The Role of Research

A tradition of imaginative research at Bell Laboratories has played a significant role in providing this nation with the world's best communication service and has made an impact on society far greater than the size of the company would suggest.

E. E. David, Jr.

Creativity, invention, and innovation are words used somewhat interchangeably to describe research, or the process of seeking new knowledge, new materials, and new techniques. Since the invention of the wheel, there have always been highly imaginative, curious, and persevering individuals involved in research. But it wasn't until the twentieth century that industry recognized its potential by establishing research as an organized company activity. And in 1968, American business and industry spent some 17.3 billion dollars to support about 5500 research and development laboratories.

More than 500 of these industrial laboratories are actively engaged in electronics and communications research. And even though Bell Telephone Laboratories' professional technical staff accounts for less than five percent of the electronics industry's total, there is ample evidence that Bell Laboratories scientists and engineers have made significant technical contributions far in excess of what their number would suggest.

What then, with this record of success, is the role of research at Bell Laboratories?

Much has been written about research! Research and the "Ivory Tower," for example, are often associated. According to this association, the motivation behind research must be pure curiosity, conjured up somehow from an intellectual brew, and the importance of the subject to society is irrelevant to the researcher. Dr. J. B. Wiesner, former Science Advisor to the President and now Provost at MIT, dismissed this puristic notion by remarking facetiously, "Pure research is research that can be *proved* to have no application." If this is the sort of work done in ivory towers, then Bell Laboratories research does not abide in such quarters.

Yet it is fair to ask: How are the subjects of research chosen—according to immediate needs of operating companies or development projects, or according to the whim of the researcher? The answer, of course, is "neither." Productive research requires ideas. Research people work on topics and problems where their ideas seem likely to generate new possibilities for communication. Research based upon needs and without ideas is not likely to be fruitful, because ideas on isolated problems are seldom produced on demand. The long sought-after cures for cancer and the common cold, for example, still elude medical researchers. Lasers and masers came not from looking for them but from alert people working in microwave spectroscopy, which at the time had no apparent application. The telephone itself was such a discovery—the product of serendipity.

Research at Bell Laboratories has integrity of purpose drawn from the goal of enhancing communication. But who is the audience for research? Who applauds, who criticizes, and who consumes the product? The Bell System in one form or another fills all these roles, but so does

Bell Laboratories Record, Vol 47
www.telephonecollectors.info

the government, the military, and the general public. In the area of government, many of our research people, as advisors, diffuse new knowledge and Bell Laboratories unique capabilities into critical situations. Moreover, four members of the President's Scientific Advisory Committee over the past eight years have been Bell Labs people, not to mention numerous other public service appointees. The universities and colleges, too, look to BTL research, as we look to them as professional colleagues. Members of our research staff become visiting professors, guest lecturers, and "visiting committee" members to facilitate the exchange of knowledge. And, of course, there are the professional societies. Research must contribute to these to remain in the mainstream of technical and scientific thought.

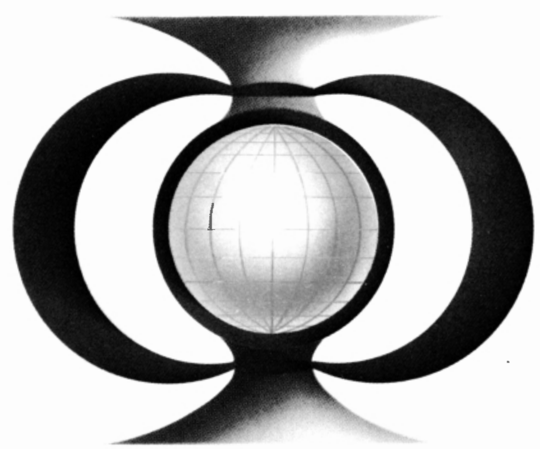
Finally, and not least, whole new industries have been spawned by Bell Laboratories research. The semiconductor industry, for example, had its beginning at Bell Laboratories with the invention of the transistor. From this beginning have come whole families of new solid-state devices and new impetus for the broad field of materials science itself. The transistor is perhaps the best known example of this, but there are many others. Lasers, new magnetic materials, synthetic quartz crystals, and polymers, to mention just a few, have all had tremendous impact on the communications industry as well as a host of other, unrelated industries. In addition, such fundamental concepts as negative feedback, information theory, systems engineering, and statistical quality control, which are widely used in industry today, are direct results of Bell Laboratories research. Thus, the audience for BTL research is broader than it might at first appear.

