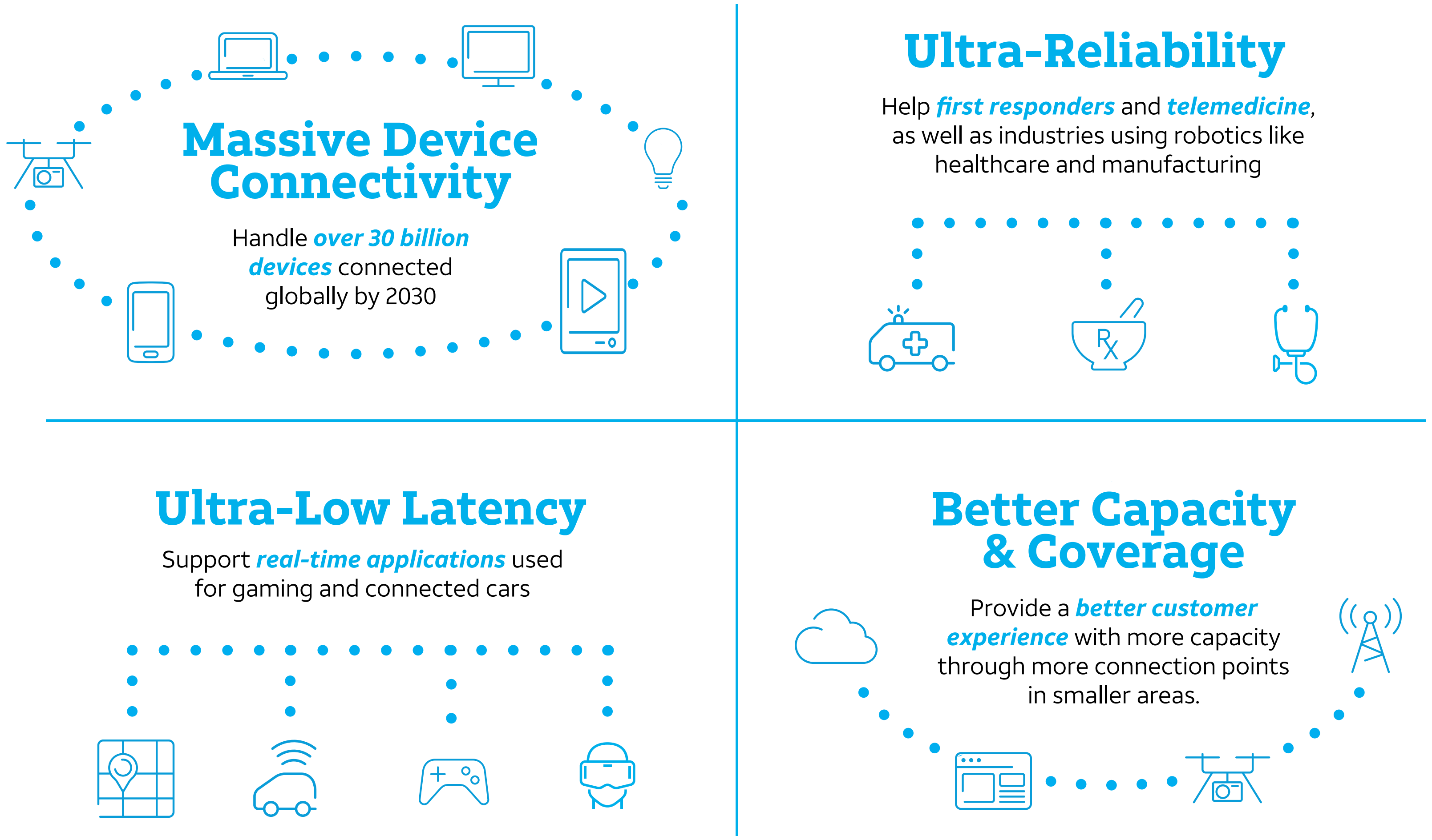
The standalone dial-up modem, which was ubiquitous at the start of the Internet era, has largely disappeared. Modems, however, are far from extinct; in fact the number of modems in active use today vastly exceeds that of even 20 or 30 years ago. Consider the number of wi-fi enabled devices found in typical homes. In addition to a wireless router, most desktop computers, notebook computers, tablets, as well as many printers, digital cameras, wireless headphones, and internet TV devices each have a wi-fi modem. A typical smart phone may have a half-dozen modem functions inside it — for wi-fi, Bluetooth, and several generations of cellular data standards such as GSM, EDGE, EV-DO, HSPA, and LTE. Wi-fi and Bluetooth only provide connections within a location; connecting the home router to the Internet requires yet another device such as a “DOCSIS” modem for cable television systems, an optical modem for light wave “fiber optic” systems, or a digital subscriber line modem (“DSL”) for access over traditional copper phone lines. Even satellite TV receivers include a very high bit rate modem to demodulate the digitized video streams.

