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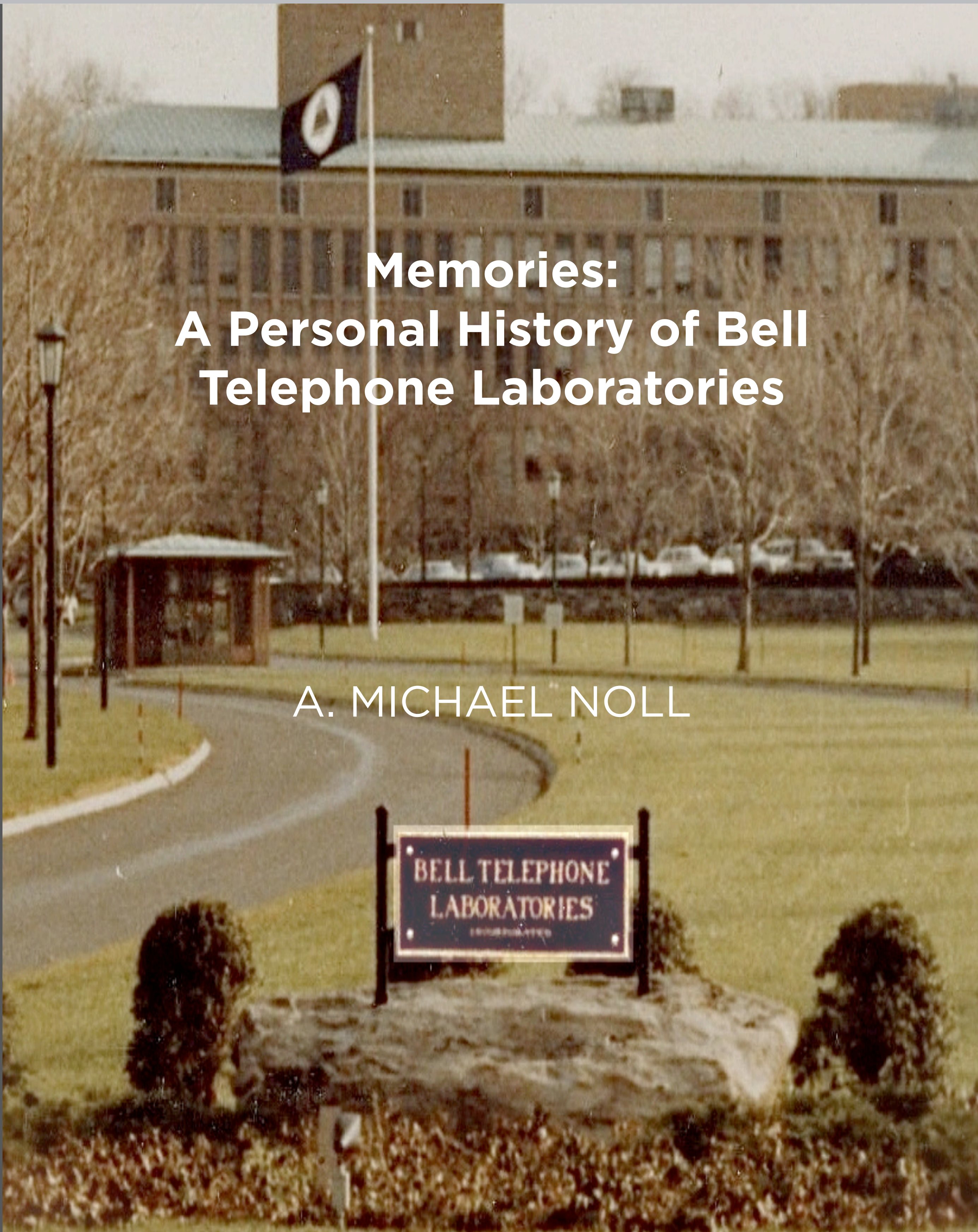
Memories: A Personal History of Bell Telephone Laboratories

A. MICHAEL NOLL



Memories: A Personal History of Bell Telephone Laboratories tells the story of Bell Labs, concentrating mostly on the 1960s, from the personal perspective of the author who actually was employed at its Murray Hill laboratory as an engineer and researcher. Bell Labs continued the tradition of Thomas Alva Edison's invention factory and had an environment that today is associated with Silicon Valley. The buildings, various locations, amenities, and most important—the people—are described to give a sense of what it was like to be at Bell Labs and why so many wanted to work there and contribute to its many inventions and discoveries.

A. MICHAEL NOLL is professor emeritus at the Annenberg School for Communication and Journalism at the University of Southern California. During most of the 1960s, he was employed as a Member of Technical Staff at Bell Telephone Laboratories in Murray Hill, NJ, and recently worked on the papers of Dr. William O. Baker, who was vice president of research during what many consider the "golden years" of Bell Labs. He brings this personal knowledge and perspective to this book

Memories:
A Personal History of Bell Telephone Laboratories

A. Michael Noll

August 6, 2015

[Cover photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs. Edited by A. Michael Noll.]

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FOREWORD

Alfred U. MacRae

Have you ever wondered how Bell Telephone Laboratories generated so many Nobel Prizes, awards, patents and major contributions to our Information Age? This book, by A. Michael Noll, answers that question by describing the people and the organization that made these triumphs possible. The book serves two purposes. First, it is a treatise to describe his activities in the 1960's when he was a Member of Technical Staff in the Research Area of Bell Labs, and the second is his promise to Dr. Bill Baker, Vice President of Bell Labs, to "tell the story of Bell Labs." It is this latter subject that makes this book so interesting and informative. In addition to the narrative, this book contains many previously unpublished photos of the people and the facilities of Bell Labs. While much has been written about Bell Labs, people who actually were employed there and thus know first hand what it was like have written little. As a past employee, the author is ideally suited to capture the essence of the attributes that enabled Bell Labs to be such an innovative organization.

The primary reason for its success is that it hired very talented worldwide scientists and engineers to work there and provided them with world-class support and facilities. The people in the Research Area in particular were encouraged to pursue new areas of science, but with the overall long-term objective of improving communications. It was a multi-disciplined staff, with physicists, chemists, material scientists, mathematicians, electrical and mechanical engineers stimulating each other. Management came from the technical ranks and thus they were able to direct the R&D and maintain a sense of excellence. Of course, stable funding was another critical factor. While the Research Area was known for its many prizes and inventions, only 10% of Bell Labs was devoted to the Research Area. Most of the people in the development organizations were involved in the initiation, development, and introduction to manufacture of the systems that enabled the Bell System to offer quality services at decreasing costs to its customers. Some of the contributions from the Development Areas included electronic switching, 800 service, digital, submarine cable, optical, microwave and satellite communications, the cellular system and even touch-tone dialing. Today's information age continues to benefit from the discoveries that originated in both Areas of Bell Labs.

After reading this book, one cannot help but ask the question, "Where are the advances in technology coming from today?" Most of the new products that we enjoy in today's information age had their technological genesis at Bell Labs. What will it take to recreate such an innovative organization that is willing to share its output with others, or is it possible?

ALFRED U. MACCRAE
Seattle, WA
May 2015

PREFACE

This is a story and personal memories of Bell Telephone Laboratories, Incorporated. Many knew it as the huge building on Mountain Avenue in Murray Hill, New Jersey. But it was the people and the excitement of the research and development that occurred there that made Bell Telephone Laboratories the ideal job of every young engineer and scientist. The emphasis of this story is on its "golden years" of the 1960s, in such topics as its people, the buildings themselves, the work environment, and its contributions to today's digital era and information age.

Today, few know of the greatness and significance of Bell Telephone Laboratories, and even of the former Bell System that supplied telephone and telephone service in the United States. Some believe that with the closing of several locations and the building in Holmdel, Bell Labs is no more. But the legacy of Bell Telephone Laboratories continues in the Bell Labs that is the R&D unit of Alcatel-Lucent and that occupies the Murray Hill facility.

Long before Silicon Valley achieved its fame, New Jersey was "the" invention and high-technology state. Thomas Alva Edison worked in New Jersey, and is credited with the earliest industrial research laboratory. The Radio Corporation of America (RCA) had its laboratory in Princeton, New Jersey. There were many smaller firms in the vicinity supplying the equipment to these large laboratories. There were universities and colleges educating a steady stream of engineers and scientists, such as Stevens Institute of Technology, Newark College of Engineering, and Princeton University. Across the rivers were the University of Pennsylvania, New York University, Columbia University, and Brooklyn Polytechnic.

At the very center of this vortex of engineering and science on the East Coast was Bell Telephone Laboratories. This is the story of the legacy of Bell Telephone Laboratories and why it matters so much even today.[1]

Dr. Alfred U. MacRae kindly shared with me his many memories of Bell Telephone Laboratories, and made very helpful comments on many drafts. At Bell Labs, he was director of integrated circuit development and pioneered ion implantation. Edward Eckert of the Bell Labs Archives and George Kupczak of the AT&T Archives and History Center were very helpful in suggesting and providing photographs, from their extensive collection, of Bell Labs and its people, along with facts and comments.

A. MICHAEL NOLL
Stirling, NJ
July 2015

[1] Two recent books about Bell Labs are: Jon Gertner, *The Idea Factory: Bell Labs and the Great Age of American Innovation*, Penguin Press, 2012; A. Michael Noll & Michael N. Geselowitz (Eds.), *Bell Labs Memoirs: Voices of Innovation*, IEEE History Center, 2011.

Chapter 1

BELL LABS AND THE BELL SYSTEM

INTRODUCTION

Long before Silicon Valley, there was a great research and development organization with its headquarters and many facilities in New Jersey. Bell Telephone Laboratories, Incorporated (also known simply as Bell Labs) was responsible for R&D for the Bell System, which supplied telephone and telecommunication service in the United States as a regulated monopoly. Bell Labs also supplied vital technology and systems for the U.S. military, for instance, early radar applications, undersea sonar, Nike missile systems, and the DEW (Distant Early Warning) Line.

Roaming the hallways of Bell Telephone Laboratories at its Murray Hill, New Jersey facility during the 1960s, I would encounter a palette of sounds, smells, and experiences. There would be spirited conversations in offices and conference rooms. Chemists in white lab coats would be in their labs, surrounded by glass equipment and chemicals, and strange odors would permeate the hallways. There were the green traces on oscilloscopes and the smell of solder. Computer generated speech and music would fill the hallways in an acoustics area. Lone mathematicians would be at their blackboards and equations. Scientists and engineers would be in the stacks of the library pouring through books and journals. Everyone seemed in a hurry on their way to a new discovery.

Bell Labs was a very large organization, with over 14,000 employees in 1965, which had grown to over 24,000 in 1981.[2] About 6 percent were in the formal Research Area – a percentage

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[2] A. Michael Noll, "Bell System R&D Activities," *Telecommunications Policy*, June 1987, p. 161-178.

that was at that level throughout most of its past. By funding, Bell Labs spent about 12 percent of its total budget on research. This research funding was included in the budgets, not only of the formal Research Area, but also in the advanced development areas. Primarily Western Electric funded the Development Areas. The Bell System (AT&T) spent about 2.8 percent of its total revenues on R&D as a whole in the mid 1960s. Research was a bargain at about 0.3 percent of total revenues of the Bell System.

Bell Labs was primarily a development organization; the well-publicized fundamental research was a small portion of the total R&D effort. However, innovation and discoveries often occurred in the development and engineering areas, some of which had their own applied research departments.

There are many terms that characterize the work done at Bell Labs: engineering, science and technology, development of products and systems, and research. There also were many disciplines represented at Bell Labs: for example, physics, materials science, chemistry, biology, mathematics, electrical engineering, and psychology. In the early 1960s, computer science had yet to be formed and was then performed within mathematics mostly.

But all these areas and characterizations blur together. What really mattered were innovation, invention, design, and discovery. Simply stated, to be at Bell Labs was to experience the excitement and fun of the challenges. That is what it was all about.

Books and articles have been appearing either about Bell Labs or which mention Bell Labs. A number of myths have developed; mostly because so little has been written about Bell Labs by people who actually were employed there and thus know first hand what it was like. This personal treatise is an attempt to document the history of Bell Telephone Laboratories, Incorporated from a personal perspective. The focus of this history is on the 1960s, while I was employed at Bell Labs, but it also spills a little into the 1970s, and also backwards into the earlier years of Bell Labs from when it was formed in 1925.

While working about 10 years ago on the papers of Dr. William O. Baker, who was vice president of the Research Area at Bell Labs during the 1950s and 1960s, he would challenge me to "tell the story of Bell Labs." This history is a response to that challenge, and I hope it is, at least in a small way, what he had in mind.

THE BELL SYSTEM

The Bell System provided telephone and telecommunication service in the United States, until its demise on January 1, 1984. The Bell System was a monopoly subject to government oversight and regulation. The Bell System consisted of a number of entities, all owned ultimately by the American Telephone and Telegraph Company (AT&T). Local telephone companies, owned by AT&T, such as New York Telephone, and Southwestern Bell, provided local telephone service. The Long Lines division of AT&T provided long-distance service. The Western Electric Company manufactured the telephone, switching systems, transmission systems, and other equipment used to provide service. At one time, Western Electric even supplied the sound equipment for early motion pictures. Bell Telephone Laboratories, Incorporated – which was owned jointly by AT&T and Western Electric – performed research and development (R&D) for the Bell System and also for the military.

Fig. 1-1. This Western Electric logo was used in the late 1960s. The Western Electric name and brand appeared on all telephones supplied in the United States by the local Bell telephone companies; it meant quality telephones that rarely broke. The Western Electric logo also appeared on many motion pictures as credit for the sound recording. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

The federal government had attempted over the decades to break up the Bell System, usually requesting a spin-off of Western Electric. As a result of an antitrust case entered in 1974, the Bell System was dissolved on January 1, 1984, and Bell Telephone Laboratories, Incorporated ceased to exist. However, a new AT&T Bell Laboratories, Inc. and a Bell Communications Research were created to perform R&D for AT&T (which still owned Western Electric and Long Lines) and the seven newly formed regional Bell operating companies (RBOCs).

It seems once started, breakups and reorganizations can become never-ending. In 1996, the former Western Electric manufacturing activities were spun off from AT&T with the creation of a new company called Lucent Technologies, which had a Bell Laboratories as its R&D entity. Another new entity AT&T Laboratories was created to perform research and development for AT&T. In 2006, the French company Alcatel acquired Lucent and renamed the combined company Alcatel-Lucent, with Bell Laboratories continuing as its consolidated R&D entity.

Although economists seem to assume that monopolies are inherently evil, the Bell System was, in my opinion, a benevolent monopoly. It was strongly committed to serving the public, to keeping prices affordable and ever decreasing, and to advancing and using the very best technology. But the times changed, and competition became the new guiding principle. Thus the Bell System was broken apart. Over time, the rationale for retaining its own manufacturing unit, Western Electric, no longer was valid, and Western Electric had become a costly liability. But AT&T was convinced that its future was in computers, and thus retained Western and divested its profitable local telephone companies – perhaps the biggest strategic blunder of all time. Eventually, in 2005, SBC Communications, formerly Southwester Bell Corporation, acquired AT&T.

One of the strengths of the pre-divestiture Bell Telephone Laboratories was the freedom to pursue long-term fundamental research and for the development areas to invent and develop new technologies that were used in the network. The Bell monopoly afforded that freedom. With the demise of the Bell monopoly, that freedom became difficult to preserve on the large scale of the past. More about what made Bell Labs what it was will be discussed at the end of this piece. This piece is mostly focused on pre-divestiture Bell Labs during the 1960s.

The formal official name for the organization formed in 1925 and disbanded in 1984 was Bell Telephone Laboratories, Incorporated. But most knew it as simply Bell Labs, or Bell Laboratories. It was abbreviated “BTL.”

After the Bell breakup of 1984, a succession of names was used for the many R&D operations that followed: AT&T Bell Laboratories, Inc.; Bell Laboratories; AT&T Laboratories; Bell Communications Research, Inc.; Avaya Labs; and AT&T Shannon Labs. All these R&D operations have some claim to the legacy of Bell Telephone Laboratories, Incorporated. However, one of the progeny has a stronger claim than the others; that one is Bell Laboratories, which is the R&D division of Alcatel-Lucent. This is because it cares about its historical legacy and also because it occupies the Murray Hill, New Jersey headquarters of the former Bell Telephone Laboratories, Incorporated.

A few years after the Bell breakup, the National Science Foundation asked me to determine the effects on Bell Labs. I studied the data for such measures as number of people involved in R&D, sizes of budgets, and number of patents before and after the breakup. The R&D effort after the breakup was fragmented, and therefore the various components had to be reassembled for a comparison. I concluded, “R&D has faired well through divestiture in terms of funding and human resources.” But I also foresaw “legitimate uncertainties and concerns about the future.”[3]

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[3] A. Michael Noll, “Bell System R&D Activities,” *Telecommunications Policy*, Vol. 11, No. 2 (June 1987), pp. 161-178. Also by Noll: “The Effects of Divestiture on Telecommunications Research,” *Journal of Communication*, Vol. 37, No. 1 (Winter 1987), pp. 73-80. “The Future of AT&T Bell Labs and Telecommunications Research,” *Telecommunications Policy*, Vol. 15, No. 2 (April 1991), pp. 101-105. “Telecommunication Basic Research: An Uncertain Future for the Bell Legacy, *Prometheus*, Vol. 21, No. 2 (June 2002), pp. 177-

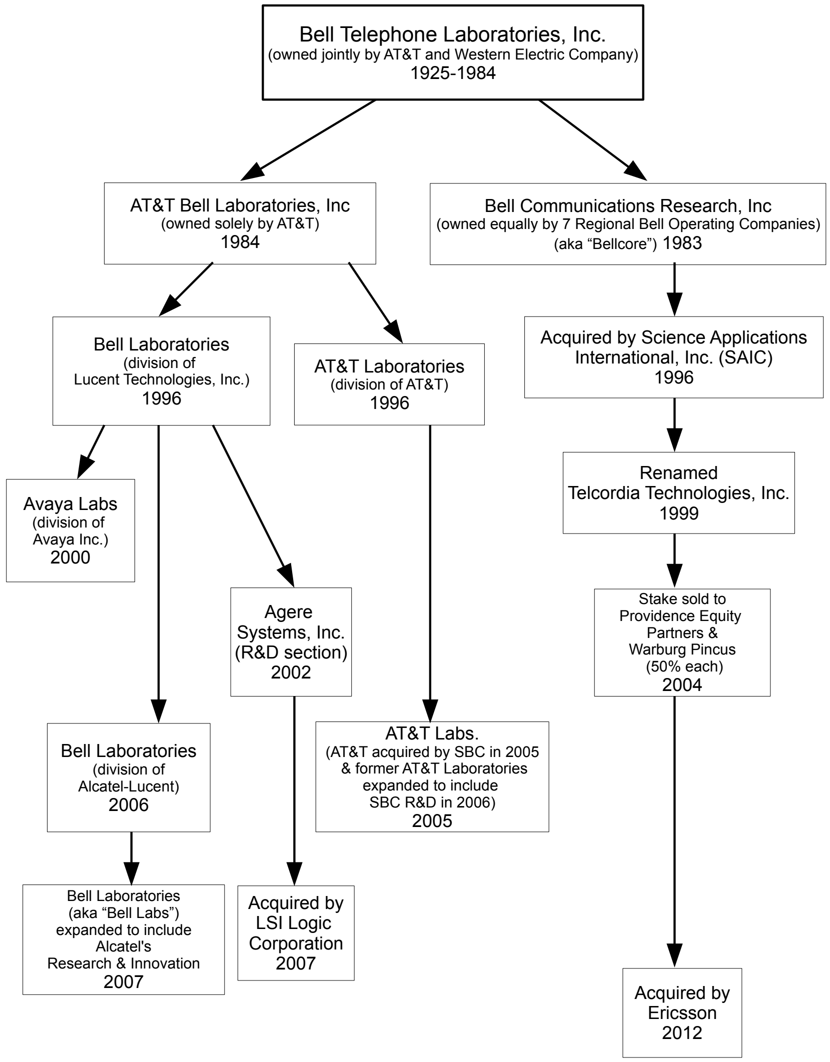


Fig. 1-2. This chart shows the history of Bell Telephone Laboratories, Incorporated (BTL) and its progeny. With the breakup of the Bell System in 1984, the scientists and engineers of BTL were assigned to the newly formed AT&T Bell

193. "The industrial research lab: a relic of the past," *Nature Materials*, Vol. 5, No. 5 (May 2006), pp. 337-338.

