TELEPHONE THEORY AND PRACTICE

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KEMPSTER B. MILLER

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MANUAL SWITCHING AND SUBSTATION EQUIPMENT

AUTOMATIC SWITCHING AND AUXILIARY EQUIPMENT

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KEMPSTER B. MILLER, M.E.

Fellow, American Institute of Electrical Engineers; Member, Western Society of Engineers; Author of "American Telephone Practice," 1904, and Joint Author of "Telephony," 1912

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PREFACE

It is now thirty years since the first edition of my "American Telephone Practice" appeared, and twenty-six years since its last revision. The day-to-day pressure of active professional work has prevented its being kept up to date in spite of frequent urgent appeals of my publishers and of an earnest desire on my part to do so.

When the present work was finally taken up in earnest, it was with the idea that it would be a complete revision of the old book under the old name "American Telephone Practice." It was soon realized, however, that this plan was impracticable. Since the last revision the telephone art had changed so radically and the industry had expanded so tremendously that to write about it, or even to think about it, in the old terms seemed inappropriate. Things like the automatic exchange system, which in 1904 were just beginning to appear as practicable to the bolder thinkers, had since become firmly established in the everyday workings of the industry. The even more revolutionary developments, like the three-electrode vacuum tube and the things that grew out of it, had not then even been dreamed of. More than all this, the very spirit of the times had changed. New conceptions of public service had crowded out the old. To have called a new work attempting to deal with this new order of things a revision of the old would have been akin to "the tail wagging the dog." Another consideration was the change that a quarter century of practical experience had wrought in the author himself. Whether for better or worse, even the old portions of the story could not be told in the same old way. And so, with real regret, it was decided to abandon the old name with the old work and let "American Telephone Practice" rest unchanged as a part of the records of telephony of the preceding generation.

In thus taking leave of this old friend I wish, at the same time, to express my deep appreciation of the reception which telephone people accorded it throughout its long life. The almost affectionate regard in which it seems to have been held has been the main stimulus holding me to the determination to prepare, if possible, a successor in kind—one that would deal with present-day telephony in about the same simple way.

Like its predecessor, "Telephone Theory and Practice" is intended, not only for the student and the beginner in telephone work, but also as a general reference text for the more advanced. Perhaps also it may, in some degree, help the reader to coordinate in his mind the various phases of the industry that are so ably dealt with in the wealth of highly specialized literature made available by the developing, manufacturing and operating companies. As an industry grows in size and complexity and as its literature becomes more highly specialized, it becomes increasingly difficult for the man engaged in it to obtain a clear view of how his particular job is related to the rest of the business. A general work of this kind ought to assist in giving the needed perspective.

A single volume attempting to cover the subject of telephony in anything like a comprehensive way would be unwieldy. Moreover it would necessarily embrace more subject-matter than all would desire. The present plan, therefore, is to issue the work in several volumes, each covering, as far as possible, a distinct broad phase of the subject.

The first of these is the present volume, "Theory and Elements." It relates principally to underlying theory and attempts to lay a general groundwork for the more detailed discussion of telephone exchange systems, lines, systems of transmission and other subjects to be dealt with in succeeding volumes.

The science of acoustics, lying at the very root of the telephone transmission problem, has been given all too little attention in earlier general treatises. I have, therefore, included a rather full discussion of sound in both its physical and its physiological aspects in order to develop the fundamental requirements for the reproduction of speech and music. In developing the rudiments of the theory of multi-frequency alternating-currents, lines exactly parallel to those used in the discussion of sound waves have been followed with a view to bringing home to the student the fact that identically the same primary conceptions are involved whether dealing with waves of air or waves of electric current.

Like its predecessor, this work is mainly non-mathematical. Wherever mathematics has been used at all it goes no higher than simple algebra or a mere suggestion of trigonometry. Even those without mathematical training should find most of it helpful, but those whose minds become blank at the mere sight of a mathematical formula are advised that they may skip it.

Acknowledgment has been made at appropriate points in the text of the sources of information on which I have drawn freely and also of the courtesy of the numerous companies who have furnished information and illustrative material. To all of these my thanks are due. I wish to express particular appreciation of the generosity of the Bell Telephone Laboratories in furnishing their many invaluable publications and in permitting the use of illustrations. Lastly my hearty thanks are due to my friend, Dr. Ralph D. Bennett of the Ryerson Physical Laboratory, University of Chicago, for his constructive criticism of much of my manuscript and his thoughtful reading of the proof. His knowledge of physical science and his clear thinking have helped me in the avoidance of errors and in the clearer statement of fact.

KEMPSTER B. MILLER.

PASADENA, CALIFORNIA,
July, 1930.

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PART I

INTRODUCTORY

The four chapters comprised within this part are intended to develop a sort of background for the beginner, to give him some conception of the broad significance of telephony, to make him somewhat familiar with the language of the art and to help him realize that the individual things treated of are not mere independent units but are intimately correlated with many other things which, all together, go to make up the telephone system.

TELEPHONE THEORY AND PRACTICE

THEORY AND ELEMENTS

CHAPTER I

MAN'S PROGRESS IN COMMUNICATION

We do not know, of course, when man began his efforts to communicate with his fellows. We are equally in the dark as to when language had its beginning. We do know, however, that the desire for mutual understanding is a predominant characteristic of man and has been the force impelling him to produce language.

We are told that the Neanderthal man, who lived in Europe during and after the fourth glacial period, was probably incapable of speech, as judged by the structure of his jaw bone. He, however, was one of the so-called "sub men," who were not the true ancestors of the human line. Some think that he was exterminated, perhaps thirty-five thousand years ago, by true man, who had no such structural speech limitation; but where true man came from and how far back *his* lineage goes we are totally uninformed. This is all hidden in the impenetrable darkness of countless thousands of years ago, and we can do no more than speculate about it.

Judging from the drawings made by true man on cave walls, probably thirty thousand years ago, and from the carvings and implements he left, we know that at that time he had risen, in artistic ability at least, far above the state of some savages to be found in some parts of the world to-day who have their own languages. We know, also, that among other things which distinguished him from the lower animals, he had a brain cavity of comparatively enormous size; and we have a right to assume that he also had vocal organs capable of almost infinite development in tonal range and flexibility, and ear mechanism of such marvelous delicacy and perceptive power as to make it potentially capable of selectively sensing the entire range of vocal sounds. In view of all this it is difficult to believe that man had not felt the need for communication and developed some sort of a language long prior to this time.

At the outset primitive man probably communicated with his fellows, in so far as he communicated at all, by means of grunts or other elemental vocal sounds, grimaces, gestures and by direct touch. At first his sounds and signs probably did not mean much, but then he did not have much capacity either to think himself or to grasp the thoughts of others, so that these crude means of communication were probably quite sufficient. His interests were relatively few and mostly concerned with propagation and self-preservation; his emotions were elemental and vigorous, and his ideas infrequent and simple. He was undoubtedly gregarious, but social demands had not yet become exacting.

Language, wherein vocal sounds are definitely associated with ideas, probably did not exist at all. It seems likely that such vocal sounds as man made at first were merely for the purpose of attracting the attention of others, or for his own personal gratification, without any intent of communication. Song may have preceded speech by ages. Song need not have definite ideas attached; speech must have (or should have).[1]

With his splendid equipment of brain capacity, vocal organs and hearing mechanism, man subconsciously began to learn that articulate sounds afforded the best means of conveying and receiving definite ideas. The combination of voice and ear was incomparably more convenient and effective than any or all of the other means combined. The flexibility and modulating power of the voice permitted almost infinite variety of sound combinations to be produced. The ability of the ear selectively to sense these sounds was as great as that of the voice to produce them. Nothing approaching this effectiveness could be had through the sense of sight, touch, smell or taste. Moreover, the vocal means of communication did not interfere with the use of the hands, eyes or other members of the body while otherwise engaged and could be used under conditions where neither speaker

[1] Jones, R. L., The Nature of Language, American Institute of Electrical Engineers, *Transactions*, April, 1924.

nor hearer could see the other, an especially important consideration before the days of artificial fire and light.

Hence, as the ages progressed, sense became associated with sounds, words became significant, and, when combined into phrases and sentences, their significance was extended. Complex ideas could be expressed and understood.

So language has been subconsciously evolved, and, as we all know, the process is still going on. It has enabled man's power of expression to keep pace with his power of thought. It has advanced his ability to communicate from a point where he could convey a few elemental ideas by simple sounds and signs, or perhaps by a knock on the head with a club, to that where the now highly developed vocal and aural organs enable him to voice and to perceive almost every shade and subtlety of thought which the now highly developed brain is capable of harboring.

Just when man began to record his ideas we do not know. That is a question for the archaeologist or philologist to answer. We do know, however, that it was far back in prehistoric times, probably as much as twenty-five thousand years ago, as is shown by the records left by primitive men on the walls of caves and on flat pieces of stone. Whether the earliest attempts at drawing were intended to express definite meanings or were merely a sort of embryonic beginning of "art for art's sake" is a matter of doubt. It is certain, however, that, as in the case of sound, man began at an early date to associate sense or meaning with the various marks he could make on rock faces or on other surfaces. At first we think his writings took the form of mere ideagraphs, wherein a single symbol, probably suggestive in form, stood for a single name, object or idea, with no thought of connecting various symbols together, as in language. Later combinations of written symbols were used to convey more complex ideas. Also various written symbols became associated with definite sounds of spoken language, and, finally, written language was so highly developed that it could express nearly all of the thoughts and shadings permitted by spoken language.

With the development of parchment, papyrus and, finally, paper, man was enabled to lend an ease of handling and portability to his writings not possible with cave walls or stone slabs. Then the coming of the printing press enabled him to multiply indefinitely his singly handmade copies. His power to *reach out* with his ideas was thus enormously increased.

The struggle for increased distance of communication has been ever present. Long before historic times man could probably convey all the ideas he had, provided only his hearers were close enough to be within the sound of his voice. By beating on hollow logs or drums, he could transmit some ideas to greater distances within ear shot, and by gestures or other visual signals to greater distances within eyesight, but all of these efforts to communicate beyond direct voice range were at a great sacrifice in facility of expression.

Signaling by waving the arms was undoubtedly among the early efforts to communicate beyond the range of the voice. Later, after fire had been mastered, smoke signals by day and fire signals by night were used. All of these methods, depending upon direct visibility, have been used by savage and civilized men and to a limited extent are now used. The present semaphore of railway practice and the "wig-wag" flag signaling used in military operations are logical modern developments of man's early efforts at signaling by arm waving. The heliograph and the various systems of flash signaling are outgrowths of the simple signal fires of prehistoric times.

The employment of couriers, at first carrying word-of-mouth messages and, later, messages written on pieces of stone, bark, skin and, in modern times, paper, formed for ages practically the whole means of communication beyond the direct range of voice and eyesight. Our present world-wide system of mails is a development of this primitive method of communication, the supplanting of the courier in a large measure by railway, steamship, automobile and airplane, having, of course, enormously extended its effectiveness in range and speed. The mails as a means of communication leave little to be desired save in one often important respect—time.

Standing at the threshold of the nineteenth century and looking back as far as we can toward the obscure ages when man had this beginning, we find that marvelous progress has been made in communication in all respects save one: instantaneous distant transmission. In that respect he was about in the position of his Neanderthal precursor. For instant communication he was limited to distances within the sound of his voice, unless he resorted to louder sounds than those of speech or to visual signals, in either of which cases his range was somewhat increased, but his power of expression was greatly curtailed by the necessity of using some prearranged code.

To illustrate: In 1775, under conditions demanding the greatest haste, what methods of communication were employed in touching off the American Revolution? Signal lights, code and word-of-mouth courier. According to song and legend, word that the British were coming, and coming by sea, was conveyed to Paul Revere across Boston Bay by lanterns hung "aloft in the belfry arch of the North Church tower as a signal light." The code was "One, if by land, and two, if by sea." Then, in turn, by his famous midnight ride, at the ponderous speed of horse-flesh, he conveyed the message "through every Middlesex village and farm" by pounding on doors and shouting. Truly archaic. Yet this was civilized man doing the best he knew how and using the most advanced means of that time. Fifty thousand years of progress had led to this!

It was not until the nineteenth century was well advanced that this standstill condition in regard to increased range of instant communication was broken and real progress began. The electromagnetic telegraph, coming about 1837, was the opening wedge. It was one of the outstanding achievements of all time and with its later developments, whereby several messages in both directions may be sent simultaneously over the same wire, or whereby many messages in all directions may be sent simultaneously without any wires, it has in itself revolutionized previous methods of fast, distant communication.

But even the telegraph requires the use of an elaborate code, which largely places it beyond the personal use of the communicators, and makes necessary the employment of skilled intermediaries—telegraphers or other operatives. Moreover, for its universal person-to-person application, the telegraph still clings to a vestige of the past in that the messenger boy—a survival of the romantic courier—is still largely used to gather the messages from their senders and deliver them at their destinations.

In 1875, just a century after the Paul Revere incident, the electric telephone was invented; and, on March 10 of the next year, it spoke its first sentence in an attic in Boston. A few days later the miracle of *distant* speech transmission was wrought. For the first time man could send his voice beyond the radius of a few hundred yards, which had been his limit for the countless ages of his existence.

This achievement is accredited to Alexander Graham Bell, a teacher of deaf mutes, a native of Scotland and a resident of the United States. Not the least astonishing feature of Bell's invention was the directness and the beautiful simplicity of his attack on the problem—so fundamentally sound that even instruments of most rudimentary character could produce the astounding result. Dom Pedro, then Emperor of Brazil, when it was exhibited to him at the Philadelphia Centennial in 1876, exclaimed, "My God, it talks." Sir William Thomson, later Lord Kelvin, the great British scientist, after seeing it at the same exposition, referred to "the hardihood of invention which devised such very slight means" to realize the desired end, and referred to the instruments themselves as of "quite a homespun and rudimentary character."

Bell gave the world scarcely more than an idea, but it was the correct idea, sound and vigorous. His instruments, feeble and crude to the point of calling forth skepticism and ridicule from the unknowing, served by their very feebleness and crudity to increase the profound admiration of the knowing. These instruments worked because they were vitalized by the spark of a great idea; an idea that was to revolutionize the ability of man to communicate with his fellows; an idea upon which the whole telephone industry, now grown to vast proportions, rests to-day, just as those two puny instruments in a Boston attic rested upon it fifty years ago. It was the beginning of a truly great art—telephony.

Bell's original telephone, now vastly improved, has been multiplied throughout the world about thirty-three million fold. His original fifty feet of line wire has grown until it now reaches all over the civilized world, having a length of over sixty-two million miles in the United States alone. Over fifty-nine million telephone conversations are now carried on each day in this country, and persons separated by the breadths of ocean and continent may now converse as clearly as if they were in adjoining rooms, their voices traveling with nearly the speed of light.

The Atlantic has been spanned and, as an early incident to this achievement, words spoken in the morning of one day on the Atlantic sea board were heard not only in Paris but also far out in the Pacific on the Hawaiian Islands in the evening of the calendar day before. Commercial telephone service is now continuously available between the entire United States and the greater part of Europe. Ships far out at sea may converse with the mainland or with other ships; aeroplanes at dizzy heights may talk with each other or with stations on land; and, lastly, a speaker with ordinary voice may address at one time a hundred thousand persons gathered in one group about him, or millions scattered over the two hemispheres.

One must believe that this recently acquired power of man to transmit his thoughts in clear language and with instant speed throughout the length and breadth of land and sea will exert an even more profound influence on human relations as time goes on. It has been said that . . . "The capacity for free intercommunication between individuals of the species has meant so much in the evolution of man, and will certainly come in the future to mean so incalculably more, that it cannot be regarded as anything less than a master element in the shaping of his destiny."[1]

If ignorance and misunderstanding are among the great causes of human strife and unhappiness, then there appears no room for doubt that telephony, which has added so immeasurably to man's capacity for intercommunication, will exert a beneficent influence in disseminating knowledge and in helping people and peoples to understand one another. If it is true that the "screen of language" tends to create and maintain international hatreds, then this advance in the art of communication must tend to break down that screen. The telephone must ultimately exert a powerful influence on language itself, since, recognizing no boundaries, it brings peoples of different tongues into conversational contact.

But we must not expect results too soon. The telegraph is less than a century old, the telephone just over fifty and radio broadcasting about ten. The habits and prejudices that have been built up through the countless ages of man's existence cannot be wiped out or even greatly altered in any such short periods of time.

[1] Trotter, I. W., "Instincts of the Herd in Peace and War"; see also presidential address of John J. Carty, delivered at Ninth Annual Meeting of the Telephone Pioneers of America.

CHAPTER II

PRECURSORS OF THE ELECTRIC SPEAKING TELEPHONE

MECHANICAL TRANSMISSION OF SOUND

The word "telephone" is derived from two Greek words, τῆλε, meaning *afar*, and φωνή, meaning either *voice* or *sound*. It is of interest to observe that the true derivation of the word does not necessarily carry into its meaning the idea of *voice* transmission. *Sound* transmission satisfies the etymological requirements nearly as well, and, in fact, it was with this meaning that the word "telephone" was first used. The word is considerably older than the electric speaking telephone, to which it is now almost exclusively applied.

When the speaking telephone did appear, it was at first commonly referred to as the "speaking telegraph," a misnomer, of course, but one naturally arising out of the fact that the electric telegraph had not, at that time, ceased to occupy the popular mind as a modern miracle. It is well to hold in mind these distinctions in terminology in briefly reviewing early developments in the art of sound transmission.

The need of increasing the range of voice transmission must be nearly as old as man's use of the voice for communication. Even today, when we shout to a person beyond our voice range, we feel this need, and primitive man, without any artificial aids, must have felt it more keenly. The Greeks tried to meet the need, when, before the walls of Troy, they employed Stentor "whose cry was as loud as the cry of fifty other men."[1]

But all such efforts involved only the straining of man's natural powers to their utmost. What was needed was artificial aid to accomplish the magic of distant speech transmission.

It seems natural that very early devices for providing artificial aid in speaking and hearing at a distance should have been in the nature of what we now call "speaking trumpets" and "ear trumpets"; instruments which serve more effectively

[1] "Iliad."

either to direct the voice toward the hearer or to concentrate the sound into the listener's ear. Devices of this nature, although they have been reinvented in modern times, probably date far back into antiquity. Indeed, it is difficult to believe that primitive man did not shout through his hands formed into a sort of trumpet, as we do to-day when we wish to send our voice to a distance beyond its natural range; or that he did not cup his hand to his ear, as we do to-day in an effort to increase the acuity of our hearing.

In his book on the history of inventions[1] Johann Beckmann 1739–1811), who has been referred to as the "founder of scientific technology," gives a chapter on Speaking Trumpets. This gives an early reference to "monstrous trumpets of the ancient Chinese, a kind of speaking-trumpets, or instruments by which words could not only be heard at the greatest distance possible, but could also be understood."

Beckmann, however, evidently did not place much reliance on these very ancient references, for, immediately after this reference to the ancient Chinese instruments, he states: "This invention belongs to the 17th century, though some think that traces of it are to be found among the ancient Grecians."