But as modems have proliferated, they have also disappeared from view. Advances in integrated circuits and signal processing techniques have allowed functions that once took multiple circuit boards (or even most of a room!) are now implemented on just a small portion of an electronic chip.

The 5G Future for Business

We expect ***5G will offer businesses so much more than just faster speeds***. 5G will unlock experiences of the future like Augmented Reality and Virtual Reality. Not only will 5G modernize businesses, ***it will disrupt entire industries***.

We also expect 5G will help handle ***massive device connectivity*** in the Internet of Things (IoT). 5G’s ***ultra-reliability*** will help industries that use robotics, like healthcare and manufacturing. 5G’s ***ultra-low latency*** will be essential for real-time applications, like gaming and live maps for connected cars. More connection points in a smaller area – along with using small cells and unlicensed spectrum, will improve capacity – and offer a ***better customer experience***.



AT&T’s on-going 5G technical trials show ***real benefits are coming for businesses***.

- In June 2017, AT&T launched a second millimeter Wave (mmWave) fixed wireless trial in Austin, TX.
  - Customer trial locations in Austin are seeing ***speeds up to 1 Gbps*** and latency rates well ***under 10 milliseconds*** at the radio link.
- mmWave fixed wireless trials are also on-going in Indianapolis, IN and are expanding to include Waco, TX; Kalamazoo, MI; and South Bend, IN.

Putting Together All the Pieces for a New Idea Can Take Time

Cellular Phones

By Byoung-Jo "J" Kim

In 1947, the same year the transistor was invented, Doug Ring's cellular concept memo was shared inside Bell Labs.

The "cell" in 'cellphones' or 'cellular networks' reflects the shape of overlapping areas of radio signal coverage provided by many radio signal transmit/receive towers over a large area, as in numerous biological cells covering the skin of a leaf. In 1947, the same year the transistor was invented, Doug Ring's cellular concept memo [1] was shared inside Bell Labs. This was 32 years before the cellular concept was described in the special cellular issue of the January, 1979 Bell System Technical Journal [2] and 36 years before the first commercial cellular network became operational in Chicago in October 1983. The idea of providing a larger signal coverage area using many smaller cells remains the foundation of modern cellular networks. In his memo, Ring credits the origin of the hexagonal layout to W.R. Young, describing it as the most efficient layout for covering a flat surface. This is in fact the same reason that this pattern is frequently found in nature, such as in skin cells, bee hives, and crystalline structures. Besides the grid layout, Ring describes frequency reuse and call handoff among adjacent cells, where cellphones (mounted in cars then imagined) would travel beyond the coverage of one cell. These aspects are the three pillars of a cellular network, being continually

Bell Labs Engineers Test Car Phone (1977)
Photo courtesy AT&T Archives and History Center