Laboratories, Inc. or to Bell Communications Research, Inc. (Bellcore). Bellcore was owned equally by the seven Regional Bell Operating Companies (RBOCs) and then went through a series of renaming and being acquired, until today it is no longer existent. AT&T Bell Laboratories was split in 1996 with the creation of Bell Laboratories as the R&D division of the newly formed Lucent Technologies and an AT&T Laboratories as a division of AT&T. AT&T Labs continues today as the R&D unit of Southwestern Bell Corporation, which acquired AT&T in 2005 and renamed itself AT&T. Lucent's Bell Laboratories continues today as the R&D division of Alcatel-Lucent. It still occupies the Murray Hill facility. As a Lucent spin-off, Avaya Labs was created and exists today. LSI Logic acquired Agere Systems. [Chart prepared by A. Michael Noll. Copyright © 2015 AMN]

This history is about Bell Telephone Laboratories, Incorporated; it is referred to as Bell Laboratories or just Bell labs. There is one small area of possible confusion though. Bell Laboratories, Inc. is a firm in Madison, Wisconsin that manufactures rodent and pest control products. It also refers to itself as Bell Labs.

Bell Telephone Laboratories, Incorporated started operation on January 1, 1925, with Frank B. Jewett as its president and Harold D. Arnold as director of research. It was formed mostly from the Engineering Department of the Western Electric Company and was housed in a building at 463 West Street in New York City. It would move to Murray Hill, New Jersey in 1941, although the West Street address remained its official headquarters until 1966.

ORGANIZATIONAL STRUCTURE AND MANAGEMENT

The professional staff had a hierarchy: Technical Aid (TA), Senior Technical Aid (STA), Associate Member of the Technical Staff (AMTS), and the most senior level, Member of the Technical Staff (MTS). Even the President of Bell Labs would refer to himself as an MTS.

Fig. 1-3. Bell Telephone Laboratories, Incorporated was initially located in New York City at 463 West Street in a building complex that extended back a full city bock. In 1941, most of the Bell Telephone Laboratories people moved to Murray Hill, New Jersey, although West Street remained its official address until 1966. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

There were many different kinds of excellent support staff, such as: machinists, photographers, secretaries, drafting people, glass blowers, clerks, and many others, all with their own titles and various levels. I recall that the drafting people were excellent professionals; they were true "artists" in what they designed and drew. The machinists were able to make the most complex prototypes and unique equipment used for research and development.

As a matter of policy, most engineers and scientists doing research were expected to perform their own work. That way the results of research would be observed directly and some unexpected finding not ignored. Technicians usually worked closely, and often in partnership, directly with their supervision. However, teamwork was an important factor in most development work.

At the very top of Bell Labs was its President – Dr. James B. Fisk in the 1960s. A number of vice presidents reported to him, mostly in charge of various development areas. Dr. William O. Baker was the vice president in charge of the Research Area, and also the patent and legal areas. Other vice presidents headed various development and systems engineering areas. Research was a formal area, but some applied research was performed in development areas, as was exploratory development. But these types of characterizations can be blurry; perhaps the time horizon of the work is more significant, with work in the Research Area being more long term and with a less uncertain outcome.

Although most of the employees in the Research Area, and some employees in development areas, had doctorates, only Dr. Fisk and Dr. Baker were referred to as "Doctor;" everyone else whether they had a doctorate or not was called by their first name or formally referred to as Mister, Missus, or the new "Ms" when it came into vogue. In this history, I will continue this tradition and usually use the formal "Dr." only for Baker and Fisk. Below vice presidents were executive directors, and then came directors, department heads, and finally supervisors.

Education mattered at Bell Labs. Bell Labs actively recruited and hired new graduates at the top of the class from various colleges and universities around the United States, Europe, and elsewhere. Most of the engineers in development were hired with bachelor degrees or master degrees in engineering. To hire more such professionally educated engineers, during the late 1950s and 1960s Bell Labs operated a large, formal education program, called the Communication Development Training Program (CDTP), and nicknamed "Kelly College" after Bell Labs president Dr. Mervin J. Kelly who created it. Newly hired engineering graduates were enrolled in a formal masters program that was taught at Murray Hill by faculty members who were bused to Murray Hill from New

York University. This was a two-year program in which the employees took courses during workdays, and some actually did nothing other than study for the courses during the rest of the week. Hundreds of newly hired employees entered it each year as a means for Bell Labs to hire and train the very best engineers. At that time, “communications engineering” was not a formal area of study at universities. A program was also created in which new hires with bachelor degrees were sent to various universities to study on campus to obtain their master degrees, with their expenses paid by Bell Labs along with partial salary. A somewhat similar program sent a few engineers with masters to study on campus for doctorates.

Fig. 1-4. Mervin J. Kelly was president of Bell Labs from 1951 to 1959. He invented the concept of branch laboratories located at Western Electric plants. [Courtesy of A&T Archives and History Center.]

Most of the MTSs in the Research Area had doctorates, and some of the people in the development areas also had doctorates. My supervisor (Reginald A. Kaenel) for a summer internship in a development area had a doctorate of science. Two of my early office mates had doctorates in psychology. A human factors area in development conducted what could be considered research, though it was applied to practical problems, such as the order of the digits on a telephone touchtone pad. I conducted human factors studies of the subjective effects of peak clipping, and also analyzed subjective data about telephone sidetone.

MTS engineers and scientists were expected to perform their own lab work, including recording their own data and interpreting it. This was so that the responsible engineer or scientist would discover any anomalies in the data or other unexpected results. Technicians and other support staff in the Research Area were for the entire department and usually were not assigned to an individual engineer or scientist.

There was a formal program of rotational assignments in which an MTS would spend a few months working at a telephone company to see how the real work was being performed and then return to Bell Labs with this practical knowledge and perhaps invent a better way to do the work. Some newly minted Ph.D. graduates would come to the Bell Labs Research Area for a year or so as an intern before leaving for a university position or even a job at another company.

A good example of the ties between Bell Labs and academia was the research in masers and lasers done at Bell Labs by Arthur I. Schawlow and Charles W. Townes. Schawlow was an MTS researcher and even a student at Columbia University, while Townes was a professor at Columbia University with a consulting contract to Bell Labs. Together they patented and assigned to Bell Labs their idea for a laser; the patent was filed in 1958 and granted in 1960.

Each engineer and scientist was issued a lab notebook in which to record and enter data and discoveries. These notebooks were bound and numbered. Any entry that might be patentable was to be read, witnessed, and signed by a colleague. All these old notebooks are stored at the AT&T Archives in New Jersey. Lab notebooks are still issued today at Alcatel-Lucent's Bell Labs.

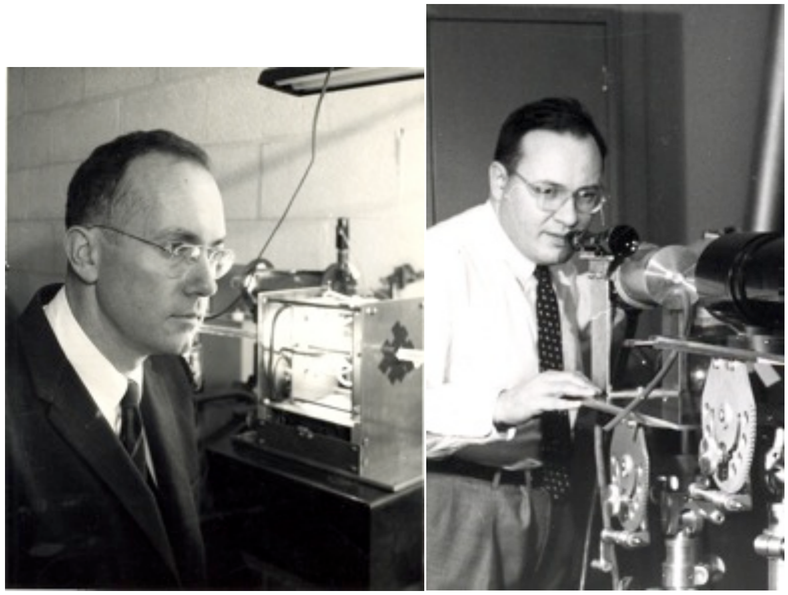


Fig. 1-5. Charles W. Townes (photo on left) invented the maser, and he and Arthur I. Schawlow (photo on right) collaborated in developing the laser. [Courtesy of AT&T Archives and History Center.]

The patent department hired the very best patent attorneys, who mostly had both engineering and law degrees. Some were initially engineers who then were sent to law school at the expense of Bell Labs. Bell Labs had a security department that was responsible for issuing ID cards and also for government security matters.

Merit Review of the MTS professional staff was a formal process conducted each year. Technical memorandums, published papers, talks, patents all mattered. I recall making a list each year of my accomplishments and giving it to my Department Head, but at the time, I had no idea what happened next in the process. I would be told at the end of the process that I received an increase in salary. What actually happened was a very elaborate and lengthy process.

Department Heads in a specific division would all gather and attempt to make a rank ordering of all their MTSs. There could be much debate and disagreement about why one person was ranked higher than another. A rough list would be established, along with comments to justify the ranking. That list would then be submitted to the director for a final rank order merit list. The list was divided into octal bands. There then would be a separate salary review, placing it next to the merit list. If a person was out of line, for example, a person had been ranked high in the merit list and lower in the salary order, then that person would get a high raise to correct the person's salary part way.

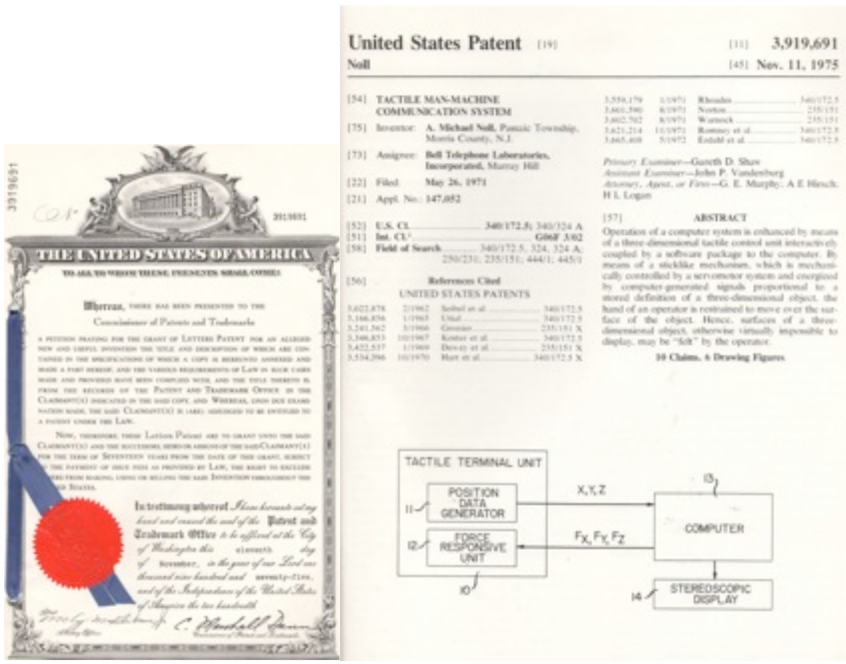


Fig. 1-6. In 1965, engineers and scientists at Bell Labs were being issued a patent a day. Shown here is Patent Number 3,919,691 for a "Tactile Man-Machine Communication System," filed May 26, 1971 and issued November 11, 1975. The inventor was A. Michael Noll; the assignee was Bell Telephone Laboratories, Incorporated.

Department heads had a copy of the official “Green Book” that contained information about salary versus age and later experience years plotted in octal bands. The plots rose sharply for young people and then flattened out, and increased overall each year for overall cost of living adjustments. An independent employee organization solicited information about individual salary and raises, but without individual identification, and published it yearly in a report for all to see.

Clearly this was a challenging process. Some people had more difficult assignments than other. Department heads were clearly biased toward their own people. There were personality clashes between department heads, which would filter down to biases toward their people and against others. It was up to the director, who also usually knew of the work being done by the various people in the larger organization, to make the final decision. Some directors would meet openly with all their people to describe the process, although any information about particular employees was confidential.

A formal yearly process determined the budget for each department at Bell Labs. Individual scientists and engineers would request funds to purchase equipment or special supplies for the coming year, and these requests would be totaled, and modified as appropriate, at the department level, and then on upward. After formal review, higher management would set funding levels.

There were different budget categories: direct charges (DC), which included salaries with loading and other operating expenses; blanket plant (BP), which included equipment; and specific plant authorization (SPA), which included expenditures for large pieces of equipment. Blanket plant items had to be ordered and delivered before the end of the budget year, with no carry-over, which could create a spending orgy at the end of the year. Sometimes, with a wink from management, blanket-plant items would be ordered and empty boxes shipped and received to avoid losing the approval for the expenditure at year-end.

If a department exceeded its budget before the end of the budget year, a spending freeze then had to be imposed. Once in a while a broader spending freeze might occur across entire divisions because of inaccurate budget estimates. Clever department heads, however, knew how to play the system to protect and even enhance their budgets. The headcount of people in a department was specified by the number of equivalent MTS (EMTS), with TAs and others as a fraction of a MTS.

Chapter 2

MURRAY HILL

BUILDINGS

The headquarters of Bell Labs was at the Murray Hill, NJ facility. The president of Bell Labs had his office there. The personnel, legal, and public relations areas were also there. During much of its early years, the entire Bell Telephone Laboratories was housed there after moving from West Street in New York City, although the West Street address remained the official corporate address until 1966.

The Murray Hill facility was located on Mountain Avenue, and its first main building was completed in 1941. The Bell Labs areas that were previously located in a building on West Street in New York City moved to the Murray Hill facility. At that time, the Murray Hill area was very rural, with farms and the associated locally operated vegetable and apple cider stands. Some of the West Street employees continued to live in New York City and took the train to Summit Station and then a bus to Murray Hill.

Murray Hill, named by its founder for the Murray Hill area of New York City, is located in the townships of New Providence and Berkeley Heights, New Jersey. The property line cuts across the front lawn of the location, and although the address and zip code are in New Providence, the buildings and thus most of the tax ratables are in Berkeley Heights. The property had to be used for research purposes only, with no manufacturing allowed.

A few years after the first building (Building 1) was completed, a second large building (Building 2) was constructed to the east and completed in 1949. The main corridor between the buildings was the second floor of buildings 1 and 2, with a concourse connecting

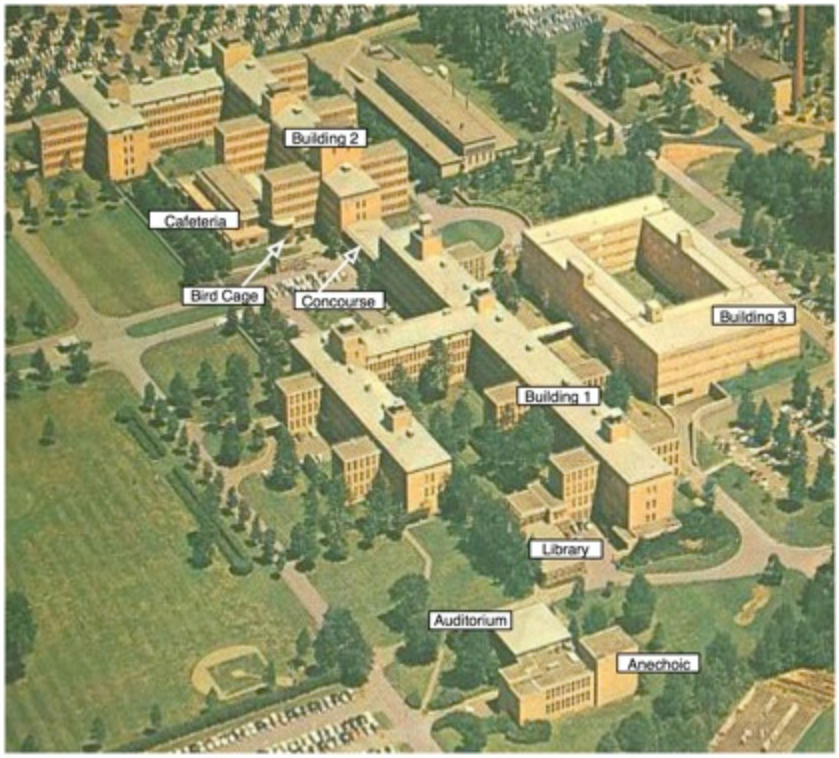


Fig. 2-1. Aerial photograph of the Murray Hill, New Jersey facility on Mountain Avenue in the mid 1960s. Research and development were performed in Building 1 (completed in 1941) and Building 2. A Concourse connected Buildings 1 and 2 on their second floors. A glass-enclosed circular staircase (called "the bird cage") went from the second floor to the Cafeteria on the ground floor. The computer center, medical offices, patent department, and administration were in Building 3 (completed in 1959). The Library was at the western end of Building 2 on the ground floor. The Auditorium and Anechoic Chamber were separate buildings on the western end of the property. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs. Captions by A. Michael Noll.]

them. A roadway passed under the concourse and was used by the little bus that came to Bell Labs from the train station in Summit. There was a stairway from the concourse to the roadway and a circular drive for the bus to turn around behind the concourse.

Before I had my own automobile, I took this bus from and to Summit everyday, after taking another bus from Newark, which was a trip of well over an hour and had to be reversed to get home.

Building 3, intended mostly as an office building, was completed in 1958 and contained the computer center, patent attorneys, medical, media relations, and classrooms. A covered ground-level unheated walkway, nicknamed “pneumonia alley,” connected Building 1 to Building 3 on its first floor. Building 3, which was a four-story structure, was air-conditioned and thus was a popular place to be during the hot summer months. In the early 1960s, some scientists made up excuses, such as the need for low humidity to make high resistance measurement, to justify their need for window air conditioners. Management ultimately gave in, and in the mid 1960s, Building 1 was air-conditioned and then Building 2. Before air-conditioning, there were electric fans in offices and labs. Windows could be opened also, but dirt from outside would blow into the labs and offices. Once in a while, it would be so hot that many people would be allowed to leave early. Bermuda shorts were another solution.

Buildings 1 and 2 each had five floors of laboratories and offices. The labs were located on each side of a main corridor; offices were in wings off these corridors. Such facilities as electric power, forced air, and exhaust were available. Wooden lab benches were used for experiments and also as work places for engineers and scientists. Technicians and some MTSs had their desks in their labs. Often two MTS would share a separate office located in the wing off the main corridor. Office doors were always kept open. A closed door at a supervisor’s or department head’s office meant serious conversation was occurring. People would meet in hallways for conversation. However, it is a myth that the buildings were designed deliberately with long corridors to facilitate interaction.

The walls were moveable metal and fixed dimensions so that offices and labs could be easily changed and reconfigured as needs required. Service, such as electrical power and common gases were provided to the labs behind a partition along the outside walls. I recall someone constructing a box for suggestions and attaching it with a magnet to the metal wall outside the cafeteria. It disappeared quickly. Management did not think it funny.

Buildings 1 and 2 each had an attic and a basement. Storage space and a few dedicated labs were in the basements, along with physical plant facilities for plumbers and electricians. Photography was located in the attic of Building 1, along with the stockroom, which was also known as the "gift shop." Bell Labs pencils, which were imprinted with "Bell System Property," and unique four-ring pads of paper and blue four-ring binders were very popular at holiday time and showed up outside Bell Labs. Employees listed the items they took on slips of paper so that their cost could be billed back to departments and work cases.

Fig. 2-2. Circular glass windows enclosed a spiral staircase from the second to the first floor of Building 2 at Murray Hill. This was known as the "bird cage" and was the entrance to the cafeteria. The photograph is from 1960. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Chemistry labs had much glass, chemicals, and exhaust hoods. Showerheads with a pull handle hung from the ceilings in corridors with chemistry labs, in case a shower was needed because of a chemical spill. Since I did not recall any drains in the floor, I wondered whether the showerheads were just props to make the chemists feel safe. However, the showerheads were tested regularly with a large drum to catch the water. There were facilities for washing eyes in case of a chemical accident. Colored lamps on the sides of corridors and various bell signals were used to summon guards and medical help in case of an emergency. A safety department assisted in the design and monitoring of laboratories that might have unsafe poisonous materials or high voltage equipment.

