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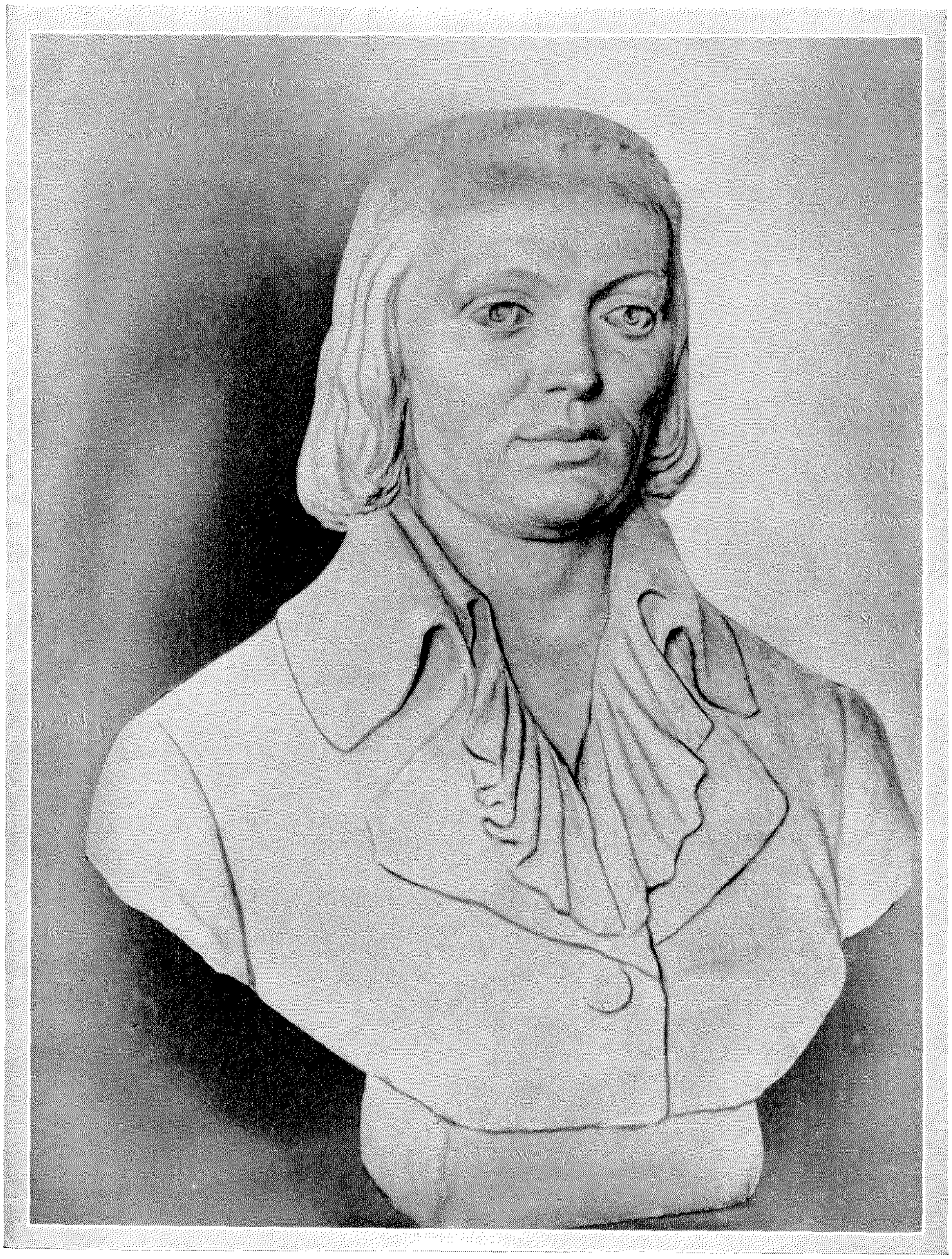


Bust of Claude Chappe.

Pioneers of Electrical Communication
Claude Chappe—IX

by ROLLO APPLEYARD

European Engineering Department, International Standard Electric Corporation

THE principles governing successful communication over long stretches of land or sea have their origin in primitive optical, acoustic, and mechanical methods of signalling. Hints of them are found in legends of Chinese dynasties, in songs of ancient Greece, in tales of Roman campaigns, and in accounts of the enterprises of Elizabethan, Jacobian, and Georgian sailors. Through revolutions, wars, and reformations, the art of signalling by such means can be traced to the last years of the eighteenth and to the beginning of the nineteenth centuries, when it attained nearest to perfection at the hands of Claude Chappe—the first administrative telegraph engineer. Several biographies of this devotee of France have been published in his own country, but in personal detail they are all inadequate; the character and magnitude of his work, and the circumstances of the years of terror in which he lived, have almost obliterated the man himself. Upon that vast sea of trouble over which his endeavours to bring about unity by improved means of communication were as beacons to humanity, the track of his own career is little more than a ripple that loses itself in the gloom of his melancholy end. The best account of him is that written in 1893 by Ernest Jacquez, Librarian of Postes et des Télégraphes in Paris. From this it appears that Claude's father, Ignace Chappe d'Auteroche—parliamentary lawyer and Directeur des Domains of the King of France, at Rouen—married on February 13, 1762, Marie-Renée de Vernay de Vert, of Brulon. They had ten children, of whom only seven survived, i. e.,

1. Ignace-Urbain-Jean Chappe, born at Leval, November 26, 1762.
2. Claude Chappe, born at Brulon (Sarthe), December 25, 1763.
3. Marie-Marthe Chappe, born at Brulon (Sarthe), December 26, 1763.
4. Pierre-François Chappe, born at Brulon (Sarthe), August 11, 1765.
5. Sophie-François Chappe, born at Brulon (Sarthe), March 4, 1767.
6. René Chappe, born at Brulon (Sarthe), September 3, 1769.
7. Abraham Chappe, born at Brulon (Sarthe), May 6, 1773.

The father died in 1784. Claude was twin brother of Marie-Marthe. Of his boyhood little is known, except that he completed at a small school at La Flèche the studies begun by him at the Collège de Joyeuse at Rouen. He was educated for the Church, and he attained to being an Abbé Commendataire; this, however, did not necessitate his performing religious duties. He was early attracted to natural science, and he became acquainted with several physicists. One of his first experiments was with soap-bubbles that were filled with gas and then electrified. He found that if two such bubbles were charged oppositely, they attracted one another, and that under suitable conditions they detonated at contact. His researches were peremptorily brought to an end on November 2, 1789, when the benefice was suppressed by the Legislative Assembly. Claude then returned perplexed and miserable to the fatherless home at Brulon, where he found his four brothers, also thrown out of employment. He rose to the occasion, however, and decided to attach himself to the new regime of republicanism in France. This he did with zeal and devotion.