What we now know as an ear trumpet was evidently exhibited at the Royal Society in London in 1668 under the name "otacousticon." It was referred to by that most versatile of diarists, Samuel Pepys, in his entry of April 2, 1668, as follows:

"I did try the use of the Otacousticon, which was only a great glass bottle broke at the bottom, putting the neck to my ear, and there I did plainly hear the dancing of the oars of the boats in the Thames to Arundel Gallery window, which, without it, I could not in the least do."[2]

The speaking trumpet, as distinguished from the ear trumpet, came into prominence about 1670, two years later.[3] A controversy arose between rival claimants for the honor of its invention, in the course of which some one characterized it as a "new

[1] Beckmann, Johann, "A History of Inventions, Discoveries and Origins," 1780–1805; translated from the German by William Johnston, published by George Bell & Sons, London, 1884.

For this and many other references, see introductory chapter of "The Telephone and Telephone Exchanges," by J. E. Kingsbury, Longmans. Green and Co., London, 1915.

[2] "The Diary of Samuel Pepys."

[3] Kingsbury, *op. cit. p.* 2.

nicknamed old invention." This characterization was probably not inapt, particularly in so far as it related to the "nickname," for, in 1671, in a treatise on the invention, one of the claimants called it the "Tuba Stentoro-Phonica."

According to this account the largest one that he had employed at that time was 5 feet 6 inches long with a diameter of 21 inches at the large end and 2 inches at the small end. Of the trial he writes . . . "when by His Majesty's special command it was tried at Deal Castle by the Governor thereof, the voice was plainly heard off at Sea as far as the King's Ships usually ride, which is between two and three miles, at a time when the wind blew from the shore."

It is interesting to note, in connection witn this age-long development of the speaking- and ear-trumpet idea, that the "megaphone" as a device for aiding in hearing has, in our own times, been attributed to Edison.[1] What Edison did was to bring his genius to bear on the crudely worked out devices of ancient times. His own biographers[2] thus set forth his work in this line.

"The modern megaphone, now used universally in making announcements to large crowds, particularly at sporting events, is due also to this period as a perfection by Edison of many antecedent devices going back, perhaps, much further than the legendary funnels through which Alexander the Great is said to have sent commands to his outlying forces. The improved Edison megaphone for long-distance work comprised two horns of wood or metal about six feet long, tapering from a diameter of two feet six inches at the mouth to a small aperture provided with ear tubes. These converging horns or funnels, with a large speaking-trumpet in between them, are mounted on a tripod, and the megaphone is complete. Conversation can be carried on with this megaphone at a distance of over two miles, as with a ship or a balloon."

Regardless of what may have been the differences in form between the single straight-sided horn, which we now call the "megaphone," and the "Tuba Stentoro-Phonica" or other speaking trumpets of ancient times, it is probable that this three-horn combination of Edison represents the culmination

[1] See Megaphone, "Century Dictionary," New York.

[2] DYER and MARTIN, "Edison: His Life and Inventions," Harper & Brothers, 1910.

of achievement in the speaking and ear-trumpet line up to that time.

As a modification of the speaking trumpet idea, one Captain John Taylor,[1] in 1845, invented an instrument "for conveying signals during foggy weather by sounds produced by means of compressed air forced through trumpets." No thought of transmitting speech was involved in this instrument, which merely produced powerful sounds derived from blasts of compressed air. Nevertheless, it was called "The Telephone" which is one of the early though by no means the first use of this word.

Another line of effort to extend the distance over which sounds could be sent, by direct transmission through air, was by means of what we now call the "speaking tube." This also is of ancient origin. Beckmann gives the following translation of a passage from della Porta, presumably from his "Magia naturalis," published in or prior to 1589.

"To communicate anything to one's friends by means of a tube. This can be done by a tube of earthenware, though one of lead is better . . . ; for whatever you speak at the one end the words issue perfect and entire as from the mouth of the speakers and are conveyed to the ears of the other, which in my opinion may be done for some miles . . . We tried it for a distance of two hundred paces, not having conveniences for a greater, and the words were heard as clearly and distinctly as if they had come from the mouth of the speaker."

In 1851 there was exhibited, at the London Exhibition, a speaking tube under the name of "telekouphonon." The same manufacturer also exhibited at that time what is thought to be a speaking trumpet, which he called the "Gutta Percha Telephone."[2]

All of the foregoing devices, whether speaking trumpets, ear trumpets or speaking tubes, worked on the principle of the direct transmission of sound through air. Another line of effort, distinctly a part of the quest for increased distance of sound transmission, was concerned with those devices which employed some solid medium, rather than air, as the vehicle for the transmission of the sound waves.

[1] Kingsbury, *op. cit.*, also "Year Book of Facts in Science and Art," p. 55, 1855.

[2] Kingsbury, *op. cit.* p. 4.

It has long been a matter of common knowledge that a light scratching or tapping on one end of a beam of wood may be distinctly heard by a person whose ear is pressed against the other end. Also, in modern times, that by placing one's ear against the rail of a railroad track, the sound of an approaching train may be heard at a greater distance through the rail than through air—and that the sound travels faster through the rail than through air. Beckmann says that knowledge of the transmission through a beam of wood "was known as far back as Pliny's time" (A. D. 23–79).

Dr. Robert Hooke, an English philosopher of astounding versatility, in the preface of the first edition of his "Micrographia," published in 1665,[1] makes the following quaint statement concerning the propagation of sound waves through bodies other than air and, particularly, through a wire:

"The next care to be taken, in respect of the Senses, is a supplying of their infirmaties with *Instruments*, and, as it were, the adding of *artificial Organs* to the natural; this in one of them has been of late years accomplisht with prodigious benefit to all sorts of useful knowledge, by the inventing of Optical Glasses.

* * * * * * *

"And as *Glasses* have highly promoted our *seeing*, so 'tis not improbable, but that there may be found many *Mechanical Inventions* to improve our *other* Senses, of *hearing*, *smelling*, *tasting*, *touching*. 'Tis not impossible to hear a *whisper* a *furlong's* distance, it having been already done; and perhaps the nature of the thing would not make it more impossible, though that furlong should be ten times multiply'd. And though some famous Authors have affirm'd it impossible to hear through the *thinnest plate* of *Muscovy-glass;* yet I know a way, by which 'tis easie enough to hear one speak through a *wall a yard thick.* It has not been yet thoroughly examin'd, how far *Otocousticons* may be improv'd, nor what other wayes there may be of *quickening* our hearing, or *conveying* sound through *other bodies* than the *Air:* for that that is not the only *medium* I can assure the Reader, that I have, by the help of a *distended wire*, propagated the sound to a very considerable distance in an *instant*, or with as seemingly quick a motion as that of light, at least incomparably swifter

[1] The entire preface to "Micrographia" is reprinted in the "Posthumous Works of Robert Hooke," London, 1705.

than that, which at the same time was propagated through the Air; and this not only in a straight line, or direct, but in one bended in many angles."

The spelling, punctuation and italics in this are given exactly as they appear in the original. This is probably the first suggestion of sound transmission through a wire. It is also perhaps the earliest recorded observation of the fact that sound travels through a solid faster than it does through air. But, so far as I am able to learn, Hooke did not describe the "Otocousticon" nor did he give any information about the kind of instruments, if any, he used at the two ends of his "distended wire." More will be said of this later.

About 1821 Charles Wheatstone, an English physicist, a man of great ingenuity and learning and, later, of large scientific achievement, took up the work of sound transmission through solids. Wheatstone began his career as a musical instrument maker and, through this practical work supplemented by ingenious and persistent experimentation, became well versed in acoustics. Later he turned his attention to electricity. The problem of the electrical transmission of intelligence became strong in his mind, and he was subsequently knighted for his work on the electric telegraph. He is perhaps best known among American telephone workers by association with the Wheatstone bridge, an instrument which, by the way, he did not invent,[1] although it almost universally bears his name.

As Kingsbury points out,[2] Wheatstone, of all the men who preceded Bell, was probably the man best fitted to have invented the electric speaking telephone. He had both acoustical and electrical knowledge, a rare combination. He also had an ingenious mind and a strong urge toward the transmission of intelligence. Moreover, he was well equipped for experimental and development work. Apparently, however, the electrical transmission of speech did not occur to him, and, while he did dream of its mechanical transmission, he could not rid himself of the idea that speech transmission (as distinguished from sound transmission) would necessarily involve vastly complicated mechanisms. As it was, his actual achievements in sound transmission went no further than that from room to room.

[1] Wheatstone's Bridge, "Encyclopedia Britannica"; also Wheatstone's Scientific Papers.

[2] KINGSBURY, *op. cit.*, p. 13.

In his earliest experiments Wheatstone observed that the sound vibrations of a tuning fork could be transmitted to a sounding board through a glass rod five feet long. Later, he transmitted "through rods of much greater lengths and of very considerable thicknesses, the sounds of all musical instruments dependent on the vibrations of solid bodies, and of many descriptions of wind instruments."[1]

This line of experimentation led him to the production, about 1821, of what he called "the enchanted lyre."[2] This consisted of a sounding box fantastically fashioned to resemble a musical instrument of classic shape. It was connected by a wooden rod with a piano located in another room, out of sight and hearing. In other cases the lyre was suspended by a wire from a piano located in a room above. However connected, the sound vibrations set up by the piano were transmitted to the lyre through the solid material of the rod or wire. This caused the lyre to give forth music as though originating within itself, much to the wonderment of the audience.

Wheatstone had some appreciation of the importance of speech transmission as well as of the difficulties of its accomplishment, as the following quotation from his paper[3] will show:

"The transmission to distant places, and the multiplication of musical performances, are objects of far less importance then the conveyance of the articulations of speech. I have found by experiment that all these articulations, as well as the musical inflexions of the voice, may be perfectly, though feebly transmitted to any of the previously described reciprocating instruments by connecting the conductor, either immediately with some part of the neck or head contiguous to the larynx, or with the sounding board to which the mouth of the speaker or singer is closely applied. The almost hopeless difficulty of communicating sounds produced in air with sufficient intensity to solid bodies might induce us to despair of further success; but could articulations similar to those enounced by the human organs of

[1] Wheatstone's Scientific Papers.

[2] New Experiments on Sound, by Wheatstone in Thomson's "Annals of Philosophy"; also, for suspended type of lyre, see article on Charles Wheatstone, "Encyclopedia Britannica."

[3] On the Transmission of Musical Sounds through Solid Linear Conductors and on Their Subsequent Reciprocation, *Journal of the Royal Institution*, 1831.

speech be produced immediately in solid bodies, their transmission might be effected with any required degree of intensity. Some recent investigations lead us to hope that we are not far from effecting these desiderata; and if all the articulations were once thus obtained, the construction of a machine for the arrangement of them into syllables, words, and sentences would demand no knowledge beyond that we already possess."

Apparently, therefore, he did succeed to the extent of feebly transmitting articulate speech mechanically; but his reference to the "almost hopless difficulty" of communicating the sound vibrations in air to solid bodies led him not to overlook but to abandon the simple course of speaking directly against a diaphragm. Instead, he proposed the astoundingly difficult course of producing sounds *similar* to those of human speech "immediately in solid bodies" in order that their transmission might be effected with sufficient intensity. Evidently, he proposed to simulate articulate speech by some sort of a machine that would, in itself, originate the various sounds of speech, and, having done this, to construct a machine that would break up and arrange these sounds into syllables, words and sentences. What he proposed was a machine that would originate speech, not one that would reproduce it as the phonograph does. Needless to say, neither Wheatstone nor anyone else has ever shown how such a machine, that could originate more than a few speech sounds, could be constructed.

It has been supposed that Wheatstone called his enchanted lyre "the telephone" as early as 1821, and that this was the earliest use of the word. Nothing however can be found in his writings or those of his associates that discloses the use of the word "telephone" before 1840. Then it was frequently applied to various devices for the mechanical transmission of sound. This use in 1840 was not, as Kingsbury surmises,[1] the earliest occurrence of the word "telephone," for as shown in Frederick L. Rhodes' recent work[2] it is of much older origin. It is to be found in a very small and rare book by G. Huth, Berlin, 1796, located in the library of Hamburg. This, in naming a plan of relaying spoken messages by speaking and ear trumpets, says: "What could be more appropriate here than the word derived

[1] KINGSBURY, *op. cit.*, p. 10.

[2] FREDERICK L. RHODES, "Beginnings of Telephony," p. 225, Harper & Brothers, 1929.

from the Greek: Telephone or Fernsprecher?" ("Telephon, oder Fernsprecher").

Wheatstone's transmission of sound through rods and wires leads naturally to a consideration of the device commonly known several decades ago by such names as "the lovers' telegraph," "the string telephone," the "mechanical pulsion telephone," etc. This in its simplest form consisted of two tin cans, the bottoms of which were replaced by a tightly stretched diaphragm of bladder or parchment, the centers of which were connected by a tightly drawn string. It is sufficiently illustrated

FIG. 1.—The lovers' telegraph.

in Fig. 1, which is taken from an early work on the electric telephone by Count Du Moncel.[1]

This simple device, had Wheatstone known of it, would have met at once "the almost hopeless difficulty of communicating sounds produced in air with sufficient intensity to solid bodies." He was on the verge of it when he connected his transmitting rod or "conductor" with "the sounding board to which the mouth of the speaker or singer is closely applied." But apparently his devices were too heavy, and he abandoned this line of attack.

As will be shown, Bell, when he attacked the problem of the electric telephone had a similar difficulty in that he could not,

[1] "The Telephone, the Microphone and the Phonograph," Harper & Brothers, 1879

at first, comprehend that such a simple thing as a thin membrane carrying a disc of iron could vibrate under the influence of the voice with sufficient intensity to produce the desired currents. Evidently Wheatstone did not know of the lovers' telegraph, and Bell in his testimony stated that he never heard of it until after the issuance of his patent.[1]

The origin of the lovers' telegraph is shrouded in mystery so far as the present writer is concerned, although others, at much earlier dates, have apparently felt no such uncertainty. In 1887, in his argument before the Supreme Court of the United States, Mr. J. J. Storrow, counsel for the Bell Company, in answer to a question of Mr. Justice Field as to when the string telephone was introduced, stated, "Two hundreds years ago it was described. It keeps disappearing and getting re-invented."[2]

Mr. Storrow undoubtedly had reference to the statement of Robert Hooke in the preface of his "Micrographia" already quoted in this chapter. Other authorities have stated without qualification that Dr. Hooke had reference to the string telephone.[3]

Neither in Hooke's "Micrographia," his "Posthumous Works" or his Biography has anything been found more definitely suggesting the lovers' telegraph than the matter herein quoted. Certainly this does not describe it, nor would it even suggest it to one not already familiar with it.

So far as Hooke's hearing of a whisper "a furlong's distance" is concerned, a speaking trumpet or an ear trumpet would have met his description equally well. He could scarcely have been referring to the lovers' telegraph as the means for making it "easie enough to hear one speak through a wall a yard thick," for even at this date it would puzzle one to use a lovers' telegraph for that purpose, without boring a hole through the wall, in which case a speaking tube would answer. As for the transmission through a wire, Dr. Hooke's description would be met by the scratching on one end of a wire, the other end of which was held to the listener's ear. Indeed, the fact that the Doctor

[1] "The Deposition of Alexander Graham Bell in the Suit brought by the United States to Annul the Bell Patents," p. 211.

[2] Oral Arguments for Bell Company in "The Telephone Appeals," p. 68.

[3] Preece and Stubbs, "A Manual of Telephony," p. 1, Whittaker & Co., London, 1893.

emphasized that his wire need not be straight, but might be "bended in many angles" is almost conclusive that he was not talking about anything like the lovers' telegraph, for, as we now know, unless they are slight and infrequent, bends are fatal to the successful performance of that instrument.

While Dr. Hooke did not describe the nature of the "Otocousticons" to which he alluded, some light is thrown on the subject by the reference in Pepys' diary, two years later, to the "Otacousticon," which was nothing more than an ear trumpet.

Hooke was probably the first to suggest the transmission of sound through a wire, and his is perhaps the earliest recorded observation of the fact that sound travels faster through a solid than through air—a real contribution to science. The diversity of his interests was amazing. They included such subjects as "Art of flying in the Air, and moving very swift on Land and Water," calculating machines, chronometers, navigation, astronomy and vivisection. He was truly a wonderful man, and hence it has been all too easy, with the knowledge of later years, to read into the vague passages of his writings more than he actually did, or meant. It is not inconsistent with his character to suppose that after making the suggestions, here quoted, in the preface of his book, he went no further in this line. It has been said in effect that his achievements might have been more profound had his interests been less diversified.[1]

Du Moncel, who wrote in 1879, at the time when the string telephone was claiming widest attention, stated:[2]

"It would be difficult to say with whom this idea originated, since it is claimed, as if beyond dispute, by several telephone-makers. If we may believe some travellers, it has long been used in Spain for the correspondence of lovers. However this may be, *it was not to be found among the scientific appliances of some years ago*, and it was even supposed by many persons that the cord consisted of an acoustic tube of slender diameter."

It is difficult to believe, if the string telephone had been of as great antiquity as many writers have considered it to be, it would not have been a common thing among the scientific appliances of the times immediately preceding the invention of the electric telephone. Great attention was being given to the

[1] Biography in "Posthumous Works of Robert Hooke."

[2] Du Moncel, "The Telephone, the Microphone and the Phonograph," Harper & Brothers, 1879.

science of sound, and this simple device would have been of great interest for its scientific value alone.

Certainly a familiarity with it would have enabled Wheatstone to have gone a step or two further than he did; and, as we shall see, it might have helped Bell over some difficult places in his work on the electric speaking telephone. But Bell did not know of it, and evidently Wheatstone did not—else why "the almost hopeless difficulty of communicating sounds produced in air with sufficient intensity to solid bodies?"

Contrary to the prevailing ideas as to the antiquity of the string telephone, I incline to the belief that it is comparatively modern, antedating the electric telephone (1875) by a few years at most. The earliest unmistakable description of it that I have been able to find is that of Adolph F. Weinhold,[1] Professor of the Royal Technical School, Chemnitz, Germany, in his book "Introduction to Experimental Physics," published in England in 1875. This reference was brought to my attention by the late Mr. Thomas D. Lockwood of Boston, whose remarkable memory was a veritable storehouse of telephonic lore.

Weinhold stated: "The transmission of sound can be strikingly shown by means of a tightly stretched piece of twine, or still better an iron wire. Each end of the cord or wire is fixed to the middle of a thin but not very small board called a *sounding-board*, which, in consequence of its comparatively large surface and great elasticity is peculiarly capable of receiving sonorous vibrations from the air, and, conversely, of communicating its own vibrations to the air." He described how the sound of a music box or of the voice could be thus transmitted over distances of more than 600 meters and with sufficient clearness to permit words to be understood and the characteristics of different voices to be distinguished. He also stated that "a short sharp cry" at one end could be heard twice at the other end, first by the more rapid transmission through the wire, and then by slower transmission through the air.

Regardless of its origin, the string telephone was a device of extremely limited application. Nevertheless, it was of scientific importance, since it taught at least two lessons in telephone fundamentals: first, that a thin diaphragm, such as a tightly stretched membrane, could take up the vibrations of the human

[1] "Introduction to Experimental Physics," p. 333, Longmans, Green and Co., London, 1875.

voice with sufficient intensity to pass them on to another solid body (the string); and, second, that so simple a thing as a diaphragm, when made to copy the original vibrations, would emit a substantial copy of the original sounds. We may profitably follow this device somewhat further to show that it was actually capable of limited useful application.