Tektronix oscilloscopes were highly sought after. They were so large and heavy that they had their own wheeled-carts. Plug-in units were used for signal amplification and for different time sweeps. Vacuum tubes were used in the oscilloscopes, which would become quite warm after hours of use. Hewlett-Packard made most of the voltmeters and audio oscillators. Soldering irons and the smell of solder resin filled many labs as engineers designed and constructed various devices and prototypes. Wires and cables were hanging everywhere.

Fig. 2-3. Nearly every engineer at Bell Labs wanted their own cart-mounted Tektronix oscilloscope, but they were costly and had to be shared. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

There were huge parking lots for the employees. All employees were treated equally, and there were no assigned spaces during the 1960s. One large lot was at the east end of Building 2; another at the west end of Building 1 by the Arnold Auditorium. There was a third parking lot behind Building 3, up a little hill. Separate entrances served all three parking lots, each entrance with a human guard to examine and check each person's photo identification card. Guards would over time get to recognize most of the employees. There is a story that an employee pasted a photograph of a monkey on the ID card, and the guard looked at it and allowed the person entry. At night, only the main entrance was available, and a sign-up sheet was mandatory for access. Watchmen made rounds at night.

Fig. 2-4. The library at Bell Labs in Murray Hill contained an exhaustive collection of scientific and technical books and journals, and was maintained by a professional librarian staff. This photograph is from 1968. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Freight elevators were located in Buildings 1, 2, and 3. They were quite large in order to move large pieces of equipment and were very slow moving. Passenger elevators were available and were more frequently used by the employees. The pagoda-like structures on the roofs, which some people in the surrounding communities believed were guardhouses, were where the motors for the elevators were housed. The roofs were copper sheets, which had turned to a nice green patina. There also were staircases for those in a hurry. I recall that John R. Pierce always used the staircases – he was always in a hurry.

The library was located in a separate one-story addition at the northwest end of Building 1. It was accessible from a stairway at the end of a short wing of Building 1. Offices for librarians were along that wing. This was a scientific and technology library, housing books and professional journals in a well-maintained world-class collection. It was one of the earliest to replace its card catalogue with a computerized index – and then destroy the cards.

Fig. 2-5. Buildings 6 and 7 at Murray Hill were completed in 1974 and were situated between Buildings 1 and 2, replacing what used to be a Concourse. Building 7 was to the rear; Building 6 with its pyramid-like structure was to the front and became the main entrance to Bell Labs. Two covered walkways extended to the sides of the pyramid, like welcoming arms. Executive offices and the library were in the pyramid structure of Building 6. This dramatic aerial photograph is from the early 1980s. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

During the early 1970s, two new large buildings (Buildings 6 and 7) were constructed at the Murray Hill location and completed in 1974, though sections were occupied in 1973. They were situated in and behind the space between buildings 1 and 2, and eliminated the concourse between them. A new cafeteria was located on the first floor of Building 6, including a large service restaurant. Covered walkways were at the front, as if embracing arms. There was a large lobby at the entrance, extending the full height of the building. Executive offices lined the lobby and had exterior balconies. The library was on either side of the second floor of this lobby area. There was supposed to be a programmable water fountain at the front, but it was never constructed; instead some trees were planted there. All this seemed costly and overly fancy. I recall Dr. Baker remarking to me decades later that this construction project was not his idea, and that he would have built to the west rather than create the concentration of the new buildings.

ARNOLD AUDITORIUM AND FREE-SPACE ROOM

At the very most westerly portion of the Murray Hill complex was a modern-looking building – the Arnold Auditorium. It was named in honor of Harold D. Arnold, a research director at Bell Labs who made significant improvements in the 1910s in the design of Lee de Forest vacuum tubes. The auditorium was designed with acoustics for human speech so that a person speaking at the front could be heard throughout the building. Conferences and professional meetings were held there in the 1960s – and even today at the Alcatel-Lucent facility.

Located next to the Arnold Auditorium was a separate building that housed the anechoic chamber, or free-space room. Gerhard M. Sessler and James D. West worked there as part of the acoustics research department. They were working on thin foils that had a permanent electric charge – called foil electrets. They invented a microphone – the electret microphone that is today used in nearly every cell phone, personal computer, and many audio devises.

With its legacy to Alexander Graham Bell, sound, hearing, and acoustics were essential topics of interest to Bell Labs research and engineering from even its foundation in 1925. Noted acoustic researchers Harvey Fletcher and Wilden Munson (responsible for the famed Fletcher-Munson loudness curves) were at Bell Labs.

Fig. 2-6. Photograph of the anechoic chamber, or free-space room. A wire grid formed the floor. Manfred R. Schroeder is standing and James E. West is sitting as they perform acoustic measurements in this room without echoes and with perfect silence. [Photo courtesy of AT&T Archives and History Center.]

Sessler and West also were responsible for the anechoic chamber during the 1960s. There was a huge thick door on the second floor of their building, which was the entry to the chamber. All the walls, floor, and ceiling were lined with sound-absorbing battens, and the floor was raised wire mesh so that it had no effect on the acoustics. Once the door was closed, there was absolute silence – a very weird feeling. The wire floor was quite bouncy, so that one had to walk slowly and carefully – it was not a trampoline. Being in the chamber was like being in a huge outdoor open field in which sound would not be reflected back, in effect, open, or “free,” space. But no sound entered either, so there was absolute silence – an eerie feeling. The anechoic chamber is still used today by Alcatel-Lucent’s Bell Labs.

Chapter 3

AMENITIES AND INFRASTRUCTURE

AMENITIES

Amenities that are today raved about as being novel in research and development labs were available in the 1950s and 1960s at Bell Labs – and after. There was a medical department on the premises, including nurses and a physician. Routines exams and facilities for emergencies were all available. Table tennis was very popular, and there were ferocious tournaments during lunchtime and after work. The Chinese game Go was quite popular at lunchtime. There were various clubs; some such as the ski club and swim club attracted singles. There were two softball fields that supported softball leagues.

The cafeteria was located on the ground floor in a wing of Building 2. It was accessible from a circular staircase from the second floor. Windows surrounded the circular staircase, which was nicknamed "the birdcage." There was a lobby on the second floor with chairs and tables where people would sometimes meet and congregate. Various card games and Go were there for play after lunch.

Service dining rooms were on the second floor and could be reserved for special luncheons, usually with visitors or important management meetings. You could have a full meal in the service dining area without a reservation, ordering from a menu and being served. The cafeteria was self-service trays with high-quality meat, vegetables, and deserts, and sandwiches that were made to order, and was open to all employees. Chance meetings occurred there often, on an ad hoc basis, if someone accidentally met a colleague in the food service area. I recall ordering a sandwich with my tray when a voice next to me would say, "Mike, do you mind if I join you?" It would be Dr. William O. Baker, who was vice president of the entire Research Area. He usually had lunch at the cafeteria and would join his researchers on an ad hoc basis.

Paychecks, vouchers, and reimbursements could be cashed at a cashier's counter. Hotel, airline, and other arrangements were made at a travel office. Travel was carefully monitored, and advance approval was required. There were lounge areas for female employees, although there were fewer rest rooms for women than for men. A large building behind Building 2 was nicknamed "the elephant house" because of its high ceilings and large open space; it contained some service shops. The garage and motor pool were located in Building 14 and included a fire engine for emergencies and also cars that could be checked out by employees.

Shipping and receiving, with a large loading dock, was located at the east end of Building 2. Various delivery trucks would be there every day, and their parcels would be then delivered to the offices and labs. There was also a loading dock at the west end of Building 1. A purchasing department placed orders for equipment and supplies from various vendors; formal approvals were required for purchase orders, with different levels of management having different authorization limits.

Large tanks stored the various gasses used in the labs. Some compressed gases were delivered in cylindrical compressed gas tanks to the labs and strapped to anchors on the walls; empty tanks were then placed in the corridors for replacement. Liquid nitrogen was delivered in insulated metal containers. Compressed air and gaseous nitrogen were provided to most labs by pipe distribution. A large boiler house supplied the heat for all the buildings, and once air-conditioning was installed, a large air-conditioning cooling structure was built behind Building 3.

Local high schools and employment agencies supplied candidates for entry-level jobs, such as typists for the typing pool, clerks to deliver mail, keypunch operators. More trained functions, such as painters and carpenters, had their own apprentice program of advancement. Typists would be promoted to secretaries, for which there were levels of seniority. Mail was delivered from receiving to various substations by pneumatic tubes and then delivered to each office by a cart, pushed usually by a mail-girl, and rarely by a mail-boy. Employees were expected to have an IN and an OUT tray, and also expected to keep their desks neat and free of paper and documents at the end of each day.

At night, the cleaning people would come around and empty trash baskets and clean the floors. Once in a while, they would also dust the tops of desks. Department heads and higher had secretaries who were expected to clean their boss's desk, file documents, take dictation, type, and even get coffee. Over time, secretaries became more independent and these kinds of non-secretarial expectations ceased.

Engineers and scientists would write their memos by hand and take them to be typed at the typing pool. Stenographers were available to type dictation. A few professional staff would have their own typewriter, with IBM Selectric™ typewriters being highly prized, but typing was perceived to be a clerical function. As computer terminals became available in the 1970s to access the time-shared Unix operating system with its word processing component, the professional staff started to do their own typing.

The official work hours were from 8:45 AM to 5:15 PM, with a break for lunch. The professional staff worked longer hours, although scientists had much leeway to manage their time. The primary metric was producing creative ideas. Two weeks of vacation were standard for new hires, although for many just working at Bell Labs was one long vacation. Unused vacation days could be carried over to the following year with approval. However, some scientists would not even bother to use their allotted vacation days and preferred to "work." In some instances, they had to be ordered to take a vacation since it was meant to rejuvenate creativity.

I recall that Edward E. David, a research director, had returned from a vacation trip along the Coast Highway in California and had a slide show in a conference room of all the photographs he had taken. Bell Labs paid trips to present a paper at a professional conference was a great perk and the opportunity for a few days of vacation along the way. Las Vegas and California were very popular destinations in the United States, as were Europe and Japan.

In addition to a photo ID card, employees also had security badges with different colors indicating different security levels. As I recall, there were three major levels of security classification: confidential, secret, and top secret, and other less-known very high security classifications. Most government-classified work was done at the Whippany, NJ facility, but some classified work was also done at Murray Hill and other Bell Labs locations. I had a security clearance and performed some research that was classified.

When I first came to Bell Labs as a regular employee in 1961, I worked in a development area and shared one large office with three others. We all reported to our supervisor, John L. Sullivan, Jr. Later, when I was transferred to the Research Area, I had my own private office – a real perk. An MTS in research was treated as if a supervisor in development in terms of a private office. But some MTS in the Research Area preferred to have a desk in the lab rather than in a private office.

There was no official uniform, but MTS engineers and scientists all wore ties and jackets. Senior management wore suits, even with vests. Chemists would usually wear white lab coats when working in their labs. While working in their labs, most engineers and scientists would remove their jackets. Jackets and ties were worn at the cafeteria. There was a sense of a professional dress code. Today, the dress code at most R&D facilities has become quite informal.

COMPUTER CENTER AND COMPUTING

The computer center at Murray Hill had the very best mainframe IBM computer for scientific and engineering purposes. The center had its own professional staff, including system programmers who were developing innovative hardware configurations and software packages. In the early 1960s, the computer center at Murray Hill had an IBM 7090 machine, which was upgraded to an IBM 7094 machine. It was huge, and the floor was raised on floor panels to allow all the cables to be snaked under the floor.

Fig. 3-1. The computer center at Bell Labs in Murray Hill around 1963 consisted of an IBM 7090 computer. Input and output were on magnetic tape. The operator monitored the operation of the computer at a console. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Computer programs and data were all entered onto IBM punched cards. There were keypunch operators to punch out the IBM cards, and also keypunch machines that engineers and others could use to punch cards themselves, or correct program errors. High-speed printers made the reams of papers listing the programs and the results of calculations. Tables of numbers would be hand-plotted to create graphs. The solution was the Stromberg-Carlson SC-4020 microfilm plotter, which was intended as a high-speed printer. However it could also create plots of data, thereby eliminating the need for hand plotting. This was quite significant since changes in programs and data could be more easily done and the results seen quickly. It was soon realized that the SC-4020 could be used for computer animation for scientific and artistic purposes.

Fig. 3-2. Punched cards were used for batch processing on computer systems in the 1960s and even the 1970s. Here in 1973 cards are being read in a card reader. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Bell Labs believed that time-shared computing was the future. A project was initiated to create a time-shared computer facility with terminals in laboratories. It was believed that IBM was not up to the challenge, and therefore a project, named MULTICS (Multiplexed Information and Computing Service), was initiated, with GE to supply the computer hardware (GE 645), MIT the system software, and BTL the systems integration. The MULTICS project was initiated around 1964. Although GE had not up-to-then made a large mainframe machine, it did deliver its GE-645 to Bell Labs as a replacement for the IBM 7094.

It became apparent that the system overhead for time-shared computing was substantial, and the project seemed doomed to failure. BTL abandoned its involvement around 1969. IBM then supplied its IBM-360 mainframe computer to BTL to replace the GE machine. The failure of MULTICS ultimately led to Unix and C. I recall the software researchers working in the attic of Building 2 on what would become the Unix operating system – from failure came a great success. The Executive Director of computing research was Edward E. David, Jr. In 1970, he left BTL to become Science Advisor to President Nixon. I would leave Bell Labs to join his staff in mid 1971.

My department head, Peter B. Denes, wisely doubted that a single central computer would be able to serve hundreds of research labs. Around 1965, he therefore obtained his own dedicated laboratory computer; initially a DDP-124 that was then upgraded to a DDP-224 (initially made by the Computer Control Company and later Honeywell). The computer system was primarily used for speech research, but was also used for computer music by Max V. Mathews and various visiting composers, such as Emanuel Ghent and Laurie Spiegel. The lab in which it was used had a raised floor for all the cables. There was a large hard disk drive with removable disk packs; a head crash was a disaster, destroying the disks and generating a horrible screech and odor.

Denes and his computer and software associates (Ozzie Jensen and Barbara Caspers) were, in effect, operating their own mini computer center, in addition to conducting speech research. Denes clearly showed the way for the future of laboratory computing, and other departments at Bell Labs followed his lead and obtained their own laboratory computers. I became involved in developing interactive, real-time, 3D stereographic hardware and software for the DDP-224 system, including 3D input devices and stereographic displays. I also designed a raster-scanned display, initially black and white, which later became color.

Fig. 3-3. In this staged photo, Peter B. Denes uses stylus tablet and knobs to control stick figures on screen connected to DDP-224 computer at Bell Labs. The interactive computer system was used in the laboratory primarily for speech research. [Photo courtesy of A. Michael Noll. Copyright © 2015 AMN]

As the years progressed toward the end of the 1960s, laboratory computers became more commonplace – along with the term "computer lab." Honeywell DDP-516 computers, with their red enclosures, were popular.

COMMUNICATION

Technical memoranda were the means of formal communication within Bell Labs. Whenever a discovery was made, a new piece of software written, a new piece of equipment designed, or anything other accomplished, it was described in a formal written document. These documents were known as Technical Memorandum (or TM for short). Year, four-digit department number, and sequential number referenced Technical Memoranda. For example, MM-62-1234-14 was the 14th TM written in department 1234 in 1962. The author or authors would be listed, along with the date and title. A distribution list would be on the second page. The front page would have a short abstract or summary. The distribution list would include the management of all areas within Bell Labs that might have an interest in the subject matter of the TM. In the Research Area, the distribution would always include Dr. Baker and also John R. Pierce. This numbering system continues today at Alcatel-Lucent's Bell Labs.


BELL TELEPHONE LABORATORIES
INCORPORATED

COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE— Patterns by 7090

MM—62-1234-14

DATE— August 28, 1962
AUTHOR(S)— A. M. Noll

FILING CASE NO(S)— 38794-23

FILING SUBJECT(S)— Computer-Produced Patterns
(ASSIGNED BY AUTHOR(S))

ABSTRACT

An IBM 7090 digital computer and Stromberg-Carlson 4020 Microfilm Printer have been used to produce a series of interesting and novel patterns. This paper describes the mathematical and programming techniques used but neglects any discussion of the "artistic" merits of the results.

Fig. 3-4. Technical memoranda were a formal means of communicating technical and scientific work within Bell Labs. Each memorandum had its own unique number, specifying the year, department, and sequence. [Courtesy of A. Michael Noll. Reproduced with permission of Alcatel-Lucent USA Inc. / Bell Labs.]

Colleagues reviewed drafts of Technical Memoranda and also any papers to be published outside Bell Labs. Their comments were very important in assuring the high quality of the written material. All talks and papers to be made or published outside Bell Labs had to be formally approved in advance. One reason was to assure that nothing patentable was prematurely released. A formal release form would be attached to a copy of the paper or abstract of a talk and this would be circulated with Bell Labs to the senior management of interested areas, and the patent department.

Talks for presentation outside Bell Labs at professional societies would usually be rehearsed in a conference room. People from interested areas within Bell Labs would attend and make critical comments. Someone would always have a stopwatch to be sure that the talk stayed within the allotted time. Graphics, usually professionally drawn by the drafting department, would also be reviewed. Comments would usually result in edits and improvements. Too many "uhs" were banished as not acceptable. All this internal criticism was quite collegial. I saw nothing like it during all my years on the faculty of a major university. It certainly was a factor that contributed to the reputation and influence of Bell Labs. These internal reviews also assured the high quality of papers published in professional journals by employees of Bell Labs. If a paper or talk passed internal review then it usually was accepted in the outside scientific world.

There was a program of seminars and colloquia with both internal and external scientific speakers. Experienced BTL scientists would talk about significant work being done at other research institutions.

Doctoral candidates would be interviewed for a position at Bell Labs in a process that included a formal presentation of their doctoral thesis. People from interested areas at Bell Labs would attend, and probing, often intimidating, questions would be asked. Some of the presentations could be quite bad, and some candidates were unable to answer questions adequately. These candidates were not hired. All this contributed to the reputation of Bell Labs.

I can recall being at a conference at which a paper had been just presented. Someone in the audience from Bell Labs would ask some probing questions, and then remark that the work just described had had been done years before at Bell Labs – much to the dismay and consternation of the presenter.

Bell Labs was part of the Bell System and thus was committed to service to the public during emergencies. Bell Labs engineers, usually from the development areas, were assigned to strike duty during labor work stoppages. I actually volunteered once or twice, mostly from interest in assisting during the emergency.

PUBLIC AND EMPLOYEE EDUCATION

A considerable effort was made to educate and inform employees, professionals, and the public about the accomplishments and work being done at Bell Labs. There was a public relations department at Bell Labs with a professional staff that performed media relations and also employee communications. There were quite a number of publications to keep everyone informed both inside and outside Bell labs.

The most formal internal publication was the *Bell System Technical Journal* (BSTJ). It published scientific and engineering papers, mostly by Bell Labs scientists and engineers, from 1922 to 1983, with about 6 issues per year. It was distributed free to technical libraries around the planet. Entire issues would sometimes be devoted to important large projects, such as the *Telstar* telecommunication satellite or a specific switching or transmission system. There also was a *Bell Journal of Economics*, which dealt with real data and not the theoretical issues typical of university research.

The *Bell Laboratories Record* was intended mostly for employees. About 12 issues were published a year. It was originally in black-and-white and included employee news along with technical articles intended for a more general audience. It then was published in color in a glossy magazine format, and renamed the *Bell Labs Record*. Scientists and engineer wrote articles for it, which were intended for a general audience. The staff of the public relations department also provided articles and other material. The *Bell Labs News* was in a tabloid newspaper format and contained news such as promotions, service anniversaries, and club photographs; it was intended broadly for all employees.