Motorola Ultra Classic
1989

Oki Model CS-1
1983

AT&T Model 3045 "bag phone"
1994

Motorola StarTAC
1996

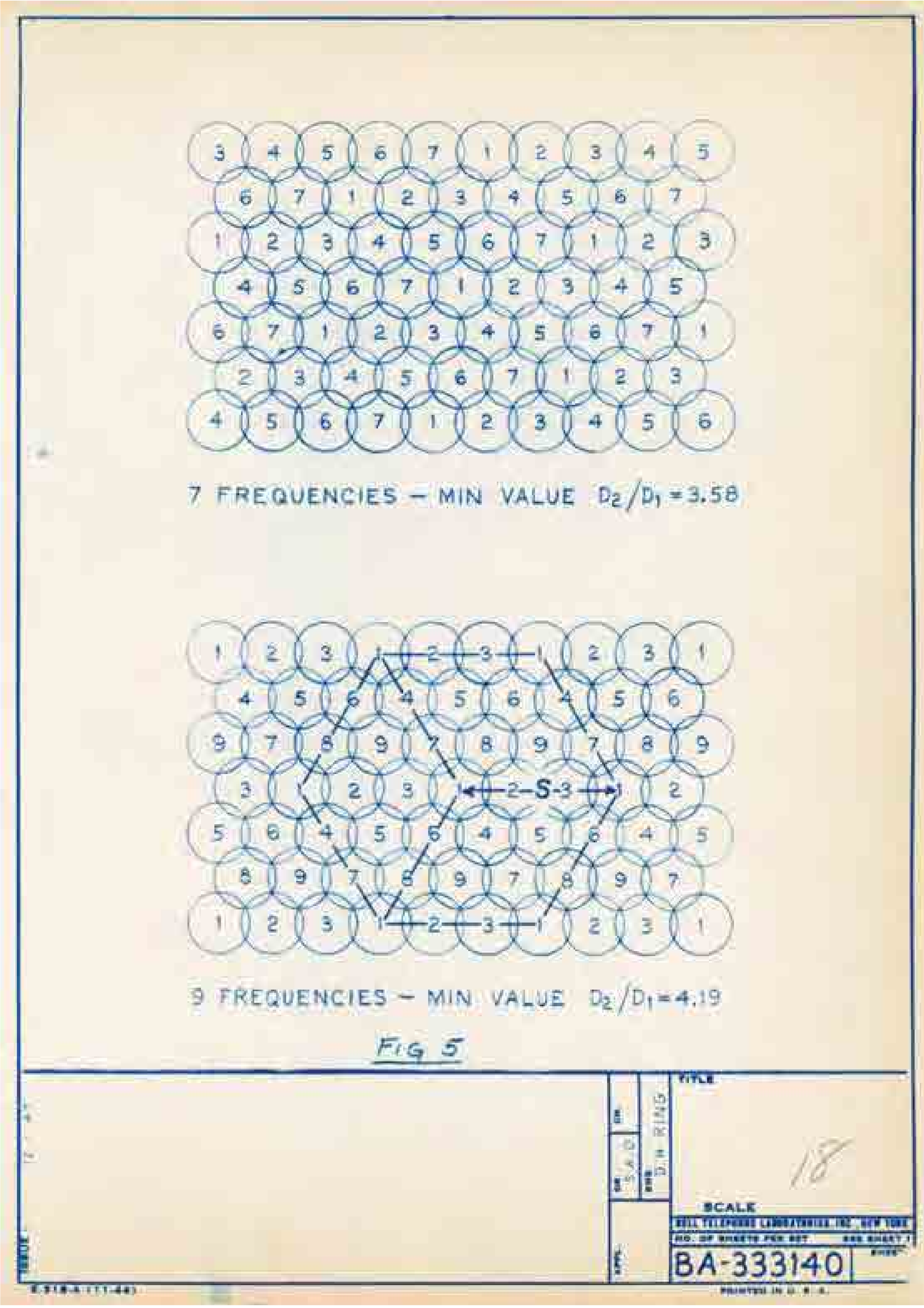
Nokia 3360
2000

RIM Blackberry 6710
2002

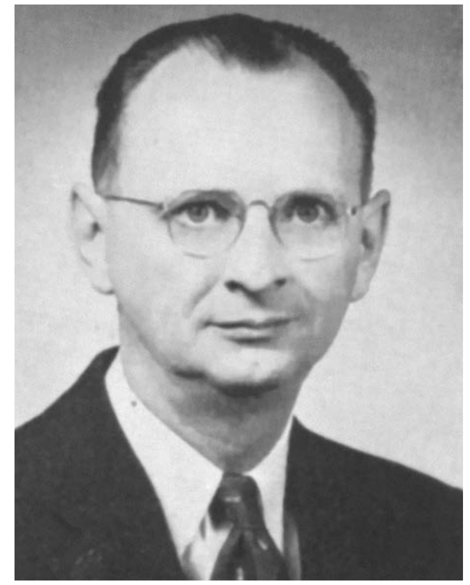
Apple iPhone
2007

Motorola RAZR
2004

Photos courtesy AT&T Archives and History Center and Michael Mills



Drawing from D.H. Ring's 1947 paper about providing mobile telephone service
Drawing courtesy AT&T Archives and History Center



Douglas Ring (1948)
Photo courtesy AT&T Archives and History Center

refined through the 5 generations of technological stages. 5G currently being developed by AT&T and many other entities around the world.

Since the cellular networks are only indirectly experienced by consumers through their cellphones (and nowadays through mostly smartphones), the phones mark more tangible milestones in the public's mind.

All first-generation cell phones were analog voice phones, most were car-mounted. Analog signals were used to carry the voice via FM type modulation. Starting with the 1st generation cellular networks, the control signals were already digital. Successive miniaturization leads to cellphones like the Motorola Ultra Classic" Cellular Phone, [ca. 1989] and AT&T 3045 Cellular "Bag" Phone, 1994, providing more portability than a car-mounted system.