The most interesting example of an actually useful mechanical telephone that has come into my own personal experience was one connecting the houses of a father and his son, located about half a mile apart in the outskirts of Vineland, New Jersey. For a period of four or five years, from about 1885 on, this was in daily practical use for intercommunication between the two families.

The telephone instrument at each house consisted of a skin drumhead stretched tightly over a circular opening, about a foot in diameter, in a flat board about eighteen inches square. This board was rigidly and permanently mounted within the house on the outside wall nearest to the other house. Its top was tilted slightly inward from the vertical, and its center was perhaps seven feet above the floor line.

A small copper or bronze wire, about No. 16 B. & S. gage, was used instead of the string of the ordinary lovers' telegraph. This led into each house through an auger hole, bored through the outside wall, exactly opposite the center of the drumhead. It passed through the drumhead and terminated in an ordinary coat button of bone, about three-fourths of an inch in diameter. It was stretched fairly taut from the diaphragm in one house to that in the other and was supported throughout its length on poles set about one hundred feet apart. The wire was hung from each pole by a loop of cord about a foot long, and, as the poles were purposely set slightly out of line with each other and the wire hung from the inside of the bend, it always swung clear of the poles. The first point of support outside each house was carefully placed so that the wire would pass through the auger hole without touching. Thus, from one diaphragm center to the other, the wire swung clear of all rigid objects. The tension of the wire was, of course, taken by the button bearing on the center of each diaphragm, which was thus pulled an inch or more out of its normal plane.

This simple arrangement afforded, without any auxiliaries, not only means for talking but also for signaling; a problem that was not so easily met in the development of the electric telephone. To use the instrument one stood on a chair and signaled to the other house by tapping with a knife handle, or similar object, on the button before him. The signal thus transmitted was sufficiently loud to be heard all over the premises of the other house. Upon response, the person at the called station also mounted a chair, and the two could then converse in ordinary tones, quite understandably. The transmitted speech, as may be surmised from our present knowledge, sounded like that of a person talking with his head in an empty barrel, but this did not seriously interfere with its usefulness.

This telephone, however, did have its drawbacks, not the least of which was the astounding noises that occurred when a bird flew against the wire, which happened frequently. The noises thus produced, while not as loud as thunder, were even more startling because they came with no warning. They would reverberate from one house to another in resounding thumps as the main wave caused by the impact of the bird would pass back and forth between the stations.

The mode of action often attributed to these mechanical telephones, that the wire or string moves bodily back and forth in the direction of its length in response to the pulls reciprocally exerted on it by the diaphragm, is, of course, in error, being contrary to the well-established theory of the transmission of sound waves through solids. What actually happens is that alternate waves of condensation and rarefaction follow each other through the material of the wire, just as they do through the material of air. The principal differences are that, in the case of the string or wire, the waves are confined to a restricted path instead of spreading out in all directions as in open air; and that, in the case of the copper wire, they travel about ten times as fast as they do in air.

The fact that the mechanical telephone has long since practically passed out of existence as a useful device (completely so far as I am aware), and that the electric telephone has increased by leaps and bounds, both in numbers and in usefulness, until to-day there are about 33,000,000 of them in daily operation, serves but to exemplify the vast fundamental difference between the two things. The mechanical telephone, depending on the actual transmission of the sound waves themselves, was naturally limited to short distances, and, by its very nature, its general adoption in the field of public utility was an impossibility. On the other hand, the electric telephone, when it came, knew no such limitations of distance or congestion or general adaptability. It was a long step indeed from the highest development of the mechanical telephone to the electric telephone, as the next chapter will show.

CHAPTER III

EARLY HISTORY OF THE ELECTRIC SPEAKING TELEPHONE

The birthday of the telephone, in 1875, is only yesterday in human history; but it was early in the history of the application of electricity to the useful purposes of man. Electrical science itself had not long since begun to merge from the vague ideas that characterized the early part of the nineteenth century into the more definite and accurate knowledge of the twentieth century.

The telephone, of course, is an electromagnetic instrument, and the whole telephone art to-day is essentially an electromagnetic art. It is significant, therefore, to observe that it was not until 1819, a little over a hundred years ago, that Hans Christian Oersted, Professor of Natural Philosophy in the University of Copenhagen, discovered that there was a relationship between electricity and magnetism. Both electric and magnetic phenomena were known in a vague way before that time. Franklin had demonstrated that lightning was an electric manifestation; Volta had given the world the electric pile; and such magnetic actions as those of the lodestone and the mariners' compass had been observed from ancient times. But, although it was suspected, no one demonstrated that the two were kindred phenomena until Oersted observed[1] that a magnetic needle tends to place itself at right angles to a wire carrying a current of electricity. This was a simple discovery, as we look at it today, but it was one of epoch-making importance. It immediately stimulated research into electric and magnetic phenomena, paving the way for the revolutionary changes which electricity has since wrought in human affairs.

Ampere immediately took up the subject and in a very short time, with masterly thoroughness, formulated the laws upon which the present electromagnetic theory is based. Soon after Oersted's discovery, D. F. J. Arago, a Frenchman, and Sir

[1] "Annals of Philosophy," p. 273, 1820.

Humphrey Davy, celebrated English chemist, independently discovered the power of an electric current to magnetize iron and steel. It was William Sturgeon, however, who in 1824 made an electromagnet and called it by that name. His magnet was formed by wrapping a bare copper wire around an iron rod which had been bent into the form of a horseshoe and insulated with varnish. The convolutions of the wire were so spaced as not to touch each other.

A little later, Joseph Henry, who has recently been called the "Dean of American Scientists," made his classic experiments on the electromagnet.[1] To him must be accredited a large amount of our knowledge regarding it. He showed that it was better to insulate the wire itself rather than the core, and, in order to do this, he gave us silk-insulated magnet wire. He showed that best results could be secured by wrapping the wire closely along the whole length of the core and in successive layers, taking care to insulate the layers from each other by an intervening wrapping of silk ribbon. He also developed the method of winding the wire on the spool, and then slipping the spool on the core, a practice largely used to-day. In fact, Henry gave us the electromagnet of to-day except for improvements in the technique of its manufacture. Several of his magnets are now in the physics museum at Princeton University.

By these methods Henry constructed large magnets of great lifting power. Of more importance to us, however, were his so-called "intensity" magnets. These were small magnets wound with many turns of fine wire and capable of being operated over considerable lengths of line.

Early in 1831 he arranged a small office bell in such a manner that it could be tapped by the polarized armature of one of his "intensity" magnets. The coil of this magnet was connected in circuit with a mile of insulated copper wire suspended about one of the rooms of his academy. This was the first instance of magnetizing iron at a distance, or of a combination of magnet and battery so arranged as to be capable of such action. It was, therefore, the earliest example of an electro magnetic telegraph, all preceding experiments to this end having been on the galvanometer or needle principle.

[1] Article on Joseph Henry, "Encyclopedia Britannica." BANCROFT, GHERARDI, and ROBERT W. KING, Joseph Henry, *Bell System Technical Journal*, January, 1926.

Henry thus blazed the trail leading to Morse's electromagnetic telegraph. He also furnished the electromagnetic essentials for Bell's telephone. In addition to this, as will be shown, he gave valuable furtherance to the invention of the telephone by showing kindly interest and advising a struggling young inventor who had come to him for assistance.

Oersted, Ampere, Arago, Davy, Sturgeon and Henry, in the work leading up to the electromagnet, established primarily one of the laws concerning the relationship between electricity and magnetism: that a current flowing in a conductor causes a field of magnetic force to exist about that conductor. This field of force may be considered as represented by "lines of force" encircling the conductor.

The electromagnet was the logical outcome of this law, since, by coiling the conductors many times about a core of iron, the fields of force due to each of the many convolutions were brought cumulatively into a comparatively small space, resulting in a greatly intensified field. The lines of magnetic force thread through the core and return through the air or other external path, always forming closed loops.

In 1831 Michael Faraday and Joseph Henry independently discovered the converse of these laws, relating to the transformation of electrical energy into magnetic. That is, they discovered that magnetic action could be transformed into electrical. They found that currents would be caused to flow in a closed conducting loop if the average intensity of the magnetic field passing through that loop was changed. The current so induced in the loop would flow only while such change was taking place, its strength would be proportioned to the rate of the change, and its direction would depend on the direction of the field and whether it was increasing or decreasing. It mattered not whether the change in the number of magnetic lines passing through the loop was caused by changes in the field itself or by a movement of the loop with respect to the field or by a movement of the field with respect to the loop. These laws of electromagnetic induction directly paved the way for the electric dynamo, just as the converse laws had paved the way for the electric motor.

These laws concerning the transformation of electric energy into magnetic and, conversely, the transformation of magnetic energy into electric are certainly the most important in the whole realm of electrical science. Singly or together they form the foundation not only of the telephone and telegraph but also of electric lighting, electric power, radio and of every other achievement by which electricity has revolutionized the methods of life throughout the civilized world.

It was during the period of the discovery and formulation of electromagnetic laws that Dr. Georg Simon Ohm, in 1827, introduced a clear conception as to the relationship between the current, electromotive force and resistance in a circuit. This, when formulated, became Ohm's Law which has immortalized his name.

It was natural that first efforts toward the transmission of intelligence by electricity should have been in the direction of signal transmission as distinguished from speech transmission.

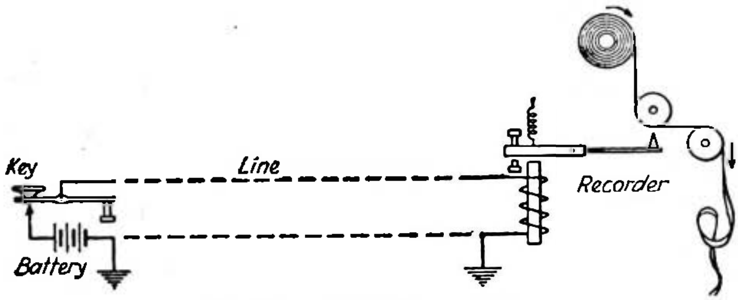

Fig. 2.—Principles of Morse telegraph.

To have aimed at the latter would have appeared then, as it did later, as a most visionary and foolish undertaking and, by some, as "wickedly defiant of God and His laws." Without overlooking the work of Wheatstone in England, already alluded to, and with due regard to that of Joseph Henry in preparing the way, it may be stated that the first practical electromagnetic telegraph was due to Samuel Finley Breese Morse, of Charlestown, Massachusetts, who was, at first, an artist of some note and then an inventor of lasting fame.[1]

Morse placed at one end of the line (Fig. 2) the electromagnet conceived by Sturgeon and developed by Henry and at the other end a battery and a key for opening and closing the circuit. Opposite one pole of his electromagnet he mounted a pivoted armature having a retractile spring with sufficient pull to hold

[1] Prime, S. I., "Life of Samuel F. B. Morse, LL.D.," D. Appleton & Company, New York, 1875.

the armature away from the magnet when no current was flowing. The free end of the armature carried a pen or stylus arranged to be brought into contact with a constantly moving strip of paper when the armature was attracted. By opening and closing the key the armature at the distant point could be caused to move up and down and thus record on the strip of paper the dots, dashes and spaces of the Morse code. The original Morse receiving instrument, now in the Historical Museum of the Bell Telephone Laboratories, is shown in Fig. 3.

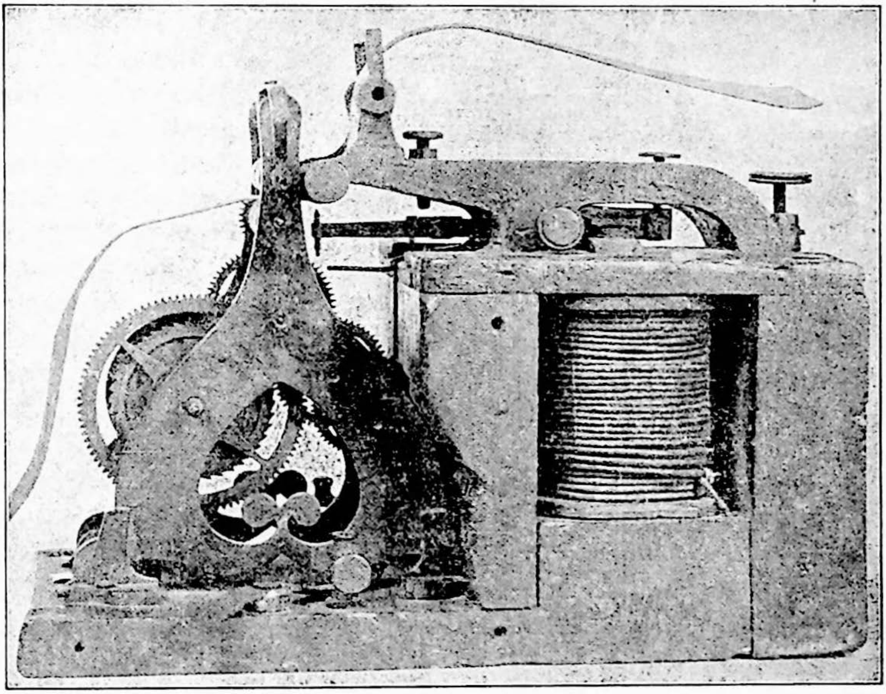

Fig. 3.—Original Morse telegraph recorder. (*Courtesy of Bell Telephone Laboratories.*)

It was not long after Morse's invention and its wide adoption that operators discovered that they could read the instruments by sound, a thing at first not believed possible. This led to the abandonment in most cases of the tape register. The receiving instrument was thus reduced to the very simple form of the well-known telegraph sounder shown in Fig. 4. This, in so far as its elements are concerned, consists of an electromagnet having a pivoted armature with a retractile spring and an anvil against which the armature lever will strike, both on its downward and upward motions.

The fact that in the Morse system of telegraphy the received signals are in the main read by sound does not mean, of course, that the system is in any proper sense one of sound transmission. While in a certain way the noise made by the sounder may correspond to the noise made by the key, this is purely incidental to the operation of the system. In fact, the noises of the sounder would occur just the same if the key were adjusted to operate without noise.

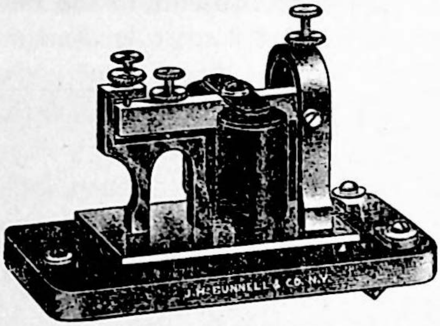

Fig. 4.—Modern Morse telegraph sounder

So far as extensive investigation by many searchers has shown, the first attack on the problem of transmitting speech to a distance by electricity was made by a Frenchman, Charles Bourseul, in 1854. Nearly all books relating to telephony have contained extracts from Bourseul's article,[1] but in view of its historical importance as being the first proposal of an electric speaking telephone and its general interest as containing early allusions to printing and autographic telegraphs, a translation is given here in full:

"The electric telegraph is based on the following principle: An electric current, passing through a metallic wire, circulates through a coil around a piece of soft iron which it converts into a magnet. The moment the current stops, the piece of iron ceases to be a magnet. This magnet, which takes the name of electromagnet, can thus in turn attract and then release a movable plate (plaque mobile) which by its to-and-fro movement produces the conventional signals employed in telegraphy. Sometimes this movement is directly utilized, and is made to produce dots or dashes on a strip of paper which is drawn along by clockwork. The conventional signals are thus formed by a combination of those dots and dashes. This is the American telegraph, which bears the name of Morse, its inventor. Sometimes this to-and-fro movement is converted into a movement of rotation. In that way we have either the dial telegraph used on railroads, or the telegraph used in the government system, which by means of two line wires and two indicating needles, reproduce all the signals of the aerial telegraph or semaphore

[1] *L'Illustration*, vol. 24, Paris, August 26, 1854.

which was formerly used. Suppose, now, that we arrange upon a movable horizontal circle letters, figures, signs of punctuation, etc. One can understand that the principle we have stated can be used to choose at a distance such and such a character, and to determine its movement, and consequently to print it on a sheet of paper appropriately placed for this purpose. This is the printing telegraph.

"We have gone still further. By the employment of the same principle, and by means of a mechanism rather complicated, it has been possible to reach a result which at first would seem to be almost a miracle. Handwriting itself is produced at a distance, and not only handwriting, but any line or any curve; so that, being in Paris, you can draw a profile by ordinary means there, and the same profile draws itself at the same time at Frankfort. Attempts of this sort have succeeded. The apparatus has been exhibited at the London Exhibition. Some details, however, remain to be perfected. It would seem impossible to go beyond this in the region of the marvellous. Let us try, nevertheless, to go a few steps further. I have asked myself, for example, if the spoken word itself could not be transmitted by electricity; in a word, if what was spoken in Vienna may not be heard in Paris? The thing is practicable in this way:

"We know that sounds are made by vibrations, and are made sensible to the ear by the same vibrations, which are reproduced by the intervening medium. But the intensity of the vibrations diminishes very rapidly with the distance; so that even with the aid of speaking tubes and trumpets, it is impossible to exceed somewhat narrow limits. Suppose that a man speaks near a movable disk, sufficiently flexible to lose none of the vibrations of the voice; that this disk alternately makes and breaks the connection with a battery; you may have at a distance another disk which will simultaneously execute the same vibrations.

"It is true that the intensity of the sounds produced will be variable at the point of departure, at which the disk vibrates by means of the voice, and constant at the point of arrival, where it vibrates by means of electricity; but it has been shown that this does not change the sounds. It is, moreover, evident that the sounds will be reproduced at the same pitch.

"The present state of acoustic science does not permit us to declare a priori if this will be precisely the case with syllables uttered by the human voice. The mode in which these syllables are produced has not yet been sufficiently investigated. It is true that we know that some are uttered by the teeth, others by the lips, etc.; but that is all.

"However this may be, observe that the syllables can only reproduce upon the sense of hearing the vibrations of the intervening medium. Reproduce precisely these syllables.

"It is, at all events, impossible, in the present condition of science, to prove the impossibility of transmitting sound by electricity. Everything tends to show, on the contrary, that there is such a possibility. When the application of electromagnetism to the transmission of messages was first discussed, a man of great scientific attainment treated the idea as Utopian, and yet there is now direct communication between London and Vienna by means of a simple wire. Men declared it to be impossible, but it is done.

"It need not be said that numerous applications of the highest importance will immediately arise from the transmission of speech by electricity. Any one who is not deaf and dumb may use this mode of transmission, which would require no apparatus except an electric battery, two vibrating disks and a wire. In many cases, as, for example, in large establishments, orders might be transmitted in this way, although transmission in this way will not be used while it is necessary to transmit letter by letter, and to make use of telegraphs which require use and apprenticeship. However this may be, it is certain that in a more or less distant future, speech will be transmitted by electricity. I have made some experiments in this direction. They are delicate, and demand time and patience; but the approximations obtained promise a favorable result."

CHARLES BOURSEUL.

Paris, August 18, 1854.

To my mind his complete article makes Bourseul stand forth in a much more impressive light than do the mere extracts of it that are usually quoted. It shows that he had thought a long way into the problem of electrical speech transmission; that he saw, at least, some of the shortcomings of his proposed method; that he appreciated the transcendent importance of the achievement, when it should have been accomplished; and that he had complete faith in its ultimate consummation by some one. His idea of causing a distant plate to take up all of the vibrations of another vibrating under the direct influence of the voice was a fine conception. But, as every experimenter during the next twenty years proved, the idea of accomplishing this by causing the original disc to *make and break* the circuit was all wrong. No one ever has succeeded in transmitting speech in that way. This was the stumbling block for the next two decades.