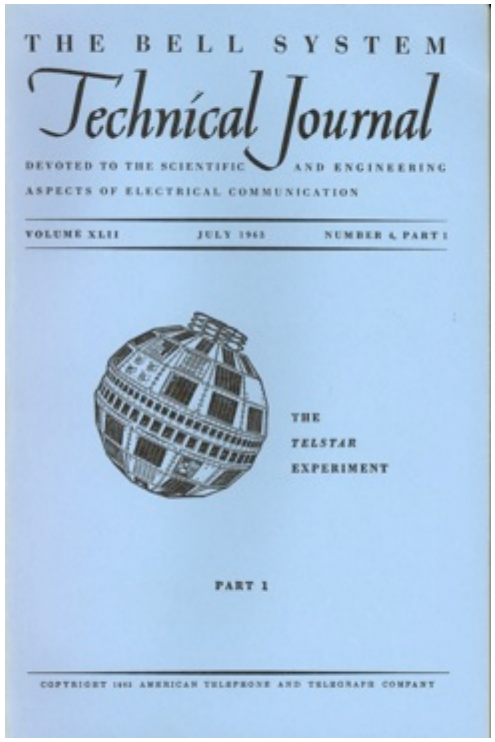


Fig. 3-5. The *Bell System Technical Journal* (BSTJ) was a formal publication of scientific and technological discoveries and innovations. Some issues were devoted to a single topic, such as this issue from July 1963, which was devoted entirely to Telstar. [Courtesy of the AT&T Archives and History Center.]

Journals printed reprints of published papers, and some of these reprints would be included in the Bell Telephone System Monograph Series, which was produced by Bell Telephone Laboratories, Incorporated. The monographs had their own blue and gray cover and were assigned a four-digit reference number. Bell System Practices (BSP) were formal instruction manuals for various Bell products and systems and how to install and use them. Bell Labs engineers usually wrote them.

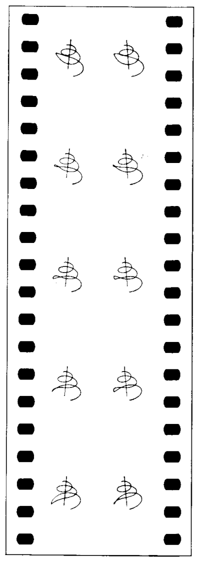
Fig. 3-6. Some published papers were reprinted in a Bell Telephone System Monograph series, with their own distinctive cover. Shown here is the cover for the 1955 paper “History of Semiconductor research” by Pearson and Brattain. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

The public relations area produced press releases and would escort members of the media in visits to Bell Labs. Members of state regulatory commissions were regular visitors. There was a formal series of advertisements, called “Report from Bell Laboratories,” which consisted of one-page reports on research projects at Bell Labs. One such report of personal interest to me was “A 3-D Glimpse of the Hearing Process,” which credited scientists Robert C. Lummis, A. Michael Noll, and Man Mohan Sondhi for a

Report from

BELL LABORATORIES

A 3-D Glimpse of the Hearing Process



THE MOVIE shows the basilar membrane as a "stereo pair" of spiral lines. The sequential frames shown here represent the motion of the membrane responding to the sound "oo" in the word "too" as pronounced by R. C. Lummis, one of the scientists responsible for the film.

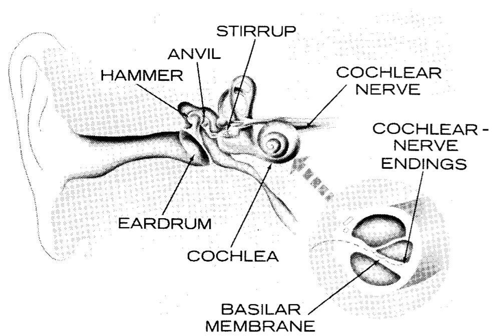
To view this illustration in 3-D, place a sheet of paper on edge between one stereo pair. Position your head so each eye sees only one image. The pictures should then seem to converge and appear three-dimensional.

For screen projection, polarized light and polarized eyeglasses are used to obtain a 3-D image.

THE BASILAR MEMBRANE is a lengthwise partition in the spiral, fluid-filled cochlea (figure). Sound, from the eardrum by way of the hammer, anvil, and stirrup, produces vibrations in this membrane. The end nearest the stirrup resonates at the highest audible tones (approximately 20,000 Hz); the end near the apex of the spiral resonates at the lowest (approximately 20 Hz).

The cochlear nerve terminates near the membrane and, by sensing the vibration at each point, converts the mechanical motion into nerve impulses which the brain perceives as a sound.

Because of its filtering and analytical functions the basilar membrane is a center of interest in hearing research. Since it is embedded in the skull, direct study is extremely difficult.



At Bell Telephone Laboratories, basic research in voice communications does not end with telephone equipment. For instance, three scientists here have made a stereoscopic motion picture showing how the ear's principal transducer—the basilar membrane—moves in response to sound.

A number of steps were involved: First, equations describing the membrane's response were converted to digital form, suitable for machine computation. Next, a program was devised so a computer could determine the precise motion of each point on the membrane as a function of any complex sound input. Finally, the resulting data were processed with another program which introduced the parallax effects inherent in binocular vision.

The output was a series of pairs of stereoscopic images. The computer drew these on the face of a cathode-ray tube where they were automatically photographed to form the frames of the movie.

In this film, the membrane's movements (actually microscopic) are greatly enlarged and slowed down for detailed examinations. Thus we have developed a promising tool for the study of hearing. For example, movies made in this way could help us evaluate theories of the basilar membrane's role in converting sound to nerve impulses. (Several complex mathematical relationships have been proposed; now we may see them in simulated action and measure their properties.)

The scientists who made this film are Robert C. Lummis, A. Michael Noll, and Man Mohan Sondhi. The membrane-response equations from which they began were originated by James L. Flanagan, also of Bell Laboratories. His work was based on anatomical measurements made by Nobel laureate Georg von Békésy of the University of Hawaii.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

Fig. 3-7. A series of one-page advertisements were created describing the various discoveries and research of Bell Labs. These ads were placed in various magazines and other publications. [Courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

stereoscopic three-dimensional computer animation of a simulation of the human inner ear.

The Bell System Science Series, initiated in 1956, consisted of one-hour programs in color for television broadcast. They were also converted to film for distribution to schools for free. The early programs in the series were written and produced by Frank Capra, and were hosted by Dr. Frank C. Baxter, an English professor at the University of Southern California, who was hired by the series. One program in the series was “Our Mr. Sun.” Dr. Ralph Bown, who was then the vice president in charge of the Research Area at Bell Labs, chaired the board of advisors for the series.

Bell System Science Experiments were experimental kits for high-school students. The kits were designed and distributed for free to tens of thousands of high-school students from about 1961 to 1968. A total of five kits was created, including: “Solar Cell Experiment;” “From Sun to Sound;” “Experiments with Crystals and Light;” “Speech Synthesis;” and “CARDIAC,” which treated computer programming. The kits included a booklet describing the scientific principles and how to use the kit.

Fig. 3-8. Bell Labs created kits to demonstrate scientific principles to high-school students and distributed these kits for free. One kit demonstrated the basic principle of speech synthesis. [Courtesy of the AT&T Archives and History Center.]

Books and booklets were written and distributed for free about various scientific topics. At least one such book became the main text for college courses about human speech and speech processing. This book *The Speech Chain* was written by Peter B. Denes and Elliot N. Pinson, and is still being reprinted and used today. *Harnessing the sun…The Story of the Bell Solar Battery* was a poplar booklet.

Bell Labs produced phonograph records about computer speech and computer music. A 10-inch 33 1/3 record "Music from Mathematics" made in 1960 was distributed in a box along with a 24-page booklet that described how computer music was created and how a sound wave could be described numerically. Bruce E. Strasser of the Bell Labs Publications Department was responsible for this phonograph record, with Max E. Mathews as Technical Consultant. Bell Labs also produced in 1963 a 7-inch LP phonograph record of computer speech, which was distributed for free for educational use.

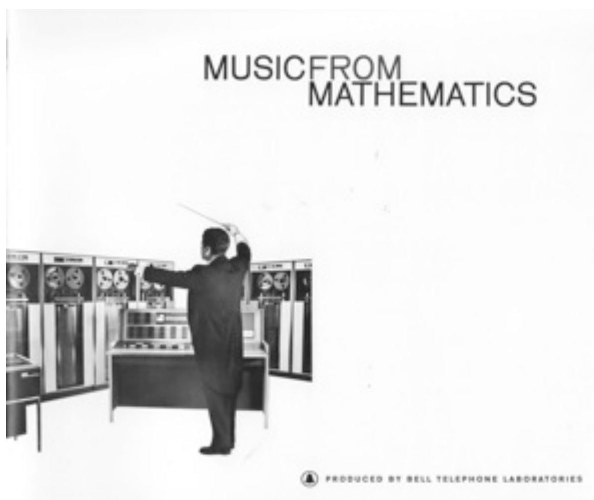


Fig. 3-9. Bell Labs produced "Music from Mathematics" and packaged it in a box that included a 33⅓ RPM 10-inch phonograph record and a multi-page booklet by Bruce E. Strasser with Max V. Mathews as technical consultant. [Photo of the cover of the booklet courtesy of A. Michael Noll. © 1961 Bell Telephone Laboratories]

An entire series of carefully documented books was produced about *A History of Science and Engineering in the Bell System*.[4] Members of the Technical Staff contributed chapters to these books, which attempted to credit all the appropriate researchers and engineers. However, in a few cases, some areas were more thoroughly described than others.

Fig. 3-10. Bell Labs produced a 7-inch 33⅓ RPM record of "Computer Speech." [Photo of the cover courtesy of A. Michael Noll. © 1963 Bell Telephone Laboratories]

There was a thick book, called the General Executive Instructions (GEI), which described the administrative procedures at Bell Labs. There were also weeklong programs for managers to learn how to handle and manage people more effectively.

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[4] The volumes in the series *A History of Engineering and Science in the Bell System* were devoted to: *Electronics Technology (1925-1975),* F. M. Smits, Editor (1985); *Communications Sciences (1925-1980),* S. Milman, Editor (1984); *Physical Sciences (1925-1980*), S. Milman, Editor (1983); *Transmission Technology (1925-1975),* E. F. O'Neill, Editor (1985); *Switching Technology (1925-1975)*, prepared by A. E. Joel, Jr., G. E. Schindler, Editor (1982); *National Service in War and Peace (1925-1975)*, M. D. Fagen, Editor (1978); *The Early Years (1875-1925)*, M. D. Fagen, Editor (1975).

There were numerous out-of-hours courses for employees taught by faculty from local schools and universities and also by employee experts. An NYU professor taught a course on Russian; a Bell Labs physicist taught courses on “modern physics” and “semiconductor physics.”

There were opportunities for summer employment at Bell Labs. I had a summer job at Bell Labs during my junior and senior years at Newark College of Engineering, and designed and constructed a difference amplifier using a negative resistance diode for amplification.

The mission of the Bell Laboratories was to assure the future of communication – and that included educating the public about the science and technology of communication. The result of such education was the next generation of scientists and engineers. And this was being done in the 1950s and 1960s – without any Federal support. STEM (Science Technology Engineering Mathematics) programs are today’s attempt to attract students to careers in science and technology. But these programs lack the support of an organization with the broad practical mission of a Bell Labs. For example, NASA is best qualified to educate the public and students about space technology since that it its mission, and NASA indeed does that very well.

Chapter 4

OTHER LOCATIONS

THE HOLMDEL FACILITY

A large complex was constructed in Holmdel, NJ in a building designed by the famed architect Eero Saarinen. A small mock-up of the building was made at Murray Hill to assist and evaluate the design of offices and labs. The initial two sections of the final building were completed in 1962 and the final two sections were completed in 1966. For fun, I used to drive down to Holmdel to

Fig. 4-1. Aerial photo of the Holmdel building, originally designed by Earo Saarinen, and the parking lots, roads, and ponds. The building was expanded in 1984. Courtesy of the AT&T Archives and History Center.]

watch the progress of the construction; my interest was also personal since the development I worked in was scheduled to move to Holmdel from Murray Hill. Development in switching, transmission, and station apparatus at Murray Hill moved to the Holmdel facility. Later Holmdel would include work in systems engineering.

The Holmdel building was decades later expanded significantly in 1982. The Holmdel property was sold in 2013 by Alcatel-Lucent to a developer for residential homes on the property and a hotel and stores in the original Saarinen building. The ultimate fate of the large building awaits the passage of time.

Fig. 4-2. The reflective glass windows of the Holmdel building looked very stark. The main entrance was covered over with dark stone. . [Photograph courtesy of A. Michael Noll. Copyright © 2015 AMN]

The Holmdel building was covered initially with dark windows that looked black from the outside. They were later changed to dark reflective glass windows, which when driving up to the building on a sunny day would reflect the sky. Some people thought it looked like a big shoebox from a distance. The interior of the building was gray and black – stark geometrics. There were two large interior courtyards extending five stories (ground plus four floors) on the sides of two interior elevator columns. The ceilings of the courtyards were glass to admit light. Narrow catwalks with railings connected the elevators to the main corridors; they were frightening to anyone afraid of heights. I usually used interior stairwells to avoid the catwalks.

Fig. 4-3. Plants and trees were placed in the atrium of the Holmdel building. Elevators were in towers in the central area of the atrium, with catwalks across to the walkways along the four upper floors. Unfortunately, the controlled low humidity was not conducive for plant growth. The somewhat stark interior with the walkways reminded some of a prison. [Photograph courtesy of A. Michael Noll. Copyright © 2015 AMN]

There were large square containers for plants, and large oval flowerpots hung from the ceiling and were supposed to be overflowing with plants. Tropical trees were planted in the courtyards. However, the controlled humidity inside the building was not appropriate for such plants, and ultimately artificial plants had to used.

There was a large water tower at the entrance to the driveway to the facility. It had three support legs, which were somewhat reminiscent of the appearance of early transistors. Large ponds, used as heat exchangers for air conditioning, were located at the front and rear of the building. These ponds attracted Canada geese, which made a mess on the nearby walkways around the ponds. Plastic swans were put in the ponds to discourage the geese from using them, but lost their effectiveness after a few years. Some creative person placed a large plastic floating monster in one of the ponds, but some maintenance person who lacked a sense of humor quickly removed it.

Offices and labs were located along interior aisles on each floor. Employees had no windows, unless an employee painted one on an office wall. There were corridors around the exterior, with the windows along one side. There also were interior walkways facing the courtyard with railings along them. The railings were designed to reduce the sense of height and the vertigo it might cause anyone with acrophobia. I recall that a number of different railing designs were tried to choose the most effective one. The use of exterior corridors, with all the offices and labs located on interior hallways, with no windows, was also used later for Buildings 6 and 7 at the Murray Hill facility. Service corridors along the rear walls of the labs provided space for gas, water, and electricity.

The main reception area was just inside the main front entrance. The area was sunken a few steps, as if its mass and weight had caused it to sink. As I recall the reception desk was stone and gray in color. The reception area was in its own courtyard extending the full height of the building. There was a large one-story cafeteria on the ground floor basement, extending out from the rear two sections of the building. It was reached from the first floor by a large staircase. Sections 1 and 2 were completed in 1962 before sections 3 and 4 were completed in 1966. The weight of the last two caused some settling which was noticeable along the ground floor corridor between the sections. Extending its sides, which destroyed its architectural proportions, expanded the original building.

The Holmdel building had a cold, impersonal environment. Some people thought the interior large courtyards of the Holmdel building looked like a prison with all the railings. Its interior was bland and impersonal. The sound of the people walking along the interior walkways was reverberant and distant. There was an Orwellian sense of uniformity that pervaded the building.

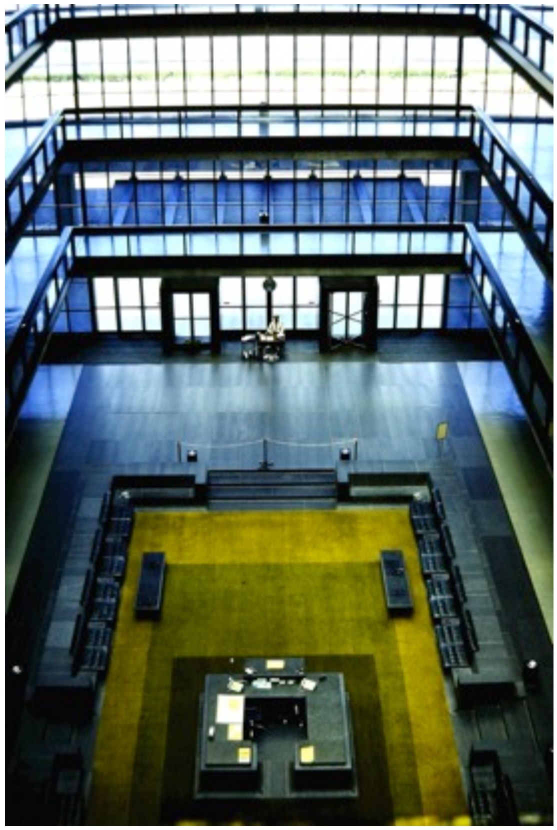

Fig. 4-4. The visitor reception area of the Holmdel building was sunken down a few steps, with sitting areas along the sides. It had a cold unwelcoming impression. [Photograph courtesy of A. Michael Noll. Copyright © 2015 AMN]

Perhaps to preserve some sense of individuality an interesting prank occurred. The people who did human factors work were moved from Murray Hill to Holmdel. I recall being told a story of how the human factors people amused themselves at lunchtime. They had determined the number of the telephone in one of the elevators, and would call that number at lunchtime when there were many people in the elevator. When someone answered, they would claim to be conducting a study of elevator service and would start asking questions as if conducting a real survey. Questions would be, “What floor do you get on the elevator? How many people are on the elevator?” The goal was to keep the person who answered the telephone on the elevator past their floor. All this was grand fun and amusement. But then one day, the executive director answered the elevator telephone, recognized who was making the call, and was not amused. That ended the prank. However, other amusements were invented, such as some employees taking to penny pitching in the hallways.

When I was working at AT&T Consumer Products, our requirements for new products had to be reviewed by the Systems Engineering organization at Holmdel. This became a source of bureaucratic paperwork and delay. We in marketing were not allowed to talk directly with the engineers at the Bell Labs Indianapolis facility – we had to go through Holmdel. The term “Holmdel” had become a curse for us.

The problem was that the systems engineers felt that they were responsible for setting the requirement and technical specifications for new products; after all, this is way it was always done in the past. However, the marketing folks felt that the systems and development engineers at Bell Labs should be following orders from marketing and the consumers that they represented. Each of these organizations disliked the other area. Ultimately, in 1983 the Indianapolis facility was removed organizationally from Bell Labs and made to report directly to AT&T Consumer Products with its own new identity: Consumer Products Laboratories. This was, in my opinion, a significant improvement.

Dr. Baker believed that a systems approach should pervade most development work, since what was done in one would affect other areas of any system. But Dr. Baker told me that he did not favor the institutionalization of a systems approach into an organization under its own vice president.

Much of the development work in switching systems was originally at Holmdel. However as the project grew, this work was transferred to a new Indian Hill facility in Naperville, IL. Holmdel became the center for development and systems work, and Murray Hill became the center for fundamental research and semiconductor development work with its world-class clean room. However, there was a creative exploratory development and applied research group at Holmdel, with its own applied research people, many with doctorates. Robert W. Lucky was one of them, and he invented a modem using an adaptive equalizer.

In my opinion, the Holmdel facility became too much of a large bureaucracy. Build a large building and the people will come, even if the work does not justify their large numbers. At one time, most of Bell Labs was housed in the Murray Hill facility. But then Holmdel was constructed, and expanded. And more space was needed – the Indian Hill facility resulted. The number of scientists in the Research Area remained fairly constant; the growth was in the development and systems areas. But this added a large R&D expense to the systems and products being made by Western Electric, making them less competitive at a time when competition was growing in telecommunication manufacturing.

OTHER LOCATIONS AND BRANCH LABORATORIES

Bell Labs scientist Karl Jansky had discovered extraterrestrial radio emissions in 1931, which became the foundation for radio astronomy. Jansky's antenna was located on the lawn of the Holmdel, NJ property; long before the Saarinen building was constructed. There were a few one-story buildings that were constructed there in the late 1920s and early 1930s. They were all razed as the Saarinen building was constructed, and the radio researchers moved around 1961 to a new long two-story building in Crawford Hill.