During an interval of comparative leisure in the country, in 1790, he conceived the idea of devising a system of communication that would permit his Government to transmit orders to a distance in the least possible time. He was aware that the problem was not new, and that it awaited solution. He discussed it with his brothers, who became his collaborators. As the result of his investigations during the next few years, three different systems were designed and operated. Briefly, they were:

(1) The Synchronised System, 1791.

(2) The Shutter System, 1791.

(3) The Semaphore System, 1792.

The first and second were examined by him tentatively. The third became established and was that most closely identified with his name.

System (1) depended upon the use of two clocks working synchronously at the sending and receiving stations, respectively. Each clock was provided with a rotating seconds-pointer that passed over divisions upon the face, and each division corresponded to a number. To transmit a phrase, the operator at the sending station struck a gong at the instant the pointer was passing the number to be signalled. A code was arranged for the interpretation of the numbers into words. In these experiments, the distance between stations was about 400 metres. As the system was impracticable for a line of many stations, Chappe endeavoured to replace the sound signal by an electric signal through a wire. Results were unsatisfactory, however, his insuperable difficulty at that time being the imperfect insulation of the conductor.

He failed to establish an electrical method. Accordingly he decided in favour of an optical system—depending upon the appearance and disappearance of surfaces of different colours and forms to indicate the precise moment of transit of the pointers past the numbers.

The first equipment used by him for (2), the Shutter System, consisted of two rectangular frames installed one at each station. The frames were fitted, respectively, with five shutters, each of which could be made to appear or to disappear at will. Further experiments revealed that elongated bodies are more clearly displayed than are shutters. System (3) was therefore devised, the equipment for which is indicated in Figure 3.

Meanwhile, a code to be employed with such signalling devices was developed by Delaunay, a cousin of the Chappes. Delaunay, who had been on the French consular staff at Lisbon, adopted as a basis the code that had been in service for diplomatic correspondence. This remained in use until 1795.

The story of the trials of those three systems is woven into the history of the French Revolution. A satisfactory demonstration that the synchronised system (1) could operate, was made on March 2, 1791, and the results were attested by responsible authorities. This was the beginning of a long series of experiments. The apparatus was often in imperfect condition, but it survived for more than a year, during which the Chappe family furnished means to cover the costs. Encouraged thereby, Claude, towards the end of 1791, went to Paris, and after many disappointments obtained authority to set up his machine at the Etoile. He was assisted by two of his brothers, and their efforts met with success. Success was short-lived, however, for one morning in September, 1792, revolutionary fanatics destroyed their apparatus, believing it to be a device for communicating with King Louis XVI, who at that time was incarcerated in the Temple. This disaster was to some extent a blessing in disguise, for it led to a transformation of designs, i. e., to the abandonment of the synchronised system, and to the adoption of the shutter principle. Disaster now followed fast upon disaster—this mechanism also was smashed and burnt by the mob. Undaunted, the brothers pressed on; they started anew with a semaphore system that ultimately became standard in France. The account of this was presented by Claude to the Legislative Assembly on March 22, 1792. He appealed for protection of his apparatus, and for a fair and conclusive trial of it by competent investigators.

At that time the Assembly itself was even less secure than the apparatus they were asked to defend. They were replaced by a Convention. The Convention of October 15, 1792, transferred the request to the Comité d'Instruction, which also was too much occupied to deal with it. Meanwhile, the need for an efficient telegraph system had become urgent. Chappe therefore continued his efforts to perfect his machine and his code. On April 1, 1793, attention was directed to his work by Gilbert Romme (1750–1795), who was impressed by the possibilities of the Chappe system. So effective was Romme's argument that the Convention decided to allocate 6,000 francs for investigating and establishing the system. Moreover, Citizen Lakanal was directed to investigate it. The result of his report was that the National Convention accorded to Chappe the title of Ingènieur-Télégraphe, and an ordinance was published making it the duty of the Garde Nationale to protect the apparatus. The employees were described as "stationnaires" —a name that continued until 1862.

Claude bore his title of telegraph engineer to the end of his days. This, and the satisfaction of having served his country, was his solitary recompense. He never forgot what he owed at this critical stage to the referees, especially to Lakanal. He thanked him for the help he had given, and he praised his courage in the encounter against ignorance and against the prejudices of such revolutionaries as Cambon and Monot. It is pleasant to be able to record the complete and lasting fellowship of the brothers Chappe in the midst of this strife. This fellowship, and this alone, enabled them to overcome the difficulties of constructing long lines of communication, to organise transport, to instruct and control the staff, and to face the situation resulting from war and financial chaos.

The circumstances of the time forced the Comité de Salut to realise the vital importance of establishing a good system of intercommunication. From August, 1793, they made decrees, signed by such names as Couthon, Barère, Hérault, St. Just, Thuriot, and Robespierre, for its immediate extension. Chappe was authorised to place his machines in any belfries, towers, or emplacements he might choose, and he could cut down any trees that might interfere with the line of vision. The owners of the land and of the trees were to be suitably indemnified, and general provision was to be made by the Government—at least in theory—for hastening the work. Supplies of workmen, cash, and the means of transport, however, were not forthcoming. Against all odds, the brothers laboured, and with such vigour that, by July, 1794, a line was established and was actually working. It included the construction of fifteen stations between Paris and Lille.

Chappe did far more than devise a piece of mechanism and a code. He combined known ideas into a working system, and he caught the true spirit of telegraphy. He bridged the gulf between (1) the transmission of a signal whereby a pre-concerted message already written or otherwise recorded, and held for reference at the distant station, may be indicated, and (2) the transmission, if desired, of a series of elementary letters or numbers, whereby any message may be sent without previous conventions other than those relating to such letters or numbers. Leaving out of account the legendary telegraphs and the tentative achievements that preceded the work of Chappe, the first telegram sent and received by an organised system was that transmitted by him from Lille to Montmartre on August 15, 1794, acquainting the Administration in Paris that the French had re-taken Quesnoy.

France at that time, invaded on all its frontiers and on all its coasts, was endeavouring to train a new army by a levée-en-masse. Barère complimented Claude Chappe in a pronouncement to the *citoyens*, ending with words too true:

"La récompense de cette invention pour les auteurs est dans la mention que j'en fais à cette Tribune."

