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The corporate form of the Bell System, unchanged now for many years, is the outcome of careful thinking for the long run. Essential in this thinking is the vigorous pursuit of research and technical innovation to insure the best possible service.

The Bell System And the People Who Built It

The Growing Years

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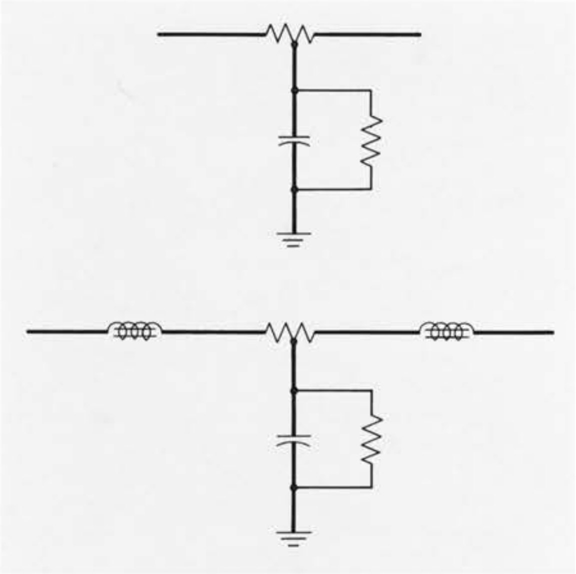
TO APPRECIATE the background for the establishment of Bell Telephone Laboratories in 1925 as a corporation, it is necessary to look at certain technical matters and see how closely the commercial advancement of telephony was related to scientific progress.

In the 1870's there was no profession of electrical engineering. There was no electric light industry; the incandescent bulb had not even been invented. There was essentially no distribution of electric power. There were no trolley cars. Sir William Thomson, who was to become Lord Kelvin, had worked out a theory on transmission of electrical signals along a cable which was adequate to explain the phenomena observed in telegraphy. It ignored the magnetic field because, at the low signaling rates or impulse rates of telegraph transmission, the counter-emf from the changing magnetic flux was small compared with the drop through the series resistance of the wire. Thus the representation of an elemental section of line by series resistance, shunt capacitance, and leakage was accurate enough to explain, within the limits of crude observations, the attenuation or decay of telegraph impulses as they proceeded along a cable, and to explain the distortion of the shape of the impulses resulting from differences in the velocities of the component frequencies.

But the human voice was something different. For one thing, the energy generated by a telephone transmitter—even with the advent of granular carbon transmitters with their inherent amplification—was infinitesimal compared with what could be generated by pounding a key. But

Editor's note: This is the second and final part of an article based on an orientation talk for new staff members at Bell Telephone Laboratories.

With the development of vacuum tube repeaters, it was possible to extend the New York-Denver circuit to San Francisco. On June 17, 1914, the last pole was erected at Wendover, Utah, on the Nevada-Utah state line and was topped with the American flag. Commercial service was started on January 25, 1915.