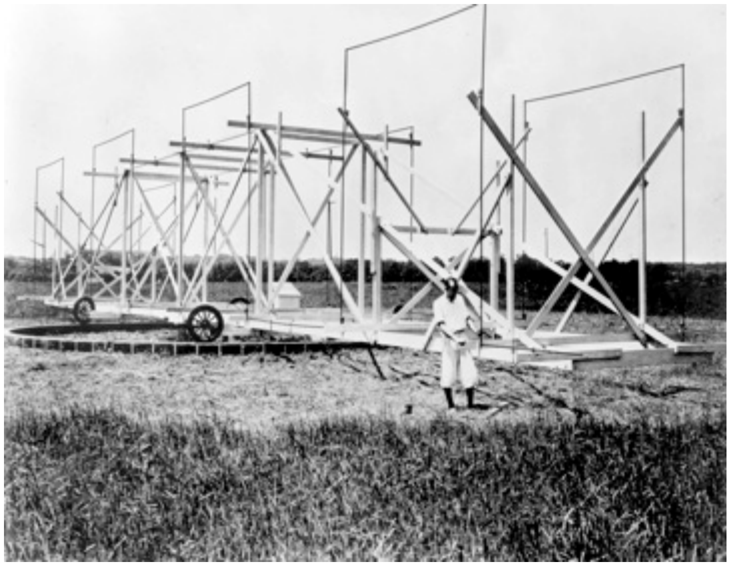

Fig. 4-5. Karl Jansky with his radio antenna in the early 1930s on the Holmdel property. The radio waves he detected formed the basis of radio astronomy. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

The Bell Labs Crawford Hill facility in Holmdel Township is about two miles away from the Holmdel Saarinen building, and still used today by Alcatel-Lucent's Bell Labs. Radio research was conducted there in the past, and wireless and optical research is conducted there today. Antenna research and design was an important topic at the Crawford Hill facility. Arno Penzias and Robert Wilson were working there in the 1964 on a horn antenna trying to determine the cause of background noise, when they realized they were actually listening to the background radiation from the "Big Bang" at the formation of the universe. They received a Nobel Prize for this discovery.

Fig. 4-6. Before the Saarinen building was constructed on the Holmdel property, a number of one-story buildings housed the Bell Labs researchers who worked there, mostly on antennas and radio waves. This photograph is from 1950, before these researchers were moved to a new building in Crawford Hill and the old Holmdel buildings razed. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Fig. 4-7. Aerial photograph of the Bell Labs Crawford Hill two-story building in 1962 after construction and before the grounds were finished. This facility is still in use by Alcatel-Lucent Bell Laboratories. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Fig. 4-8. Aerial photograph of the Bell Labs Whippany facility around 1961. Classified research and development under contract to the military was performed there. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

A complex in Whippany, NJ housed military research and development; and research and development in radar, in guidance for the Nike missile, and in underwater sound were conducted there. The Indian Hill facility in Naperville, IL housed development work in switching technology and systems.

Dr. Mervin J. Kelly in 1943 suggested “a permanently resident Laboratories design function” at Western Electric plants. This became the formal branch locations of Bell Laboratories at many Western Electric plants, or “Works,” as they were known. Some of these Western Electric plants with Bell Labs branches at them included: Allentown and Reading, PA (transistors and electronic components); Indianapolis, IN (telephones); Merrimack Valley, MA (transmission equipment; Winston-Salem, NC (military equipment); Columbus, OH (switching equipment); and Atlanta, GA (undersea and copper and optical cable).

Fig. 4-9. Bell Labs R&D in switching was conducted at the Indian Hill, Illinois complex, consisting of many buildings, shown here in 1983. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

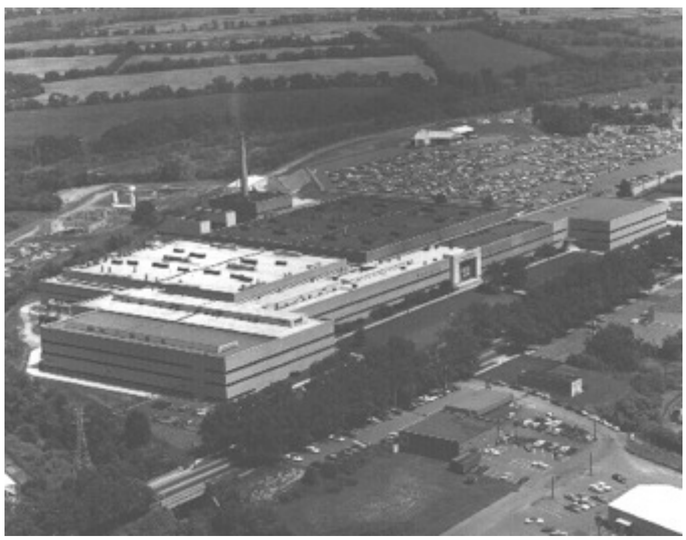

Fig. 4-10. Electronic components, such as transistors, were designed by Bell Labs and then manufactured at the large Western Electric plant in Allentown, PA. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Typically, designs from the development organizations in Holmdel and Indian Hill were transferred by paper to the relevant Western Electric plant, with the local people responsible for correcting problems and improving on the original designs. Early commercial transistor production began in 1951 at the Allentown Works. Western Electric Company had its own Engineering Research Center (ERC), located in Princeton, NJ to perform R&D investigations of manufacturing systems and technologies.

Chapter 5

IMPACT

THE TRANSISTOR

The most famous invention to come from Bell Labs was the transistor. This one invention was a major contributor to today's information age and digital era – although many other less-famous discoveries and innovations from Bell Labs also were significant. The transistor was invented at the Murray Hill facility.

Fig. 5-1. The first transistor was a point-contact device (shown here), invented in 1947 at Bell Labs in Murray Hill by John Bardeen and Walter Brattain. The following year William Shockley conceived the bipolar junction transistor, and all three shared the Nobel Prize in Physics in 1956. [Photo of the original transistor courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

After the patent was issued, Bell Labs freely gave technical advice on the subject and low cost "rights to use" of the invention. This spawned a new electronic industry; often causing vacuum tube companies to revise their business plans. Bell Labs invited professors to Murray Hill for an education in semiconductors, and these professors went back to their universities and created semiconductor courses and lab experiments, which resulted in graduates with expertise in what became a booming electronics industry.

Fig. 5-2. Posed 1948 photograph of the three scientists at Bell Labs who are collectively credited with the invention of the transistor and who shared the Nobel Prize in Physics in 1956: William Shockley (sitting), John Bardeen (standing left) and Walter Brattain (standing right). Actually Bardeen and Brattain invented the point-contact transistor in 1947, with Shockley conceiving of the bipolar junction transistor the following year. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Three Bell Labs research physicists are credited with the invention of the transistor: John Bardeen, Walter Brattain, and William Shockley. All three shared the Nobel Prize in Physics in 1956. Actually, Bardeen and Brattain invented the first transistor – the point-contact transistor – in December 1947. Shockley conceived of the bipolar junction transistor a year later. As early as 1952, Shockley had proposed a solid-state device for amplification in which an electric field throttled the flow of electric current, but there were problems because of the existence of surface states. The solution would ultimately be accomplished with the MOSFET (Metal-Oxide Semiconductor Field-Effect Transistor), invented at Bell Labs by Dawon Kahng and Martin M. Atalla in 1959. This MOSFET is now the basis of almost all silicon integrated circuits.

In 1947 there were only a few digital computers. One of the earliest, the ENIAC machine, was constructed at the University of Pennsylvania's Moore School of Electrical Engineering and became operational in 1946. It used over 17,000 vacuum tubes, and IBM punched cards were used for input and for output. Around 1939, George R. Stibitz of Bell Labs had constructed a relay-based computer for complex number calculations.

Digital computers were very rare in the 1940s, and were not the motivation for the investigation of solid-state semiconductors at Bell Labs. Amplifiers were required for long-distance telecommunication. These amplifiers used vacuum tubes, which consumed much electric power, were noisy, generated much heat, and wore out over time. There was considerable motivation to discover a solid-state replacement for them.

DIGITAL ERA

Today's digital era is based on many of the discoveries and innovations that came from Bell Labs. The telegraph with its use of dots and dashes to encode the symbols of the alphabet could be considered the first "digital" application. Much innovation and investigation was motivated by how to send more and faster telegraph signals. But converting analog waveforms to the zeros and ones of digital was a major discovery, rivaling the telegraph.

Fig. 5-3. Harold (Harry) Stephen Black invented negative feedback in 1927, scribbling his invention on a sheet torn from a newspaper while on a ferry to New York City on his way to the West Street facility. [1941 photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

In 1932, Harold Stephen (Harry) Black stated the sampling theorem on which the principles of converting a signal from analog to digital format are based. This was perhaps the beginning of the digital era. Earlier, in 1927, Black had invented negative feedback, for which he is most famous. Negative feedback enabled noise and distortion to be controlled in amplifiers – the world of analog. Digital was another way to overcome noise and distortion.

When we think of digital, computers come immediately to mind. But before computers were digital, they were analog machines in which voltages were varied to perform arithmetic operations. As late as the early 1960s, the prefixes “analog” and “digital” had to be placed before “computer.” In 1937, George Stibitz used electromechanical telephone relays to construct a binary calculating machine based on Boolean algebra – in effect, an early digital computer. In 1939, he completed a machine for calculating complex numbers.

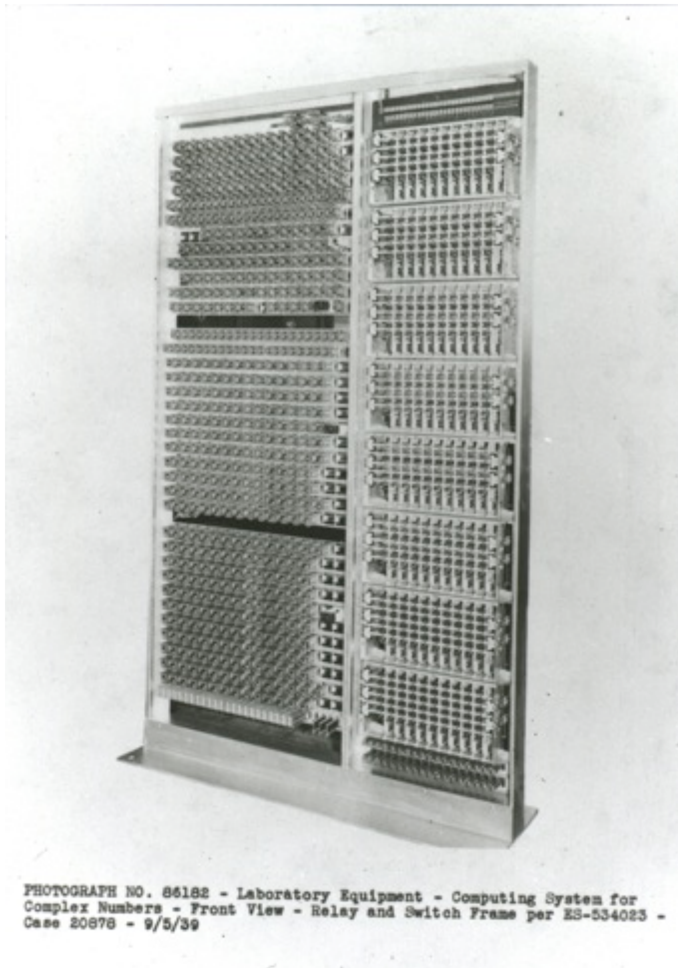

Fig. 5-4. In 1939, George Stibbitz constructed a computer to calculate complex numbers, using electromechanical crossbar switches. Two years earlier he constructed a binary calculator from relays, one of the earliest digital computers. Stibbitz investigated Boolean logic and is credited for the term “digital,” [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Originally investigating the transmission of telegraph signals, Harry Nyquist in the mid 1920s showed that the maximum rate that a telegraph signal could be sent was twice the bandwidth of the channel. This topic would later attract the attention of the mathematician Claude E. Shannon. Applied to digital, the Nyquist rate means that the sampling of a signal had to be at a rate at least twice the maximum frequency in the signal. This is known as the Nyquist sampling rate. It is also known as the Nyquist-Shannon sampling theorem, but as an engineer, I like to give sole credit to Nyquist.

Fig. 5-5. Photograph from 1960 of three significant researchers at Bell Labs. John R. Pierce (left) was responsible for the *Telstar* communications satellite. Rudolf (Rudi) Kompfner (center) invented the travelling wave tube and was a close friend of Pierce, who brought him to Bell Labs from England in the early 1950s. Harry Nyquist (right) worked on the stability of negative feedback amplifiers and also on the relationship between bandwidth and telegraph speed. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

In a 1928 paper, Ralph Hartley presented a measure for the amount of information in a signal. His measure was in decimal digits. Later a measure would be proposed by Shannon based on binary digits. In two issues of the *Bell System Technical Journal* published in 1948, the paper “A Mathematical Theory of communication” was published. Shannon proposed the "bit" as a measure of information. John W. Tukey, of Bell Labs and Princeton University, coined the term as a contraction of "binary digit." Shannon treated the theoretical maximum Information capacity of a noisy communication channel. In earlier research, Shannon had applied Boolean algebra to switching circuits.

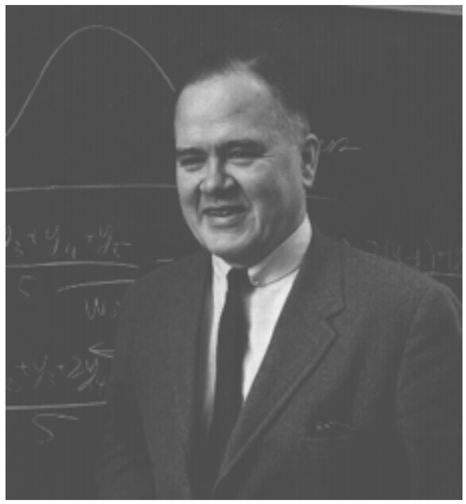

Fig. 5-6. Mathematician John W. Tukey coined the term "bit" to describe a binary digit. In addition to being at Bell Labs, Tukey was also on the faculty of Princeton University. [1965 photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Pulse code modulation (PCM) is the backbone of digital. Black at Bell Labs and others elsewhere contributed to its formulation and development. In a paper published in 1948 in the *Bell System Technical Journal*, Claude E. Shannon, Bernard M. Oliver (who later became the director of research at Hewlett Packard), and John R. Pierce proposed a PCM system for multiplexing together 24 digital signals. Their proposed system became the T1 digital multiplex system used for local digital transmission of telephone signals.

In 1967, Manfred R. Schroeder and Bishnu S. Atal conceived linear predictive coding (LPC) for compressing digital speech signals to conserve bandwidth. Nearly all of today's wireless cell phones use some form of LPC. In a paper published in 1979, Schroeder, Atal, and Joseph L. Hall observed that the masking perception of the human ear might be applied to bandwidth compression. This concept would later become the basis for MP3 compression, expanded and developed by a team of workers at Bell Labs and elsewhere.

Fig. 5-7. Ken Thompson (sitting) and Dennis Ritchie (standing) invented the Unix operating system in the early 1970s at Bell Labs. They are shown in this 1972 photograph at a terminal connected to a Digital Equipment Corporation PDP-11 computer. Variations of their Unix system are today the basis for many computer and tablet systems. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

The application of digital computers was expanded by research at Bell Labs in the 1960s into such areas as computer music, computer art, and computer animation. Stereoscopic 3D animation was also developed, along with 3D input and output devices during the 1960s. Force feedback in 3D was devised as a means to present the physical feel of shapes and objects. The core operating system used today in Apple® computers and Google's Android™ system is a variation of Unix. Dennis Ritchie and Ken Thompson at Bell Labs developed Unix in 1969. It was written originally in assembly language and then later in the C programming language conceived by Ritchie.

Not only theory and concepts contributed to the digital era, but also hardware and devices from Bell Labs. Of course, the transistor invented in 1947 and 1948 later became absolutely essential to digital computers and systems. Bell Labs, in addition to its invention of the transistor, developed and perfected many of the techniques and tools that are used in making transistors and integrated circuits, including photolithography, diffusion, ion implantation, and epitaxy and electron beam lithography for mask making. Solar cells were invented at Bell Labs. Charge-coupled device (CCD) imagers for digital cameras replaced photographic film. The foil electret microphone invented in 1962 by Gerhard Sessler and James E. West is used today in nearly every cellphone.

Fig. 5-8. Gerhard M. Sessler and James E. West invented the foil electret microphone at Bell Labs in 1962. Electret microphones are used today in cell phones and high-quality audio microphones. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

INFORMATION AGE

Innovations, discoveries, and systems from Bell Labs created much of the basis for the information age. Digital is just one way that information can be encoded; the term "information" is much broader, and includes analog and digital formats, speech, video, images, data, and other modalities.

Shannon's model and theory of information has already been mentioned as one of the foundations of the digital era, but it was also essential to the information age. Shannon is virtually synonymous with "information." His simple model of a transmitter, receiver, and noisy communication channel is very well known. Shannon proved that the maximum capacity C of a communication channel with a bandwidth B and a signal-to-noise ratio of S/N is:

$$C = B \log_2 (1 + S/N) \text{ bits per second.}$$

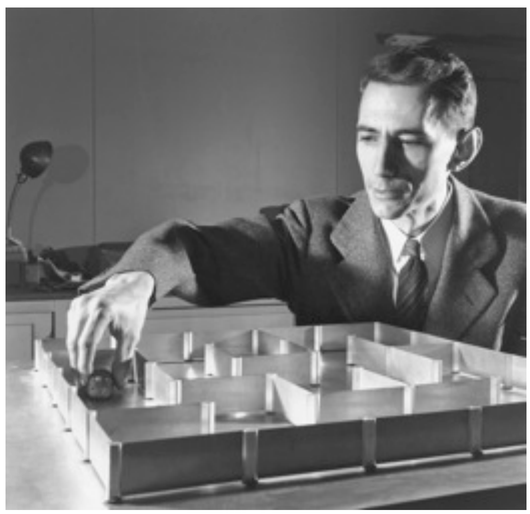

Fig. 5-9. Claude E. Shannon in 1952 with his electrically controlled mechanical mouse, named "Theseus." The mouse, through trial and error, would "learn" the solution to the maze through electromechanical relays and was an example of "intelligent behavior." [Photo courtesy of AT&T Archives and History Center.]

Shannon's concept and measure of information was in a technical, mathematical sense, but it has been applied to music, art, and nearly everything else – mostly inappropriately. John Pierce, who knew Shannon quite well, was upset by the misuse of Shannon's theories and concept of information. However, it was much more than just theory from Bell Labs that linked the planet with communication technology to send information to everyone, anywhere.

Fig. 5-10. Claude Shannon (right) is known as the father of information theory because of his innovative mathematical analyses of signals and the capacity of communication channels. This photograph from 1955 shows him with researcher Dave Hagelbarger (left). [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Theory is great, but the application of telecommunication engineering along with a host of innovations from Bell Labs linked the planet with nearly instantaneous communication – the very foundation of the information age. The communication went everywhere, was affordable, and was available all the time.

Alexander Graham Bell's vision of natural human speech over distance was achieved.

Telecommunication systems involve both the transmission of signals and also their switching. Advances discovered at Bell Labs along with sophisticated engineering occurred in both of these areas.

Telegraph signals were carried over copper wires. A pair of copper wires still today carries signals to many homes. But copper-wire pair did not have the capacity to carry a large number of signals across the country. Also signals become faint with distance and needed to be made larger by amplification. The amplifiers that accomplished this were called repeaters, since they in effect "repeated" the signal. Vacuum tubes accomplished amplification and were ultimately replaced by the transistor – invented at Bell Labs. Broadband media were developed along with the multiplexing techniques to transmit very many telephone calls over a transmission medium.

Fig. 5-11. Ten pairs of coaxial pipes formed a single cable in the L4 carrier system, first placed in service in 1967. The cable was buried underground with repeater amplifiers every 2 miles. [1965 photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Coaxial cable has considerable bandwidth and signal-carrying capacity. The L1 coaxial system went across the United States with three coaxs carrying a total of 1,800 two-way voice circuits and with vacuum-tube repeaters placed every 8 miles. The L5E coaxial system installed in 1978 carried 132,000 two-way voice circuits.

Coaxial cable was also used in submarine cable systems under the Atlantic Ocean; the first TAT-1 system entered service in the mid 1950s with a maximum of 72 voice circuits. The TAT-8 system was the first to use optical fiber, which was made at the Western Electric plant in Atlanta. Undersea cables in the mid 1990s had progressed to digital rates of 5 G bps and nearly 100,000 voice circuits.