To communicate with this broad audience, research must interpret new knowledge so that its implications are clear. What new possibilities may spring from new knowledge and understanding? Research must answer. This answer must be communicated in an understandable form, documented so that a new landmark of knowledge is thereafter available to scholars and technologists. Last year alone members of the research area produced approximately 1200 technical memoranda, 750 papers for magazines and journals, 4 books for publication, and made application for 160 patents.

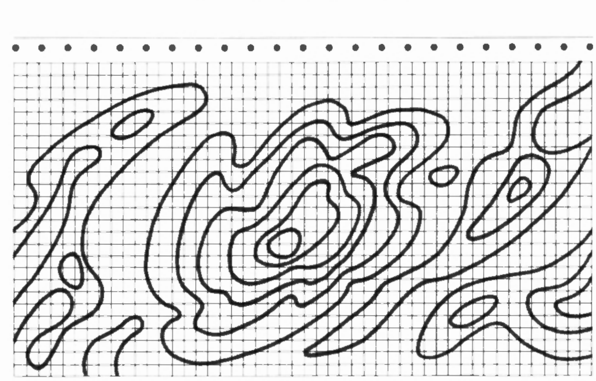
Publication and writing are powerful means for communicating, but demonstrations of new possibilities often have more impact. J. R. Pierce of Bell Labs believes that research must strive to demonstrate the "newly possible." The mission of research in this view is *both* to create new

Bell Labs research projects have opened up exciting new areas of study . . .

Radio Astronomy



Magnetic Field Effects



Bell Laboratories Record, Vol 47
www.telephonecollectors.info

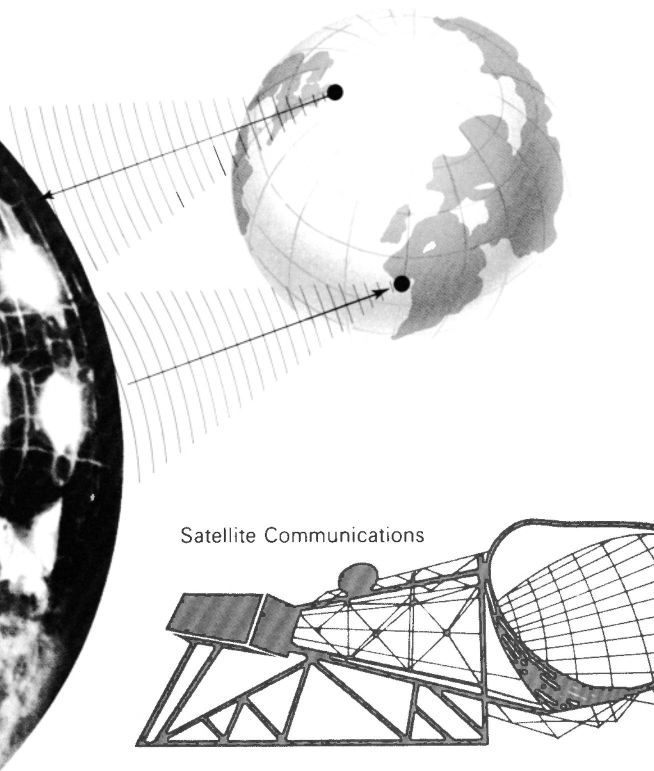
knowledge and technique, *and* to demonstrate the new feats of communication they make possible. A prime example is the Echo experiment done in Pierce's Division. This was the first demonstration of high-quality satellite communication between points on the earth. It was much more startling and convincing than any study or even an eloquent description could have been. More important, much was learned as a result of the experiment. Essentially, none of the new knowledge produced from the experiment could have been anticipated from an "armchair" approach.