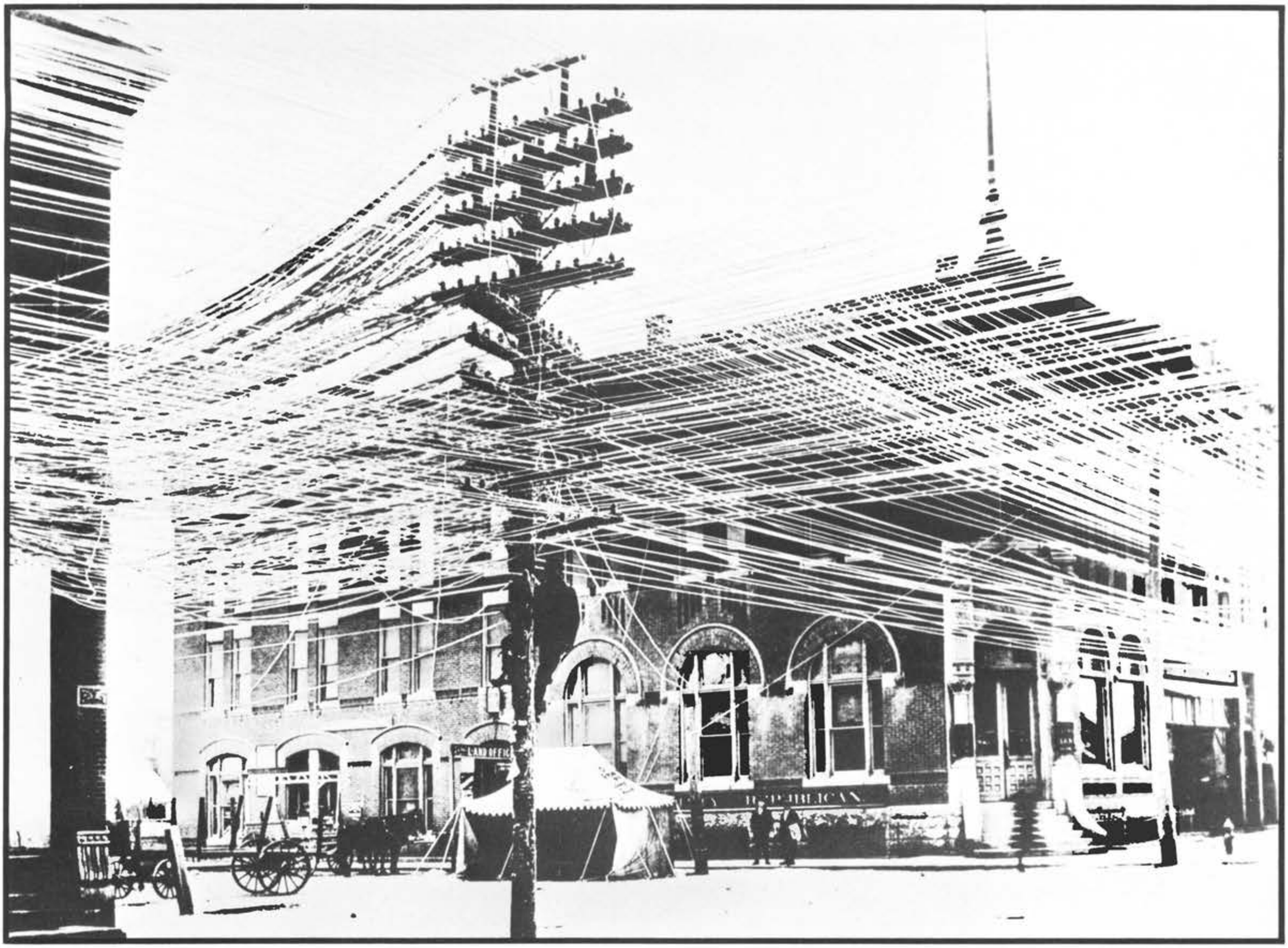


Early transmission theory, adequate for the low frequencies of telegraph, was based on representation of an elemental section of line by series resistance, shunt capacitance and leakage (top). Heaviside's analysis (1887) showed the importance of series inductance at voice frequencies and suggested the deliberate addition of inductance elements (bottom) to reduce attenuation.

more than this, the voice spectrum extended into the hundreds, even thousands, of cycles per second. No one knew how far it had to extend for good intelligibility. As the early practitioners, known as electricians, struggled to coax telegraph wires to carry the voice over longer distances, they were increasingly frustrated and baffled. They didn't know, for instance, about skin effect, which in an iron wire is very substantial even at voice frequencies. Thus, they couldn't understand why the voice died out much faster than the dc resistance of iron had led them to expect, requiring that they resort to copper conductors for the longer distances, and large expensive conductors at that, to keep the resistance low. They were beset by "earthy" problems: getting reliable connections, overcoming electrical interference. When they tried to put wires underground in cables to get around the great congestion on poles and the susceptibility to storm damage, they couldn't understand why the transmission got so much worse, and especially why the voice became muffled and indistinct in addition to getting weaker.

In academic circles, though, some important studies were going on. In 1884 Lord Rayleigh described his calculations on the decay of voice signals along a deep-sea telegraph type of cable. He showed that at a frequency of around 600 cycles per second, which he knew was in an important part of the voice spectrum, the *iterative* effect of this attenuation, mile after mile, would probably limit the range for telephony on such a cable to some tens of miles. Oliver Heaviside, following on earlier work of Kirchoff and others, was developing the mathematics of propagation during this period, including the beneficial effects of inductance, both for correcting distortion and for reducing attenuation. It was Heaviside, for example, who showed in 1887 that if series inductance were present, to an extent where the power factor of the series element of an elemental section of line is the same as the power factor of the shunt element, then the attenuation and time delay would theoretically be the same for all frequencies, giving a "distortionless" line. But in those days there was a wide communications gap between the academics and the "electricians." This was due as much to the aloofness of the theoreticians of that time, and their disinclination to express their conclusions in handbook terms, as it was to the preoccupation of the hard-pressed practitioners with their immediate problems. It is understandable that the idea of an added impedance in the line was a hard thing to get across. It just wasn't their way of thinking.