Microwave radio carried signals across the United States. The initial system in 1950 carried only 2,400 two-way voice circuits. Radio towers were located about every 26 miles to receive, amplify, and retransmit the radio signal. Microwave technology progressed with the use of polarized radio waves and single-sideband transmission.

This ever-increasing capacity of transmission systems was a major reason for the continued decrease in the cost, and hence the price, of long distance telephone calls, across the country and under the oceans.[5] Today, optical fiber is used for transmission systems across countries, under oceans, and increasingly to homes. Lasers are essential in these systems that seem to have virtually unlimited capacities. Researchers involved with Bell Labs, Charles H. Townes and Arthur I. Schawlow, invented the maser and the laser.

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[5] A. Michael Noll, "A Study of Long-Distance Rates: Divestiture Revisited," *Telecommunications Policy*, Vol. 18, no. 5 (1994), pp. 355-362

Fig. 5-12. Long-distance telephony utilized a series of microwave towers about every 26 miles to relay signals across the United States. The horn antenna, invented at Bell Labs, allowed radio waves to be polarized and doubled the capacity of earlier systems. [1962 photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Communication satellites also are used to carry signals over great distances. The *Telstar* telecommunication satellite, promoted by John R. Pierce and his colleague Rudolf (Rudi) Kompfner, first operated across the Atlantic Ocean on July 10, 1962. *Telstar* used a traveling wave tube (TWT) for broadband, high-power amplification of the received radio signal. Kompfner developed the TWT in England, and later joined Bell Labs as an associate of Pierce to continue working on TWTs. Eugene F. O'Neill directed the *Telstar* project.

Telstar was an active communications satellite in the sense that it received a signal, amplified it, and then retransmitted it back to Earth. The earlier *Echo* was a passive satellite, first launched by

NASA in 1960 and operated by Bell Labs. *Echo* was a large, 100-foot diameter balloon that was inflated in a low orbit about the Earth. Radio signals were bounced off its reflective surface, and a large 50-foot horn antenna located at the Bell Labs Crawford Hill facility in Holmdel Township, New Jersey received the faint signal. Arno Penzias and Robert Wilson used this horn antenna at Crawford Hill to investigate radio noise interference and accidentally to discover it was from the "Big Bang." Bell Labs built an even larger horn antenna in 1961 at Andover, Maine for the Telstar project. David C. Hogg is credited for the construction of both horn antennas.

Fig. 5-13. The active communications satellite *Telstar* was placed in low-Earth orbit in 1962 and relayed telephone, television, and facsimile signals. This heralded the beginning of satellite telecommunications. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Telstar was placed in a relatively low orbit, and transmitted television, telephone, and facsimile signals. Today's communication satellites are placed in geostationary orbits at 22,300 miles above the equator. The round-trip delay of about ½ second is a serious problem for instantaneous two-way communication. But satellites are a great way to broadcast broadband TV signals to large geographic areas, to remote places on the globe, and to ships on oceans.

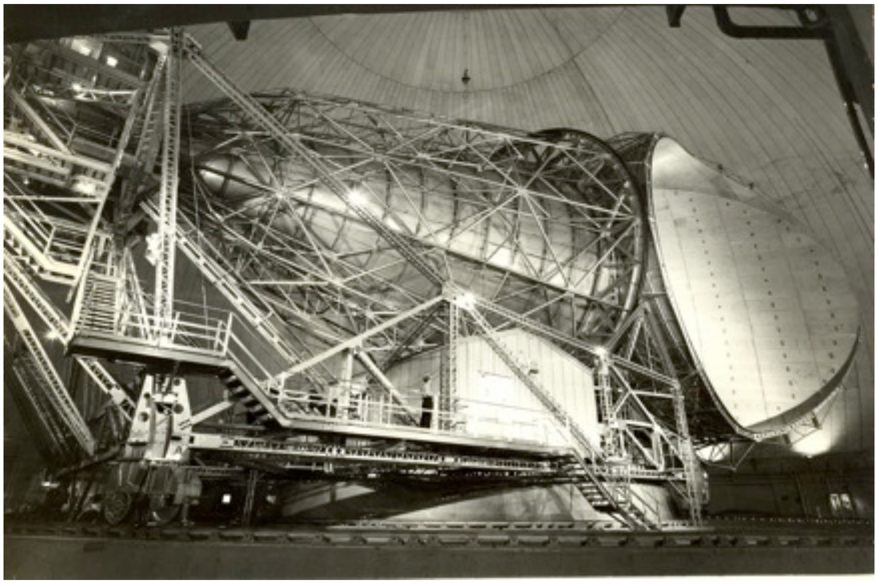

Fig. 5-14. A large horn antenna was located at Andover, Maine as a ground station for the *Telstar* satellite in1962. The antenna was housed in a large dome and was able to turn and tilt to track the rapidly-moving satellite, which was in a low orbit about the Earth. [Photo courtesy of AT&T Archives.]

Two-way telecommunication requires signals to be switched. In the earliest days, human telephone operators performed this switching by using wire cords to patch one circuit to another. In 1892, switching became automated with the invention of electromechanical switching by Alom B. Strowger – an undertaker and non-Bell person. Strowger invented this switch to avoid the human operator he believed was directing business to his competitor. The Bell System initially ignored his step-by-step system. But Bell Labs finally came through with its crossbar electromechanical switching system in 1938, after an earlier panel system that did not perform very well.

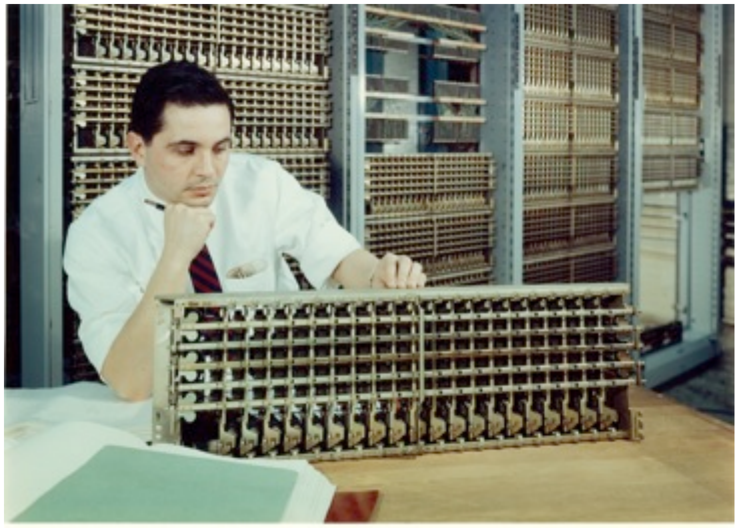

Fig. 5-15. The crossbar switch was developed at Bell Labs and first installed in the Bell System in 1938 and saw service until the early 1990s. The basic switch was a 10-by-20-matrix switch, consisting of electromechanical relay contacts. [1960 photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

The electromechanical control of a switching system became electronic with the development and first installation in 1965 of the Western Electric No.1 ESS machine, which used electromechanical reed switches to connect the lines. The Western Electric No.4 ESS machine, first installed in 1976, used a digital switching fabric and integrated circuits. The 5ESS® all-digital switching system was first installed in 1982. Western Electric's competitor Northern Telecom had its DMS™ electronic digital switching system, first installed in 1978. Today the digital switching of voice and data is accomplished mostly by packet switching, which is the underlying technology of the Internet and its precursor, the ARPANET, and which was developed with Federal support.

Fig. 5-16. The 5ESS® switching system was manufactured initially by Western Electric, with its initial installation in 1982, and later by Lucent Technologies. It is an all-digital switching system with time-slot interexchange. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Cellphones use low-power, wireless radio for two-way communication. An area is divided into many cells, which can be then re-used over a large area. The cellular system concept was invented at Bell Labs in the 1940s, with first commercial service of Advanced Mobile Phone Service (AMPS) in 1983 in Chicago. Government policy was a significant cause of the service delay. Today wireless is digital with speech compression and also Internet data access. Each new generation of wireless service is more sophisticated technologically, with ever increasing demand for radio spectrum bandwidth.

There are peripheral technologies involved in telecommunication. The network needs to be told the source and destination of a communication – a process known as signaling. The touchtone dial with multi-frequency key pulsing is one way that signaling is accomplished. Common Channel Interoffice Signaling (CCIS) was invented at Bell Labs so telephone numbers could be transferred across the network. Most signaling is done digitally today on packet networks.

Fig. 5-17. Touchtone dialing, with push-button dials, replaced rotary dial in telephone instruments, starting in 1963. Today few people would have encountered a rotary dial. Shown here is a Trimline® telephone with the Touchtone dialer in the handset. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Long-distance voice circuits can suffer from echo, which is eliminated by echo cancellation, accomplished by dynamic adaptive filters. Homer Dudley invented vocoders decades ago at Bell Labs. Today the term "vocoder" applies to techniques used to reduce – or compress -- the bandwidth of speech signals. Compression is essential in wireless cellular systems, but with compression usually comes a compromise with speech quality. Data communication over the telephone network required modems between the computer and the telephone line. Today data communication is more direct, perhaps over a local wired or a wireless network, such as Wi-Fi, that connect to some sort of broadband medium through a router.

Fig. 5-18. The sound spectrograph machine made a two-dimensional analysis of the frequency components in a sound signal and displayed the results on a rotating drum. In this photograph from 1966, Toni Presti is shown adjusting the spectrograph machine. Today such sound spectrographs are made in real time with software in hand-held tablet computers. The spectrograph was important is secure speech processing and in underwater sound. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

MILITARY WORK

Bell System through Bell Laboratories and Western Electric made significant contributions to the efforts of World War II and the Cold War. The Bell Labs physical facility for military work was located in Whippany, NJ. Bayer Healthcare acquired the Whippany property for its US headquarters in 2013, although military work had halted there years before. However, during World War II and much of the Cold War important research and development was performed at the Whippany facility.

World War II radar (a British invention) equipment was designed at Whippany and then manufactured by Western Electric. High-power, microwave magnetron tubes and microwave propagation were investigated there, along with electrical computers for fire control, initially analog and then digital after World War II. There was much work related to acoustics, in such areas as underwater sound and sonar, air-raid sirens, and military telephones. Communication systems were designed, including secure speech, mobile radio, and a global military communication network.

Fig. 5-19. During World War II, Bell Labs designed radar antennas and installations, which were manufactured by the Western Electric Company for the military. [1942 photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

After World War II and the subsequent Cold War, the work was extended to air defense, such as the Nike missile system, antiaircraft fire control, missile guidance, and ballistic missile defense. The work in underwater sound was expanded to complex systems with acoustic arrays and signal processing. The radar work became airborne for the Airforce and shipboard for the Navy. Work was performed in the systems engineering of command and control systems. All this work was done at the Whippany facility, but military work was also done elsewhere, such as in New Mexico.

Fig. 5-20. Bell Labs designed the guidance system for the series of Nike antiaircraft missile systems. The Nike Hercules missile is on the left; the Nike Ajax is on the right in this photo from 1960. The Nike Zeus was aimed against ballistic missiles, but was not implemented. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Toward the end of World War II, a group was formed in Los Alamos to perform the engineering and assembly of atomic bombs. This group was moved to Sandia Base and in 1948 was named the Sandia Laboratory. It was under the University of California, whose Regents Committee was responsible for Atomic Energy Commission (AEC) work and decided that this kind of activity was no longer appropriate. Dr. James B. Fisk was at the AEC and suggested that Mervin J. Kelly of Bell Labs survey the entire Los Alamos operation. Finally in 1949 the AEC asked the Bell System to take over the operation of the Sandia Laboratory, which it did through the creation of Sandia Corporation, operated by Western Electric and Bell Laboratories on a not-for-profit and feeless basis. Some of the executives at Sandia came from Bell Labs on a rotational basis.

The Sandia Laboratory was responsible for the development and manufacture of nuclear bombs and areas such as bomb ballistics. Later, it became more involved with the definition and design of bombs, including their testing and the detection of tests. In the 1970s, the work was extended to high-power lasers and electron beams and solar energy. The Lawrence Livermore Laboratory was also operated by the University of California but was responsible for the physics, design, and more theoretical aspects of nuclear weapons.

Fig. 5-21. Bell Labs designed the DEW (Distant Early Warning) system Line of radar installations to detect enemy bombers. The DEW Line was stationed across the artic of Canada. [1956 photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Bell Labs also became involved during the 1960s in Cold War work. The development of the DEW (Distant Early Warning) Line was one area. An area that I recall involved determining the difference between underground nuclear tests and natural seismic events like earthquakes. Sheridan Dauster Speeth, a research psychologist at Bell Labs, ingeniously suggested speeding-up the recordings to audible frequencies so that human subjects could then listen to them. The subjects were able to reliably distinguish bombs from quakes. I personally was involved with classified research in underwater sound, and recall visiting the Naval Research Laboratory in Washington, DC to obtain data for experimentation.

In 1962, Bell Laboratories was asked to assist NASA in its manned-space exploration Apollo project. This was done through the creation of Bellcomm, Inc. owned by AT&T and Western Electric. It provided services to NASA on a not-for-profit and fee-less basis. Some of the services included systems engineering, spacecraft guidance, and communication systems. Bellcomm was disbanded in 1972.

Bellcomm

Fig. 5-22. Bellcomm was a Bell System unit that performed the planning of communication systems for NASA's Apollo moon mission. Its professional staff came mostly from Bell Labs, and AT&T and Western Electric jointly owned it. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

General Dwight David Eisenhower certainly would have known of the significant role of technology during World War II and thus of Bell Telephone Laboratories. As President, he would have a natural affinity for Dr. William O. Baker, who in 1955 became in charge of research at Bell Labs. Baker was a strong champion of information and thus would have natural interest in furthering the use of information technology in the work of intelligence by the National Security Agency. The involvement of Baker with Washington would continue with President John F. Kennedy, with the continuation of the Cold War and also the space race. The intelligence community reveres Dr. Baker, and the prestigious William Oliver Baker Award is given annually to honor his contributions.

Chapter 6

DIVERSIONS: SOME SERIOUS -- SOME FUN

Personal projects were called "government jobs." At Christmas time, the glass blowers would make ornaments. Jewelry was made at the mechanical shops and plating facilities. However, there also were formal diversions that could be quite serious, enjoyable, and even lead to interesting research and discoveries. Diversions were done for visitors; for example, a glass replica of a candlestick telephone was created by glass blower Duke Dorsi as a gift for a visitor from Sony.[6] Some diversions were done after hours on weekends and holidays; for example, my initial computer art was clearly a diversion, done outside my formal assignments. The diversions described below were some of the ones in which I was involved.

Employees signed a contract, accompanied by a dollar bill, giving Bell Telephone Laboratories, Incorporated ownership of everything they invented and did – at work and even outside work. All intellectual property was assigned to Bell Labs. Thus, my computer art was outside my formal work assignments, but since it was done using a Bell Labs computer, Bell Labs owned it. Ultimately, Bell Labs decided it did not want to own the art, and the legal department formally assigned ownership to me. Only the legal department and its patent attorneys had formal authority and responsibility over the intellectual and physical property of Bell Labs – not even Dr. Baker could give it away.

Philharmonic Hall. Philharmonic Hall opened in 1962 at Lincoln Center in New York City. Leo Beranek was responsible for the

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[6] A color photograph of the glass candlestick telephone blown by David (Duke) Dorsi was used for the cover of the 2011 book *Bell Labs Memoirs: Voices of Innovation* by A. Michael Noll and Michael N. Geselowitz, published by the IEEE History Center.

acoustics, and proclaimed before the Hall was open that the acoustics would be perfect. Unfortunately, the music critic for *The New York Times* had a quite different opinion and proclaimed that the Hall was an acoustic disaster. Beranek was dismissed, and the assistance of Bell Labs was sought to investigate the problems. Manfred Schroeder was in charge of a group of researchers to study the problem, and because of my interest in classical music and audio, I volunteered to join.

I recall one evening when we were at the Hall taking measurements throughout the night into the next morning. I recall that sound absorbing panels were used to cover the entire rear wall of the Hall. I stood on the podium and clapped my hands. The sound reflected off the rear wall and came back quite strongly. It was then that I formed the opinion that the spherical shape of the rear wall was the cause of the acoustic problems – but I was not an expert in acoustics. Schroder did mathematical analyses and concluded that the reflecting panels in the ceiling acted as an acoustic filter and were the cause of the problems. The space between the panels was closed, but the problems of the hall only worsened. Consultants were enlisted to suggest changes, but nothing worked to solve the problems. One consultant had the seats changed to have solid wood backs, which allowed a couple more rows on the main floor.

I recall one time when Schroeder and Max Abramowitz (Philharmonic Hall's architect) were standing at the front of the Hall. Abramowitz looked back at his Hall, and with tears in his eyes wondered whether the acoustics would ever be remedied. I recall Schroeder with George Szell attending a concert to listen to the acoustics. Numerous changes were made over the decades to remedy the acoustic problems, but the poor acoustics only worsened and became more consistent throughout the hall. The hall is now known as Avery Fisher Hall – but a new name and additional acoustic changes did nothing to resolve the problems.

Board members had approached New York Telephone to request the assistance of Bell Labs regarding the acoustic dilemma. However, at least one person at AT&T objected to such assistance as being out of the scope of Bell Labs. Bell Labs continued the work nevertheless.

“The Human Use of Computing Machines.” Dr. Baker realized the coming significance of the use of digital computers as a tool in research and wanted to make the academic community more aware of their application. He decided that the way to do this was to host a conference at Murray Hill to which academics would be invited from various universities around the country. Peter Denes and I were given the task to organize and plan the conference, which was held in June 1966.

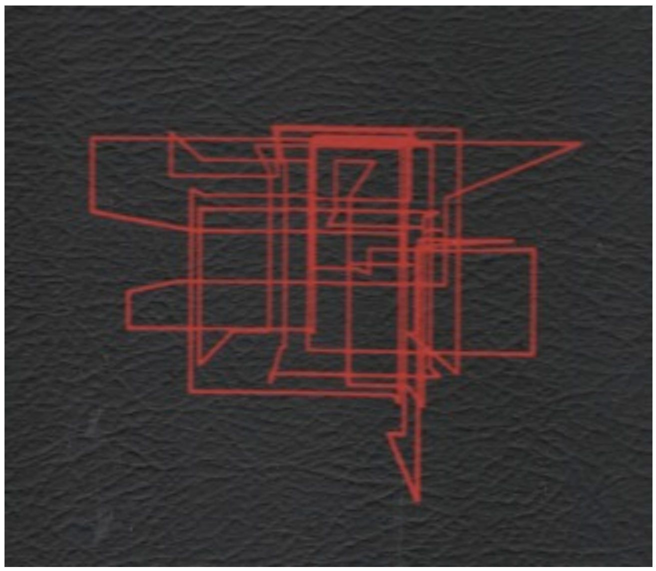

Fig. 6-1. A symposium on “The Human Use of Computing Machines” was held at Bell Labs, Murray Hill in June 1966. A piece of digital computer art by A. Michael Noll was used as the logo for the conference and was printed on all hand-outs and promotional materials. [Courtesy A. Michael Noll. © 2015 AMN]

One question was what to name the conference. I recall a meeting in Dr. Baker’s conference room attended by many of the senior management of Bell Labs. Each person would write a suggestion on a slip of paper and pass it up to Dr. Baker, who would read it aloud. After much thought, my suggestion of "The Human Use of Computing Machines," which was a play on the title of a book by Norbert Wiener (*The Human Use of Human Beings*), was adopted. One of my pieces of computer art was used as the graphic theme for the conference.

Peter Denes and I were working nearly full-time on organizing the conference. John R. Pierce became annoyed that it was taking so much of our time that he quipped, "A job not worth doing is a job not worth doing well." I was petrified that his apparent negativism could be the end of my career at Bell Labs. But it was Dr. Baker – not Pierce – who was strongly behind this conference.

Well over a hundred academics attended the conference, with all their travel expenses covered by Bell Labs. Each attendee was invited personally to attend. I recall that Ken Knowlton, Frank Sinden, and I showed examples of computer animation. All presentations were carefully rehearsed in advance, and printed summaries of the presentations were given to the attendees. This was a costly event, but I believe it had much impact and significance on the use of computers in academic research.