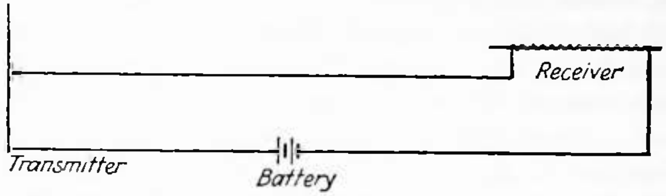

Fig. 5.—Principles of Reis' make and break telephone.

The next inventor to attack the problem was Philip Reis, a German physicist. In 1861 he constructed what he called a "telephone" and, during the succeeding period of several years, constructed several models, all exactly alike in principle. The theory of Reis' method may be understood from the diagram of

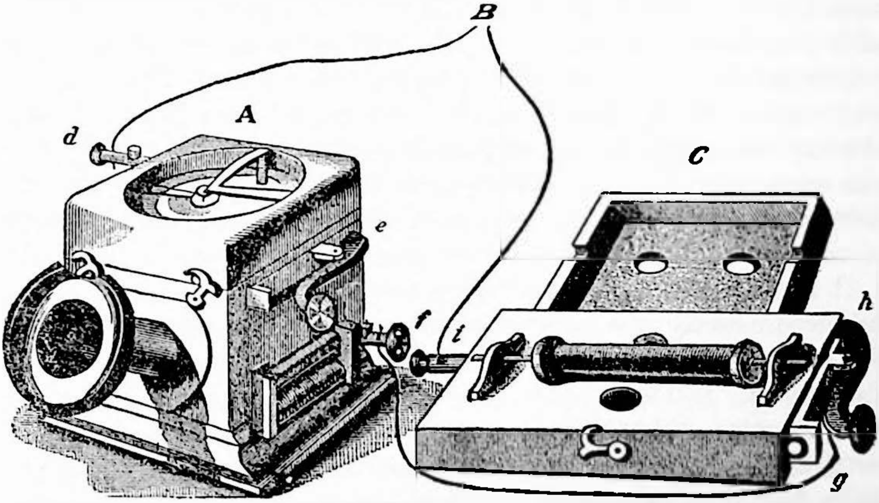

Fig. 6.—Set of Reis instruments.

Fig. 5, which shows the bare essentials of his instruments. Figure 6 shows one of his sets of instruments.[1] This consists of what he called the "telephone proper," at the left, and the "reproducing apparatus," at the right. In the "telephone

[1] U. S. *Reports*, vol. 126, p. 67, Supreme Court of the United States, October term, 1887.

proper," which was the transmitter, he employed a diaphragm consisting of a flexible membrane ("skin from the intestines of a hog") tightly stretched over a circular opening in a wooden box. To the center of this membrane was affixed a small plate of platinum connected by a flexible strip of metal to the binding post *d*. An angular piece of metal, shown above the diaphragm, carried a small platinum foot which rested on the platinum contact in the center of the diaphragm. This angular piece of metal, which formed a sort of rider on the diaphragm, was electrically connected to the telegraph key *e* mounted on the side of the box. From this the circuit continued through the telegraph sounder mounted just below the key and terminated on the binding post *f*. The receiver consisted essentially of a knitting needle around which was wound a coil of silk-insulated copper wire. This was mounted on a hollow sounding board or box so as to augment whatever sounds were given forth by the needle.

The action of the device, as described by Reis,[1] was as follows: "If now sufficiently strong tones are produced before the mouthpieces, their vibrations will put in motion the membrane and the angular little hammer (*winkelförmige Hämmerchen*) which lies on it; for every full vibration the circuit is once opened and again closed (*einmal geöfnet und wieder geschlossen*), and thereby are produced at station C in the core of the coil, just the same number of vibrations (*ebensoviele schwingungen hervorgebracht*) which are there perceived as tones or as combinations of tones (*accords*)."

It is seen that, so far as his transmitter was concerned, Reis followed exactly the path outlined by Bourseul—that of having the diaphragm, under the influence of the voice, make and break the circuit.

The action of his receiver was based on a phenomenon known as "Page's Effect." In 1837 Professor Page of Salem, Massachusetts, had discovered that a rod of iron suddenly magnetized or demagnetized would emit faint sounds. This was probably due to some sort of molecular or sub-molecular rearrangement causing slight changes in the dimensions of the bar, a phenomenon now known as "magneto striction." It was on these sounds, augmented by the sounding board, that Reis' receiver depended. The fact that telegraph apparatus was included by Reis in all his instruments is mute but eloquent testimony of the inability of

[1] *Ibid.*, p. 62.

these instruments to talk. This telegraph apparatus was, as stated in one of Reis' circulars, for convenience in experimenting.

Reis' telephone could be depended upon to transmit only the pitch of musical sounds. Obviously, it had difficulty in differentiating between sounds of different loudness, for a small break was likely to cause the same noise in the receiver as a large one—all either could do was to cause a complete cessation of the current. But what was even more important, the Reis instrument failed to transmit and reproduce the third and, so far as speech is concerned, the most vital characteristic of sound—its quality or timbre. As will be shown, quality or timbre depends neither on the pitch nor the loudness but on the number of overtones comprised in the sound and on their relative intensities with respect to the fundamental tone. Of course, the simple make and break of Reis' transmitter could not transmit quality because if the contact broke in response to the vibrations of the fundamental tone, it had no power to act in response to the more rapid vibrations corresponding to the overtones.

Reis' telephone attracted wide attention and was known among scientists of his time both in Europe and America. Numerous articles of that time describe it and its performance in detail. But not one of them even suggests any other mode of operation than that of making and breaking the circuit in accordance with the vibrations of the transmitter diaphragm. All agreed that the apparatus did reproduce melody—not, however, in the voice of the singer or of the musical instrument being used but in a voice all its own, which has been likened to the buzzing of an insect.

For something like a decade after Reis' efforts, no apparent advance was made in the art of electrical telephony. In 1874 Professor Alexander Graham Bell, then residing at Salem, Massachusetts, attacked the problem. Bell was a teacher of deaf mutes. He and his father and grandfather before him specialized in the science of sound and particularly in the art of teaching to speak those who were dumb because of having no sense of hearing. As a result of his training Bell had a greater knowledge of acoustics than of electrical science. It was probably this that led him to succeed where others had failed.

In 1874 Bell was working on a harmonic telegraph by which he hoped to send several simultaneous messages telegraphically over a single wire. He had strongly in his mind the problem of speech transmission or, as he called it, the "transmission of vocal sounds by telegraph." The evidence shows conclusively that at this time Bell had conceived the correct method for the transmission of speech. He saw the reason for the failure of Bourseul and Reis and had it firmly in mind that, in the successful electric speaking telephone, the transmitter would be required to impress on the current, flowing in the line, undulations which would correspond in form to the motions of a particle of air engaged in the sound vibration.

Early in 1875 Bell visited Washington and called on Joseph Henry to seek his advice about his plan for "the transmitting of the human voice by telegraph." Henry showed much interest, said he though it was the "germ of a great invention," pointed out the difficulties in the way of its successful accomplishment, and when Bell told him that he thought he lacked the necessary electrical knowledge to overcome these difficulties, his laconic answer was "get it."

The encouragement thus given to Bell by the great scientist had a profound effect. The fact that such a man as Henry had not characterized his idea as visionary and impractical, as nearly everyone else had done, greatly increased his confidence.

The thought that a reed or disk forming the armature of an electromagnet might be made to vibrate in accordance with the sound of the voice and thus generate the sought-for undulating currents in the coil of the magnet had occurred to Bell. He felt confident that such a method, theoretically, would give him the desired currents undulating in conformity with the undulations of the sound waves. But he dismissed the idea because he thought the energy of the voice would be too feeble to generate currents sufficiently strong to result in sounds loud enough to be heard. Apparently, Henry in his interview had agreed with him that this method was correct in principle but probably impractical.

It was on June 2, 1875, that the feasibility of generating undulatory currents in this way was accidentally and dramatically demonstrated to Bell. On this day, he and his assistant, Thomas A. Watson, were experimenting on the harmonic telegraph in a hot garret in Boston which constituted his laboratory. In this harmonic telegraph a number of electromagnets of the kind shown in Fig. 7 were connected in series in the same circuit. Before the pole of each magnet there was a steel reed forming the armature. Each receiver was tuned to vibrate at a frequency different from that of the others. The idea was that each would vibrate selectively in response to current of its own frequency impressed in the line by the transmitters. What happened on the occasion can best be told in Mr. Watson's own language.[1]

"I had charge of the transmitters, as usual, setting them squealing one after the other, while Bell was retuning the receiver springs one by one, pressing them against his ear as I have described. One of the transmitter springs I was attending to stopped vibrating and I plucked it to start it again. It didn't start and I kept on plucking it, when suddenly I heard a shout from Bell in the next room, and then out he came with a rush,

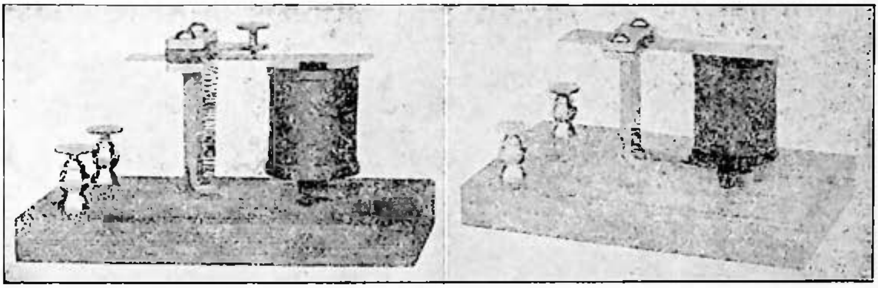

FIG. 7.—Bell's vibrating reed (transmitter left, receiver right). (*Courtesy of Bell Telephone Laboratories.*)

demanding, 'What did you do then? Don't change anything. Let me see!' I showed him. It was very simple. The make-and-break points of the transmitter spring I was trying to start had become welded together, so that when I snapped the spring the circuit had remained unbroken while that strip of magnetized steel by its vibration over the pole of its magnet was generating that marvelous conception of Bell's—a current of electricity that varied in intensity precisely as the air was varying in density within hearing distance of that spring. That undulatory current had passed through the connecting wire to the distant receiver which, fortunately, was a mechanism that could transform that current back into an extremely faint echo of the sound of the vibrating spring that had generated it, but what was still

[1] Birth and Babyhood of the Telephone, by Thomas A. Watson, address delivered before the Third Annual Convention of the Telephone Pioneers of America, Chicago, October 17, 1913.

WATSON, THOMAS A., "Exploring Life," D. Appleton and Company, New York and London, 1926.

more fortunate, the right man had that mechanism at his ear during the fleeting moment, and instantly recognized the transcendent importance of that faint sound thus electrically transmitted. The shout I heard and his excited rush into my room were the result of that recognition. The speaking telephone was born at that moment. Bell knew perfectly well that the mechanism that could transmit all the complex vibrations of one sound could do the same for any sound, even that of

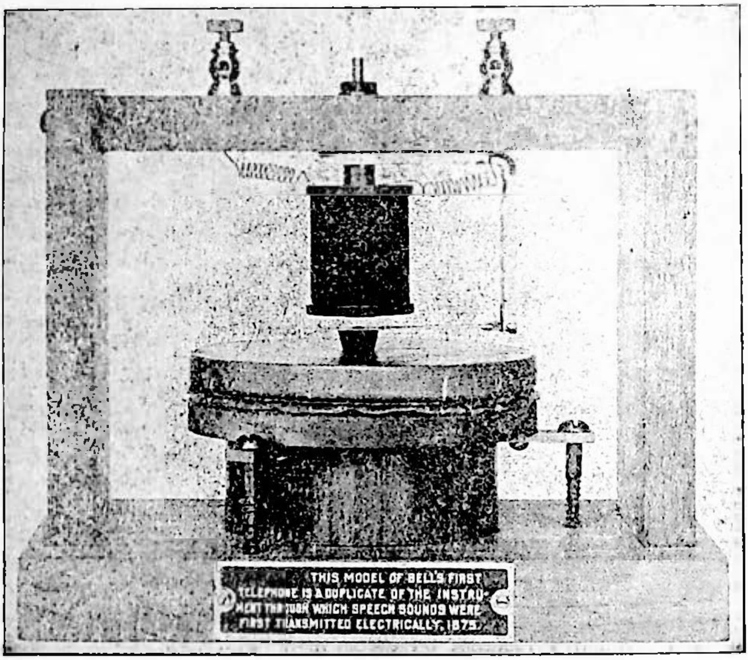

FIG. 8.—First electric speaking telephone. (*Courtesy of Bell Telephone Laboratories.*)

speech. That experiment showed him that the complex apparatus he had thought would be needed to accomplish that long dreamed result was not at all necessary, for here was an extremely simple mechanism operating in a perfectly obvious way, that could do it perfectly."

After many repetitions of this experiment with different reeds that same afternoon, Bell sketched out for Watson the plan for the telephone instrument he was to make. So simple was it in construction that Watson had it ready to test the next afternoon.

This, the first speaking telephone, is shown in Fig. 8. It consisted merely of an ordinary frame on which was mounted one of Bell's harmonic receivers like that of Fig. 7. A tightly stretched parchment drumhead was mounted on this frame, the center of which was fastened to the free end of the receiver armature. The idea of this instrument was that the diaphragm or drumhead would take up the vibrations of the voice and force the armature into exactly similar vibrations. These, in turn, by electro-magnetic induction, would cause currents in the winding of the magnet that would undulate in conformity with the vibrations of the voice.

The receiver used with this first transmitter, according to Watson, was merely one of Bell's vibrating reeds (Fig. 7) held so closely against the ear of the listener as to damp its natural rate of vibration.

On the first trial,[1] the night of June 3, 1875, Bell could hear nothing, but Watson, on account of his more acute hearing and Bell's more vigorous voice, could unmistakably hear the tones of Bell's voice and "almost catch a word now and then." The trial was disappointing to Bell, but, nevertheless, it showed him that he was on the right track.

The building, 109 Court Street, Boston, in which these events occurred, is still standing (1930). On it has been placed a bronze tablet reading as follows:

HERE THE TELEPHONE WAS BORN, JUNE 2ND, 1875
THE BOSTONIAN SOCIETY AND THE NEW ENGLAND
TELEPHONE AND TELEGRAPH COMPANY
PLACED THIS TABLET MARCH 10TH, 1916

Being convinced that his principle was sound, Bell next devoted himself to the preparation of his patent application. This was filed in the United States Patent Office on February 14, 1876. So novel was the invention that the patent[2] issued only three weeks later. It was probably the most valuable patent ever issued in any art or in any country. It was entitled "Improvement in Telegraphy" and was directed not only to the "telegraphic" transmission of speech but of signals as well.

[1] Birth and Babyhood of the Telephone, by Thomas A. Watson, address delivered before the Third Annual Convention of the Telephone Pioneers of America, Chicago, October 17, 1913.
[2] U. S. Patent 174,465, March 7, 1876.

Figures 5 and 7 of the patent are reproduced as Figs. 9 and 10, respectively. Figure 9 (Fig. 5 of the patent) was used to show the general principle involved, whether used in the transmission of signals or of speech. It will be recognized as exhibiting exactly the conditions which existed in the reed plucking incident on June 2, 1875, at which time, as Watson says, "the birth cry

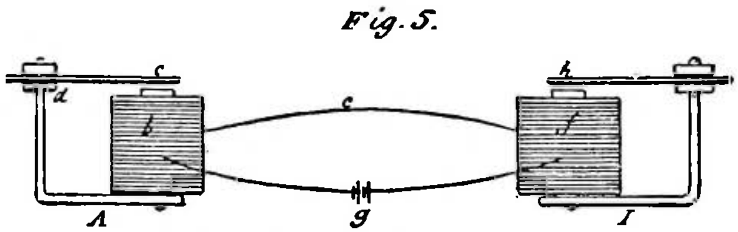

Fig. 9.—Figure 5 of Bell's patent.

of the telephone was heard." Two of the reeds, such as those of Fig. 7, are connected in simple series relation in circuit with a battery. If the reed *c* is made to vibrate from any cause, it will, by electromagnetic induction, cause undulatory currents to flow in the coil *b*. These will cause the magnet *f* of the distant instrument to exert a varying attraction and thus cause its reed *h* to vibrate.

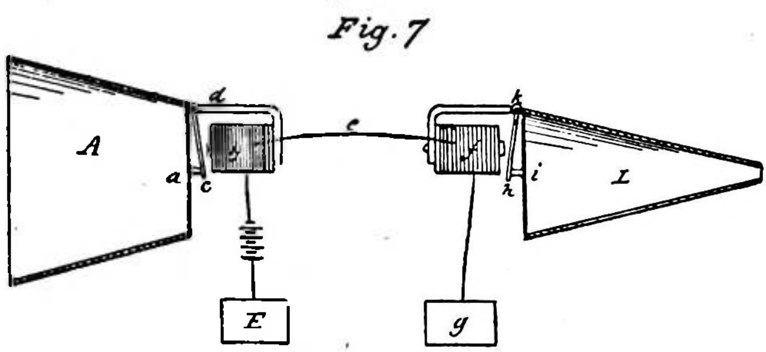

Fig. 10.—Figure 7 of Bell's patent.

This mode of operation, as applied particularly to voice transmission, is illustrated in Fig. 10 (Fig. 7 of the patent). At the transmitter, a diaphragm is tightly stretched over the small end of a speaking trumpet or mouthpiece, while, at the receiver, another diaphragm is similarly stretched over the large end of an ear trumpet or earpiece. To the centers of these diaphragms are attached the free ends of their respective armatures. The sound vibrations of the voice are thus taken up by the transmitter diaphragm and imparted to its armature, while the similar vibrations produced in the receiver armature are imparted to its diaphragm, thus reproducing the sound. Bell realized that in speech transmission he should, as far as possible, get away from any fixed rate of vibration of his armatures, and, accordingly, in Fig. 7 of the patent, the armature of each instrument was loosely pivoted instead of being spring mounted.

The part of the patent specification relating particularly to the telephone occupied not more than about twenty-five lines of print, but it revealed Bell's grasp of the problem in hand. It disclosed not only the fundamental method, without which no one then or since has been able to transmit speech electrically, but it also gave a perfectly feasible plan of practicing that method. By it he told the world for the first time how to transmit speech electrically. Following its instructions any skilled electro-mechanic could have made and used the invention.

Even if, up to the time of filing his patent application, Bell's device had never spoken a word or if it never had had any experimental work done on it, this description alone would have sufficed. It is to the man who shows the world how to make and use an invention that the patent laws of the United States confer the honor and the reward.

While the accidental discovery at the time of the "reed plucking" incident showed Bell the feasibility of the magneto principle of operation, he, even then, realized that the action of the magneto transmitter would be feeble. His patent application clearly showed that he had other and more powerful methods in mind. Among these was that of having the transmitter vary the external resistance of a circuit containing a battery and receiver. Under this plan a battery, which could be made as strong as desired, would furnish the current, and the slight energy of the voice would operate a sort of valve to cause undulations in this current. Sometime before March 10, 1876, he worked on the practical development of this method, and one of his early embodiments of it in working form is crudely illustrated in Fig. 11, a sketch made by Mr. Watson and used in connection with his deposition in one of the numerous patent suits in which Bell's invention became involved.[1] Incidentally,

[1] General Brief for Bell Company, p. 472, Supreme Court of the United States, October term 1886.

this sketch is quite typical of the kind of sketches telephone men draw for each other today.