Nevertheless, there was a dawning awareness among telephone men in the Boston laboratory that deeper analysis and insights were needed in this new and subtle art, and the services of consultants from the universities and elsewhere were gradually enlisted. In 1885 Dr. Hammond V. Hayes took charge of what was called a "mechanical and testing department." By 1890 this department included John Stone Stone, of whom Hayes said, "He was the first of my associates to show an interest in the theoretical principles underlying the telephone art." Stone was also the first to show an appreciation of Heaviside and his equations. In 1897 Dr. George Campbell arrived on the scene. Campbell was a quiet, ivory-tower mathematician type who nevertheless by 1899 discovered, simultaneously with Professor M. I. Pupin of Columbia University, that the benefits of inductive loading—the adding of inductance—foretold by Heaviside could be realized in a practical way by locating coils at discrete points along the line. He was able to specify what the maximum distance between the coils could be, as related to the highest frequency to be transmitted—a discovery of enormous prac-



Wire line congestion such as this in Pratt, Kansas, led to extreme unreliability in bad weather, forcing the introduction of underground cable. The inherently high attenuation of cables posed a serious problem, but this was alleviated when Campbell and Pupin (1899) worked out the theory of periodic loading.

tical importance which was to double the distance that could be reached over open wires on poles and triple or quadruple the distance over pairs of wires in cables. The gain was greater in a cable because the inherent inductance was so low to begin with, on account of the proximity of the two wires of each pair.

Campbell soon afterward extended his circuit theory to the invention of the wave filter, which was so basic to multichannel telephony later on.

Another achievement of that period was the practical application of the phantoming principle, where one takes two voice circuits and gets a third or "phantom" circuit "for free" by superposing it through careful balancing methods. For many years, until carrier or "frequency division multiplex" came into widespread use, phantoming was the one and only way of appearing to get something for nothing. Nearly all long-distance circuits were phantomed. The very word "phantom" is symbolic of the mysteriousness of the telephone art early in this century to many who practiced it.

Another of the great characters of the Bell System was John J. Carty of Cambridge, Massachusetts. Carty had been one of the original boy operators in the Holmes burglar alarm exchange in Boston. He had taken increasingly responsible posts in the New England Telephone and Telegraph Company and in the Metropolitan Company of New York, which became the New York Telephone Company. Carty had spearheaded important developments, such as the adoption of balanced pairs of telephone wires instead of single wires with return through the ground. This eliminated much of the interference from other wires and from the growing power distribution industry. He had developed the first theory of transposition, whereby it was possible to balance out the crosstalk that accumulated over long distances from one pair of wires into other pairs. Looking ahead to nationwide interconnection, Carty had insisted on standardization in telephone quality and practices and had pressed for methods of quantitative measurement in the laboratory and in the field. He is considered the founder of the profession of telephone engineering. Carty's position in Bell System history on the technical side parallels that of Theodore Vail on the management side. In 1907 Carty was promoted from Chief Engineer of New York Telephone to Chief Engineer of AT&T. It was he who planned and executed the move of the Boston laboratory staff in that year to New York. Some of the staff went to AT&T headquarters and others joined forces at 463 West Street with the Engineering Department of the Western Electric Company, the forerunner of Bell Laboratories.

Meanwhile, on the business side, the 1890's had been a hectic period. The Bell patents had expired in 1893 and 1894, leaving the field wide open for the formation of independent telephone companies. Small companies had sprouted in great numbers around the country and many cities were served by two competing companies. By 1907, which was a year of nationwide financial panic following a time of wild inflation, almost half of the telephones in the country were non-Bell. Western Union too was trying to get back in and start a rival system. Again Theodore Vail, who had resigned many years before, was brought back as president of AT&T. It was the same Vail with the same vigor. In fact, he not only brought the ship safely through the storm and acquired most of the independents, but for a while he directed Western Union as well, being president of both companies from 1910 to 1914. Vail had always considered that the two services were complementary and should be integrated. But the Justice Department had a different view, and the amiable combination came to an end.