Apollo 1 disaster. In January 1967, the NASA Apollo 1 command module had a catastrophic fire resulting in the deaths of three astronauts: Gus Grissom, Roger Chaffe, and Ed White. Pure oxygen along with plastic material in the space suits and lining much of the interior of the capsule contributed to the disaster. The missile to which the command module was attached was not fueled or a massive explosion would have resulted.

An audio recording had been made of the communications between ground stations and the capsule. Each astronaut had a push-to-talk switch located at the end of a cable, known as the cobra cable because of its shape. Bell Labs was asked to analyze the audio recording to determine who said what during the last few seconds of the disaster.

A small team of researchers was created, led by James L. Flanagan, and which included me. I applied my cepstrum pitch analysis to the recording in an attempt to identify who was speaking. However, when someone shouts, pitch increases significantly making identification nearly impossible. Jack MacLean and I later performed a controlled study of shouted speech to determine how much the pitch changed. We discovered that clipping the peaks actually improved the intelligibility of shouted speech.

"2001: A Space Odyssey." Arthur C. Clarke knew John R. Pierce. Clarke had suggested the use of satellites for telecommunication; Pierce was responsible for the *Telstar* telecommunication satellite. Clarke was a renown writer of science fiction; so too was Pierce, though less famous. Pierce published his science fiction under the pseudonym J. J. Coupling, a term used to describe a quantum mechanical effect in describing the electrons in atoms. For the movie "2001," the producers of the movie approached various technology and other companies for their assistance and advice. Bell Labs and Pierce were approached. The speech-synthesized song of "Daisy, Daisy" had been made at Bell Labs and was used in the movie as the computer HAL had an emotional breakdown.

Pierce had an idea for a Picturephone booth to be used on the orbiting space station in the movie and asked me to help. Pierce wrote a scenario, and I designed a Picturephone for the booth. A draftsman at Bell Labs expanded my sketches, and all the material was supplied to Clarke's people. It even included a Bell System seal, which was placed on the side of the booth in the movie. After the movie was released, someone at AT&T saw it and objected to me about the use of the Bell System seal. As a result of a legal consent decree, the Bell System was restricted to domestic telecommunication, and the use of the seal implied that the Bell System was now operating in space. I said that Pierce had approved its use, and that settled the matter. Pierce could be quite strong in his opinions, and I guess AT&T did not want to tangle with him.

Howard Wise. Howard Wise operated an art gallery on West 57th Street in New York City. Early in 1965, he saw random dot stereogram images made by Bela Julesz on the cover of the magazine *Scientific American*. He invited Julesz to exhibit these works at his gallery, and Julesz invited me to join with my computer art. The show was held in April 1965. Julesz and I were now "artists" in the New York art community. However, AT&T was not pleased with the idea of art being created at Bell Labs and objected to the show. It occurred anyway, but efforts had to be made to limit publicity about Bell Labs.

Fig. 6-2. A small deck of IBM punched cards announced the exhibit of "computer generated pictures" by Bela Julesz and A. Michael Noll that were exhibited at the Howard Wise Gallery in New York City from April 6-24, 1965. [Photo courtesy of A. Michael Noll. Copyright © 2015 AMN]

Visitors. There were many interesting visitors to Bell Labs. I invited Leopold Stokowski to visit, and a snowy day in 1968, the Bell Labs limousine picked him up in Manhattan and drove him to Murray Hill. We showed him the anechoic chamber and also how we were using computers in music. He was fascinated, and we all had a lively conversation in one of the service dining rooms. Many years earlier in 1933, Stokowski conducted the Philadelphia

Orchestra in the first transmission of stereophonic audio by Bell Labs.

Fig. 6-3. Famed conductor Leopold Stokowski participated in the first stereophonic sound transmission from Philadelphia to Washington, DC in 1933. Stokowski is shown here adjusting some equipment, watched by Harvey Fletcher who was in charge of acoustics research then at Bell Labs. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

The conductor Hermann Scherchen visited Bell Labs to see the work in computer music, which did not impress him since he felt he could do as well with some audio oscillators at his electronic music studio in Gravesano, Switzerland. Scherchen was impressed, though, with the work in computer animation.

The Korean video artist Nam June Paik contacted me at Bell Labs in 1966 with an interest to learn how to use digital computers to create art and animation. He then visited Bell Labs, and studied programming with James Tenney and me in 1967 and 1968. Paik actually programmed some images and animations, but the rigor and algorithmic structure of programming was quite different from his hand’s-on approach to video art. Charlotte Moorman was a frequent visitor each year as she planned her yearly *Avant Garde Festivals* in New York City. Bell Labs people frequently contributed to these events. Roy Disney visited in the mid 1960s and was shown our work in computer animation, but he failed to grasp its implications for Disney.

Fig. 6-4. Stokowski visited Bell Labs on a cold snowy day in 1968. He is shown here at the DDP-224 computer. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

In the mid 1960s, CBS was producing a new TV show with Walter Cronkite: "The 21st Century." One of its staff people visited Bell Labs, was impressed with the work in computer animation, and wanted to use my 4D lettering animation for the main title sequence for the show. But, I was not able to create a font suitable for the show. However, the technique was used to create the title sequence for the 1968 documentary "Incredible Machine," produced by AT&T. Producer Walt DeFaria visited Bell Labs. He liked the 4D lettering, and it was used for the main title sequence for the 1969 NBC color TV special "The Unexplained," written by Arthur C. Clarke.

A magician visited Bell Labs and bent spoons in the cafeteria, claiming the use of parapsychology and mind over matter. Some scientists seemed fooled by these shenanigans and wanted to conduct serious research of parapsychological phenomena. Pure mental communication might be a threat to conventional telephony, some believed, but in the end sane judgment prevailed. However, some of us did investigate divining rods, and thought we had discovered a water pipe under a lawn behind Building 2. Again, saner judgment finally prevailed, and we abandoned our fun.

Chapter 7

PERSONALITIES

RALPH BOWN

Dr. Ralph Bown initially worked on vacuum tube development for AT&T's research department and then transferred to Bell Labs in 1934. He became Vice President, Research in 1951 and was Dr. William O. Baker's mentor and predecessor in that position. Bown set the tone of research at Bell Labs and the philosophy of its management. When Baker became Vice President, Research in 1955, he mostly followed what Bown had already set in motion. One need only read what Bown wrote about the management of research to understand what Bell Labs was all about and what made it so great.

Bown gave a talk in 1952 about his philosophy of research, and it was published in 1953.[7] He observed, "The vitality of a research organization is only a composite of the spirit of the people in it." He described many factors essential for a great research organization, such as the "freedom of publication," "a technical or scientific objective," "a sufficient technical preeminence and fame to attract the admiration and allegiance of desirable members," and "the maintenance of an open door." Bown defended "the freedom to say no to any other group or individual who may come bringing a problem to which it is proposed that research energy be devoted." He did not believe in "the genius of a great inspirational leader" and warns, "Any laboratory which is built around the dominance of its director…is ill prepared to cope with its future."

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[7] R. Bown, "Vitality of a Research Organization and How to Maintain It," *Proceedings of the Sixth Annual Conference on Administration of Research*, 1953, pp. 31-35.

Fig. 7-1. Photograph of an oil painting of Dr. Ralph Bown, who was Vice President, Research at Bell Telephone Laboratories, Inc. from 1951 to 1955, which hung in the office of Dr. William O. Baker. Bown and Baker both sailed together off the Cape Cod coast, and it seems likely that Bown groomed Baker as his successor for the position of Vice President, Research, which occurred in in 1955. [Photo courtesy of A. Michael Noll.]

Patents were very important to Bell Laboratories. In a 1954 article, Bown described the role and importance of patents to the Bell System – and also to society as a whole.[8] A photograph in this

[8] Ralph Bown, "Inventing and Patenting at Bell Laboratories," *Bell Laboratories Record*, January 1954, pp. 3-8.

article shows the covers of seven patents issued to Bell Labs during just the week of October 12, 1953. Bell Labs was indeed an invention factory. This level of patentable invention continued, and a total of 540 patents were filed, and 350 issued in 1983.[9] The 1956 Consent Decree that settled an antitrust case against AT&T stipulated that all existing patents would be licensed royalty-free and new patents would be licensed at reasonable rates. AT&T was also restricted to solely the communications field.

WILLIAM O. BAKER

One of the few pictures hanging on the walls of the office of Dr. William O. Baker was a large, nicely framed oil-painting portrait of Dr. Ralph Bown – a testament to Baker's respect for him. Baker succeeded Ralph Bown, who was Vice President for only a few years. Bown and Baker sailed together at Cape Cod and clearly were personal friends. One wonders whether Bown recognized Baker's unique abilities and groomed him for the promotion. Baker continued as Research, Vice President to 1973, and was certainly one of the most influential research leaders of the time.

Baker received a doctorate in physical chemistry from Princeton University in 1939 and joined Bell Labs in May of that year. He was promoted to Head of Polymer Research in 1948 and rose through the ranks fairly quickly after then, ultimately becoming Vice President of the entire Research Area in 1955.

Baker knew personally nearly everybody at Bell Labs in his research organization. His memory was fabulous, and he easily recalled names, research done by individual scientists, and even details about family members. He approved all promotions in the Research Area. His executive directors kept him informed about every detail of the work in their individual areas, but Baker also always seemed to sense the bigger picture of where the research could lead or be applied. It was Baker who played a significant

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[9] A. Michael Noll, "Bell System R&D Activities," *Telecommunications*, June 1987, pp. 166.

role in getting Bell Labs to abandon the waveguide project and instead focus on optical fiber. It was Baker who would appear before meetings with telephone company executives and explain the importance of research and its payoffs.

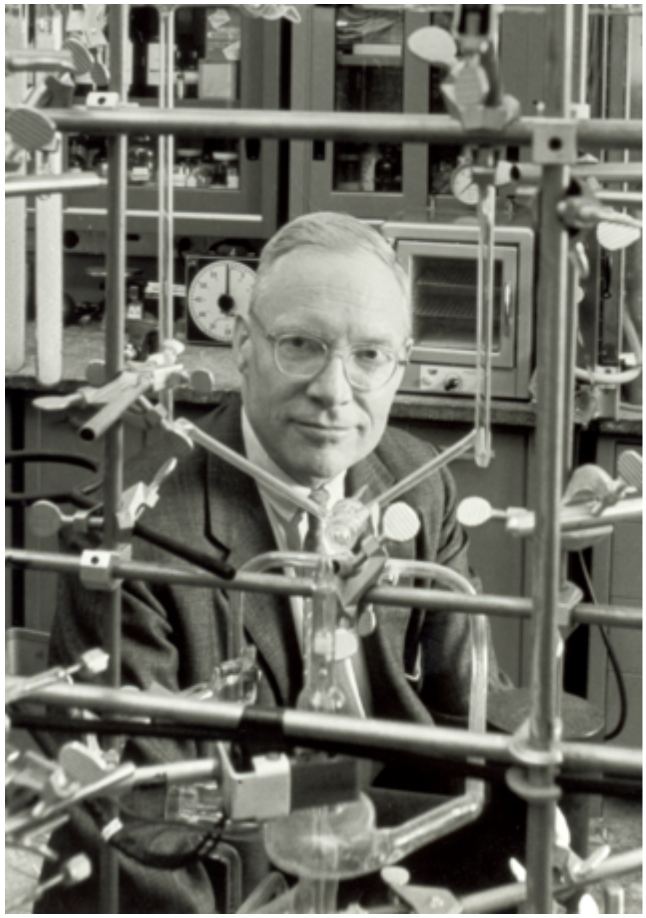

Fig. 7-2. Dr. William O. Baker was Vice President, Research at Bell Labs from 1955 to 1973 – what is considered the "golden years" of Bell Labs. He came to Bell Labs in 1939 with a fresh doctorate in chemistry from Princeton University and worked as a chemist, in such areas as artificial rubber and carbon. He advised many Presidents of the United States on matters involving science and technology and national security. [Photo courtesy of the AT&T Archives and History Center.]

Baker was a copious note taker, and he retained all these notes. Yet his memory was incredible, of names and facts. When I would visit him at Bell Labs after he had retired, I would meet him in his conference room – never his office. After an hour, he would rise and say he had another appointment. He knew that it was awkward to get someone to leave from his office, as opposed to from a conference room from which he could leave.

Baker became upset when people would claim that the research of the past was "pure" and researchers had complete freedom to do anything. He would correct these misperceptions by pointing out that research was carefully managed in a way that the researcher believed they had much freedom. But areas of research were indeed chosen and directed. Baker always believed that some application would flow from the discoveries of the researchers at Bell Labs. Baker was proud that the digital era and information age came from work at Bell Labs.

William O. Baker was responsible for the foreign diversity of scientists and engineers at Bell Laboratories. He stated that hiring the best minds from other countries was "a conscious effort" during the 1950s and 1960s, starting around 1955.[10] According to Baker, "Bell Laboratories was notorious for not having done that over the years before this." However, according to Baker, the management of AT&T was concerned about the foreign hires and felt only Americans should be hired. Baker defended the foreign hires because Bell Laboratories would benefit from "their brains and their intelligence." And they indeed were hired from such countries as Germany, India, Japan, and Great Britain.

Much of what Dr. Baker did was in Washington, DC. That started with President Eisenhower, who asked Baker to recommend a new organizational structure for military communications. The result was that the old Army Signal Corps and similar functions of other units were finally merged into a new organization, the Defense Communications Agency (DCA) in 1960.

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[10] Taped interview (transcribed) of William O. Baker in his office at Bell Labs in March 28, 2002 by A. Michael Noll.

Baker was *ex officio* science advisor to many Presidents of the United States, including Eisenhower, Kennedy, Johnson, Nixon, and Reagan. His "Baker Report" of 1958 had a major impact on the intelligence community during the Cold War in such areas as the use of digital computers and satellites. He was a close confidante of Presidents Eisenhower and Kennedy. Baker and Clark Clifford spent an afternoon listening to President Nixon bemoan his problems toward the end of his presidency. Baker was one of the longest serving members of the President's Foreign Intelligence Advisory Board (PFIAB).

JOHN R. PIERCE

John R. Pierce[11] is probably most famous for the *Telstar* relay communications satellite. Less famous was his coining of the name "transistor" for the "semi-conductor triode," which was invented by scientists in his division. In 1958, Pierce became the executive director of communication sciences research at Bell Labs. Before then, Pierce and his close colleague at Bell Labs, Rudolf (Rudi) Kompner, worked on traveling wave tubes. In 1971, Pierce left Bell Labs to join the faculty at Cal Tech and also became chief engineer at the Jet Propulsion Laboratory. In 1980, he went to Stanford as visiting professor of music.

Pierce had an active interest in all the research that occurred in his division. I recall him barging into my office to examine the results of some of my research. I was petrified. Manfred Schroeder told of how whenever he was in Pierce's office to inform him of some news, Pierce would pick up the phone and immediately repeat the news to Baker. Pierce would state that Baker was the only person at Bell Labs he was afraid of. For me, Pierce was the only person at Bell Labs that made me nervous. I was both nervous and flattered when Pierce asked me in 1990 to co-author a new version of his book *Signals*.[12]

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[11] The John R. Pierce papers are at The Huntington Library in San Marino, CA.
[12] John. R. Pierce and A. Michael Noll, *SIGNALS: The Science of Telecommunication*, Scientific American Books (New York), 1990.

Fig. 7-3. John R. Pierce (shown in this photograph from 1965) was the driving force behind the *Telstar* active communications satellite. As a research engineer, Pierce worked on high-gain high-frequency vacuum tube amplifiers. He had a strong interest in computer music and after retirement was at Stanford University's Center for Computer Research in Music and Acoustics. His papers are at the Huntington Library in San Marino, California. [Courtesy of AT&T Archives and History Center.]

Pierce was a skilled explainer of technology for a general audience. He wrote books on such topics as musical sound, the telephone, information technology, and signals. He wrote science fiction under the pseudonyms J. J. Coupling and John Roberts. Under the Roberts pseudonym in 1949 about "Credit," he wrote:

> "You can seek credit. Maybe you can get it.
> Don't bother whether for your work or others;
> Credit is credit; never mind the source."

Pierce had strong views and was willing to express them. In 1959, he stated, "the ferreed (reed relay switch) will not cure ESS's problems." He was correct, and it was ultimately replaced by digital switching systems. In a letter to me dated 1986, Pierce stated: "Information theory has a strange fascination for the wooly headed. Unlike cybernetics which is all wool and a mile wide, it has a well defined core … and is presented beautifully in Shannon's [publications]." He decried the "expensive nonsense in machine translation." I mentioned earlier his quip: "A job not worth doing is a job not worth doing well."

While Dr. Baker was very warm and outgoing towards people, Pierce was shy and could appear abrasive. While Baker would hint obliquely and indirectly at what he wanted done and leave one guessing; Pierce would be direct and precise. Baker was always the politician; Pierce was confrontational, critical, and satirical. Though very different in personalities, they were both geniuses and extremely creative and effective leaders, who contributed to the accomplishments of the Research Area of Bell Labs during the famed "Golden Years" of the 1950s and 1960s.

A LITTLE PERSONAL HISTORY

Manfred R. Schroeder was my department head in the summer of 1962 when I had a temporary rotational assignment to the Research Area. Schroeder outlined his idea to use a short-term version of cepstrum analysis for the determination of the time-varying pitch of human speech. My job was to implement it, using a block-diagram compiler programming language (BLODI). It worked!

Bruce P. Bogert, M. J. R. Healy, and John W. Tukey invented and described the cepstrum in a published paper, which Schroeder had seen. Bogert worked in military research at Whippany; the cepstrum was intended to help distinguish the source of underground disturbances. Schroeder recognized that a continuous cepstral analysis might determine the pitch of human speech; I showed him correct. But I then investigated cepstral analysis of underwater sounds, thereby completing the circle of bring the research back to its military initiation. This is a fine example of the synergistic interactions of researchers at Bell Labs.

A few years later after I had completed the Communications Development Training Program and had been awarded a masters degree, I was transferred to the Research Area under Schroeder, who had been promoted to research director level. My department head was Peter B. Denes – one of the Hungarians who, like Bela Julesz, had immigrated to the United States. My research continued into new means of pitch determination and its use in synthetic speech. I also continued my work in computer graphics, art, and animation – but all that is another story for another time and place.

I resided in Newark, NJ in a neighborhood that suffered the Newark riots of 1967. My mother and I were activists, and we conducted investigations of waste and corruption at the local level. I wrote two white-paper case studies about the results of our investigations, which included statements from neighbors and others. I gave these reports to John Pierce who gave them to Dr. Baker, who then passed them on to Edward E. David when he became Science Advisor to President Nixon. Perhaps as a result of these reports, I was invited in 1971 to join David's staff at the Executive Office of the President in Washington.

I still remember the day when Dr. Baker telephoned me in my office at Bell Labs to ask how I would respond if I was offered a position on David's staff. Dr. Baker expected an immediate reply – and I was soon off to Washington. But that too is another story. I took a leave of absence from Bell Labs, just in case I did not like Washington and needed to return to the security of Bell Labs. My last day at Bell Labs was the day I received my doctorate from Brooklyn Polytechnic Institute. In Washington, I was concerned with privacy and computer security and also a joint US-USSR program.

After two years in Washington, I indeed returned to Bell Labs. But it had changed. John Pierce had left, and Dr. Baker had been promoted to president of Bell Labs and no longer led the Research Area. In my opinion, their replacements did not have the vision of their predecessors. I could sense that Bell Labs had changed, and not in a good way. Its days of the past “golden years” were about to change, though it would take another ten years to the breakup of the Bell System and the formal end of Bell Telephone Laboratories, Incorporated.

Chapter 8

PROBLEMS – NOT ALL IDEAL

It was clear to me that the management and employees of Bell Labs and also of the local Bell telephone companies were committed to their responsibility of serving the public. They all believed that responsibility came with the Bell monopoly. However, over time the nature of the provision of telecommunication service changed with new entrants wanting to be involved. To its credit, Bell Labs did invent the modular plug in 1975 so that consumers could easily connect telephones to the network, but that was under pressure from the Federal Communications Commission (FCC).