On August 30, 1794, Chappe transmitted news of the recovery of Condé. This message arrived during one of the sittings of the Convention, and caused indescribable enthusiasm.

Today the names Quesnoy and Condé—i. e., Condé-sur-Escault, 12 km. north-east of Valenciennes—have comparatively little significance. In 1793–1794 they meant nearly everything. The wars of the French Revolution were at their height. The position of France was desperate. Her frontiers were assailed by allied forces including those of England, Holland, Prussia, Austria, Spain, the Italian States, Hanover and Hesse. The road to Paris was open, and the French army was not yet able to break the lines of communication of the enemy. Marseilles and Lyons had revolted against the French Government. An English fleet, on August 28, 1793, under Vice Admiral Lord Hood, held Toulon. Between France and perdition there stood but two barriers: (1) the incoherence of the allies, each having different objects in view, (2) the singleness of purpose that Carnot had succeeded in establishing amongst all units of the French army. Ultimately there was added to these the annihilating force of numbers that the French levée-en-masse brought into the field; for France was the most populous country in Europe. In 1793, Quesnoy and Condé had been captured by the allies, Mainz had surrendered to them, and Valenciennes had capitulated. In June, 1794, Carnot—after diligent preparation—began his campaign of unremitting attack, especially against the Austrians. The allies failed to concentrate; at the battle of Fleurus, June 25, 1794, they fell into confusion and were scattered, towards Holland and towards the Rhine. Then was it that the French under Jourdan regained the precious area that included the fortresses of Landrecies, Quesnoy, Valenciennes, and Condé. For about two months there was some suspension of active hostilities, but towards the end of 1794 frost set in with exceptional rigour, the Low Country became a continuous sheet of ice, and the French under Pichegrue and Jourdan proceeded to invade Holland. The allies fell back, the French pursued, and—welcomed by the Republican party of Holland—entered Amsterdam on January 18, 1795. A Dutch Revolutionary Committee then came into being, and some citizens of Amsterdam placed the three-coloured cockade in their hats. De Winter—who in 1794–1795 was a General of Brigade in the French service—to crown the victory, moved his troops across the ice and took posession of the Dutch fleet that he was destined ultimately to command. The actual operation was led by Moreau, of the French cavalry, who with the support of a single battery of horse artillery made a dash to the north, as far as the frozen Helderstroom. Sword in hand those troops traversed the Island of Texel and, to the amazement of Europe, captured the vessels. Without the telegraph these results could not have been achieved. The French war plans were drawn up under Carnot, a member of the Committee of Public Safety, and one of the best engineers in France. Edward Baines, writing in 1817, says:

"The balloon—hitherto considered as a philosophical toy incapable of affording any solid advantage to mankind—was converted into an elevated observatory, by means of which the position, evolutions, and numbers of the enemy could be readily ascertained; at the same time that the telegraph, with a few simple motions, served to communicate the result of a siege, or of a battle, with the accuracy, if not the minuteness, of a dispatch, and with a celerity that in some measure rivalled the progress of sound."

It is therefore not surprising that when news of victories reached Paris the Assembly accorded praise to Claude Chappe.

In September, 1794, the Comité de Salut formulated a project to establish a telegraph towards the north by a semaphore system on the Chappe model, associated with distinguishing signals by flags. The work was begun, but financial difficulties impeded all operations. Promises of Government assistance vanished into thin air, and before the next year was ended, employees on that line to the north were dying of hunger. Yet, at the end of that year, another line was projected. This was to connect Paris and Landau (49° N. 8° E.). The construction was to be carried out in four divisions, centered respectively upon Paris, Chalôns, Metz and Strasbourg, under the management of Claude Chappe. His duties were administrative as well as technical, and he had charge of the factory in Paris where the equipment was made and adjusted. It was at this time that he left his quarters at No. 23, Quai d'Orsay, at the corner of the Rue du Bac, and went to No. 9, Rue de l'Université—the headquarters for his new Administration.

The scheme was laid down by the authorities with extreme care, but without funds. As Engineer-in-Chief, he was to receive 600 livres a month, and his brothers 500 livres each a month. Wages were fixed for the work, down to those of the office boy, who was assigned 125 livres a month. Unfortunately, along the slippery path of good intentions, payments failed to keep pace with promises.

It was at that time estimated that when the telegraphs were complete it would be possible to transmit a message to the extremities of France within an hour. The prime need was to ensure service between Paris and Strasbourg. From 1794 to 1798 service was actually maintained. The line passed through fifty stations, by way of Chalôns, Verdun, Gondrecourt, Saint-Quentin, Metz, Marimont, and Dingsheim. Difficulties resulting from lack of remuneration of staff led to painful results. An attempt was made to pay in kind instead of in cash, but not even this materialised. In default of payment, construction work in 1796 became disorganised. Workmen lost all zeal, and even the redoubtable Claude became despondent. Still more distressing were the conditions that he had to meet in the enterprise to the north. In his extremity, well knowing the penetrative and stimulating forces of a telegram, he turned his invention upon the authorities by dispatching to them the remonstrance:

"Des fonds, des fonds, encore une fois, des fonds, autrement nous ne pouvons rien faire. Addressez-les à Port-Malo" . . .

"Point encore de fonds, nous perdons depuis près de huit jours un temps extrêmement précieux . . . cette situation me desespère . . . Je fais tout pour assurer le prompt succès de l'établissement que je dirige; *de l'argent, ou point de ligne de Brest*. Salut et Fraternité. Chappe, ingénieur."

Yet he was invincible; he finished the line in seven months. It passed from Paris to Broué, Chaumont, Bruyères-aux-Bois, Avranches, Saint-Malo, Lanrodec and Guipavas, to Brest. This telegraph system remained under the administration of the French Marine until 1801. In 1799 the Strasbourg line with fourteen stations was established in Alsace for purely military purposes. It was abandoned in 1815.

An impression of Claude Chappe, loyal amidst all the turmoil. has been recorded by Jacquez. It is from a secret report from a Justice of the Peace at Lille to the Executive of the Central Bureau at Paris:

"Le plus petit, qui est l'aîné et que l'on connaît ici sous le nom de l'ingénieur, parce qu'il est l'inventeur de la machine, a paru toujours joindre à beaucoup de lumières un attachement sincère à la République."