It was during that second presidency of Vail—and the inspiration was jointly his and Carty's—that the most spectacular telephone achievement of the early twentieth century came about. This was the transcontinental line. The New York-Chicago line had been extended in 1911 an additional thousand miles to Denver, where the Mountain States Telephone and Telegraph Company of today was just being formed by a consolidation of smaller companies. The line was built with large copper wires—No. 8—a sixth of an inch in diameter, and was inductively loaded. There were two pairs of wires, giving two two-way telephone channels (a two-way telephone channel is called a "circuit"), plus a third circuit obtained by phantoming. These heavy wires—more like rods, really—were strung on thousands of poles stretching across the plains and the desert. It was a big and venturesome project and, for its time, a triumph of engineering and construction as great as we might claim for the transatlantic telephone cable, the coast-to-coast microwave, the TELSTAR® satellite project, or any other communications achievement we have taken pride in in this more advanced age.

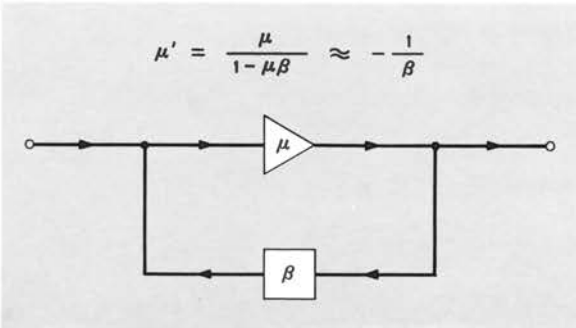
But Denver was the end of the line—the point of exhaustion. There was nothing left. The engineers who planned that long and slender route hoped it would somehow extend ultimately to the coast. They knew, however, that this would depend on developing some kind of amplifier that might respond to the voice currents before they became too feeble, and build them up to a level where they could be projected on to more distant points. Bell System people had been working on this, and there were already amplifiers of several sorts—mechanical amplifiers, mercury arc amplifiers—that demonstrated this possibility, but they were either too crude and cumbersome or too imperfect in response to be really promising for practical use in a long system. In one of those wonderful instances in history where the solution turns up just when the need becomes critical, the vacuum tube or audion of deForest was recognized by telephone men in 1912 as the answer to their prayers. In a concentrated research and development program by physicists and engineers at West Street, the audion was converted into the practical high-vacuum device that was so urgently needed.

In the following year, 1913, the construction crews from Denver started to lay out a route to Salt Lake City. Similar crews from Pacific Telephone headed eastward to meet them, knowing that successful coast-to-coast telephony would no longer be prohibited by those perversities of nature that figured in the equations of Kelvin, Heaviside, and Rayleigh, but would depend rather on being able to negotiate the hardships of rugged country and get the line built. And against all possible natural obstacles, that line across the mountains and salt flats was finished on schedule. Vacuum tube repeaters were located at Philadelphia, Pittsburgh, Chicago, Omaha, Denver, Salt Lake City, and Winnemucca, Nevada. In mid-1914, the first trial conversations were held from coast to coast. In January of 1915, Alexander Graham Bell, from an office in New York, placed the first official transcontinental call to Thomas Watson in San Francisco—the same Watson who had been his assistant in the attic laboratory in Boston where the first telephone was made nearly 40 years before.

Looking back at that period, we can see two great values emerging from it which profoundly affected the development of communication and shaped the character of today's Bell System. One was the demonstration, in an industry so clearly based on science, of the importance of doing fundamental research to acquire new knowledge and understanding. The other was the experience of planning and carrying out, on schedule, large and difficult operations that took advantage of that new knowledge: operations involving many interrelated factors and with stiff requirements that pushed the art to its limits. From this experience there is a tradition of being able to organize and draw on a great variety of talent, as we increasingly have to do in the very complex developments of the present day.

Telephone men installing the last leg of the transcontinental line, and living in wagons, had to surmount severe hardships of ice, windstorms, scorching heat, combined with rugged country.

The telephone has come a long way since that historic call in 1915. From a single transcontinental line, furnishing three circuits, our capacity for simultaneous coast-to-coast conversations has grown to many thousands. The time for setting up a call has dropped from more than 20 minutes to more like 20 seconds. The charge for three minutes has dropped from over $20 to a couple of dollars or less—at night, one dollar or less. What has happened to the quality of transmission you would have to hear, from recordings, to appreciate. The progress has been a continuous thing because, early in the game,



Until it became possible to build high-gain amplifiers inexpensively, the time was not ripe for H. S. Black's revolutionary concept of negative feedback shown above. By appropriate connections from the output to the input circuit, most of the inherent gain of an amplifier is sacrificed in return for great improvement in stability.