In accordance with Watson's description given at the time, the diaphragm against which the voice is to be directed is shown at *A*. To its center is attached a cork *B* from which depends the "plunging wire" *C* connected to the binding post *H*. The vessel *I*, of glass, is partly filled with acidulated water to the level *J*, and into this water the point of the plunging wire *C* dips "just enough to make sure that it will never vibrate out." Near the edge of the vessel is a stationary metal rod *G* immersed deeply into the liquid. This forms the other terminal of the instrument.

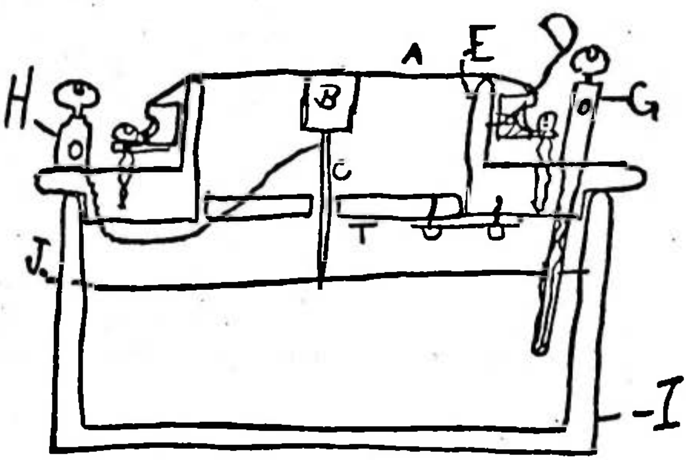

FIG. 11.—Watson's sketch of Bell's liquid transmitter.

The mode of operation was thus described: "The current, in passing from the rod *C* *to* the liquid, the upper surface of which is shown by the line *J*, experiences considerable resistance *at the contact of the rod and the liquid*, and that resistance is, other things being equal, proportionate to the area of contact. If that rod just dips into the liquid an extremely short distance, then its vibrational movement up and down will *notably* vary the area of contact, and consequently notably vary the electrical resistance at that point, and therefore the current which is affected by that resistance."

It was with an instrument of this kind that the next milestone in the history of the telephone was passed. With it the telephone spoke its first sentence. Evidently the achievement came rather unexpectedly, for, as Mr. Watson says, had he and Bell known that the instrument they were about to test was to prove the best of any that had gone before, they would probably have rehearsed the event and decided upon some such impressive message as Morse's "What hath God wrought?" Instead of that the message was quite commonplace—merely the simple request, "Mr. Watson, come here. I want you." It is needless to say that Watson came.

Nearly forty years later, on January 25, 1915, on the occasion of the opening of the transcontinental line between New York and San Francisco, Bell, in New York, speaking, through an exact replica of his first instrument, said again to Watson, "Mr. Watson, come here. I want you." But this time Watson did not come so quickly, for he was over three thousand miles away in San Francisco.

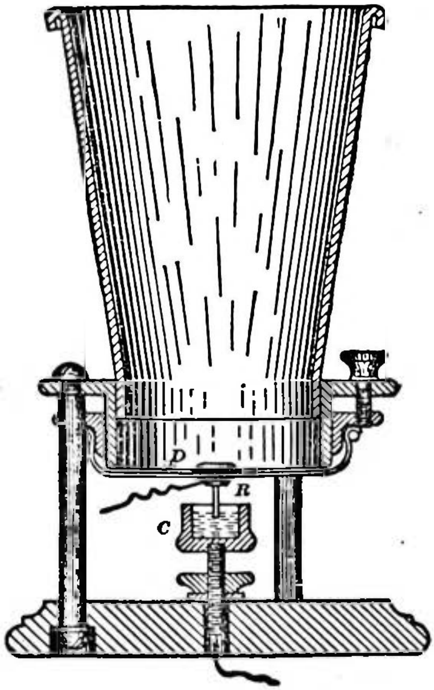

Fig. 12.—Bell's Centennial liquid transmitter.

This incident is parenthetically introduced at this point for two reasons: It shows how fundamentally perfect had been Bell's original conception; and it affords a striking illustration of the improvements that have been made in all phases of telephone transmission aside from those involved in the telephone instrument itself. The layman is likely to think of the telephone art as being represented by the instrument on his desk or wall, into which he talks and to which he listens. He does not realize that between him and the person with whom he is conversing there is a network of lines, switchboards and other instrumentalities which, taken together, form one of the most intricate and highly developed organizations yet conceived by man. This incident at the opening of the transcontinental line showed that, throwing away all of the advancement that had been made in the telephone instrument itself, the improvements in the line and other parts of the system were such as to enable an instrument, which, in Bell's time, had succeeded imperfectly in making itself heard over a line perhaps fifty feet in length, to transmit understandable articulation to another instrument across the continent.

Bell decided to exhibit the telephone at the Centennial Exposition held in Philadelphia in 1876, and for that purpose he had Mr. Watson make additional models of all of the more successful instruments that he had used up to that time. These are shown in Figs. 12, 13 and 14 and require little further description.

In the Centennial model of the liquid transmitter (Fig. 12), the "plunging rod" of the earlier instrument was made of a short rod of carbon *R*, and the liquid was either of acidulated water or mercury held in a metallic cup *C*. The Centennial model of the magneto transmitter (Fig. 13) consisted of an electromagnet *H* in front of the core *C* of which was adjustably

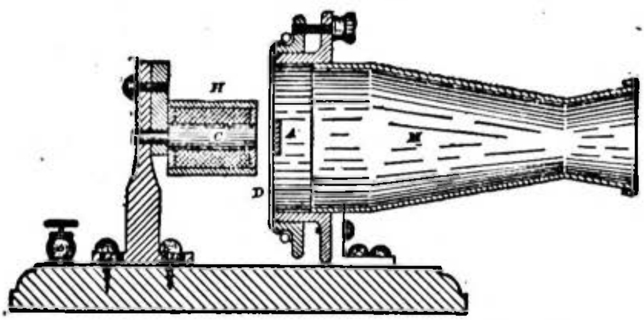

Fig. 13.—Bell's Centennial magneto transmitter.

mounted a diaphragm of goldbeater's skin *D* carrying a small iron armature *A* at its center. The Centennial magneto receiver (Fig. 14) consisted of a tubular magnet, composed of a coil *H*, surrounding a soft iron core *C* inclosed in an iron tube *E* which was about 1¾ inches in diameter and 3 inches long. This tube was closed by a thin iron armature or diaphragm *D* which rested loosely on the upper face of the iron tube. It was held in place merely by the magnetism of the core and was not secured at one edge by a small screw, in which form it is often but erroneously illustrated.

It was the performance of these instruments at the Centennial that caused the profound sensation that has been referred to in Chap. I. It was fortunate that on the board of awards of the exposition were two of the outstanding physicists of that time—Sir William Thompson, later Lord Kelvin, and Joseph Henry. The layman was inclined to scoff or to disbelieve, but these men were inspired not only by the astounding performance but also by the simplicity of the means by which it was accomplished.

With all of his Centennial magneto instruments Bell employed a battery in the circuit to magnetize the cores and thus secure the magnetic fields in which the iron armatures vibrated. He had discovered, however, at the time of the reed plucking incident, that the instruments would work, through less powerfully, without any battery in the circuit.[1] This was true

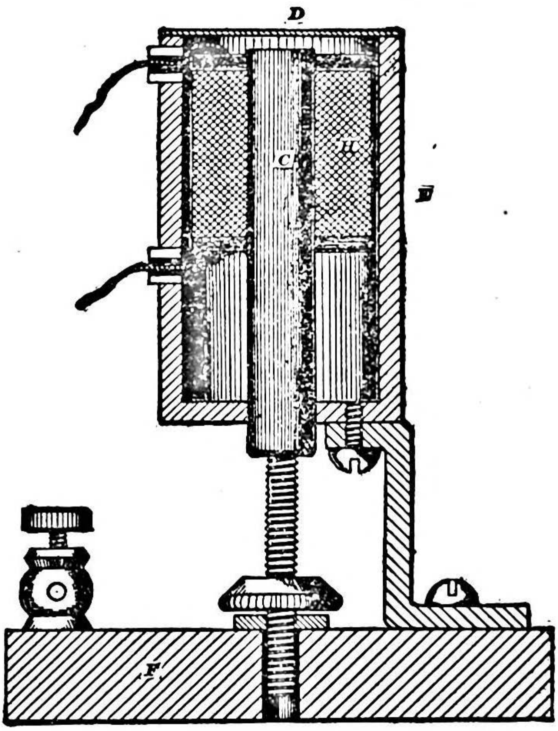

FIG. 14.—Bell's Centennial receiver.

because his iron cores, probably of none too good quality, had previously been strongly magnetized and retained enough residual magnetization to afford the necessary field. This, of course, led to the use of a strong permanent magnet instead of one that had been weakly magnetized merely as an incident of its earlier history. Then followed a period of experimentation during which all kinds and shapes of magnets and diaphragms

[1] General Brief for Bell Company, Supreme Court of the United States, October term, 1886, p. 52, letter from Bell to Gardiner G. Hubbard, June 2, 1875.

were tried and from which emerged the prototype of the modern telephone receiver. It was then used, however, as both receiver and transmitter. Two such instruments are shown diagrammatically in Fig. 15. They are connected together in the line circuit without any battery—the simplest form of telephone system. Each instrument is alternately transmitter and receiver. When transmitter, it is a dynamo, converting the energy of the voice into alternating currents; when receiver, it is a motor, converting these currents into useful work.

FIG. 15.—Two magneto telephones connected by line.

Bell's contribution to the progress of the world was succinctly set forth in his famous "fifth claim" which he himself drew, and which reads as follows:

"5. The method of, and apparatus for, transmitting vocal or other sounds telegraphically, as herein described, by causing electrical undulations, similar in form to the vibrations of the air accompanying the said vocal or other sound, substantially as set forth."

Probably no patent claim has ever been subject to so many and to such vigorous attacks as has this one. As soon as the importance of the telephone was realized by the public, numerous inventors claiming to have antedated Bell, and others, interested from other motives, launched suits for the purpose of breaking down this patent and, particularly, its fifth claim. There were hundreds of these suits, some of them finally being brought to the Supreme Court of the United States. Against all these attacks the patent was invulnerable. Every decision in every court from the lowest to the highest was in its favor, and, when the litigation had ended, Bell's position as the original inventor of the telephone had been established beyond dispute, and his patent had been adjudicated as broad enough to cover all known methods of transmitting speech by electricity.

The patent has, of course, expired, but it is of interest to note that no one, even to this time, has been able to suggest a method of transmitting speech electrically that did not fall within the scope of Bell's fifth claim.

No history of the early development of the telephone would be complete without some further allusion to these patent controversies. Of course, the early proposal of Bourseul and the later attempts of Reis to carry out Bourseul's teaching were among the principal pieces of ammunition used by the attacking parties. It is perfectly clear in the light of present knowledge why the methods of Bourseul and Reis could not succeed. The "make-and-break" principle was obviously all wrong. Furthermore, Reis' receiver, depending on the "Page Effect," would have been most inefficient even if it had been coupled with a transmitter based on the correct principle.

Claims have been made by those who came after Bell that the Reis instrument could be made to talk. But in so far as this has ever been done, it was done by so adjusting the transmitter as to make it impossible for it to break the circuit at all. So adjusted it might operate very inefficiently as a variable resistance transmitter. This was not, of course, the teaching of Reis but of Bell. In view of our present-day knowledge, and after a review of the documentary evidence contemporary and prior to the time of this controversy, one can not fail to be impressed with the soundness of the action of the Supreme Court in disposing of the alleged anticipation by Bourseul, Reis, Van der Weyde and all those who followed the make-and-break principle.

The following is a part of the decision of the court[1] which finally disposed of the Reis matter:

"We have not had our attention called to a single item of evidence which tends in any way to show that Reis or any one who wrote about him had it in his mind that anything else than the intermittent current caused by the opening and closing of the circuit could be used to do what was wanted. No one seems to have thought that there could be another way. All recognized the fact that the 'minor differences in the original vibrations' had not been satisfactorily reproduced, but they attributed it to the imperfect mechanism of the apparatus used, rather than to any fault in the principle on which the operation was made to depend.

"It was left for Bell to discover that the failure was due not to workmanship but to the principle which was adopted as the basis of what had to be done. He found that what he called the intermittent current—one caused by alternately opening and closing the circuit—could not be made under any circumstances to reproduce the delicate forms of the air vibrations caused by the human voice in articulate speech, but that the true way was to operate on an unbroken current by increasing and diminishing

[1] U. S. *Reports*, vol. 126, p. 544, Supreme Court.

its intensity. This he called a vibratory or undulatory current, not because the current was supposed to actually take that form, but because it expressed with sufficient accuracy his idea of a current which was subjected to gradual changes of intensity exactly analogous to the changes of density in the air occasioned by its vibrations. Such was his discovery, and it was new. Reis never thought of it, and he failed to transmit speech telegraphically. Bell did, and he succeeded. Under such circumstances it is impossible to hold that what Reis did was

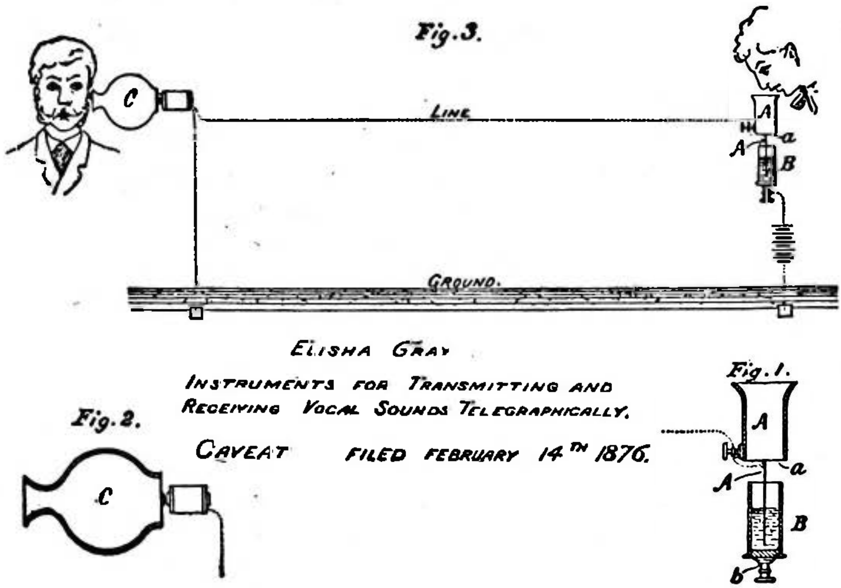

FIG. 16.—Drawing of Gray's caveat.

an anticipation of the discovery of Bell. To follow Reis is to fail, but to follow Bell is to succeed."

Another important contestant in this series of litigations was Elisha Gray. By a strange stroke of chance, Gray filed a caveat in the United States Patent Office a few hours later in the same day that Bell filed his application. The drawing in Gray's caveat is reproduced in Fig. 16. The intended mode of operation is obvious. Bell's liquid transmitter (Figs. 11 and 12) depended on variation in the extent of the immersion of the electrode, while Gray's instrument, owing to the great extent to which the vibrating electrode was immersed, depended rather on the variation in the length in the conducting path through the liquid itself, obviously a faulty principle for this purpose.

But, ignoring the question as to the practical operation of Gray's instrument, a caveat, by its very nature, is an admission by the inventor that his invention is not complete—that it is an idea upon which he intends to work further, and upon which he intends to file an application when it is sufficiently developed in his mind. Gray, like Bell, had been working on a harmonic telegraph and did produce a successful one. He was not diligent, however, in following up his idea for a telephone, for he dropped the matter for a number of years after filing his caveat. It was not until after the importance of Bell's telephone had been appreciated by the public that the Western Union Telegraph Company acquired Gray's alleged rights and opened fire on the Bell patents, claiming that Gray was the prior inventor. Somewhat later it transpired that the Western Union Company's own counsel, after a most extended study, advised his client that the rights of Gray could not possibly prevail as against those of Bell, and, on the basis of that advise, the Western Union Company settled the matter out of court.

Another principal contestant was one Daniel Drawbaugh of Eberly's Mills, a small village in Pennsylvania. Drawbaugh, a man of limited education but of considerable ingenuity and skill as a mechanician, was well known in his village circles. He claimed to have made successful electric speaking telephones several years prior to Bell's. A remarkable phase of this contest was that his interests brought forth many witnesses who testified that he had done so, and that they had actually heard his instruments speak. Although Drawbaugh had visited the Centennial and had seen Bell's instruments there, and although he had been aware of the fame that had come to Bell as a result of his invention, he apparently remained indifferent. It was not until several years had elapsed and after he had fallen into the hands of the promotors of a telephone company, which was started for the purpose of exploiting alleged inventions of its own, that Drawbaugh put forth his claim and appeared as a contestant.

The Supreme Court was divided on the question of Drawbaugh's rights. The majority decided against him however, and in favor of Bell on the general ground that it was not within the scope of conceivable human conduct for a man of Drawbaugh's intelligence, if he had made all of the telephones that he claimed to have made prior to Bell's time and had them in his shop at the time he visited the Centennial, to have remained silent for a period of about four years thereafter. The court stated that they had not overlooked the testimony of the large number of witnesses to the effect that Drawbaugh made successful instruments but that the effect of this testimony had been completely overcome by the conduct of Drawbaugh from the time of his visit to the Centennial until he was put forward by the promotors nearly four years after. The court said further:

"The news of Bell's invention spread rapidly and at once, and it took but a few months to demonstrate to the world that he had achieved a brilliant success. If it were known at Eberly's Mills alone that Drawbaugh had been doing the same thing for years in his shop there—and it certainly would have been known all through the little village if it had actually been done—no one can believe that the public would be kept in ignorance of it until four years afterward . . ."

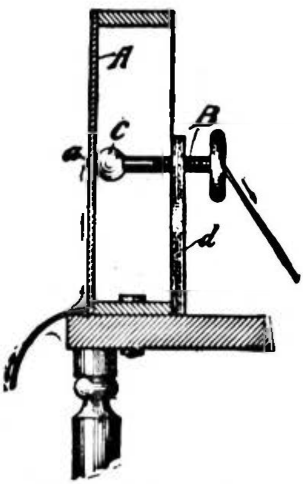

Fig. 17.—Berliner's transmitter.

The contributions of a few important inventions by Edison, Hughes and others should be recited before closing this brief outline of the history of the telephone during its infancy.

Bell's liquid transmitter embodies the main principle upon which subsequent successful battery transmitters are based—a battery furnishes the current and the transmitter actuated by the voice serves to modulate it. It was not long, however, before a much better means than Bell's was devised for putting this principle into practice.

The first step toward this was one made in 1877 by Emile Berliner, of Washington, D. C. He filed a caveat and later in the same year applied for a patent on a transmitter, depending upon the principle, already well known, that if the pressure between two conducting bodies forming part of an electric circuit be increased, the resistance of the path between them will be diminished, and, conversely, if the pressure between them be decreased, a corresponding increase of resistance will result.