In an attempt to ameliorate conditions arising from lack of financial resources, Claude proposed to the Ministry that they should make a charge for telegrams:

1. For industrial affairs, commerce and banking.
2. For exploiting a newspaper.
3. For operations of a national lottery.

Only one of these suggestions was quickly put into effect—the lottery proposal, and this—as he predicted it would—paid for the greater part of the telegraph service. Amongst his other ideas, Claude devised a system of secret communication between Calais and Dover—a project taken up by his youngest brother, Abraham. It formed part of Napoleon's scheme to invade England in 1803.

During the years 1794 to 1799 Claude appealed to all the sentiments of the Administration, he had recourse to the most ingenious means to prevent the telegraph from suffering in the general distress, he formulated measures for placing the whole upon a sound financial basis, but the combined circumstances of strife within France, and aggression from without, at last weighed him down. Nerve and mind, under the load, began to revolt. The load increased, for in 1804, Napoleon demanded the immediate establishment of telegraph service between Paris and Milan by way of Lyons. Between Paris and Lyons there were ultimately fifty-eight stations.

The continual stress imposed by the new project severely tried Chappe. Nor was it only troubles arising from the work that undid him. In 1797 the usual cruel annoyances to which inventors are subjected by those who claim to have anticipated a successful device, had a disastrous mental effect upon him. He took up the challenge of those who claimed priority. This action was followed by the customary exchange of letters of incrimination and revenge. Then came the end. He had gone to study upon the terrain emplacements for further stations on the line to Lyons. He became restless and irritable and manifested symptoms of hysteria. At the completion of the work he returned to Paris, declaring that an attempt had been made to poison him in a village near Lyons. Finally he fell into a state of melancholy that no distraction could cure. On January 23, 1805, in a garden, his friends found his body at the bottom of a well.

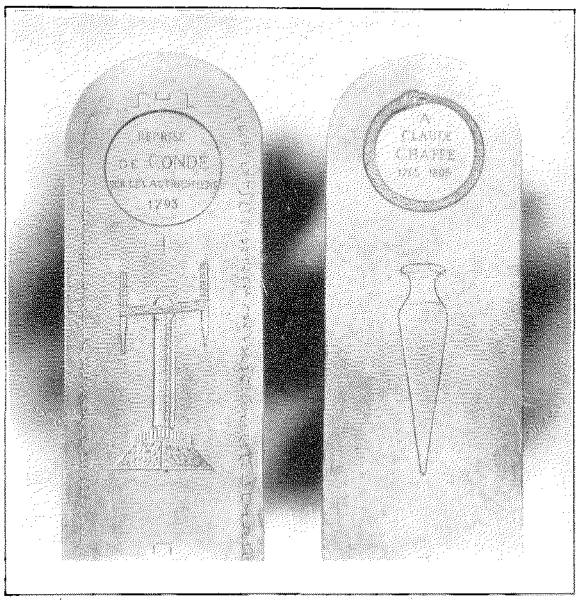


Figure 1—Monumental Stones at the Entrance to the Administration of Telegraphs in Paris, No. 103, Rue Grenelle.

He was buried first in the cemetery at Vaugirard, but subsequently at Père Lachaise,

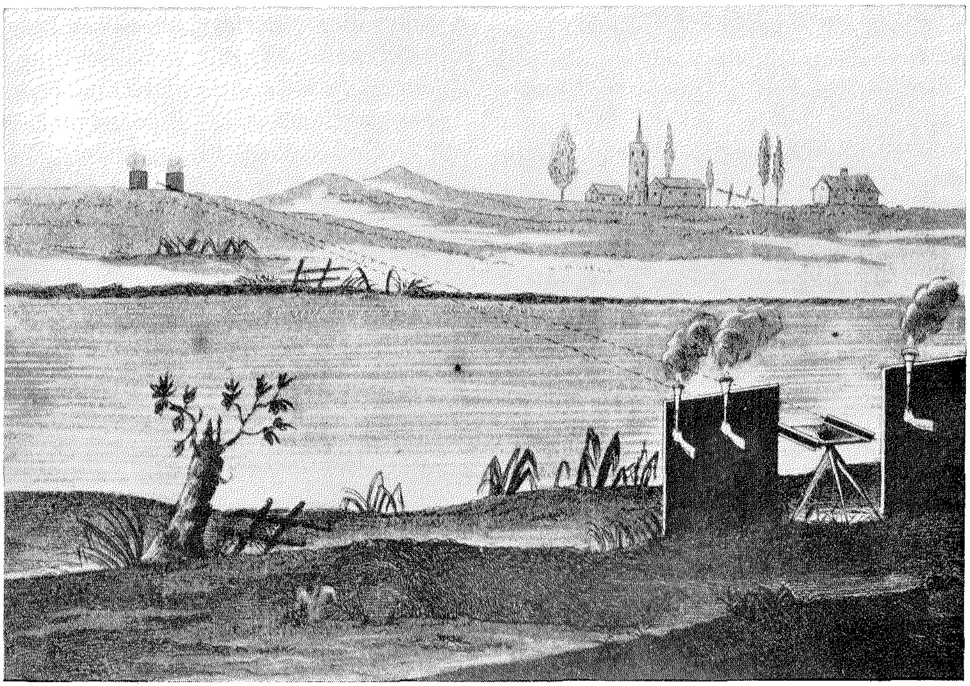


Figure 2—Ancient Greek Method of Signalling by Torches.

The alphabet is divided into five columns, of which four have five letters and one has four letters. Torches are hidden behind two walls—one to the left and the other to the right. To indicate the twenty-fourth letter, expose five torches to the right, which indicates the fifth column, and four torches on the left to indicate the fourth letter in that column. Tubes were fixed on each wall to direct the view. This method produced only feeble results.

at the side of his brother, Ignace, who died on January 25, 1829. The transfer took place on January 29, 1829. Their tomb bears the simple inscription "Chappe." According to M. Palhols, who investigated the matter, the tombstone from Vaugirard was presented in 1859 to the Administration of Posts and Telegraphs in Paris. It was then cut into two slabs (Figure 1) of half-thickness and placed at the entrance of No. 103, Rue Grenelle which since 1840 had been the headquarters of that Administration. The inscription contains two errors, for Claude Chappe was born in 1763, not in 1765; moreover, Condé was recovered in 1794, not in 1793, the date upon the stone.

It has been remarked by his biographers that the Chappe telegraph became famous first by the announcement of the recovery of Quesnoy in 1794, and that it ended its career in 1855 when it was called upon to transmit an account of an incident of like consequence—the taking of Sebastopol. In the Crimea, before transmitting this last message, it had served for eighteen months the military interests of the French army, and throughout moved with the troops.