The 2nd generation digital voice phones were much smaller and cheaper, mainly due to lower power consumption enabled by digital transmission formats, such as the low-cost Nokia 3360 Cellular Phone, the 'small-is-better' Motorola StarTAC, and the most well-known "fashion phone" Motorola RAZR. The Motorola RAZR was a 3rd generation wideband cellphone.

Given birth during the 3rd generation of cellular technology, the iPhone transformed the whole industry with the popularization of the smartphone, whose potential was glimpsed earlier through the Blackberry.

The concept for communications anywhere first crystalized in 1947 in Ring's internal memo — "Mobile Telephony — Wide Area Coverage", but took another 36 years to be realized. The successive introduction and expansion of cellular technology its integration into everyday life and business has driven the expansion of capabilities: SMS (Short Messaging Service), Internet access over limited data capabilities of 3G, smartphones and their huge demand for data capacity to name a few. Each "next generation" of wireless technology spurs the imagination of the users to greater demand for mobile communications. The latest 5th generation is projected to explode with IoT usage which will move our world from communications anywhere to communications anywhere with anything.

References

[1] Doug Ring, "Mobile Telephony – Wide Area Coverage," *Bell Laboratories Technical Memoranda*, 1947

[2] V.H. MacDonald, "Advanced Mobile Phone Service: The Cellular Concept", *Bell System Technical Journal*, Vol 58, No. 1, January, 1979, pp. 15-41.

Project AirGig™

The Promise of Broadband Everywhere

by Paul Henry

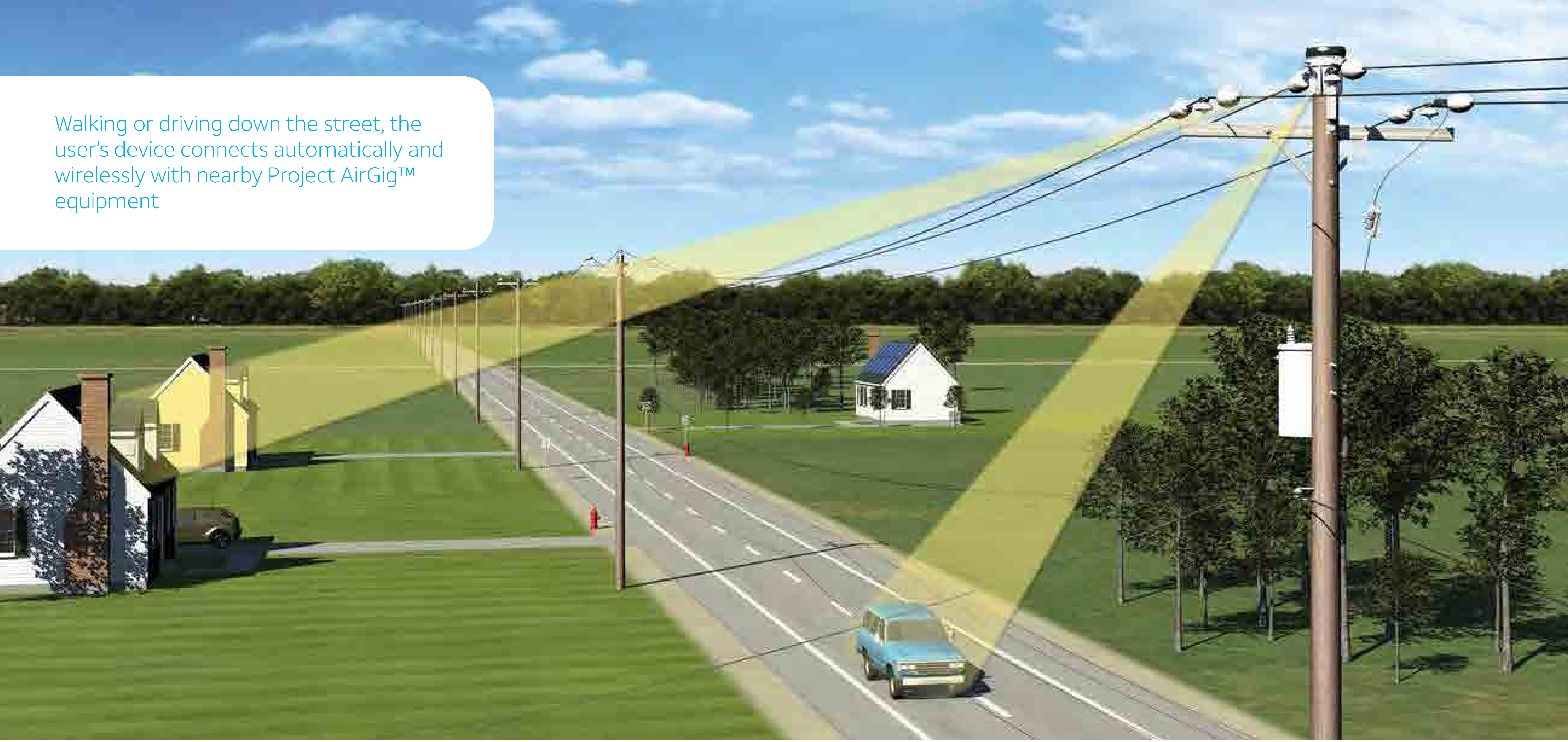
Project AirGig™ is a transformative technology that could one day deliver low-cost, multi-gigabit wireless Internet speeds using ordinary power lines. Now in the trial phase, the hope is that this technology will be easier to deploy than fiber, can operate over license-free spectrum and, in conjunction with 4G-LTE and 5G cellular services, expected to deliver broadband connectivity to homes and mobile or handheld wireless devices wherever there are power lines — whether urban, rural or underserved parts of the world. Project AirGig™ delivers this last-mile access without any new fiber-to-the-home; it leverages the electric power grid, an infrastructure that's already been deployed. This means connected experiences become an everyday reality — regardless of location. Almost unique among technological advances, Project AirGig™ represents the opportunity for a single infrastructure to serve two distinct, non-competing industries — telecommunications and power utilities. It operates over existing electric power lines, but utilizes extremely high frequency millimeter waves rather than conventional 60 Hz alternating current.