Berliner's transmitter is shown in principle in Fig. 17, which is a reproduction of the main figure in his subsequently famous patent. In this *A* is a vibratory diaphragm of metal against the center of which rests the metal ball *C* carried on a thumbscrew *B*. When the diaphragm is thrown into vibration by the voice, the pressure on the contact between it and the ball *C* is varied. This varies the resistance of the circuit through them and causes corresponding undulations in the current flowing.

At about this time Edison introduced carbon as the best material for the contacts to be used for varying the resistance with changes of pressure. This contribution by Edison was an important step in the development of telephony. Up to the present time no material has been found to even approach carbon for all-round effectiveness for the purpose. Of the 33,000,000 telephones in service in the world to-day, all, with perhaps insignificant exceptions, employ carbon transmitters.

An early type of Edison's carbon transmitter consisted simply of a button of compressed plumbago bearing against a small platinum disc secured to the diaphragm. The plumbago button was held against the diaphragm by a spring, the tension of which could be adjusted by a thumbscrew.

Many descriptions of Edison's carbon transmitters have alleged a peculiar property of carbon by which it changes its electrical resistance under changing pressure. Apparently however, carbon does not have this property in any such degree as would account for its variable resistance action in telephone transmitters. No marked change can be noticed in the resistance of carbon rods when subjected to a range of pressures from zero up to their crushing points. What is believed to account for the variable resistance effects in any carbon transmitter is the variation, under changing pressure, of the *intimacy of contact*, either between the surface of the carbon bodies themselves or between them and the contiguous electrodes, whether of carbon or metal. This, of course, does not explain why carbon is superior to all other conductors for variable resistance purposes, but it is, at least, in accordance with the loose-contact phenomenon, now to be referred to.

Professor David Edward Hughes made a most valuable contribution tending toward the perfection of the battery transmitter. By a series of interesting experiments, he demonstrated conclusively that a loose contact between the electrodes, no matter of what conducting substance they are composed, is better than a firm strong contact. The apparatus used in one of his earlier experiments, made in 1878, is shown in Fig. 18 and consists simply of three wire nails, of which two form the terminals of the circuit containing a battery and a receiving instrument. The circuit was completed by a third nail laid loosely across the other two. Any vibrations in the air in the vicinity caused variations in the intimacy of contact between the nails and corresponding variations in the resistance of the circuit. This was a very inefficient form of transmitter, but it cleverly demonstrated the action of loose contact. Hughes became famous not only for his contributions to electrical science and practice but also for the simplicity and homely qualities of his laboratory apparatus—well exemplified in this experiment.

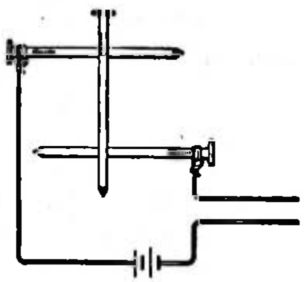

Fig. 18.—Hughes' nail microphone.

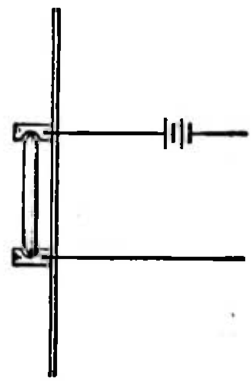

Fig. 19.—Hughes' carbon microphone.

Another form of transmitter devised by Hughes, and called by him the "microphone," is shown in Fig. 19. This consists of a small pencil of gas carbon, pointed at each end, supported between two blocks of carbon fastened to a diaphragm or sounding board. These blocks are hollowed out in such a manner as to hold the pencil loosely between them. The blocks form the terminals of the circuit. This instrument, though crude in form, is of remarkable delicacy and is well termed "microphone." The slightest noises in its vicinity, even those incapable of being heard by the ear alone, produce surprising effects in the receiving instrument. This particular form of instrument is, in fact, too delicate for ordinary use, as any jar or loud noise will cause the electrodes to break contact and produce deafening noises in the receiver. Practically all transmitters of to-day are of the loose-contact type, this having entirely superseded the first forms devised by Edison, in which the electrodes were more firmly held together.

In speaking of Professor Hughes' work on loose contacts and the microphone, an English electrical paper[1] says: "The microphone is a striking illustration of the truth that in science any phenomenon whatever may be turned to account. The trouble of one generation of scientists may be turned to the honor and service of the next. Electricians have long had sore reasons for regarding a 'bad contact' as an unmitigated nuisance, the instrument of the evil one, with no conceivable good in it, and no conceivable purpose except to annoy and tempt them into wickedness and an expression of hearty but ignominious emotion. Professor Hughes, however, has, with a wizard's power, transformed this electrician's bane into a professional glory and a public boon. Verily, there is a soul of virtue in things evil."

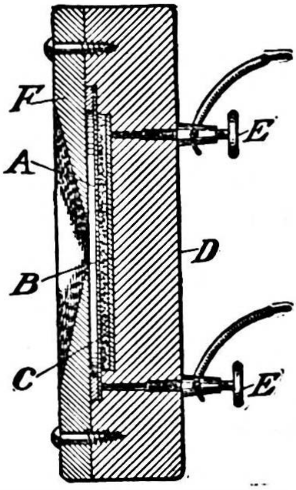

FIG. 20.—Hunnings' granular carbon transmitter.

In an article in *Nature*, June 27, 1878 Professor Hughes thus describes the conditions necessary for microphonic action: "If the pressure on the materials is not sufficient, we shall have a constant succession of interruptions of contact, and the galvanometer needle will indicate the fact. If the pressure on the materials is gradually increased the tones will be loud but wanting in distinctness, the galvanometer indicating interruptions; as the pressure is still increased, the tone becomes clearer, and the galvanometer will be stationary when a maximum of loudness and clearness is attained. If the pressure be further increased, the sounds become weaker, though very clear, and, as the pressure is still further augmented, the sounds die out (as if the speaker was talking and walking away at the same time) until a point is arrived at where there is complete silence."

Another valuable contribution was made in 1881 by Henry Hunnings, an English clergyman. He devised a transmitter wherein the variable resistance medium consisted of a mass of finely divided carbon granules held between two conducting plates. His transmitter is shown in Fig. 20. Between the metal diaphragm *A* and a parallel conducting plate *B*, both of which are securely mounted in a case formed by the block *D* and a

[1] *Telegraph Journal and Electrical Review*, July 1, 1878.

mouthpiece *F*, is a chamber filled with fine granules of carbon *C*. The diaphragm and plate form the terminals of the transmitter, and the current from the battery must, therefore, flow through the mass of granular carbon between. When the diaphragm is caused to vibrate by sound waves, its movements cause variations in the intimacy of contact between it and the granules, between the granules themselves and, to a less extent, between the granules and the rear plate. The resistance offered in the conducting path through them is thus varied and the desired current undulations produced. This transmitter, instead of having one or a few points of variable contact, has a multitude of them. It can carry a larger current without heating and, at the same time, produce greater changes in its resistance than the forms previously devised, and no ordinary sound can cause a total break between the electrodes. Although modern transmitters are quite different in form from this, their principle is the same. The use of granular carbon is well-nigh universal.

Edison made another important contribution to the early development of the telephone by using an induction coil in connection with the battery transmitter.

The induction coil used then and now for telephones employing a local battery is made as follows: Around a core formed of a bundle of soft iron wires is wound a few turns of comparatively heavy insulated copper wire. Outside of this is wound another coil consisting of a greater number of turns of fine insulated copper. The transmitter, together with the battery, is placed in a closed circuit with the winding of a few turns, while the winding of many turns is included directly in circuit with the line wire and the receiving instrument. This arrangement is shown diagrammatically in Fig. 21. A switch is included in the transmitter circuit to prevent the waste of battery while the telephone is not in use.

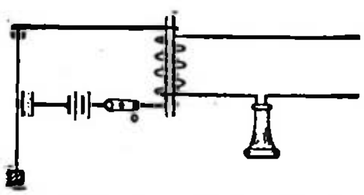

FIG. 21.—Transmitter in local circuit of induction coil.

The coarse winding is termed the "primary winding," because it is associated with the primary source of current, the battery; while the fine winding is termed the "secondary winding," because the currents flowing in it at the transmitting station are secondary, or induced, currents.

In action a current flowing in the primary winding produces a field of force extending through the core and into the surrounding space. Any changes caused by the transmitter in the strength of the current produce changes in the intensity of this field. As the secondary winding lies in this field, these changes will, by electromagnetic induction, cause currents to flow in the secondary winding and through the line wire to the distance receiving instrument. In good induction coils the electromotive forces set up in the secondary coil bear nearly the same ratio to the changes in electromotive force in the primary coil as the number of turns in the secondary bears to the number of turns in the primary.

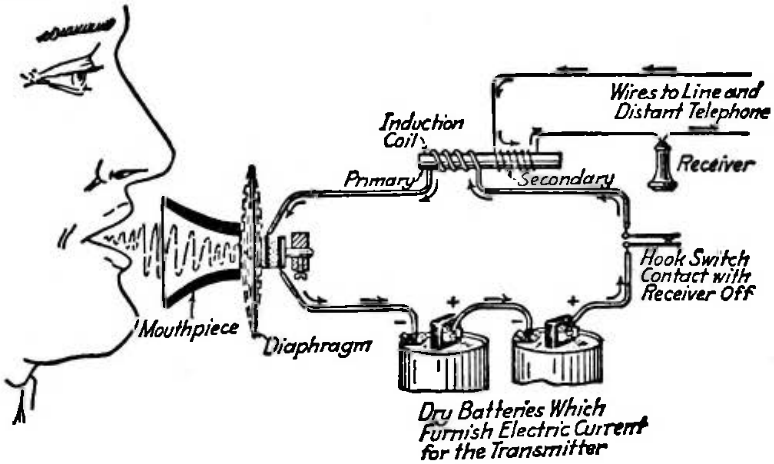

FIG. 22.—Talking circuit of a local battery telephone.

The use of the induction coil with the transmitter accomplishes two very important results: first, it enables the transmitter to operate in a circuit of comparatively low resistance, so that the changes in the resistance produced by the transmitter bear a larger ratio to the total resistance of the circuit and, consequently, produce greater changes in the current flowing; and, second, the step-up action of the coil produces higher electromotive force at the terminals of the transmitting station, thus enabling transmission to be effected over greater line resistances.

The arrangement diagrammatically shown in Fig. 21 is given somewhat pictorially in Fig. 22, this being one of Mr. Ray H. Manson's excellent pictorical diagrams. These two diagrams go no further than the actual talking apparatus. They show the "talking circuit" of a "local battery" telephone.

The difference between the two diagrams, both showing exactly the same circuit arrangement, deserves passing comment. The pictorial suggestiveness of Fig. 22, while of value to the beginner, is found to be unwarranted in practical work. In the first place, the illustration of parts with even this degree of detail would lead to impossible confusion in a really complex diagram. In the second place, such detail is unnecessary. Once the underlying principles of a piece of apparatus are understood, it may be represented by the merest symbol. To illustrate further, Fig. 23 shows exactly the same arrangement with even greater simplicity than that of Fig. 21. Thus has come about what may be called the "sign language of the telephone"—of which more will be said later.

We have now traced the early development of the elemental parts of the "talking set," the transmitter, receiver and induction

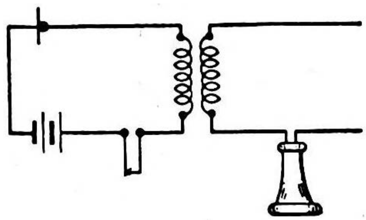

Fig. 23.—Talking circuit of local battery telephone.

coil—the parts actually used in taking the sounds of the speaker's voice and reproducing similar sounds in the listener's ear. Briefly reviewing this development:

Bell gave us the fundamental method involved in all telephony today. In addition, his receiver is the prototype of all modern commercial receivers. He also is responsible for the broad idea of the variable resistance transmitter.

Berliner contributed the idea of causing varying pressure between two transmitter electrodes to vary the resistance of the circuit; Edison introduced carbon as outstandingly the best electrode material; Hughes gave the knowledge of the loose-contact principle; Hunnings the use of granular carbon and, finally, Edison the induction coil as an adjunct to the transmitter.

All commercial telephones today employ the principles introduced by these men.

CHAPTER IV

THE TELEPHONE SYSTEM

To the average layman the *telephone* is merely an instrument, but to the telephone man it is a *system*. According to his experience and breadth of vision, the system he visualizes may be the small collection of associated apparatus with which he is immediately concerned; it may be the telephone exchange of his village, town or city; or it may be some grander conception, as of a universal system, which, by wire lanes and ether lanes, shall so cover the face of the globe as to place all people, whether on land or sea or in the air, in speaking relation with one another—the ultimate destiny of the art. Any one of these interpretations and many others may be correct. The term "telephone system" may comprehend little or much.

In the broader view, the most comprehensive telephone system so far actually achieved is that covering the entire United States from ocean to ocean and reaching into Canada, Mexico, South America and across the Atlantic to most of Europe. Some idea of the extent to which this covers the United States may be gained from Fig. 24, in which each dot represents an exchange area and each line a wire route.

The recent linking together of the United States and England by several separate wireless telephone channels has permitted the establishment of daily commercial service, which allows the people within reach of the vast wire networks of the United States and of Western Europe to converse with one another. A transatlantic telephone cable is in course of construction to make this service more reliable and to give more channels. Truly these are impressive steps toward the concept of a world-wide telephone system suggested in the opening paragraph. That concept is not as Utopian as it may at first appear. From the purely technical standpoint it could be achieved now. No doubt the telephone system of the world will be extended into all civilized countries as fast as it is commercially warranted.

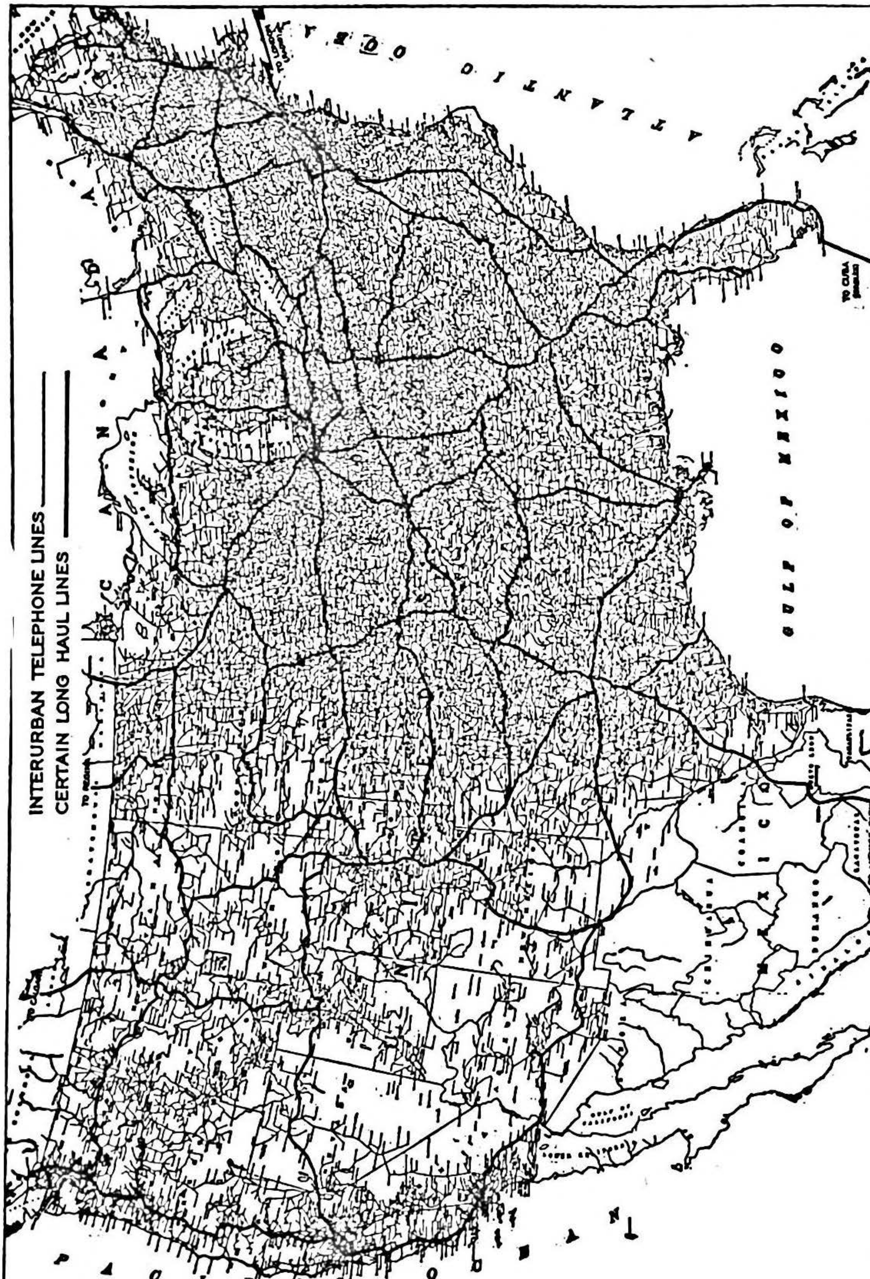

FIG. 24.—Toll line system in United States. (*Courtesy of Bell Telephone Laboratories.*)

But comprised within such a supertelephone system there are innumerable other systems, of many kinds and of varying degrees of complexity, performing numerous and diverse functions.

In the first place, there are the exchange systems themselves. Each of these is a complete system of local intercommunication. They are of many kinds and may be classified in various ways. For instance, there are manual, automatic and semiautomatic exchanges, according to whether the central office switching is done by hand, by machine, or by a combination of the two; and, on another basis of classification, there are single or multi-office exchanges, according to whether there are one or several central offices serving the exchange area in question.

Each exchange system in turn comprises within itself a number of minor systems, each performing a separate function or group of functions. Among these may be mentioned: systems by which current is supplied to the transmitters of the telephones; systems by which the telephone user signals to the central office operator; systems of attaching one or several telephones to a single line; systems of selectively or non-selectively ringing the bells on a line to which several telephones are connected; systems by which the patrons are charged for the service rendered, and so on.

Then, as distinguished from the exchange system, there is the long-distance system. No one has succeeded in drawing a sharp line to show where the exchange system ends and the long-distance system begins. As a matter of fact, there is no such real line, for the two are inextricably interwoven, and any such line of demarcation as is needed for administration purposes must, of necessity, be drawn in arbitrary fashion.

On the map the long-distance system looks rather simple, consisting merely of lines connecting the various dots representing the cities and towns. Actually, it is far more complex, for, in addition to the lines, there are long-distance switching systems and various systems for improving the efficiency of the lines. Among the latter are phantom, composite and carrier current systems by which each line is made to carry more than one message at a time. There are also the loading and repeater systems which allow small wires to serve where large ones would otherwise be required. Altogether, the long-distance system is one of the most remarkable triumphs of engineering. Some of its devices, without which electrical communication on its present scale would be impossible, have come about only through the combination of most ingenious inventive skill, the deepest research in the realm of modern science and mathematical reasoning of a very high order.