There are other techniques for communicating from research to its audience. For example, research people consult and advise their colleagues in development, engineering, and operations. They are educated, in turn, through these interactions, and they develop a keen awareness of important unsolved communication problems. Thus, the audience is far from passive.

For research to have impact on the world, much besides research is necessary. Bringing new knowledge and techniques to bear on real problems requires engineering, development, trials, production, marketing and distribution, and evaluation and improvement. Research people recognize these functions as a vital adjunct to their work. These interactions with all segments of the community encourage the researcher to take a worldly view of his work.

Yet, despite the urgencies and demands of the world, the researcher retains an allegiance to his profession and his specialty, be it engineering, physics, chemistry, or mathematics. It is from this allegiance and from professional excellence that research draws its freedom—freedom to decide the subjects for research which are both relevant and important. This freedom of decision is vital, for it is not always obvious to the uninitiated just how some apparently esoteric subject fits the larger context of human communication. In the words of W. O. Baker, Bell Labs Vice President for Research, "research must 'look away' from everyday pressures of the on-going development and engineering enterprise toward the vistas opened by new knowledge and technique." This viewpoint requires a thoughtful, professionally excellent approach.

Individuality, some say eccentricity, characterizes research people. In any enterprise, people are the key; in research it is particularly so! Individuals make research imaginative or routine, creative or repetitious, inventive or stereotyped. In this day of large projects, research is still largely an individual pursuit. Research



Satellite Communications

people *do* communicate with others for stimulation, but the essence of creation is individual thought. "Brainstorming" is not a research technique.

The individuality required of research people sometimes does have its correspondence on the personal side. Yet, research people traditionally go on to leadership positions outside of research. Some 15 out of 32 members of Bell Laboratories top technical management team (President, Vice Presidents, and Executive Directors) got their start in the Research Area. Research is a fertile source of leadership not only for Bell Laboratories and the Bell System but for other industry and academia as well.

Research in this image has been notably successful at Bell Laboratories by any measure. Whole new scientific fields have been created: for example, radio astronomy. Basic contributions to physical science appear: the first demonstration of electron diffraction. Principles which span the fields of biology, physics, chemistry, and engineering have been uncovered: the feedback principle and information theory. Clearly, this is a hard act for today's researchers to follow. Yet there is every reason to believe that research today is even more productive than in the past.

Competition is much greater, however. Some years ago, very few industries had research organizations—almost none besides BTL, GE, Westinghouse, Philips, Dupont, and a few others. Today there are over 5500 such companies. The number of people in research nationally has grown tenfold in the last fifteen years, and the national research budget by as much. Thus, research accomplishments do not have the prominence they once did, and it is more crucial to pick and choose the fruitful paths. Resources for research (equipment and facilities) and manpower for research (people of excellence) are in strictly limited supply. How we use them is more crucial today than ever before to the health of the research enterprise, the Bell System, and the nation. Despite this, or perhaps because of it, there is no formal administrative mechanism to allocate research resources. In research we cannot measure cost-effectiveness, nor can we depend upon the much-heralded government technique, known as PPB (Planning, Programming, Budgeting), which requires a five-year projection of objectives and costs. Rather, the general subjects thought to be important are selected, and the best professionals obtainable in these fields are brought together and allowed to pursue their own program with perceptive reviews by their colleagues. David Slepian, a Bell Labs mathematician, said ". . . research should be ordered in the large but random in the small." Research has a strong element of spontaneity which can be smothered by too close direction. Yet the overall goals of research *can* be stated.

The policy of encouraging individual initiative within broad fields has led to a policy of *continuity with renewal* that has been notably productive. To take an example, the subject of visual communication research has a long history at Bell Laboratories, dating back into the 1920's and 30's. Bell Laboratories research in television is as old as the technology itself. As early as 1925 Bell Laboratories demonstrated the transmission of still pictures over wires, and in 1929 first demonstrated color television. The development of coaxial cable that same year laid the groundwork for modern network TV. Work in visual communication research has gone on continuously, sometimes by many people, sometimes by fewer, always looking to the young recruit to bring renewal in the form of new viewpoints and to prevent inbreeding.