Amongst the last of the Chappe telegraph services may be recorded:

1. Narbonne to Avignon by way of Montpellier (1831–1834).
2. Avranches to Cherbourg (1833).
3. Avranches to Nantes.
4. Bordeaux to Narbonne by way of Toulouse (1834).
5. Narbonne to Perpignan (1840).
6. Dijon to Bescançon (1840).
7. Bayonne to Behobie (1846).

In France, the Chappe telegraph was for many years in service, in harbours for signalling to vessels, on battlefields for signalling the positions and movements of the enemy, in sieges for signalling to the relieving contingents. By its means the Minister of War corresponded with Army divisions, and the Minister of the Interior with the Departments of France. At Paris, when this system had been perfected, they could receive communications from Lille in two minutes, from Calais in four minutes five seconds, from Strasbourg in five minutes fifty-two seconds, from Toulon in thirteen minutes fifty seconds, from Bayonne in fourteen minutes, and from Brest in six minutes fifty seconds.

From Paris to Behobie, at the far south-west of France in the Basses-Pyrénées, a signal could be sent under normal circumstances in about forty minutes. By 1852, at the moment that the electrical telegraph was substituted for the Chappe telegraph, the Chappe lines comprised nineteen branches, and a total length of more than 4,000 kilometres, including 556 stations. Similar lines, of a military character, working on a simplified system were established also in Algeria.

The angular settings of the wings were limited to seven positions, each 45° from the next—in practice making sixty-three variations, or 252 when combined with the four movements of the cross-arm. In its later form each setting could indicate a syllable or an entire word. The range was limited to that of their telescopes, i. e., to from six to eight miles on the level. The nearest telegraph to Paris was then at Montmartre. From Paris to Lille, from ten to twelve stations were necessary. At night, torches or lanterns were sometimes used upon the arms. In another method, for night service, translucent illuminated code signals or figures were employed.

In 1795 Chappe had pointed out that benefits might be conferred upon France by transmitting weather reports by his telegraph. A weather report service, however, was not completely organised until 1856.

The word "télégraphe" does not appear in his communication to the Assemblée Legislative of March 22, 1792. On that occasion he described his invention as a "tachygraphe"—rapid writer. In April, 1793, the word was changed to "télégraphe"—the far writer—as the result of a conversation between Ignace Chappe and Miot, Chef de Division à l'Intérieur.

Chappe was fully aware of the extent to which in ancient methods of communication the general principles of his devices had been adumbrated; he knew that the value of his work was in the adaptation of those principles to the needs of his time. He designed the mechanism to secure the greatest visibility, strength, lightness, durability and ease in operation.

The alternative systems (1) (2) and (3) happen to have been investigated by him in the sequence in which the basic principles came down through the ages. The first synchronised method in Europe probably dates from about 300 B. C., for the Greeks adapted their clepsy-

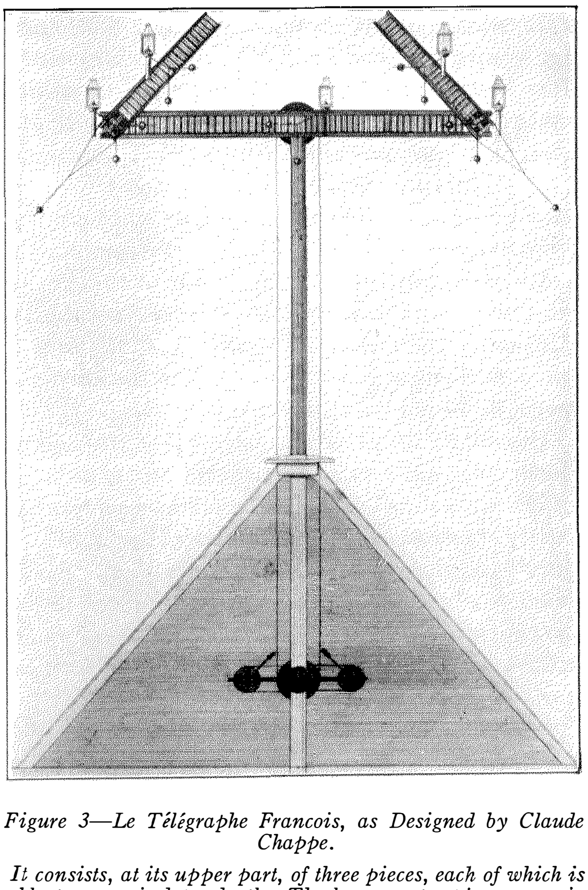


Figure 3—Le Télégraphe Francois, as Designed by Claude Chappe.

It consists, at its upper part, of three pieces, each of which is able to move independently. The large centre-piece or main arm, is a long parallelogram, at the extremities of which are fitted the other two pieces of wings, each able to take four angular positions, 45° apart. Together they can produce 196 shapes, each of which has a conventional value. The small "répétiteur" below the structure can be observed by the operator to check the movements.

drae to the purposes of signalling. The clepsydrae in effect were water-clocks depending upon a steady flow of water—literally the "*stealing*" of water—from or into a vessel containing a float. The float carried a vertical rod or flat strip. Upon such a strip phrases could be written in horizontal lines, or the letters of the Greek alphabet could be displayed in a vertical line. Arrangements were made for similar equipment to be supplied at successive stations along the line of communication. By raising a torch, the flow of water could be ordered to start at each station simultaneously. By raising the torch a second time, the flow could be stopped at all stations and the message could be read opposite a datum mark on the apparatus. In addition, the Greeks made use of a method sufficiently explained by Figure 2. The plan of communicating letter by letter was abandoned, and did not enter again into practice until the sixteenth century. The Romans and Gauls made use of signalling towers on a vast scale, and they certainly had a system of prearranged phrases with identification signals by beacon fires. Frequent use was also made of a line of signallers who shouted from mouth to mouth. Homer states that the voice of Stentor, the Greek herald in the Trojan war, was as loud as that of fifty men combined. Alexander the Great (323—356 B. C.) is said to have had means whereby a stentorian voice could be heard by all his army.

Questions of priority concerning pre-electric telegraphy are rendered complex partly because of the slow development of ancient devices, and partly because that development related not only to equipment, but to codes, cyphers, vocabularies, dictionaries, alphabets, and numerical arrangements, all directed towards facility of transmission. Questions of priority relating to early forms of telegraphy were disposed of once for all by Bouvet, a missionary to Asia, who pleasantly declared that the Chinese had used the methods for 4,000 years, and that they were all invented by Fohi, the founder of Chinese science.