The Bell monopoly over telephone instruments no longer made sense. Companies other than Western Electric wanted to sell switches and other equipment to the local Bell telephone companies. Competitors wanted to provide lucrative and highly profitable long-distance service to business and residential consumers. In 1972, the government had entered an anti-trust case against AT&T.

To me, it was clear by the mid 1970s that the Bell System was doomed. Bell Labs employees were asked to write to their elected representatives about the government’s antitrust case against the Bell System. I did a back-of-the-envelope study that concluded that residential telephone service was subsidizing business service. As punishment, I was told to leave Bell Labs, but I then transferred to AT&T. Freedom of thought was no longer tolerated at Bell Labs, although it would take ten years for the big ship finally to break apart in 1984.

There could be arrogance at Bell Labs when it came to developing new products; Bell Labs management and engineers believed they knew what was best for consumers. The Picturephone was a prime example. It was developed by Bell Labs during the mid 1960s, and introduced into service in Chicago in 1971. Consumers simply did not want it. Bell Labs executive vice president Julius P. Molnar championed the Picturephone at Bell Labs, and it cost over $500 million to develop. The only consumer research was a demonstration at the New York World's Fair of 1964. "Bell Labs knew best" had become the belief, but in this case, the result was what came to be called "the Bell System's Edsel."[13]

Nearly all the professional staff was male. Few women were attracted to careers in science and technology back then. But there were special programs at Bell Labs to attract women to both technical and non-technical areas. Women were expected in the 1960s to be secretaries or support people working in stenography and typing pools, or operating keypunch machines. But there was no conscious effort to avoid hiring female scientists – there simply were not many. Nor were there any female engineers – most women just did not study engineering back then. Bell Labs was beginning to make efforts to recruit women and to give them opportunities to work at Bell Labs during summers, with the hope to attract them to science and engineering. Some women entered local doctoral programs, with the encouragement and at the expense of Bell Labs and were later promoted to full MTS status. I recall some in the speech area who were supported by Bell Labs to study and obtain doctorates and were promoted to MTS level. Others were ultimately promoted as a result of the substantive research and work they performed.

There were a small number of women in the Research Area, but most did not have doctorates and thus were seen as second-class citizens. There were notable exceptions, such as Elizabeth (Betty) A. Wood, a world known crystallographer who advised many in the solid-state area about crystals. She wrote a classic book about crystallography that was translated into many languages.

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[13] A. Michael Noll, "Anatomy of a failure: picturephone revisited," *Telecommunications Policy*, Vol. 16, No. 4 (May/June 1992), pp. 307-316.

This was not just a female issue. There were males in the Research Area who lacked doctorates, yet were doing research at the MTS level. A few were given full MTS status, such as Bishnu S. Atal, Leon Harmon, and me. Atal and I ultimately did obtain doctorates through part-time study at Brooklyn Poly. My dissertation involved the design of a three-dimensional force-feedback system.

I recall upon graduation from undergraduate college that I was surprised when one of my fellow students told me that he was not interviewing for a job at Bell Labs since he believed that Bell Labs did not hire Jews. However there actually were a number of Jews at Bell Labs, some in senior management, in the early 1960s when I arrived there. My guess was that this might have been a policy from the distant past that had become a myth that it still existed. Bell Labs wanted to hire the very best, regardless of religion, ethnicity, or anything other than the quality of their minds and intellect.

There were the kinds of romantic encounters that one would expect at any large facility. Mutual interest was acceptable, but forced encounters were not, and the Bell Labs security area would intervene. A formal policy was enacted that one could not report to one's spouse or romantic partner. Rumors and gossip kept tongues wagging, sometimes with much interest. Secretaries seemed to know more about these romantic entanglements than did most of the scientists and engineers who were much more interested in their research and work.

The Research Area at Bell Labs received its funding from AT&T. But not all of the research done was acceptable to AT&T. In particular, one specific person at AT&T criticized and objected to the work in computer music and art, but the work nevertheless was strongly defended by John R. Pierce and Dr. Baker. AT&T questioned the measurements being done at Philharmonic Hall, even though the request for assistance had gone through very formal management channels. AT&T also funded much research work in the development areas at Bell Labs.

The sound spectrograph machine was used to investigate human speech. Speech spectrograms had contours and looked somewhat like fingerprints. They thus were called “voiceprints.” Larry Kersta was a researcher at Bell Labs, and he made a business out of the use of voiceprints in criminal investigations. The problem was that voiceprints did not have the unique characteristics of fingerprints, and there thus was a real danger in their use to obtain convictions in criminal cases. This became an embarrassment to Bell Labs, and some of its researchers testified against the use of voiceprints in court cases.

But all these were little problems compared to far larger ones having to do with the very nature of the Bell System and its manufacturing entity. During its early years, Western Electric Company (WECO) was very efficient in making the very best telecommunication equipment. But its customers – the local Bell telephone companies – had no option but to purchase from WECO. Over time, competition slowly came to the equipment market, and other companies made telecommunication equipment that was as good as that supplied by WECO, perhaps even better, and at lower prices.

Western Electric had been in a protected environment for far too long and had become far too large with far too many people and thus inefficient. The development projects undertaken by Bell Labs likewise suffered as a consequence. A good example was the switching systems in which every component needed to be designed fresh rather than obtained on the open market. The transistors being made at the Western Electric Allentown facility were too costly and not competitive. In the end in 1984, AT&T retained Western Electric so that it could enter the computer business. This was an absolute failure.

One would have expected that some sort of large industrial entrepreneurial park would have formed around the Murray Hill facility – but it did not. There were, however, just a few firms in such areas as traveling wave tube amplifiers, power supplies, and an optical polishing company. Each employee assigned all rights to any inventions or other intellectual property to Bell Labs when they were hired, for which they were given a dollar bill. This helped to eliminate any incentive to leave and take an invention away to start a new business. Also, the nature of the Bell monopoly in which there was protection from any competition meant that the type of people attracted to Bell Labs themselves avoided personal risk. Thus the majority of them came and stayed, but some did leave to start a new business or become a professor at an academic institution. Those who left usually were very successful in what they did.

By 1980, the management structure of Bell Telephone Laboratories, Incorporated had grown significantly in size and complexity. Ian M. Ross was President, reporting to Dr. William O. Baker, Chairman of the Board. Three Executive Vice Presidents reported directly to Ross: Customer Systems (Sol J. Buchsbaum), Network Systems (John S. Mayo), and a Staff organization (H. W. Collier) that included Finance, Personnel, and Public Relations. Buchsbaum and Mayo had a number of Vice Presidents reporting to them for such development areas as Military Systems, Data Communications, Switching Systems, Transmission Systems, and Electronics Technology. Also reporting directly to Ross were Research, with N. Bruce Hannay as Vice President; Legal, with William L. Keefauver as Vice President and General Counsel; and a Project Planning Organization with four Executive Directors.

There were over 60 senior managers in the 1980 organization chart. With only four more years to its ultimate demise by the Bell breakup of 1984, Bell Labs had grown considerably with facilities and buildings all over New Jersey and the United States; it perhaps was no longer manageable. Some senior managers had been transferred from other areas and did not have the personal background and technical experience to understand the new assignments.

The Holmdel building was expanded in 1982, but even that was not sufficient space; and satellite labs were opened in New Jersey at West Long Branch, South Plainfield, Freehold, Neptune, and Lincroft. What had happened to the vision of 1941 to have research and development together all in one facility at Murray

Hill? Two decades later, the large Holmdel building was constructed, and then expanded two decades after and satellite labs occupied all over New Jersey, with other large facilities in other States. At a time when competition was growing in telecommunication, the response of Bell Labs was also to grow – not become more efficient "lean and mean." The end sadly was already in sight; the Bell breakup of 1984 simply formalized it.

Chapter 9

CONCLUSIONS

RELEVANCE

Relevance to the real-world problems of the Bell System was always of concern at Bell Labs, even to the researchers performing the actual research. However, it was the task of management to identify and assure the relevance. Relevance can be a challenging and controversial topic. What some might consider not relevant, others might consider very relevant. Sometimes relevance motivated research; other times the relevance was discovered after the research.

Fig.9-1. The Bell System seal was placed on telephone booths and symbolized quality service. Variations of it, becoming more modern over time, were used from 1889 to the final dissolution of the Bell System in 1984. [Courtesy AT&T Archives and History Center.]

The relevance of many areas of research was quite obvious, such as materials research. W. Lincoln (Linc) Hawkins and Vincent L.

Lanza used polyethylene as sheathing for telephone cable, thereby replacing lead. Radio research was applicable to long-distance transmission. Mathematics was relevant to telephone switching and computer logic. Other areas were not as immediately clear as to their relevance. As a bench-level chemist at Bell Labs, Dr. Baker solved the problems encountered with synthetic rubber during World War II.

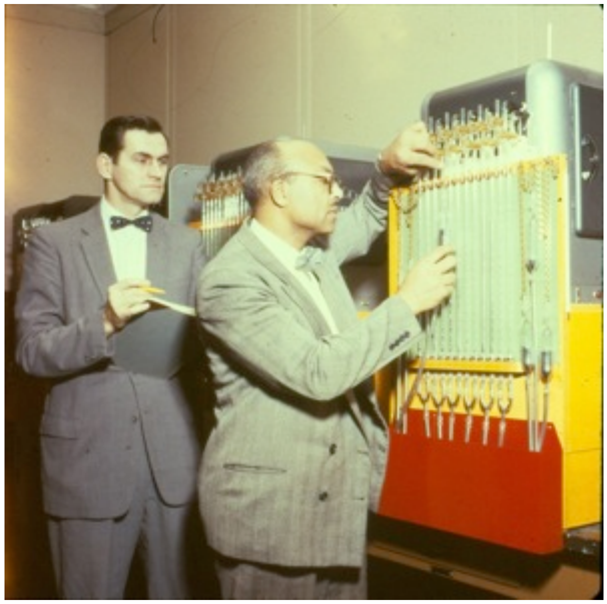

Fig. 9-2. Polyethylene replaced lead as sheathing of telephone cables as a result of the research of Lincoln Hawkins (right), show here in this 1958 photograph with his colleague Stretch Winslow. [Photo courtesy of Alcatel-Lucent USA Inc. / Bell Labs.]

Research in computer music was claimed to be relevant to speech synthesis, but I am hard pressed to cite any actual innovations or discoveries in computer music that were relevant to the interests on the Bell System. Computer animation was useful for the display of engineering data in two and three dimensions. The research done in human depth perception by Bela Julesz was fascinating and won Julesz a MacArthur Award, but had little or no direct relevance to the interests of the Bell System. Psychological research into learning and perception was relevant to the training of telephone operators and other employees of the Bell System. Computer art was relevant to the design of advertisements for the classified pages of the telephone directories supplied by the Bell System.

Clearly the timeframe of the relevance is significant. Longer-term relevance requires more faith than short-term application. It took much faith in future relevance to justify the solid-state semiconductor research that resulted in the invention of the transistor. Speech research resulted in the discovery of ways to synthesize human speech with less bandwidth. The most immediate application was to classified areas of government security work. Later, speech synthesis and compression became applicable to wireless cell phones. The Unix operating system today is the basis of many personal computers.

Research in economics was very relevant to the Bell System, and a economic research group was created in the early 1970s. Edward Zajac, who had programmed some of the first computer animation at Bell Labs, headed the group, which even had its own professional journal. The rationale for economics research was that the government had its economists who touted the advantages of competition and the evils of the Bell monopoly; the Bell System needed its own economists to respond and conduct research.

Some of the research performed at Bell Labs had much benefit to the public and was truly technology in public service. Mechanical (invented in 1929) and electronic (1960) artificial larynxes were developed at Bell Labs as aids to those who had their larynx (or voice box) removed, and enabled them to produce speech. They were made available at cost to all those who needed them. In 1920, Western Electric made an electronic hearing aid, though large and heavy. The transistor invented at Bell Labs was made available royalty-free to companies, which used them in small, portable hearing aids. The beam of a CO2 laser invented ay Bell Labs was used as a surgical knife. In the mid 1960s, an argon-ion laser was adapted for photocoagulation by Eugene Gordon and Edward Labuda at Bell Labs.

Fig. 9-3. Nobel Prizes to Bell Labs Scientists

PRIZE	SCIENTISTS	DISCOVERY	FACILITY
1937 Physics	Clinton J. Davisson	Wave nature of matter -- 1927	BTL (West Street)
1956 Physics	John Bardeen, Walter H. Brattain, and William Shockley	Transistors – 1947-48	BTL (Murray Hill)
1964 Physics	Charles H. Townes	Maser-laser – 1957	BTL (Murray Hill) and Columbia University
1972 Physics	John Bardeen	Theory of superconductivity	BTL (Murray Hill). Continued research at the University of Illinois at Urbana-Champaign.
1977 Physics	Philip W. Anderson	Electronic structure of magnetic and disordered structures – 1958	BTL (Murray Hill)
1978 Physics	Arno A. Penzias and Robert W. Wilson	Cosmic microwave background radiation – 1964	BTL (Crawford Hill)
1981 Physics	Arthur I. Schawlow	Development of laser spectroscopy	BTL (Murray Hil)
1996 Physics	Douglas D. Osheroff	Discovery of superfluidity in Helium-3	BTL (Murray Hill). Research at Cornell

			University and continued at BTL.
1997 Physics	Steven Chu	Laser cooling and trapping of atoms	BTL (Holmdel)
1998 Physics	Horst Störmer, Robert Laughlin, and Daniel Tsui	Fractional quantum Hall effect – 1982	BTL (Murray Hill)
2009 Physics	Willard S. Boyle and George E. Smith	Charge-coupled device – 1969	BTL (Murray Hill)
2014 Chemistry	Eric Betzig	Super-resolved fluorescence microscopy	Initiated research at AT&T Bell Laboratories (Murray Hill). Completed research at Howard Hughes Medical Institute.

Notes:
• BTL = Bell Telephone Laboratories, Incorporated
• West Street facility was in New York City; Murray Hill, Crawford Hill, and Holmdel facilities were in New Jersey.
• Many of the Nobel Prizes were shared with others.
• The research for some of the Prizes was initiated before coming to Bell Labs, continued after leaving Bell Labs, or done while also affiliated with another institution.
• Nobel Prizes are awarded to individuals – not an institution

LESSONS

Bell Labs was a unique place, in many ways. The list of innovations and discoveries that came from Bell Labs was extremely impressive. Indeed, today's information age and digital era came or was initiated mostly from Bell Labs. The number of people affiliated with Bell Labs who obtained Nobel Prizes is impressive, particularly for an industrial research facility. But the awards go further with many Bell Labs people being elected to the National Academy of Sciences and the National Academy of Engineering, as well as being awarded the National Medal of Technology, the National Medal of Science, and numerous technical society awards.

The uniqueness was much more than awards, inventions, and discoveries. It seemed everybody wanted to get a job there. But what factors made it so productive and successful? John R. Pierce had his own list of factors; so too did others. This section summarizes and discusses the factors that made Bell Labs what it was.

As mentioned much earlier, the Bell System was a monopoly with secure and stable income. This meant that most of the research done at Bell Labs could take a long-term view, although regulators had to be informed of the payoffs. Innovations and discoveries made their way into equipment and systems used within the Bell System, resulting in reduced costs and rates for telephone service. As one example, continued advances in transmission systems resulted in increase in capacity and thus lower rates for long-distance service.[14] Advances in technology – not competition – reduced long-distance rates.

The writing of lengthy research proposals and complex peer-review processes are common for university academic research. All that was avoided at Bell Labs. It was only necessary to convince a department head of a project.

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[14] A. Michael Noll, "A study of long-distance rates: Divestiture revisited," *Telecommunications Policy*, Vol. 18, No. 5 (1994), pp. 355-362.

Researchers and engineers had the freedom to take chances and to sometimes fail. But there was not complete freedom to do any kind of research at Bell Labs. Management knew how to make it seem that way to the researchers. New scientists were hired based upon their dissertations and areas of interest that had to match areas of interest at Bell Labs. Once at Bell Labs, they were given the very best resources and apparent freedom to pursue their research. But there were yearly merit reviews, and if someone were not producing results, transfers or changes in assignment would occur. If it appeared that a research topic was not going anywhere, it was discontinued.

I recall entire areas of research and even exploratory development projects that were halted since years had passed with no significant results. One cancelled research topic dealt with investigation of pigeons and intelligence. A cancelled development project dealt with the use of millimeter waveguides for transmission – it was ultimately replaced with optical fiber.

The vast majority of the work at Bell Labs was the development of specific switching and transmission systems and station apparatus. The closeness of researchers to such practical problems was an excellent stimulation of research that attempted to solve real-world problems. If a development project encountered obstacles, research people were readily available to consult and help. The free flow of ideas through Bell Labs through Technical Memoranda facilitated the transfer of technology and research.

Bell Labs had a broad, clear mission, namely, to assure the future of communication in the United States. Communication came to be defined broadly and included not only interpersonal communication (the telephone) but also communication between people and computers (what was then known as man-machine communication) and communication between machines (data communication).

The most significant factor was the quality of all the people who worked at Bell Labs – all levels and job descriptions. Bell Labs was not a building. It was **people** who made Bell Labs. Management rose through the ranks and thus intimately knew Bell Labs. Department heads in the Research Area were expected to continue their own research activity. In some cases, a promotion to department head, along with its obligatory paperwork was viewed as a burden and not an honor. People who worked at Bell Labs wanted to be there – it was hard to keep them away. They were there at night, weekends, and even holidays. Yes, it was the employees caring about Bell Labs – wanting to be there, proud to be there – that made Bell Labs what it was in the 1960s.

There were real bosses in the Research Area at Bell Labs. The bosses were technically and scientifically competent, since they rose through the ranks. They were keenly interested in the work that was being done in their areas. I recall John Pierce bursting into my office to see for himself the results of my work in which he was most interested – he had to see for himself. By doing so, Pierce had bypassed two levels of intermediate management.

Nearly all who came to Bell Labs made it their entire careers. However, some would leave to start their own companies, to work at other technology companies, or to have academic careers. The Bell breakup of 1984 changed all that as many were forced to choose between staying with the new AT&T Bell Laboratories or with the new Bell Communications Research, although some were not even given a choice. Another breakup in 1996 would force more career choices and changes. Such uncertainty is not good for long-term research, and the Bell telephone companies simply did not relish nor know how to nourish and support fundamental research. The reduction in financial support for fundamental research resulted in the departure of good scientists, often to universities. And Western Electric and its successor Lucent simply could not afford it at the levels of the past.

John R. Pierce, In a letter dated June 18, 1986 to me, enclosed a short essay he wrote entitled “Some Thoughts About Laboratories and Research Therein."[15] His thoughts about what made Bell Labs such a great success included: "The good laboratories had real missions." "Above all, a laboratory needs a clear purpose." "The goal of the research at Bell Labs was very long range, and stability of funding is very important in pursuing long-range goals." "Another matter is the nature of top management, which…was made up of engineers [who managed] more for the fun of helping things to happen."

Pierce worried about the changes that occurred after the 1984 Bell breakup. He observed that "manufacturing is a far less stable source of income than that provided by an essential service." He was concerned that "…AT&T hasn't found out what business it will be in, and until it does, AT&T Bell Laboratories can [not] have a clear mission." He concluded, "The mission was absolutely essential to the research done at the old laboratories, and that [broad national] mission is gone and has not been replaced."

What made Bell Telephone Laboratories such a powerhouse of research and development was not the buildings or physical location – it was its **people**: its researchers, engineers, and support staff. It was its management, and their commitment to innovation, along with a philosophical vision of assuring the future of telecommunication.

[15] A copy of the letter and essay are in the collection of Pierce papers at The Huntington Library in San Marino, CA.

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ABOUT THE AUTHOR

A. Michael Noll is Professor Emeritus of Communications at the Annenberg School for Communication and Journalism at the University of Southern California. He retired after working there as Professor of Communications for about 25 years, including two years as dean of the School. He was a researcher at Bell Telephone Laboratories in Murray Hill during the 1960s, working on speech processing, computer animation and art, and force-feedback. During the early 1970s, he was on the staff of the White house Science Advisor. He worked in marketing at AT&T on visual communications and videotex. Noll has published nearly 100 professional papers, over 150 editorials and opinion pieces, and 12 books about telecommunications. His current research has been on the papers of William O. Baker and John R. Pierce and on the history of early digital art and music at Bell Labs.