Over the years, this research philosophy has produced extraordinary insights and techniques. Herbert Ives' research in the 1920's and 30's yielded a basic understanding of flicker fusion in vision—the phenomenon in which a flashing light is seen as continuous when the rate of flashing is high enough. Millard Baldwin showed that the human eye, in seeing a color image made by red, green, and blue pictures superimposed, requires that only the green be sharply focused. This knowledge strongly influenced the engineering of both black and white and color TV for public broadcast. Thereby, pictures for high-quality viewing could be transmitted over Bell System lines and broadcast to the public by local stations within the stringent bandwidth limitations set by economics.

In the early 1950's, Carl Feldman, W. M. Goodall, R. L. Carbrey, and their associates demonstrated digital transmission of pictures and explored the requirements for adequate subjective quality. This work highlighted the vast disparity between the modest information-handling capacity of human vision and the much larger capacity of television channels. There seemed to be great waste of a scarce resource, namely, transmission capacity, commonly equated to bandwidth. This realization led to a search for ways of sending pictures using less bandwidth.

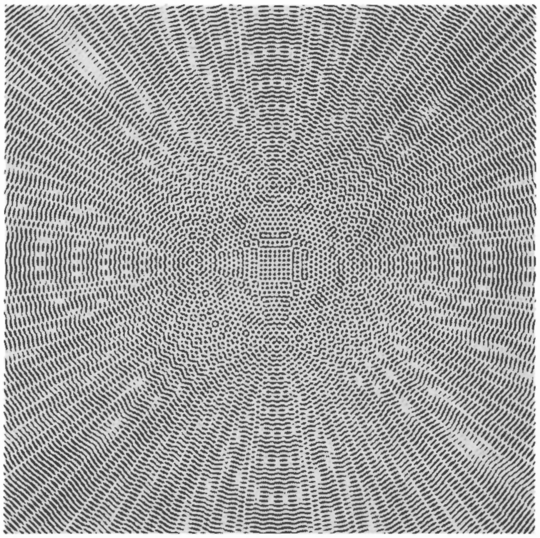
Many people over the years since the early 1950's have contributed to research in picture transmission. B. M. Oliver (now Vice President of Hewlett-Packard) and E. R. Kretzmer of Bell

Bell Laboratories Record, Vol 47
www.telephonecollectors.info

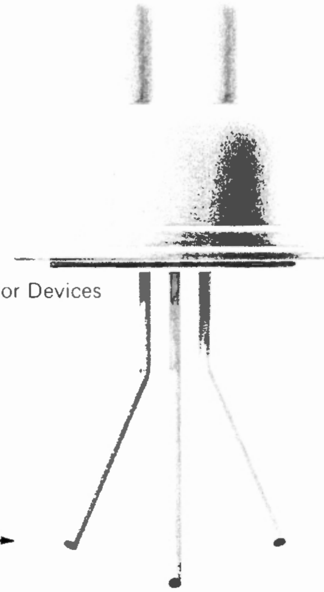
Research at Bell Labs extends from investigations into . . .

To tangible results such as . . .