Following upon the earliest workers, groups of inventors, including Kirchner (1550), Scheventer (1636), and the Bernouillis, endeavoured to transmit messages by means of musical instruments, each note representing a letter. One of the Bernouillis devised an instrument formed of five bells, by means of whieh he could express all the elements of the alphabet.

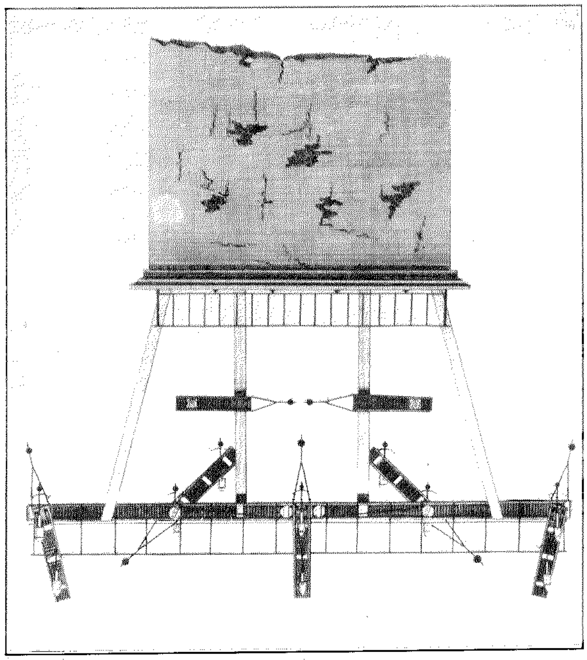


Figure 4—The Machine Invented by Monge about 1798. It was placed for a long time at the Tuileries, and a great number were constructed to operate on the line to Landau. Another machine was set up near Metz. According to Ignace Chappe, it never came into service.

The method of transmission of signals in England during the middle ages consisted in hoisting barrels or beacons upon masts, towers, or hills. At the beginning of the sixteenth century, occult science was in vogue, and those possessed of rudimentary scientific knowledge often preyed upon credulity by suggesting that they had powers of communicating by mirrors through the agency of the moon and stars and magnetic influence. François Kesler signalled letters of the alphabet by means of a lamp suspended from a hook in a subterranean tunnel. In front of the lamp was a screen that could be raised or lowered by a lever. He also signalled by the aid of smoke issuing from a barrel. In Kirchner's method, described in his "*Ars magna lucis umbrae*," the message was written upon a mirror, the sun was the source of light, and the light was converged upon the distant station by a lens. It was a kind of magic lantern. Kirchner's object was "not merely to communicate the most secret thoughts of the heart to a distance, but also to transport to the eyes of a friend at an enormous distance your profile or silhouette." Thus Kirchner anticipated television. In 1663, the Marquis of Worcester suggested a day or night plan of signalling by exposing letter shapes.

There is a legend that in 1670 the King of England heard speech shouted through a trumpet from a distance of 1½ English miles, and that he sent the trumpet to Deal Castle. The Governor of Deal Castle reported that the trumpet enabled communication to be carried on across three English miles of sea. It was invented by that "ingenious mechanist" of Hammersmith, Sir Samuel Morland (1625–1695). The mouthpiece was shaped to prevent lateral loss of sound. Morland wrote a treatise on this "Tuba Stentorophonica" and in 1666 he also gave an account of "A new method of Criptography."

In 1762 Benjamin Franklin experimented with the transmission of sound under water. In 1783 came Ganty and Biot with their tubes. They transmitted speech through 395 metres of tube by speaking very loudly. At 951 metres, speech was scarcely audible.

In 1763 Monsieur de Morogues published his "*Traité des Evolutions et des Signaux*"—a theoretical treatise on signals in which he introduced the idea of having a special flag to indicate the signification of a set of flags, for example, numbers or letters.

A noteworthy advance in optical communication was made when so-called "Indian Fire" was imported to England for signalling purposes. It was used with specially good effect in 1787, when by means of it the Observatories of Paris and Greenwich were for the first time brought into agreement, across the English Channel. The "Indian Fire" was contained in small boxes that burnt for about 2¾ minutes; it is said to have been unaffected by wind or rain.

Under the title of "Synthematographie," F. A. B. Bergstraesser wrote, in 1785, a treatise in German on the earlier modes of signalling. He described methods of communication that had been used by day and by night for military and other purposes during the centuries. It was estimated that one of the schemes would require 6,000 or 7,000 "coups de canon" to dispatch twenty words fifty miles. He explained certain numerical and alphabetical codes, and the employment of various shapes and solid letters for mechanical signalling. Moreover, he gave an account of methods of transmission by rods and bevel gears, shutters, pivoted arms set at various angles, torches, lanterns, and in fact, by the whole of the devices available up to and during his time. A copy of his work, in five volumes, was presented by him to George III, and is now preserved in the British Museum Library.

Another remarkable treatise entitled "Histoire de la Télégraphie" was written by Claude's elder brother, Ignace Urbain Jean Chappe, who is described as "Ancien Administrateur de la Télégraphie." This was published in Paris in 1824. A second edition appeared in 1840. It embodies some of what is told by Bergstraesser, but in addition, it gives an account of the scientific principles to be observed, especially with regard to visual signalling; it reviews the contemporary state of knowledge of the subject throughout Europe at the beginning of the nineteenth century, and it includes some precious details concerning the work of Claude. This book contains a valuable introduction by Abraham Chappe, the youngest brother of Claude, in which is reviewed the history of the subject, with comments upon the part taken by the Chappe family in its development. Figures 2–6 are reproduced from this treatise.

Between 1808 and 1819 indirect light was thrown upon the subject by John Macdonald, F. R. S., a retired Lieutenant-Colonel of the Royal Artillery. In one of his contributions, he purported to describe "Experiments upon the Relative Times of Burning of Fuses"; but, fortunately for telegraph history, he digressed widely to attack "the present imperfect state of telegraphic communication." As early as 1797, Macdonald in England emphasised the importance of developing telegraphy as a science; he also prepared a telegraphic dictionary, and a three-figure system for conveying words, phrases, and sentences. In 1810 he laid his scheme before the naval authorities. Mr. Barrow—who was then "the man of science at the Admiralty"—declared the dictionary to be "precisely what is wanted." The result was, to some extent, satisfactory for the Royal Navy. Spelling was avoided. Everything was by numbers. Macdonald's next step was to point out that the telegraph, as it was applied on land in 1810, merely expressed one figure at a time. He urged the Admiralty to adopt a three-figure system for their line telegraphs.