Throughout the whole realm of telephony, the system must be kept in mind. Just as each individual piece of equipment must function properly within itself and also with respect to all the other pieces which go to make up its particular minor system, so all the minor systems must function properly within themselves and in relation to all the other minor systems which go to make up their particular major system. And, in the last analysis, all of the major systems must, with proper coordination, act as units in that comprehensive scheme which, for want of a better name, I have called the *supersystem*.

It is the purpose of this chapter to sketch in merest outline the course of development of some of the important phases of telephone systems. The details of this sketch will be filled in as far as possible when the various elements of apparatus, circuits, outside plant construction and method are taken up in the chapters to follow.

Such a preliminary outline should facilitate the more detailed discussion. It should also help one to keep in mind that the things being treated of are not detached units but are, in large measure, intimately correlated in function, and often in form, such other parts comprised within the system.

Talking Apparatus.—The germ of the telephone system was of course Bell's instrument. It was the thing out of which the whole telephone industry has grown. Let us first see how this germ *per se* has developed. In its original form it was a rudimentary affair. Its transmitting power was feeble, it was fragile, clumsy, unstable and, on the whole, quite unfit for commercial use even under the limited requirements of its time. Without considering the effects of improvements that have been made in telephone lines and in other parts of the system, some idea of the extent of the development of the instrument itself may be gained when it is stated that the telephone of to-day is of itself about thirty-two thousand times more powerful in its ability to transmit speech from person to person than was Bell's original instrument. Moreover, the present instrument is so rugged as to successfully stand rough handling and other vicissitudes of use, is pleasing in appearance, convenient in form, permanent of adjustment and, although complicated, is withal a thoroughly practical affair. In numbers, it has grown from one to many millions.

Signaling Apparatus.—The talking instrument alone would be of restricted utility. The early telephone had difficulty in making itself heard when applied directly to the ear and, unless too harshly treated, was quite unable to attract the attention of persons even a few feet away. Signaling apparatus had to be devised. The problem was not so easily solved as with the mechanical telephone, where, by means of mere thumps on the diaphragm at the transmitting station, sufficiently loud sound signals were produced by the diaphragm of the receiving station. The electric telephone was too delicate a device for such rough usage; but it is interesting to note that early attempts were made to signal in this way, as in the case of "Watson's thumper" later to be described.

It was natural that early efforts at signaling should have been by means of battery current and battery bells. This, however, involved difficulties with respect to maintaining batteries of sufficiently high voltage and bells of sufficient reliability. The use of both the battery and the battery bell for signaling purposes passed out of the art at an early date. Later, the battery came back, but not the battery bell.

To meet the early deficiency of the battery as a source of signaling current, the so-called "magneto generator" was adopted. At first this was a mere adaptation of the old magneto electric machine devised primarily for giving people electrical shocks. It was in fact nothing more than a small hand-operated alternating-current dynamo. As later developed, and as still used in rural communities, it had a coil of wire which by means of a hand crank and suitable gearing could be made to revolve rapidly between the poles of a permanent horseshoe magnet. This change from battery current to hand-operated generator current was apparently contrary to the trend of modern development, since it substituted man power for fuel power. Nevertheless, it was an important step, for it solved the problem of generating currents that were well suited for distant signaling. The alternating currents of the magneto generator had sufficient power and voltage to be effective over lines of considerable resistance, and the range of frequency easily attained was about right for successfully operating signal bells. The availability of this kind of signaling current at once led to the production of a simpler and more rugged form of bell, the polarized bell or "ringer," as it is generally called. This bell was developed by Watson in the form essentially as used today.

The Telephone Set.—With the development of suitable signaling apparatus, the prototype of what we now call the "magneto telephone"[1] or "magneto telephone set" employed in "magneto systems" was evolved. To-day we speak of the transmitter, receiver and induction coil as forming the "talking set" and of the combination of generator and ringer as the "signaling set." As the talking and the signaling sets are used alternately, it was found necessary to provide, within the telephone, some sort of switching device so that they could be alternately connected with the line, and so that neither set would interfere with the functioning of the other. This led to the "hook-switch" an important element of all telephone sets. Because it is so made and placed as to form the only object upon which conveniently to hang the receiver after use, it automatically carries out this switching function without thought on the part of the telephone user.

The magneto telephone was used almost universally until a few years before the beginning of the present century. Then, as will be shown, there began a reversion to the use of battery as a source of signaling current. One of the results of this has been the doing away with the magneto generator except in the telephone systems of small communities, where the magneto system still survives. For such use, nothing as good has been found to supplant it. Watson's polarized bell, however, has survived in universal use. Like Bell's receiver, it will be found in practically every telephone station throughout the world to-day.

The magneto system required that each telephone station be provided with two independent sources of electrical energy; one a battery to supply direct current to the transmitter, the other the magneto generator to supply alternating current for

[1] The term "magneto telephone" has two different connotations. Ordinarily, in present-day parlance, it means a telephone set that is provided with a magneto generator for signaling. Frequently, however, it is used in its eariler sense as applying to Bell's original instrument or to its outgrowth, the modern receiver or hand telephone.

operating the distant signals. This was an uneconomical arrangement. It meant a great scattering both of investment and of maintenance effort. To-day, practically all except rural communities are served by what is called the "common battery system." In these both sources of energy at the telephone stations have been done away with, thus bringing about a great simplification of the telephone set. The reason for doing this and the manner of its accomplishment may be best understood in connection with the treatment of exchange systems.

The telephone set was thus reduced to its lowest terms, both in regard to the kind of things comprised within it and to the simplicity of its operation by the user.

Party Lines.—The simplest system of telephone communication is formed by two telephones permanently joined by a single line. While useful, the limitations are obvious. These limitations soon gave way under the avalanche of inventive effort that began with the introduction of the telephone, and that is still going on with ever increasing vigor.

The first efforts toward making the telephone system available for communication between more than two points were in the direction of connecting more than two telephones with a single line. Thus arose what we now call the "party line," meaning, of course, the "multiparty line." Such an isolated party line, even when extended to its utmost capacity in point of the number of stations connected, can, at best, serve for communication between a limited number of telephones and for only one conversation at a time. Notwithstanding these limitations, the isolated party line is still used, particularly in rural districts where the number of stations in a community is but few, or in other cases where a few stations of common interest are to be served. The isolated party line still seems the best if not the only practical solution for the intercommunication problem in certain pioneer rural districts, where the settlers are so few and their combined resources so meager as to make a more elaborate system unavailable. It has formed the nucleus about which many larger systems have been built.

There are cases in the western part of the United States where a single telephone line runs through a narrow mountain valley connecting the telephones of as many as forty or fifty farmers. This, of course, is not the best form of telephone service, but it is a veritable boon to those who, without it, would often be almost completely isolated. From this sort of thing, the so-called "farmer's line" business has grown up. It is a troublesome and also important factor of telephone service; troublesome because of the difficulty of affording adequate service under adverse conditions at a price within the range of the patrons; and important because necessary as a part of the large conception of what telephone service should be.

The Exchange.—The idea of the telephone exchange, whereby a number of lines are brought to a common point and there provided with facilities for connecting and disconnecting them at will, opened the way to the complete removal of the limitations inherent in the isolated line.

As pointed out in an earlier work,[1] the first idea of an exchange that I have been able to find was that of Dumont in 1851.[2]

Not having the telephone, Dumont based his idea on the use of telegraph instruments for sending and receiving messages. As indicating the extent to which he had grasped the general idea of grouping lines and of connecting them for communication, one of the figures of his British patent is reproduced here as Fig. 25. The central point marked 0 in the diagram he called the "central station." This station and all of the subcenters numbered from 1 to 16 were provided with apparatus for connecting the lines. The mode of operation may be understood from the following quotation from Dumont's specification:

"Each house has an electric wire connecting it to the station, and a double electric apparatus, one at the subscriber's house and the other at the neighbouring station to which it is connected. The houses are telegraphically numbered from one to any number. Thus, suppose the house number 3, connected to station No. 1, and the occupant of house No. 3 is desirous to communicate with the house 287, connected with the station 12, the subscriber of the house No. 3 signalises to station 1, the number 287. The clerk of the station No. 1 then directs the central station 0 to place the wire 1.0 in communication with the wire 0.12. When this is done, the clerk signalises to station 12 the No. 287. The clerk at station 12 then connects wires 0.12 with the wire 12.287.

"This accomplished, the clerk of station No. 1 finally connects the wires 3 and 1.0 and a direct and intermediate communication

[1] "American Telephone Practice," 4th ed., p. 174, 1905.

[2] British Patent 13,497, 1851, to Dumont.

is then established between the houses 3 and 287, and both subscribers may correspond privately."

We must accord to Dumont not only the basic idea of exchange operation but also of multioffice operation with what we now

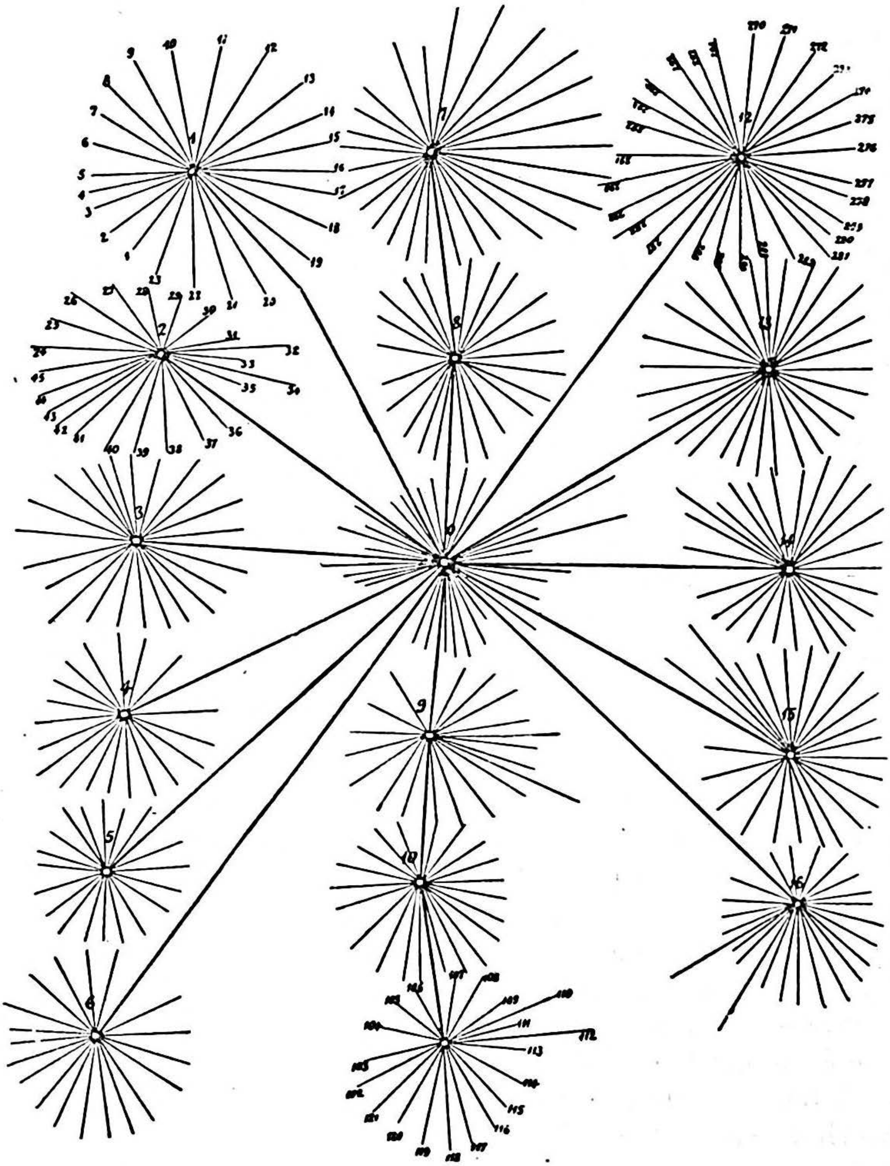

FIG. 25.—Dumont's telegraph exchange.

call "trunks" extending between the offices to enable the subscribers of one office to talk with those of another. Evidently he did not anticipate much traffic, for, instead of employing "direct trunks" between each pair of offices as we now do in congested areas, he centered all trunks at one office and routed all calls through that office by connecting the trunks in tandem. This system of "tandem trunks," particularly as illustrated by the string of offices 7, 8, 0, 9, 10, etc., extending down the center of Fig. 25, is what we employ to-day in connecting widely separated and relatively unimportant offices, where the traffic does not warrant direct trunks between each pair of offices. Furthermore, Dumont is apparently the first to have designated the patron of such a service as the "subscriber."

So far as is known, nothing ever came of Dumont's idea. When the world was ready, even for a telegraph exchange, the invention apparently had to be made again. We think, however, that the name of Francois Marcelin Aristide Dumont, a French engineer, deserves a place in the telephonic hall of fame.

A so-called "telegraph exchange" was later established in London, evidently without the teaching of Dumont in mind, for this London exchange contained no equipment for interconnecting the lines. It merely permitted each subscriber to communicate with the central office.[1]

In 1874, just before the birth of the telephone, a telegraph exchange system was put into use in New York City. It was for connecting lawyers who chose to subscribe and was, for this reason, called the "law system." The telegraph instruments, which were of the dial pattern, were subsequently replaced by telephone instruments, and thus originated, as far as I am able to find, the first telephone exchange system. It was from this particular system that the well-known law telephone system, widely used in later years, took its name.

Apparently the telephone exchange had its practical beginnings in about 1878. These beginnings were made almost simultaneously in a number of cities in the United States. Few had any conception of its real significance. But what did the first telephone engineer think about it? Bell had the vision to see with remarkable clarity some of the possibilities of the thing which his genius had created. In a letter, dated March 25, 1878, written to British capitalists he says, in part:

"The simple and inexpensive nature of the telephone, on the other hand, renders it possible to connect every man's house, office, or manufactory with a central station, so as to give him

[1] KINGSBURY, J. E., "The Telephone and Telephone Exchanges," p. 80, Longmans, Green and Co., London, 1915.

the benefit of direct telephonic communication with his neighbors. at a cost not greater than that incurred by gas or water.

"At the present time, we have a perfect network of gas-pipes and water-pipes throughout our large cities. We have main pipes laid under the streets communicating by side pipes with the various dwellings, enabling the members to draw their supplies of gas and water from a common source.

"In a similar manner, it is conceivable that cables of telephone wires could be laid underground, or suspended overhead, communicating by branch wires with private dwellings, country houses, shops, manufactories, etc., etc., uniting them through the main cable with a central office where the wire could be connected as desired, establishing direct communication between any two places in the city. Such a plan as this, though impracticable at the present moment, will, I firmly believe, be the outcome of the introduction of the telephone to the public. Not only so, but I believe in the future wires will unite the head offices of the Telephone Company in different cities, and a man in one part of the country may communicate by word of mouth with another in a different place."

With the increasing realization of the possibilities of the telephone exchange, there began a period of intense development to provide the devices and the systems necessary to utilize them. But as the development progressed so did the possibilities. Each accomplishment opened up new visions of things yet to be done. And this process is still going on. In 1926, for instance, more than two new telephone patents were issued in the United States for every one that expired.

Telephone Switching.—The course of telephone exchange development may be illustrated most strikingly by considering the switching art, which relates to the appliances and methods employed at the central office by which lines are connected for conversation and afterward disconnected.

At the outset there were no switchboards except the very rudimentary ones that had been employed in telegraphy. These were at first used, but it soon became apparent that they could not cope with the more exacting and enormously extended requirements of telephone exchange work. The whole switching art had to be built up from practically nothing.

At first these switchboards were required to interconnect perhaps a dozen lines or less. Equipment had to be developed even for this now simple requirement. The old telegraph switchboard of the crossbar type proved cumbersome and unreliable. In its place was developed a type wherein each line terminated at the central office in a connection socket or "jack" and in a visual signal or "annunciator." In order to connect the lines for conversation, flexible conducting cords were used terminating at each end in a metallic plug adapted to fit into the jacks. In order to assure firm contact between the plug and the jack, and also to accomplish certain switching operations, each jack was provided with a spring which was lifted by the inserted plug, hence the name "springjack."

The Manual Switchboard.—Thus the manual switchboard in telephony had its beginning. It is still used more extensively than any other type and its development has been one of the outstanding achievements of the art.

It must be remembered that in this development, the switchboard had at all times to be coordinated with the telephones at the subscribers' stations and *vice versa.* It is, therefore, natural that the first switchboards were of the so-called "magneto type," employing electromagnetic annunciators as line signals because these were well adapted to respond to the alternating currents from the magneto generators of the subscriber's telephones. These early switchboards were adapted to use on grounded lines only because, at that time, no one realized that any other kind of line would be required.

At first the number of lines was so small and the "traffic" so light that only one operator was necessary. Later as the number of lines and traffic increased the "load" had to be divided. This was done by assigning to each of several operators as many lines as she could conveniently attend and serve. The jacks and annunciators thus assigned to different operators were located on different sections or "positions" of the switchboard. As a result of this distribution, the telephone engineer was soon confronted with the problem of connecting two lines together whose jacks were not within reach of a single operator. This led to the so-called "transfer switchboard," employing local trunk lines extending between the sections or positions occupied by the different operators. By means of these, an operator answering a call on one of the lines assigned to her position could "transfer" the connection to the operator at whose position the called line terminated, the connection between the two lines being established through the trunk.

This plan of employing intermediate trunks and two operators for completing a connection between two lines terminating in the same office was obviously uneconomical. A much better plan was soon devised. This resulted in the so-called "multiple switchboard" of which Leroy B. Firman, of Chicago, was the first proponent.

The idea back of the name multiple switchboard is that of multiple terminals for each line. The line signals and the corresponding incoming terminals ("answering jacks"), of which there is one for each line, are distributed in groups among the operators' positions in accordance with the ability of the operators to attend to them, exactly as in the transfer system. In addition, each line is provided with a number of outgoing terminals ("multiple jacks"), and these are so placed along the face of the board that one of them will lie within the field directly reached by each operator. By this means each operator, no matter what position she occupies, has within her reach a terminal or jack for every line. Without the assistance of any other operator, therefore, she may answer any call on the group of lines whose answering jacks are located on her position and complete the connection with any other line in the entire office. The number of lines for which this multiple arrangement is possible is evidently limited by the number of terminals that can be placed within the field of reach of an operator.

With the growth of the number of subscribers' stations and lines, the question of conservation of space on the face of the switchboard became increasingly serious. Also, the necessity of providing and maintaining a separate battery and magneto generator at each subscriber's station became more and more irksome. Relief in these and in other respects was afforded by the advent, in the early nineties, of the "common-battery" switchboard. This was a revolutionary change and has been universally adopted in all exchanges except those serving small communities.

The common-battery system has also been called the "central-energy" system. In it, as each of these names indicates, all the hitherto scattered sources of electrical energy are replaced by a common source located at the central office. A single battery of sufficient voltage and capacity is used to supply talking current to all of the subscribers' transmitters. Having this current supply for transmitter operation, it is equally available for operating the central office signals. Hence, as a result of this one change, the necessity for the magneto generator and the local battery at the subscriber's station disappeared.

The economy of this step was obviously very great. Instead of having perhaps ten thousand local batteries and ten thousand magneto generators located under ten thousand different roofs, there was one large battery located under one roof. Economies were also permitted in other directions. Among them was that of space on the face of the switchboard. The steady voltage common battery lent itself admirably to the use of incandescent lamps for central office signals, whereas the magneto generators did not. As a result, miniature incandescent lamps replaced the old magnetic drops on the switchboard. They occupied but a fraction of the space, gave better signals, were automatically self-effacing and were more reliable in operation.