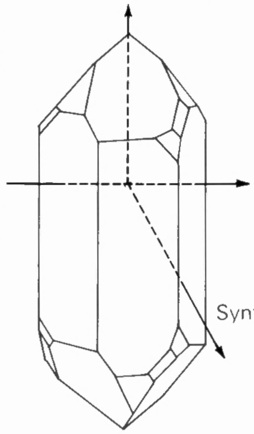
DNA



Holography

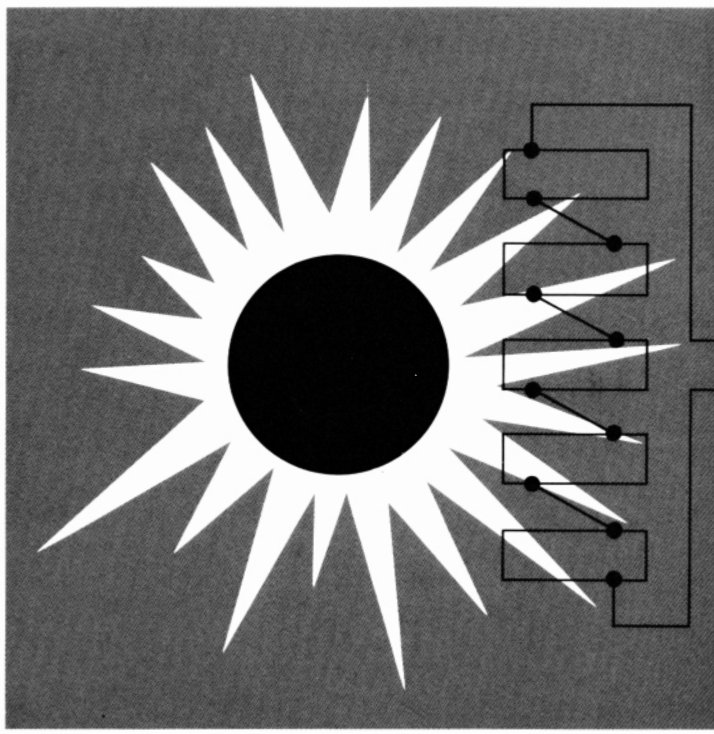


Semiconductor Devices

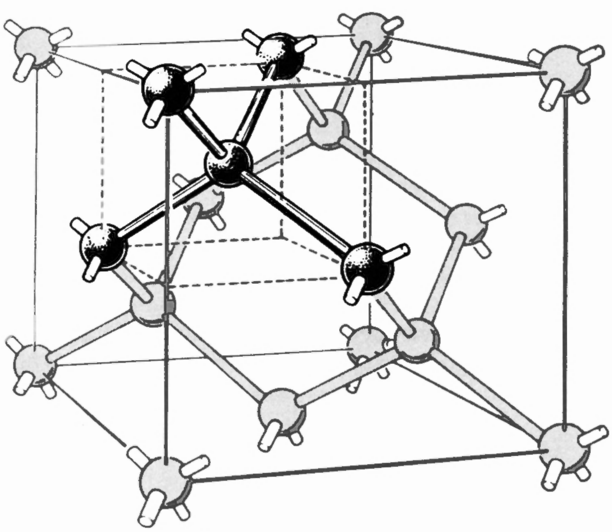


Synthetic Crystals

Polymers



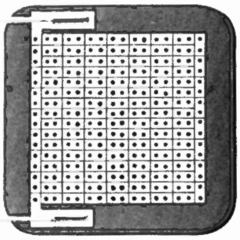
Solar Batteries

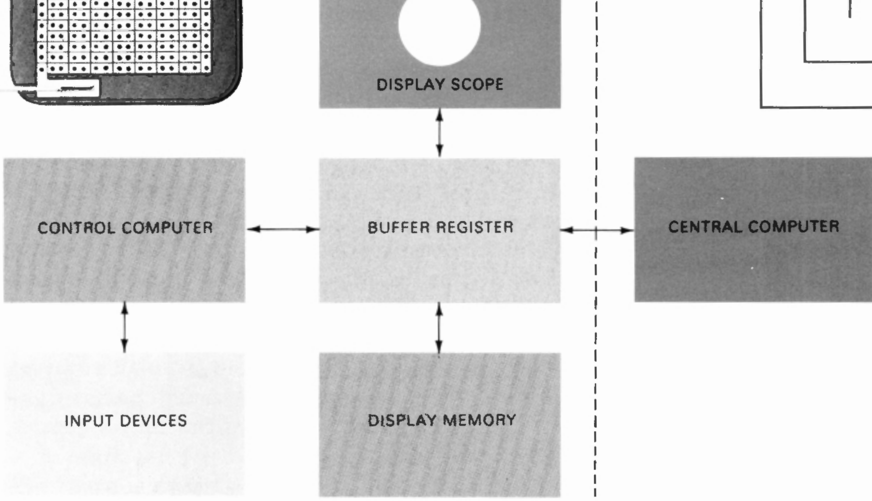


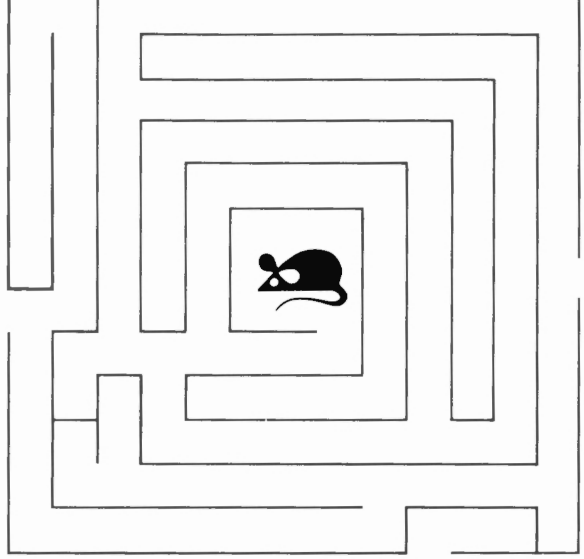
X-ray Crystallography

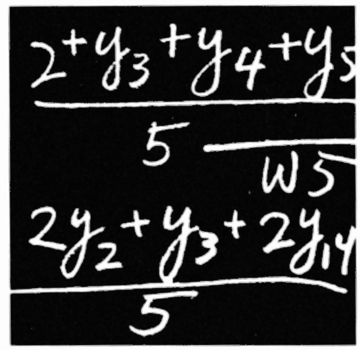
Some research that leads to better communications includes . . .

magnetic memory devices basic to ESS









Labs were among the pioneers who showed how the statistical properties of pictures could be used to reduce bandwidth. Later, C. C. Cutler, J. L. Kelly, Jr., and R. E. Graham showed how to code pictures into less than half the bandwidth required with pulse code modulation. This coding again took advantage of the structure of the pictures themselves, namely, that most pictures are composed of a few areas of detail alternating with large, visually flat areas separated by sharp edges. Most recently, W. T. Wintringham and F. W. Mounts have found a way to achieve an 8-to-1 reduction of bandwidth compared with PCM by using the similarity between successive transmitted pictures. All of this activity is now being focused on the PICTUREPHONE® "see-as-you-talk" telephone, for it is here that transmission requirements, particularly over long distances, become crucial for economic reasons.