> Low-cost, multi-gigabit wireless Internet speeds using ordinary power lines.

Pole-mounted Installation for Project AirGig™
Illustration by John MacNeill

The regenerator and inductive power supply are housed in an egg that snaps over the medium-voltage wire. The 5G wireless equipment is mounted on the top of the utility pole.

Walking or driving down the street, the user’s device connects automatically and wirelessly with nearby Project AirGig™ equipment



Wireless Link to Mobile Unit and Wireless Drop to Residence
Illustration by John MacNeill

More than a decade ago, AT&T Labs engineers had worked on experiments to deliver broadband over power lines (BPL). Back then, broadband meant merely megabit speeds. The technology worked well, but couldn’t keep up with Internet users’ demands for higher data rates. So engineers shifted their focus from BPL to millimeter wave (mmWave) technology — a region of extremely high radio frequencies (roughly 30 GHz and above), where bandwidth, and therefore data traffic capacity, was plentiful and licensing requirements were minimal. They were intrigued with the possibility of uniting mmWave technology with power lines, which no one up to that time had achieved in a practical way. The challenges were many. If a viable system was going to be built (if it was even possible!), every aspect of the technology — mmWave characterizations and inductive power supplies, to name a few — would need to be created from scratch. There were no engineering guidelines, no handy how-to manuals.

The first experiments were a skunkworks initiative involving just a handful of engineers — strictly off-the-books. Their rudimentary apparatus transmitted data signals using plastic funnels from a local auto parts store covered with aluminum foil, placed next to unenergized power cables. These tests produced unexpectedly positive results, and caught the attention of higher management, especially Henry “Hank” Kafka, an engineer himself, who secured the funding needed to support a deeper look into this new technology. Thus was Project AirGig™ born. Addressing myriad technical challenges, the Project AirGig™ team created a stream of innovations as they staked out new territory. Since

A key feature of Project AirGig™ is its support of the recognition by utility companies that they need to evolve toward the "smart grid."

it was expected that Project AirGig™ would be widely deployed, cost considerations were paramount. Developing a technology capable of high performance and reliability while also achieving low cost made the engineering task especially daunting. Particularly challenging was the design of the signal regenerator, the device that attaches to the power line and boosts the signals as they travel on their way. The engineers devised a unique inductive coupler that could power the regenerator by extracting energy from the magnetic fields created by the alternating current in the power line itself. Other noteworthy innovations included inexpensive plastic antennas and an overall packaging concept called an "egg" that allowed a complete regenerator to be packaged into a small, footballshaped split plastic container. A unique hinged design allowed it to be easily snapped over the power line, thereby reducing installation costs to a minimum. To date, there are close to 300 patents or filed patent applications related to Project AirGig.™

The connection from the utility pole to the end users – the "drop" in telecommunications parlance — is achieved wirelessly using 4G-LTE or 5G cellular technology. Whether the user is "fixed" — at home or in the office — or mobile — walking or driving down the street, the user's device connects automatically and wirelessly with nearby Project AirGig™ equipment.