He says that shutters were judged to be better adapted than semaphore arms to the English climate, "it being supposed that a certain number of shutters would be better seen than the same number of arms acting conjointly." This judgment, however, is in direct opposition to that of the Chappes. The shutter telegraph to which Macdonald refers gave sixty-three combinations. In the Royal Navy, at that time, three and sometimes four figures were telegraphed simultaneously, i. e., by one hoist of flags. He directed attention also to the relative merits, in regard to visibility, of a shutter and a "semaphoric wing." In particular, he pointed out the difference in this respect between an arm nine feet in length lifted high in the atmosphere, and a shutter grouped with five others at a low station. He asked for a trial of shutters against arms on a line of eleven or twelve miles. His book contains the following remarkable peroration:

"It is unnecessary to dwell here on the incalculable benefit that would arise to commerce, to public revenue, to private convenience, and to public safety and security, by establishing a ramified telegraphic system, extending from the metropolis to the principal seaport towns, inclusive of a methodised intercourse with the principal cities situated to the right and left of such lines of communication. Such an undertaking would be a sublime attempt at an approximation of time and space; and would be truly worthy of the high character of our mighty nation. I, an obscure and humble individual, advanced in age, and passing on to that country from whose bourne no traveller returns, venture to prophesy that future ages will see this magnificent idea fully realised. Let it be recollected, that a less simple plan, the establishment of mail coaches, was at the time deemed impracticable and visionary. Man is a progressive animal."

Macdonald devoted great attention to the question of a numerical system. In the development of telegraphy, this was an important step, and he sums up the situation in a paragraph as follows:

"The most essential improvement in naval signals has arisen from the invention and application of *numerical order*. This simple, but luminous improvement is generally ascribed to Monsieur de la Bourdonnais; but those who have looked closer into the subject, know that Bishop Wilkins in his "Secret and Swift Messenger" not only recommended the method of signalling by notation, but describes the mode of execution. Dr. Hook, who is the inventor of the Land Telegraph, a species of which he mentions, recommended a numerical plan to the Royal Society. Kirchner very nearly hit on the invention, and Gaspar Shottus in his *Technica Curiosa*, expressly mentions it. With all this, it must be confessed that Monsieur de la Bourdonnais brought the plan to considerable perfection."

The book referred to is "Mercury, or the Secret and Swift Messenger, shewing how a Man may with Privacy and Speed communicate his Thoughts to a Friend." It is by John Wilkins (1641) and is an ingenious work on cryptology and modes of rapid correspondence.

Between the years 1784 and 1788 a method of signalling by means of troops formed up into various shapes was suggested; and a Dutch officer, Boucheuraeder, trained soldiers to perform in this manner in Holland. Telegraphy became in fact a vogue, and there were not lacking then as now telegraphomaniacs who pestered Administrations with impracticable schemes.

Bergstraesser, Macdonald, and Ignace Chappe all paid tribute to a much earlier writer, Sir Robert Hook (1635–1703), the mathematician and advocate of aeronautics. The discourse given by this great Englishman at the Royal Society of London, on May 21, 1684, is concise and instructive:

Dr. Hook's Discourse to the Royal Society. May 21, 1684, on "Shewing a Way how to Communicate one's Mind at great Distances."

"That which I now propound, is what I have some Years since discoursed of; but being then laid by, the great siege of Vienna, the last year, by the Turks, did again revive in my Memory; and that was a Method of discoursing at a Distance, not by sound, but by Sight. I say therefore 'tis possible to convey Intelligence from any one high and eminent Place, to any other that lies in sight of it, tho' 30 or 40 Miles distant in as short a Time almost, as a Man can write what he would have sent, and as suddenly to receive an answer, as he that receives it hath a Mind to return it, or can write it down on Paper. Nay, by the Help of three, four, or more, of such eminent Places, visible to each other, lying next it in a straight Line, 'tis possible to convey Intelligence, almost in a Moment, to twice, thrice, or more Times that Distance, with as great a Certainty, as by Writing.

"For the Performance of this, we must be beholden to a late Invention, which we do not find any of the Antients knew; that is, the Eye must be assisted with Telescopes, of Lengths appropriated to the respective Distances, that whatever Characters are exposed at one Station, may be made plain and distinguishable at the other that respect it.

"*First*, For the Stations; if they be far distant, it will be necessary that they should be high, and lie exposed to the Sky, that there be no higher Hill, or Part of the Earth beyond them, that may hinder the Distinctness of the Characters which are to appear dark, the Sky beyond them appearing white: By which Means also, the thick and vaporous Air, near the Ground will be passed over and avoided; for it many Times happens, that the tops of Hills are very clear and conspicuous to each other, when as the whole interjacent Vale, or Country, lies drowned in a Fog. Next, because a much greater Distance and Space of Ground becomes visible, insomuch that I have been informed by such, who have been at the Top of some very high Mountains, as particularly at the Top of the Pike of Teneriff, that the Island of the Grand Canaries, which lies above 60 Miles distant, appears so clear, as if it were hard by; and I myself have often taken Notice of the great Difference there is between the appearing Distance of Objects seen from the Tops and Bottoms of pretty high Hills, the same objects from the Top appearing nearer and clearer by half, and more than they do when viewed from lower Stations of the Hills; and this not only when the Space between them was land, but where it was nothing but Sea. I have taken Notice also of the same Difference from the Prospect of Places from the top of the Column at Fish-street-Hill, where the Eye is, in good Part, raised above the smoaky Air below.

"*Next*, the height of the Stations is advantageous, upon the account of the Refraction or Inflections of the Air; which Inflections of the Air are many and very great, sometimes in an Air which seems, to the naked Eye, the most clear and serene. Insomuch that That alone does wholly confound the Distinctness of Objects appearing at a Distance; now the greater Part of these arise from Commotions of the more dense Air that is near the surface of the Earth, by the Rarefaction of some Parts of it, caused by Heat; which rarified Parts ascending, do make the Objects seen through it, to seem to dance and undulate, which is in great part avoided, if the Prospect be from an higher Place. Besides, the Nature of the Air itself, at great Heights, approaches nearer to the Nature of the Aether, which more powerfully propagates the Impulses of Light."