Recent research at Bell Laboratories on color perception by D. E. Pearson and C. B. Rubinstein is also crystallizing in the PICTUREPHONE application. Overall, a vast store of knowledge and technique has been accumulated over the years. This resource has come from research on human visual physiology and psychology, the physics of display and camera devices, and system experiments over a 40-year span. The accumulated wisdom is proving invaluable in broadening the Bell System's horizons to include person-to-person visual communication along with facsimile, pictorial data, and broadcast TV. Yet, at any one time, the effort has not been massive, nor is it likely to become so.

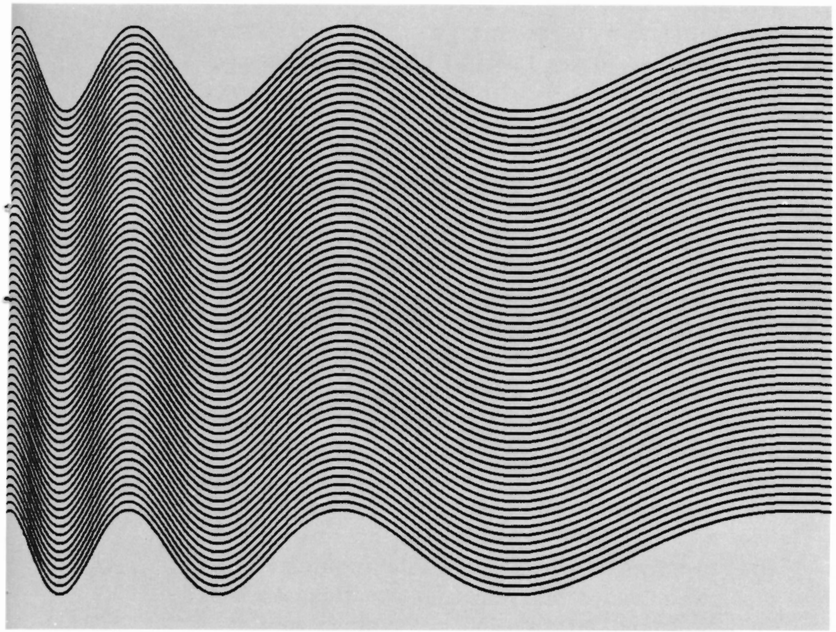
The rapid and apparently unrestrained growth of research on the national scene has led to what some people think is a state of gigantism. Research at Bell Telephone Laboratories has not expanded to this extent in the same time. Our research tradition goes back many years, and we have grown much more deliberately than most industrial and many government research activities. This does not imply that the research picture has been unchanging. On the contrary, just as our example in visual research shows, there is constant renewal through new people, reorganized activity, and, most of all, new ideas in all of our research activities.