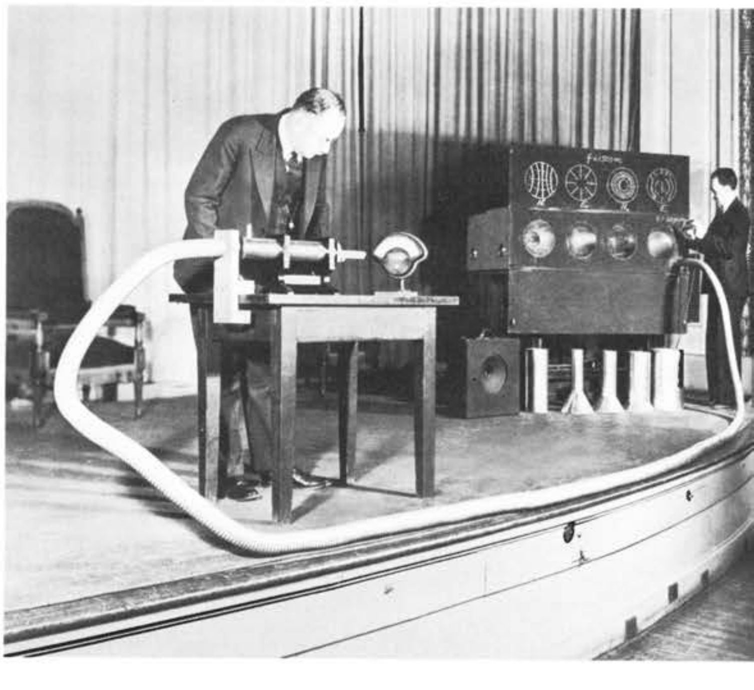
the needs of a fast-growing industry had marked out the major areas where organized technical effort must be concentrated and the management of the System had provided the backing. These areas became broadly categorized as transmission (the lines outdoors and the circuitry indoors); switching (concentrated in the central office); and instrumentalities for the customer. Moreover, in telephony as in few other fields, the force of scientific research in support of engineering development had been increasingly felt. By the early 1920's, the development programs and the number of personnel needed in these categories, together with supporting research, had become so large as to suggest that a separate organization would be more effective. Thus, on the first of January, 1925, Bell Telephone Laboratories attained its own corporate identity as the Research and Development arm of the Bell System, owned jointly by AT&T and Western Electric.

The early history of the Bell System could be considered to end at this point; but since the emphasis has been on the motivations and ways of thinking of men who are no longer here, a few examples from people who are still active should be considered. In the 1920's, when multiplex was moving ahead fast and transmission engineers were interested in long-haul systems with hundreds of channels, the repeater problem looked almost insoluble because no one knew how to make the amplifiers linear enough or stable enough. If only a factor of ten had been needed, it might have been possible to do it, with hard work, in some straightforward way; but an improvement of hundreds or thousands was needed, not just ten. In the early days of radio, many of us had used positive feedback or "regeneration" to increase the amplification in our one-tube radio sets. But as amplification got cheaper, the thought of trading some of it to get linearity and stability occurred to only one man—Harold Black at the West Street Laboratory. His negative feedback principle, representing a new way of thinking, stands out as one of the really revolutionary technical concepts of all time.

Just a little later, our George Southworth, concurrently with Professor Barrow of MIT, transmitted waves through hollow pipes. This was quite startling to some of us who had been educated to handle Maxwell's equations and knew all about radio waves on two conductors, and in free space with *no* conductors. It just hadn't been our way of thinking to imagine waves so short that they could "fit"—so to speak—inside one conductor.

One more transmission example would be pulse code modulation (PCM). For years it was necessary for our engineers to economize on bandwidth, and they had invented single sideband transmission for that purpose. PCM, with its

George Southworth's work on waveguides represented a new way of thinking about radio waves. The photo below was taken at his first public demonstration of waveguide transmission before the Institute of Radio Engineers on Feb. 2, 1938.