With the development of the common-battery multiple switchboard, manual switching reached the basis on which it rests to-day. The practical ultimate capacity of a single multiple switchboard unit has been found to be in the neighborhood of 10,000 lines. This, therefore, is the limiting capacity of a single office. When more lines than that are to be served, other offices are added, and the old transfer idea again resorted to. In some of the more congested metropolitan areas, the density of telephone development is so great as to require several 10,000-line switchboard units in a single building serving a relatively small area.

The Automatic Switchboard.—It is surprising that almost as soon as the idea of central office switching was put into practice, a few ambitious inventors conceived of doing this switching automatically. They proposed to dispense with the operator and, instead, employ means whereby the subscriber could, by remote control, perform his own switching operations at the central office.

The efforts toward such a difficult accomplishment while the art was yet so young were thought to be misdirected. So-called "practical" men had nothing but intolerance toward the idea, and ridicule was heaped upon those who persisted in such efforts. For many years little headway was made. This is not surprising, because the technique of the telephone art, even in its simpler phases, had not yet been sufficiently developed to form a foundation for the practical accomplishment of this difficult feat.

These earlier workers in the automatic field were followed by such men as Alexander E. Keith of Chicago, Illinois, George William Lorimer of Brantford, Ontario, and later of Ohio, and a host of others who had not only the vision but also the practical ability to make their dreams come true. A few automatic exchanges that may be considered practical were established in the United States and Canada during the early years of the present century. Among the more notable may be mentioned those at Fall River, Massachusetts, in 1903, Grand Rapids, Michigan, in 1904, Columbus, Ohio, and Peterboro, Ontario, in 1905. The number of such exchanges grew, and gradually the idea began to dawn on those in control of the larger affairs of the telephone business that the automatic exchange was a really practical affair.

It was not until the World War, however, that the real economic possibilities of automatic or machine switching came to be generally appreciated. As a result of the conditions during and following the war, the market value of female labor was greatly increased. Young women, who previously had been satisfied with relatively low wages for telephone operating, found more remunerative if not more attractive work in other fields. A readjustment of operator wages had of necessity to follow. This was one factor which greatly altered the relative economies of the manual and the machine methods of operating. That the ability of the manual system to cope with the constantly increasing traffic loads was being more and more severely taxed in large metropolitan areas was another factor. More will be said later of the relative economies of the two systems, but at this point it may be stated that there is general belief among telephone engineers and those companies and governments who are responsible for telephone operation in a large way, that the machine-switching system in some of its forms will gradually replace the manual in all large cities. How far down in the scale of size of communities this change will go is still a matter of wide difference of opinion and consequently of much discussion.

There has also been much discussion as to how the machine-switching equipment at the central office should be controlled, or, more strictly speaking, by whom it should be controlled.

The plan now generally adopted is to have the subscribers do it. Another plan, whose advocates are decidedly in the minority, is to have a comparatively few operators do it. It is simply a question of whether substantially the same switching machines at the central office shall be directed by the dials on the subscriber's telephones or by "adding machine key boards" manipulated by operators, who receive their instructions from the subscribers. There is much to be said for each plan.

For reasons not altogether logical, the subscriber-controlled systems are referred to by such names as "full automatic" or "full mechanical," and the operator-controlled systems are variously designated as "semiautomatic," "semimechanical" and "automanual." In any event, they are all properly "machine-switching systems."

The Telephone Line.—In thus briefly tracing the development of the telephone *per se* and of central office switching practice, it must be kept in mind that no less radical and no less important developments have been simultaneously going on with respect to the lines that connect the subscribers with the central office and also with those that connect distant central offices with each other.

In the early days the fact, previously discovered by Steinheil, that the earth could be used for the "return" conductor of an electric circuit was made use of in telephony, as it already had been, and still is, in telegraphy. Accordingly, a single wire was used for the line and this was connected to earth through the terminal instruments at each end to effect the return path. Such lines are termed "grounded lines."

At first outdoor telephone lines were made of iron. Ordinary copper wire was recognized as being a far better conductor and also as being non-corrosive under weather conditions, but it had too little tensile strength to stand the stresses encountered in open-wire construction. An important step was taken by Thomas B. Doolittle, who, as early as 1877, experimented in the direction of making a sufficiently strong wire of copper by the simple expedient of omitting the annealings between the successive drawing operations. Hard-drawn copper wire, resulting from Doolittle's investigations, has become the accepted standard for aerial telephone line wire, except in the case of relatively short and less important lines where iron, on account of its cheapness, is still used to a considerable extent.

The grounded line almost proved the undoing of the telephone business in its early days. With it strange and unaccountable noises were heard in the telephone instruments, some of which even to-day are only imperfectly understood. Some of these noises were due to natural phenomena, others to "man-made" causes. Of the former, induced currents from distant lightning and earth currents, possibly due to changes in the earth's magnetic field, may be mentioned. Of the latter, induction and leakage currents from telegraph or other telephone lines were at first the principal if not the only ones. But these were soon supplemented by the far more devastating effects of stray and induced currents from the electric railway, to say nothing of the induction from electric light and power distribution systems.

The sole remedy for all of this trouble from external sources was found to be in the use of the "metallic circuit." This means a circuit formed of two wires of equal size and the same material placed as close together as practicable and occupying, as far as possible, equal average distances from all external disturbing sources.

In spite of the increasing difficulties the general use of grounded lines persisted for more than a decade, partly because of the obvious economy of using one wire instead of two and partly because of uncertainty as to the real remedy. The coming of the electric railway in the late eighties precipitated the issue. Litigation with the railway companies ensued in which the telephone interests finally lost.

Regardless of the legal aspects, it is now easy to see that the inevitable thing for the telephone companies to do was to adopt the metallic circuit. It is now almost universally used. Only in a comparatively few locations that are remote from other interfering electrical systems, and in those cases where the necessity for economy forces the user to tolerate the disturbance does the grounded line still persist.

The elimination of line disturbances was not the only problem with respect to telephone lines. Another was that of wire congestion. Practically all outside line wires were suspended from housetop fixtures, chimneys and poles. There was no system to it. The wires ran helter-skelter with slight attempt at orderly arrangement. The congestion and the confusion constantly increased with the growing number of telephones, and the adoption of metallic circuits, while curing one trouble, made this one worse.

The tangle of overhead wires in the downtown areas of cities became a menace to life and property, to say nothing of its bad appearance. To clean up this mess and to provide for the great expansion to come was a Herculean task. There was no experience to serve as guide, for never before had the necessity arisen of placing so many wires in such close proximity with each other. The development of the technique for the orderly and effective arrangement of bare wires on poles and for the placing of a large number of wires in cables and disposing these overhead, underground or underwater has been one of the ever present problems of telephony. Its various phases cannot be even referred to in the outline sketch of this chapter; but to illustrate the nature of some of the problems involved and of some of the results achieved, the development of one item alone, telephone cable, will be briefly mentioned.

Telephone Cable.—The use of bare wires requires a considerable separation of the wires from each other. One reason for this is the necessity of preventing actual contact when they are violently agitated by wind or other causes. This separation that is a requisite of "open-wire construction" is at variance with the space economy that is essential when it becomes necessary to stow away a large number of wires in a very small space. Out of such considerations arose the demand for telephone cable, wherein a large number of wires, carefully insulated from each other, are bound closely together under a common covering.

This had been done to a limited extent in telegraphy, but when the single-wire telephone lines were thus treated, it was found that their talking efficiency was impaired or ruined, and also that whatever was said on one wire could be heard almost equally well on all the others, a phenomenon known as "cross-talk." These facts alone would have sounded the death knell for the general use of grounded circuits even in the absence of other considerations.

At first it was thought that the remedy for cross-talk and other inductive disturbances in cable was to be found in the character of the insulation, but finally it was learned that the only panacea was to use two-wire circuits throughout, the wires being twisted together in such a way as to produce a complete transposition every few inches.

Naturally, rubber, on account of its high insulating and moisture resisting properties, was one of the early materials used for insulating the cable wires. This proved objectionable because of the high specific inductive capacity of rubber and its high cost. Obviously, because of its low specific inductive capacity, air would be the ideal insulator, but it does not afford the mechanical properties necessary to keep the wires apart. A loose wrapping of dry paper was found to be the closest approach to this ideal. It afforded the necessary mechanical separation, was of itself a good insulator, and its many interstices contained a large amount of air. Dry paper, however, is exceedingly susceptible to moisture and moisture is ruinous to good insulation. This difficulty was overcome by enclosing the bundle of wires in a continuous lead pipe forming an air-tight sheath. Such is the cable now universally used for the wires of telephone lines.

Early cables had a maximum capacity of about 50 pairs of wires. Later, 200-pair, 400-pair and 600-pair cables were successively evolved, the limiting outside diameter remaining approximately the same—somewhat less than 3 inches. At this stage, the increase in size stopped for about a decade, but the progress toward a larger number of pairs was again resumed, and we now have 1,800-pair cables containing over 3,600 wires. Cables of even larger capacities are in sight.

The economies resulting from this cable development have been enormous. They are due not only to the saving in copper and other material but also to other factors, such as the saving in poles or underground ducts. Some idea of what the use of this type of cable has meant in the telephone business may be gained from the fact that a single one of these cables, less than 3 inches in diameter, may be made to carry as many wires as, with ordinary open-wire spacing, would be carried on thirty parallel pole lines each having twelve 10-pin crossarms.

The constantly increasing demand for cables carrying more and more wires brought other problems than those involved in making, putting in place and maintaining the cables themselves. The maximum outside diameter of the cables has remained the same, being limited by the sizes of existing underground ducts. On this account an increased number of wires has meant smaller wires with consequently increased electrical resistance; and more crowding together of the wires has meant greater electrostatic capacity between the conductors of a pair. These changes were in themselves deleterious to the transmission efficiency of the conductors both for speech and signals. In order to maintain the required over all standard of transmission for long-distance as well as local communication, more powerful transmitting devices, more sensitive receiving devices and more efficient auxiliary devices were necessary, all working toward a system of balanced economy. Conversely, each improvement in transmission equipment has at once been met with the demand for cables with a greater number of conductors, the improved transmitting efficiency of the apparatus permitting a further sacrifice in conductor efficiency without overstepping the limiting requirements of satisfactory telephonic transmission. Nothing could better illustrate the interrelationship between the various parts of a telephone system.

So far this outline has considered the telephone line merely in so far as it affords a conducting path, in the ordinary sense, from one place to another. There remains to consider the very important work that has been done toward improving the *effectiveness* of the line. These efforts have taken three directions:

a. To make the line a better path for telephone currents. This has led to the practice called "loading."

b. To reinforce the energy supplied to the line at various points along its length. This has called forth the "telephone repeater."

c. To make a given line carry more than one message at a time. From this has grown "phantom," "simplex" and "composite" circuits and, finally, "carrier-current" systems.

Loading.—Every telephone line has a certain electrostatic capacity. The two wires may be considered as forming the plates of a condenser, and the insulation between them the dielectric. This electrostatic capacity instead of being localized, as in an ordinary condenser, is distributed throughout the length of the line. It will be shown that this distributed capacitance has a deleterious effect on the transmission of rapidly varying currents, tending not only to attenuate but also to distort voice currents. It will be shown that inductance coils, likewise, have a deleterious effect on the passage of such currents through them; and that, in a general way, inductance and capacitance act oppositely in producing these bad effects.

Oliver Heaviside, the great British mathematician and physicist, suggested that these opposing effects might be made to neutralize each other in the transmission of rapidly varying currents. It was not until 1899, however, that Michael Idvorsky Pupin showed exactly how the distributed capacitance of a telephone line could be neutralized for a given range of frequencies by the employment of inductances of specific amounts located at stated intervals along the line. Pupin showed the way as a mathematical and physical conception. His work was taken up by Campbell and other mathematicians, physicists and engineers of the American Telephone and Telegraph Company, who have developed the art of "loading" to its present high state of efficiency.

The economies resulting from loading have been enormous. The use of loading coils permits very much smaller copper wires to be employed in the transmission of speech than would otherwise be required. This alone has had a profound influence in making possible the extensive use of the small-wire cable. The resulting savings are due not alone to the economy in copper but also to many collateral advantages, such as allowing the use of fewer and lighter poles and of a smaller number of underground ducts.

Repeaters.—Unlike loading, repeaters do not aim to improve the conducting path for the voice currents, but rather to reinforce these currents by introducing new sources of energy at various points along the line. In this way the amount of energy arriving at the distant point may be made substantially the same or even greater than that leaving the starting point.

The repeater has always been an attractive mark for inventors. Efforts to produce one naturally took the form of a mechanical coupling between the vibratory part of a receiver and that of a transmitter. In this way the receiver would, as it were, talk to the transmitter, and the transmitter, as usual, would act as a valve in causing modulations in the stronger current of a local source. It was easy to make these mechanical repeaters work in one direction. It was more difficult to make them work successfully in both directions. Moreover, the mechanical inertia of their vibratory systems was always a serious drawback, particularly since it acted unequally on vibrations of different frequencies, thus producing distortion.

In spite of these difficulties, Mr. Herbert M. Shreeve, of the American Telephone and Telegraph Company, produced a successful mechanical repeater which was used with moderate success on the transcontinental lines of the American Telephone and Telegraph Company. It probably would have been further improved had not the vacuum tube repeater been produced at about that time. This, being devoid of mechanical inertia, was so vastly better than the mechanical repeater, both in principle and in practice, that it at once removed further incentive to work along the mechanical line. With the vacuum tube repeater practically distortionless amplification was possible, while with the mechanical repeater it was not.

To show what the repeater means on the New York-San Francisco line, the following quotation from a recent paper by Messers. H. H. Nance and O. B. Jacobs is given:[1]

"Without telephone repeaters but with other parts of a long telephone circuit unchanged, the delivery at the receiving end of the amount of power ordinarily obtained would require startlingly large amounts of power at other points in the circuit. For example, in the case of a San Francisco-New York connection, the amount of power ordinarily applied at San Francisco would be required near Harrisburg, Pa. All of the power introduced ordinarily at all points in the line would be required at a point near Pittsburgh. Power sufficient to light two 20-c.p. incandescent lamps would be necessary near Chicago, while the power of a five-kw. radio station would be required near Omaha. The requirements continue to rise rapidly until, near Rawlins, Wyo., a 50,000-kw. generator would have to deliver its entire rated capacity to the circuit, while at San Francisco, something in the order of the estimated *total world production of mechanical and electrical power would be needed.*

Let us suppose, however, that a 50,000-kw. generator delivered its entire output to the circuit at San Francisco, and overlook, for the moment, what would happen to the line if any such amount of energy were applied. The power received at New York would be of the order of one five-hundredth of a microwatt, *which would have to flow for about* 25,000 *years in order to equal the energy required to light a 25-watt lamp for one minute.*" (Italics mine.)

Simultaneous Messages.—Efforts to send more than one message at a time over a wire are older than the art of telephony. Bell was trying to do this telegraphically before he invented

[1] NANCE and JACOBS, Transmission Features of Transcontinental Telephony, presented at the Pacific Coast Convention of the American Institute of Electrical Engineers, Salt Lake City, Utah, September 9, 1926.

the telephone. By properly combining two metallic circuit telephone lines a third or "phantom" circuit is made available, thus permitting three simultaneous conversations over two "physical" lines. Then there are various "simplex" and "composite" systems, wherein the two telephone wires of a line may, in addition to carrying telephone messages in the regular way, also carry one or several simultaneous telegraphic messages. These systems have long been in regular commercial use.

Of later origin, however, are the so-called "carrier-current" systems, by which a telephone line, used in all the foregoing ways for transmitting telephone and telegraph messages, may be made to carry as many as six additional telephone messages without interference. These carrier-current systems make use of the fact that vibrations having frequencies above about twenty thousand cycles per second are inaudible. Currents lying within successive bands of frequencies above the audible range, therefore, may be applied to the telephone line without interfering with its ordinary operations. Each of these successive bands of inaudible frequencies is made to afford a separate "channel" of telephonic communication. This lies at the very threshold of the radio art.

Some idea of the benefits derived from these methods of simultaneous transmission may be gained from the fact that on some of the main open-wire circuits of the transcontinental line as many as twenty two-way communication channels are derived from two pairs of wires. Of these, six are telephone and fourteen are telegraph channels.[1] Again, on a single conductor submarine cable, extending from Catalina Island to the mainland of California, eight different channels are secured, one an ordinary direct telegraph circuit, one an ordinary telephone circuit, and six carrier-current circuits.[2]

Interrelationships.—Telephone plant is comprised roughly within three general classifications, subscribers' station equipment, central offices and lines. In the foregoing pages something has been said of the trend of development of each, and of how these developments have necessarily been correlated in order to

[1] Nance and Jacobs, *op. cit.*

[2] Carrier Current on Submarine Cables, by H. W. Hitchcock, presented at the Pacific Coast Convention of the American Institute of Electrical Engineers, Salt Lake City, Utah, September 9, 1926.

produce not only an operative system but also a system properly balanced from the economic standpoint.

In the last analysis the telephone system includes *personnel* as well as *plant*. Regardless of the extent to which labor-saving machinery may be employed, the human element will always be of vast importance in it. Human effort must always be concerned not only with the workings of the system within itself but also in establishing and maintaining the proper relationships with the public served. And in this connection let it be kept in mind that the contact between the telephone system and the public it serves is one of peculiar intimacy. The telephone has a personal touch with its patrons that is of a different kind from that found in any other public utility service.

There is also a peculiar relationship as to both equipment and method not only with respect to the practices of a single company within itself but also to those of different companies whose lines require to be connected for long-distance service. The underlying reason for this is that the commodity supplied is *intercommunication*. Always two persons are involved in a telephone conversation and, frequently, two or more operating companies. A bad instrument or a faulty line at one subscriber's station, or an improper operating method on the part of his company, may affect the service of another subscriber, whether a neighbor or one located in the next county or state or even across the continent. No such interrelationship exists in like degree in any of the other public utilities. In the case of water, gas or electricity a consumer merely gets his commodity from a pipe or wire and, except for this, is largely unrelated to and independent of the other consumers.

If each operating company or other operating organization went its own way without regard to others, there would result a heterogeneous conglomeration of equipment and practices which, while sufficing for service within individual areas, would fall far short of the best possibilities of the industry. In following such a course, no company could possibly keep step with the progress of the art.

This correlation in order to be effective must be extended to all parts of the system. The ability to talk successfully between New York and San Francisco on overhead wires or between Boston and Washington on underground wires does not rest alone on the power or the sensitiveness of the telephone instruments at the terminal stations. The most powerful and sensitive instruments known could not do it unless all other parts of the system were properly coordinated. Not only the subscribers' instruments themselves but also the relatively short subscribers' lines connecting the two stations to the respective central offices, the equipment at the central office by which the subscribers' lines are connected with the through trunk lines, the trunk lines themselves and, in fact, every link and element involved in the connection must be properly related to the others, in order that the limiting losses permitted by practical telephone transmission may not be exceeded. Somewhat less efficient transmitters, for instance, might suffice, but the sacrifice in this respect might require the expenditure of many millions of dollars in line conductors. And so with each element of the plant; undue loss in one calls for increased cost in others.