Wide scale deployment of 5G cellular technology — the key to ubiquitous multi-gigabit wireless connectivity — will require a dense network of small cells, cells far smaller than the familiar 'macro-cells' used on today's cellular deployments. This 'densification' requires a cost-effective approach to connecting these small cells into the national broadband network. Project AirGig™, which leverages the ubiquitous power-line grid, is ideally suited to this task. By reducing the need to deploy new optical fiber, Project AirGig™ becomes even more economically attractive.

To provide multi-gigabit 5G service in less-populated areas, where a dense array of small cells is neither needed nor cost-justified, Project AirGig™ will employ a Radio Distributed Antenna System (RDAS), an innovation that extends the reach of the pole-mounted 5G cellular radio transceiver. Rather than relying solely on transmitting wireless signals directly from the transceiver, RDAS transports a replica of the signal over power lines and then reconstructs and radiates it from a remote antenna some distance away.

Lastly, a key feature of Project AirGig™ is the collaboration with utility companies as they evolve toward the "smart grid." The data required by the power company for real-time management of its power-line network can use Project AirGig™ capability already in place on those same power lines. This enables a wide variety of smart-grid applications, such as support for utilities' meter-reading, appliance and usage-control systems, as well as detection and pinpointing the location of power-line disruptions, such as encroaching tree branches or actual line breaks.

In conjunction with power companies, AT&T is now conducting trials of Project AirGig™ to demonstrate its high-speed capability and reliability under actual field conditions. Many lessons will be learned and the details of the system that emerges may well be substantially different from the ones under trial. But of one thing we can be confident: Project AirGig,™ coupled with 5G cellular technology, has opened the door to the possibility of broadband Internet connectivity for nearly everyone served by an electric utility. Where this technology is deployed in the future, if power is available.

To provide multi-gigabit 5G service in less-populated areas, where a a dense array of small cells is neither needed nor cost-justified, Project AirGig™ will employ a Radio Distributed Antenna System (RDAS)

Our **Contributors**

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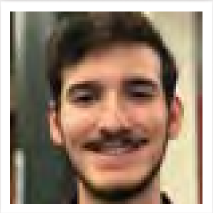
Sheldon Hochheiser is AT&T Corporate Historian and manager of the AT&T Archives and History Center facility in Warren, New Jersey. Sheldon joined the AT&T Archives as a historian in 1988. He has been studying the history of AT&T and U.S. telecommunications ever since, and is the world's leading expert on the company's history. Sheldon holds a Ph.D. in History of Science from the University of Wisconsin — Madison, and a B.A. in Chemistry-History from Reed College. In addition to his years at AT&T, Sheldon has served on the faculties of Rensselaer Polytechnic Institute, the University of Minnesota, and the Stevens Institute of Technology, and as a historian for the Rohm and Haas Company and the IEEE. Sheldon is an active member of the Society for the History of Technology and the Business History Conference.

Dan Gruspier

Daniel Gruspier is a high school senior at the Academy of Allied Health and Science. He was an intern at AT&T Labs in Middletown during the 2017-2018 school year.

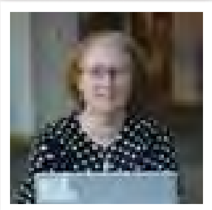


Leon Lubranski

Leon Lubranski is a member of the Wireless Network Architecture and Design Organization. His activities during his career with the Labs has included the design of integrated circuit packaging, supporting the delivery of both domestic and international communications services, and systems engineering for wireless transport. Prior to joining AT&T he worked in the defense industry where he had responsibility for structural, vibration, and thermal analysis for naval vessels and aircraft electronic systems.

Doug Olsen

Doug Olsen is an accomplished telecommunications professional with 30 years of engineering experience. His current role is Principal Member of Technical staff in the AT&T Labs Middletown, NJ complex where he is a member of the D2.0 Packet Optical Network team. Doug is one of the lead network design engineers for AT&T's Layer 2 transport network called IPAG or IP Aggregation. Doug has his B.S. in Mechanical Engineering from Rutgers University, and his MBA in Finance from St. Johns University.

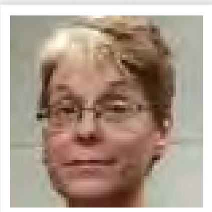


Kathy Tse

Kathleen Tse has worked on a number of major photonic transformations in AT&T's network. Her current role at includes developing strategy for next generation photonic technologies including metro and long-haul technologies, and she leads a small team of engineers across the country. Kathy received a PhD degree in Engineering from Brown University and a BSc From Cornell University. She received AT&T's Medal of Science and Technology for her work on AT&T's ULH backbone.