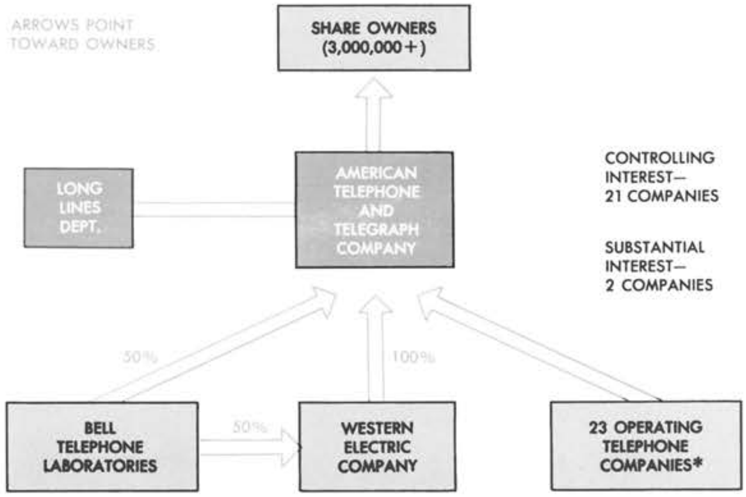
need for wide bands, had been patented by Rainey of Western Electric in the 1920's for picture transmission, and by Reeves of ITT in the 1930's for speech. And thanks to some engineers who were able to think ahead to the day when bandwidth would not be so expensive and might profitably be traded against other parameters, PCM is now paying its way handsomely in the System and figures prominently in future plans.

Similarly, in *switching*, new concepts and ways of thinking led from the comparatively simple step-by-step through the faster and more sophisticated crossbar, with its centralized intelligence, to the powerful stored program approach of electronic switching system (ESS), and have led to ever-increasing speed and flexibility in the nationwide network.

Likewise in *instruments*, and customer equipment generally, today's way of thinking is to consider the user and his personal preferences, expressed or unconscious, in designing for the utmost in convenience, comfort and appearance.

Finally, having survived two world wars during which the Bell System had to beg customers *not* to use the service, we succeeded within a few years in getting across in the System a new point of view, a new way of thinking, a marketing philosophy that recognized the need for vigorous promotion, the need to anticipate future trends, to assure availability of service when wanted; the need for wide choice and attractiveness in instruments. And astute observers of the industrial scene have said that it is only by thinking this way—being ahead of demand, enterprising, taking studied risks—that we can continue to "prove in" private ownership of so basic a public service as communications. The objective must be, and is, the best possible service at the lowest cost consistent with financial safety.

In the same year that Bell Laboratories was organized, there appeared in the Harvard Business Review an article entitled "Competition is the Life of Trade." The author, speaking of the telephone monopoly as standing head and shoulders over all other public utilities in the extent, cheapness, and standard of its service, remarked that even though, as a utility, we did not have the spur of necessity and fear which competition offers, nevertheless few if any competitive industries had moved forward with greater energy and creative genius. "The thing is a modern miracle," he wrote, "which I can only explain to myself by assuming that the men who conceived, created, and have developed the telephone were men of the rare auto-motive type whose driving power came from within, and who, therefore, did not need the external stimulation which competition alone can give."



* EFFECTIVE JULY 1, 1968 THE DIVISION OF SOUTHERN BELL TELEPHONE AND TELEGRAPH COMPANY WILL RESULT IN A 24TH OPERATING COMPANY KNOWN AS SOUTH CENTRAL BELL TELEPHONE COMPANY.

The corporate structure of the Bell System of today (above) is based on the structure put **together** *by Vail at the turn of the century. It was not until 1925, however, that a separate company, Bell Telephone Laboratories, was formed with specific responsibility for research and development for the System.*

It is said that J. J. Carty always looked at the enterprise as a plant, an organism that must constantly grow and renew itself. John J. Scanlon, vice president and treasurer of AT&T, stated in an FCC hearing that the customer's interest is in a service constantly growing in convenience and usefulness. Ben S. Gilmer, president of AT&T, testified in the same hearing that the fundamental motivation of our business is to *enhance* the value of our service. This is their way of thinking. As planners of the technical future of this enterprise, Bell Laboratories has the obligation to observe a way of thinking in which the possibilities for tomorrow's innovations are not circumscribed by the limitations you see today. We are fortunate to have a top management, from the Board Chairman of AT&T down, which understands the potency of research and exploratory development, is willing to pay for them, and wants our ideas converted to usefulness promptly and effectively.

Thus, as a recently retired officer of Bell Laboratories observed, if we say to ourselves, as Thomas Jefferson did, "Hats off to the past," we must follow through with his admonition: "coats off for the future."