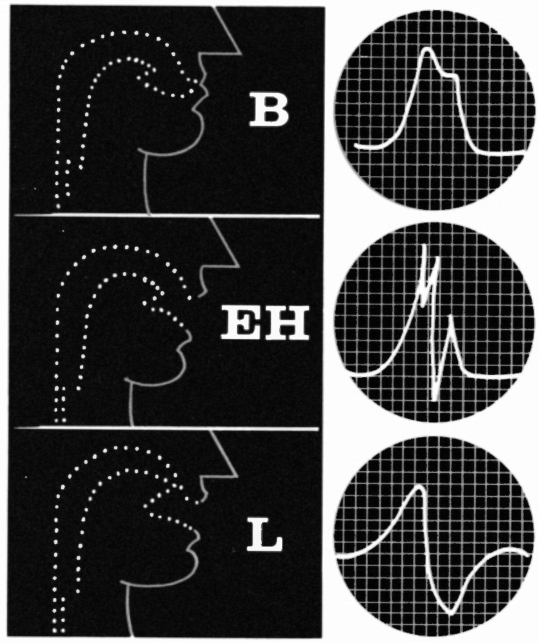
At the moment, there are about 1100 technical people involved in research at Bell Laboratories; some 800 of these are highly specialized professionals, most of whom have doctorate degrees. Among the remaining 300 technical support people, most have baccalaureate or technical institute degrees. Our research budget is some $40 million per year. Significantly its growth is

Bell Laboratories Record, Vol 47
www.telephonecollectors.info

Shannon's information theory and his famous mechanical mouse and maze

Computer-Aided Design





Electronic Synthesis of Speech

somewhat less than the growth of the overall Bell Labs budget, reflecting Bell Laboratories' traditional stability of research funding and burgeoning development commitments. For comparison, the overall Bell Labs figures for 1968 were 10,000 technical personnel and $370 million budget. Nationally, it is estimated that $1.6 billion per year is spent in the universities alone on basic research. Industry spends even more. The amount for Bell Laboratories is small compared to the overall figures, and the conclusion is inescapable—by any standard of reference, Bell Laboratories research has had an impact out of proportion to its size.

Perhaps its greatest impact resulted from the invention of the transistor at Bell Labs by Bardeen, Brattain, and Shockley. This event brought the world to a new age of electronics—an age of portable radios the world over, an age of transistorized control of factories, aircraft traffic, and power distribution, to name but a few. The modern electronic digital computer also is a child of the transistor. None of these things, nor many others, would be possible without the high reliability and low cost of solid-state electronics. But this is a familiar story!

Less widely known is the influence of the transistor on its parent science, physics. Twenty years ago, research in solid-state physics was pursued by a few industrial and academic scientists in at most 10 to 20 institutions in the United States. Though some of this work was inspired by the drive to understand the properties of solid matter, the larger part stemmed from the use of solid-state rectifying diodes in the old crystal radio sets and in World War II radar receivers. The natural galena crystals used in early radios were replaced in radars by silicon and germanium prepared specifically for that task. Overall, however, the effort in solid-state physics was small. By contrast, a National Academy of Sciences report indicates that today it is the largest subfield of physics, that some 25 percent of all physics Ph.D.'s are granted in that subject, and that 25 percent of all physicists are working in that field.