Zoe Goodman-Frost

Zoe's career at AT&T spans 32 years. During this time, some of the projects she has been involved in include the development of fiber optic based biosensors, laser beam propagation through the atmosphere, technology analysis and certification for the AT&T Network, and Mobility Gateway architecture and design. After 9/11, she served on a team doing consulting work for the Department of Defense and Homeland Security. She is currently working on Project AirGig™. Zoe has a doctorate in physics from Yale University, is married with a daughter, and plays the cello.



Elisabeth Patterson

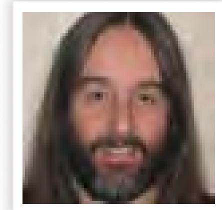
Elisabeth Patterson has worked in the Telecommunications industry since 1990, as a writer, instructional designer, project manager and instructor, including teaching overseas and training military instructors. Since 2011 she has supported AT&T Cloud services, including CaaS and AIC. She holds a B.A. from Yale University and a Masters in Technology Management from the Stevens Institute of Technology. She and her husband, George, live in Middletown NJ.

Byoung-Jo "J" Kim

Byoung-Jo "J" Kim (IEEE S'93 – M'98) received his B.S. from Seoul National University, Korea in '93, M.S. in '95 and Ph.D. from Stanford University in '97 all in Electrical Engineering. He had worked and consulted for several wireless start-up companies in the Silicon Valley before joining AT&T Labs-Research in '98. One major theme of his work is to combine the advancement of wireless systems research from Electrical Engineering and that of mobile systems research from Computer Science. His recent interests cover 5G, LTE, radio propagation, multi-interface/domain mobility, security, radio resource instrumentation/management, next-generation cellular network architecture, and related industry standards. He maintains both eternal hope and heightened skepticism towards bold claims of major breakthroughs in his and other fields of knowledge.

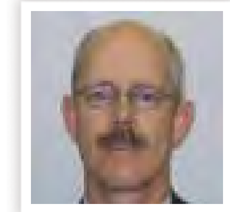
Tony Hansen

Tony Hansen is a graduate of Stanford University and South Dakota State University, in computer science/engineering, electrical engineering and mathematics. He is a software engineer, martial artist, author, maker, genealogist, avid reader, and a student for life. He has about a dozen Raspberry Pis and micro controllers performing various tasks, multiple 3D printers, lots of power tools, and loves the smell of solder. He still prefers using the command line for many things.



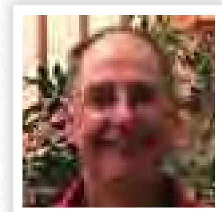
Tom Willis III

Thomas Willis graduated in 1987 with a Ph.D. in Electrical Engineering specializing in electromagnetics from the University of Michigan. His graduate studies at Michigan were supported under an AT&T Ph.D. Fellowship. After graduation, he came to work at AT&T Bell Laboratories in Holmdel, NJ. He currently works in the area of microwave wireless communications at AT&T Laboratories in Middletown, NJ. His most recent assignment has been on Project AirGig™.



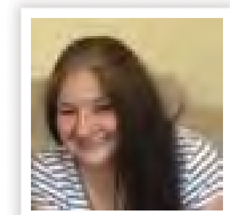
Mike Neubelt

Michael Neubelt received his B.S. degree in electrical engineering from the University of Connecticut, Storrs, CT, USA. He is a Principal Member of Technical Staff at AT&T Research & Development Labs, Middletown, NJ, USA where he works on the design, development and deployment of International DWDM networks. Prior to joining AT&T he spent 24 years working in aerospace research on fiber optic gyroscopes and in telecommunications research on ultra long- haul transmission for undersea fiber optic networks. In his spare time, he raises puppies for the Morristown Seeing Eye, coaches high school sailing and is a scout leader in the Boy Scouts of America. He and his wife, Melanie, raised five children and reside in New Jersey.



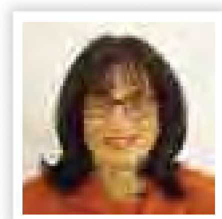
Ken Reichmann

Kenneth (Ken) Reichmann holds a B.S. in physics and a M.S. in electrical engineering. At present, he is a Principal Member of Technical Staff in the Access Architectures and Devices department at AT&T Labs, concentrating on broadband wireless technologies. Prior to this, he was an experimental researcher in the areas of optical communications for residential and business access, metro transport and cellular backhaul. Ken is the author of over 130 peer-reviewed publications and has 45 patents to his name. He has been a speaker, a technical sub-committee member and chair for major optical communication conferences and remains a technical journal reviewer. Ken is a Senior Member of the IEEE.