Another field in which Bell Labs research has played a central role is computing, both digital and analog. In 1938 George Stibitz recognized the possibility of using telephone relays to carry out numerical mathematics in the binary number system. He had liberated the calculating machine from the notched wheel, and he built a computer which could perform complex number arithmetic. This machine was demonstrated to a meeting of the American Mathematical Society at Hanover,

Bell Laboratories Record, Vol 47
www.telephonecollectors.info

New Hampshire, in 1940 with the aid of a teletypewriter connection to New York City. Such mathematical expertise continued in men like C. E. Shannon who, in 1948, recognized the congruence between Boolean algebra and the topology of networks of binary elements. From this came the principles of logical design which are at the base of today's computing machines and, of course, telephone switching systems. Later in the 1940's John Von Neumann at the Institute for Advanced Study established the principle of the stored program.

These were the beginnings of modern computing. The first commercial stored program computers became available in the early 1950's. It was commonly said that a general-purpose computer could do anything for anyone—it was simply a matter of programming. The complexities thus concealed were legion. This prompted R. W. Hamming of Bell Laboratories to say that a large computing machine without a reservoir of utility programs and language translators (commonly called software) is about as useful to a researcher, or for that matter any user, as a battleship without a crew is to a weekend sailing buff.

From this realization came the concept of the hardware-software machine—a machine whose electronics are supplemented by stored programs which make it accessible and useful to a wide variety of users. Hamming and his colleagues created the first machine of this kind, drawing on other industrial and academic resources. These hardware-software systems were based on the IBM 650 and 704 computers, and it is from this work that today's time-shared, multiprogrammed, high "throughput" systems come. The thinking behind such systems has given computing the scope to invade all fields of learning and enterprise, and we are still pursuing this goal. The effort centers in two areas: graphics, and an ambitious hardware-software system called MULTICS (Multiplexed Information and Computing System). The latter experiment is aimed at providing a shared archive of software, user programs, and data for the research and development community at Bell Laboratories.

These activities have provided vital tools for research and development. But research is having an even more direct influence on communication. We are coming to recognize that in the digital realm the traditional distinctive functions of switching and transmission are actually inseparable. This point of view was demonstrated by the so-called ESSEX experiment conducted by researchers in the 1950's (see ESSEX: *A New Concept in Telephone Communications,* RECORD, *February 1961*). There, both the information flow and the instrumentalities to route and convey the information were digital. Thus, the technologies and indeed the science of computing and communication merge and feed upon each other. We have yet to see the full impact of this confluence. That must wait upon the art and science of integrated circuitry.

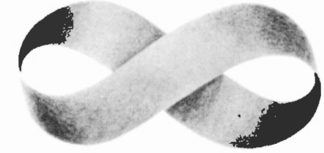
These examples aptly illustrate the depth and impact of research, but they do not indicate the breadth of the effort. What range of subject matter is the concern of BTL research? Bell Labs President, J. B. Fisk, has said that any subject "relevant" to communication is within Bell Laboratories' scope. This is a broad field indeed!

Research at Bell Laboratories is organized into four divisions. There is the Physical Research Division concerned principally with basic physics and device physics. The Communication Sciences Division includes mathematics and the many disciplines that support communication. The Systems Research Division operates across the interface between the basic communication disciplines and communication functions such as switching and information processing; this division also spearheads research on systems principles, such as optimization. The Materials Division is concerned with chemistry and metallurgy and with materials processing.

Clearly, there is considerable overlap, as intended, for it is characteristic in today's world that traditional fields of knowledge are no longer distinct. To solve the problems of modern communication requires collaboration between disciplines. One practitioner of this style was H. T. Friis, eminent researcher and mentor of the "old" Holmdel. He placed emphasis on diversity. Exclusive concentration on one narrow subject was not his style, nor that of his people.

The science and technology of communication is peculiarly broad, including subjects from chemistry, physics, and mathematics to linguistics, psychology, and even elements of economic theory and sociology. The Bell Laboratories tradition of versatility in research is well matched to the challenge of overlapping and changing disciplines.

Bell Labs' success story never really ends. The search for better, faster, less distorted communications is as endless as this endless loop.



Bell Laboratories Record, Vol 47
www.telephonecollectors.info