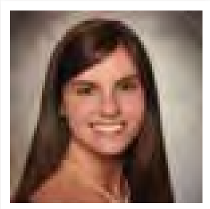
Beatriz Ugrinovic

Beatriz Ugrinovic is an LMTS at AT&T Labs, in the Wireless Network Architecture and Design organization. She joined Bell Labs in 1986 as an MTS in the Network Operations Systems Planning Group and became Director of the International Network and Private Line Development District (2000 to 2014), responsible for designing the architecture for AT&T's Layer 1 Network for Asia-Pac and Latin America. Beatriz studied Electronics Engineering at the Universidad Mayor de San Andres, in La Paz, Bolivia, and obtained her MSc degree in Electrical Engineering from the University of Texas at Austin, in 1984.



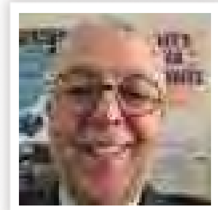
Magda Nassar

Magda joined Bell Labs in 1982 and continued her career in AT&T R&D until her retirement in 2017. As an Assistant VP, Magda was responsible for the design of the VoIP core network infrastructure and VOIP services. Most recently, Magda led the VOIP Network infrastructure virtualization. Earlier in her career Magda led the planning of AT&T SS7 signaling and switching for Intelligent Services. Magda Played a key role in the development of the AT&T Global Network Operation Center. Magda holds a PhD and an MS in EE from Case Western Reserve University, Ohio. She received her B.S. in EE from Cairo University, Egypt.



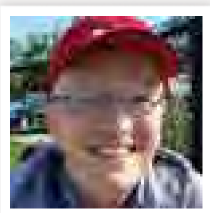
Samantha Lelah

Samantha Lelah, a student from Rowan University, interned during the summer of 2017 at the Bedminster location under the Andre Fuetsch organization. She is interested in pursuing a career in communications and hopes to obtain some freelance article writing opportunities in the future as well. Samantha enjoys all types of research and especially liked exploring AT&T's extensive past with technology



Dave Hayward

Dave Hayward joined AT&T Bell Labs in June of 1978 and has worked in some part of AT&T since then. His first project at the labs was developing software for Dataphone II modems. Over the years he contributed to many products and services including phone systems for small businesses, secure voice telephones, high speed networking multiplexers, credit card processing networks, integrated voice/data access services, voice over IP networks, and integrated circuits for digital subscriber line modems. Dave has bachelor's and master's degrees in electrical engineering from The Cooper Union and Rensselaer Polytechnic Institute, and holds several patents. He and his wife, Laura, live in Lincroft, NJ where they raised their four children.



Al Morton

Al Morton is a Lead Member of Technical Staff at AT&T Labs, Middletown, New Jersey. He has been a chairman and recognized contributor in US and International network performance standards committees for more than 25 years. He authored or co-authored more than 31 IETF RFCs, and is a committer on several Linux Foundation projects. He has worked at Bell Labs, the U.S. Army Satellite Communications Agency, and Computer Sciences Corporation. Al spends his spare time making and enjoying music with friends and family on the New Jersey Shore and Chicago, Illinois.

Sal Talamo

Sal Talamo started his career with AT&T in June of 1985, initially performing certification for Dataphone II modems. He has contributed to numerous AT&T product and service offerings spanning modems, DSUs, high speed networking multiplexers, integrated voice/data access services, voice over IP networks, software defined networking and network function virtualization. He has led technical planning teams and engineering and development for AT&T's network. Sal completed his B.S. and M.S. degrees in Electrical Engineering from the NYU School of Engineering. He and his wife, Donna, live in Matawan, NJ with their two children.

Paul Henry

Paul Henry, a Fellow of AT&T and IEEE, joined AT&T (Bell) Laboratories immediately after receiving his Ph.D. in physics from Princeton University. He has published papers or patented inventions in several fields, including millimeter-wave radio techniques, cosmology, wireless systems, optical communications and data security, as well as serving as a Technical Editor of IEEE Communications Magazine and Guest Editor for the Journal of Lightwave Technology. Dr. Henry's current research emphasis is on circuits and systems for broadband Internet connectivity to homes and businesses.

Golden Boy

Commissioned by AT&T President Theodore N. Vail in 1916 and originally called the "The Genius of Electricity," its purpose in 1916 was to express the power of electricity and service to humanity worldwide. With three 12K Volt power lines in his right hand and lightning bolts in his left, he was second only to the Statue of Liberty. He was first located at AT&T's headquarters at 195 Broadway in NYC. In 1930 he was renamed "The Spirit of Communication" and now resides in our Dallas headquarters.

The Genius of Electricity (1966)
Photo courtesy AT&T Archives and History Center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