He then explains that there must be no hill interposed between stations, because the air above that hill will be very apt to disturb the clear appearance of the object. There is to be one telescope at each terminal station, and two at each intermediate station, and times are to be agreed upon for operation.

"Next, there must be a convenient Apparatus of Characters, whereby to communicate any Thing with great Ease, Distinctness and Secrecy. There must be therefore, at Least, as many distinct Characters, as there are necessary Letters in the Alphabet that is made use of . . . and those must be either Day Characters or Night Characters."

His plan was to use shaped letters by day and torches by night, to represent either letters or whole sentences. He adds:

"I could instance a hundred Ways of facilitating the Method of performing this Design with the more Dexterity and Quickness and with little Charge; but that, I think, will be needless at present . . . The same Character may be seen in Paris, within a Minute after it hath been exposed in London."

He realised that there might be many applications of such a method, particularly for cities or towns besieged, and for "Ships upon the Sea."

Sir Robert Hook utilised two or more shapes to form a multiplicity of signals, as probably the Greeks did in time immemorial. Ignace Chappe points out that in like manner Sébastian Truchet had combined two tiles—each coloured in two tints arranged diagonally—to give sixty-four changes. Here was the germ of the *dot* and *dash*, and of kindred two-tone and double-key systems of telegraphy. Ignace Chappe gives credit to Buria, a member of the Academy of Science of Berlin, for having suggested the reduction of the alphabet to a set of signs formed of two characters, and for pointing out that by such a binary system, for example, two prisoners might communicate by two different sounds—a knock and a scrape—which could be done by the heel of a boot, another precursor of a two-tone scheme.

From this sketch of the condition of knowledge concerning telegraphy in the early days of the Chappes, it is seen that the task before them was not to discover but to select and to coördinate. Of ideas there was untold wealth; of those powers of discrimination that spring from scientific research, there was lamentable poverty. The importance of scientific investigation is well illustrated by the advance made by Claude consequent upon his mastery of the principles of visibility. Ignace has left a record of the results of these investigations. He explains that although it is easy to signal by an arm or a rod for a short distance slowly, difficulties increase rapidly with the distance and with multiplicity of stations. The moving part, whatever its shape, must be light enough for transport up mountains, towers and other buildings; it must have surface enough to be seen, and yet strength enough to resist wind. It must therefore be exceptionally strong. Movements must be rapid and simultaneous, they must demand very little force, they must be capable of exact repetition without confusion, they must be free from ambiguity, they must remain unaltered during exposure. The brothers found it well to have available a large number of primitive signals for service matters, and a phrase code for the operator. Economy of time had always to be considered. Exceptional difficulties arose, as Hook had predicted they would, from atmospheric changes and from the effects of refraction of heated air. Special attention had therefore to be given to the form and colour of the exposed bodies. Experiments proved that upon a white ground a black disc is lost sight of at less distance than is a black line of the same width. Of two unequal black lines of the same breadth, the longer is visible from a point more remote than is the shorter. Black is preferable to white, because the visibility of the contours of an opaque body results largely from contrasts between the object and the background. There is always danger that an exposed body will be confused with what is around it, even if it is a white body upon a black background, because the contrast only relates to the points or lines of apparant contact between two surfaces. Contrasts are diminished by vapours, clouds, and refractions. Black backgrounds diminish contrasts. To avoid these difficulties they raised the bodies above all other terrestrial bodies—as modern "sky signs" are raised.

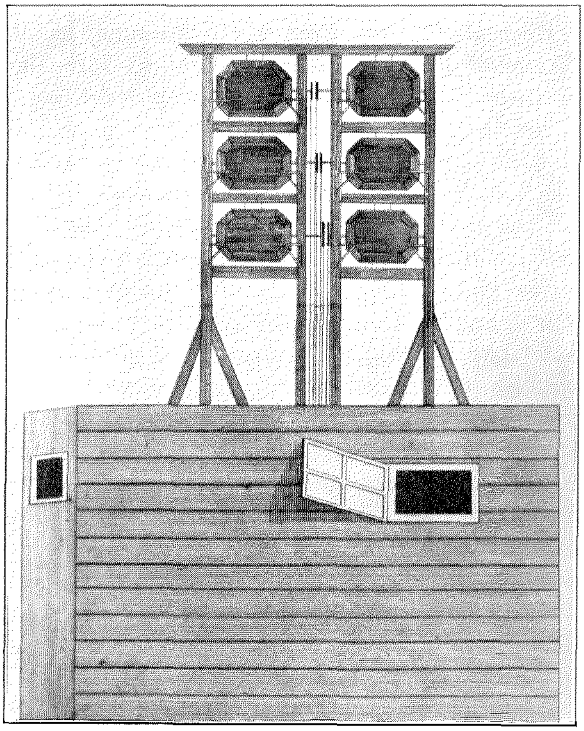


Figure 5—Apparatus Fixed on the Admiralty Building, Whitehall, London, in 1796.

A frame with six shutters. It was sometimes necessary to make more than one signal to express a letter. Moreover, the proximity of the shutters to one another was apt to lead to confusion, especially in a smoky or foggy atmosphere. It is said to have served only twenty-five days in a year. A different machine, similar to Figure 8 was substituted, probably about the year 1810.

Experience showed that the shape of bodies seen at a great distance is lost when they reflect directly the light of the sun. It was for this reason that Chappe used planes inclined in various directions to form contrasts, or as Ignace says: "faire contraster, par ce moyen, le télégraphe avec le diaphanéité" of the atmosphere. The arms were therefore formed of inclined planes, resembling the sails of a windmill, (Figure 3).

Experiments were made to determine the best shape of opaque bodies for the purpose. A long parallelogram was found to be best. It had to be of comparatively slender construction, so as to present small resistance to wind. The battens were spaced to allow free passage of air, and they were sloped to prevent direct reflection of the sun's rays.

At first the diametral arm (Figure 3) was arranged to stop in one or other of six angular positions. Ignace says, however, that a body that is not perceived when it stands alone, may become so when it is near to another. Consequently, the number of angular positions assigned to the diametral arm was reduced to four, and a wing was added at each end of it. These wings were set in angular positions, thus increasing the number of signals that could be made with the machine. Each of the two wings could take seven positions with regard to the arm, the result being that 7 x 7 x 4 shapes were in general obtained.

Another principle at which they arrived was that acceleration is best achieved, not by unduly quickening the movements, but by care in ensuring that each signal conveys a clear idea.

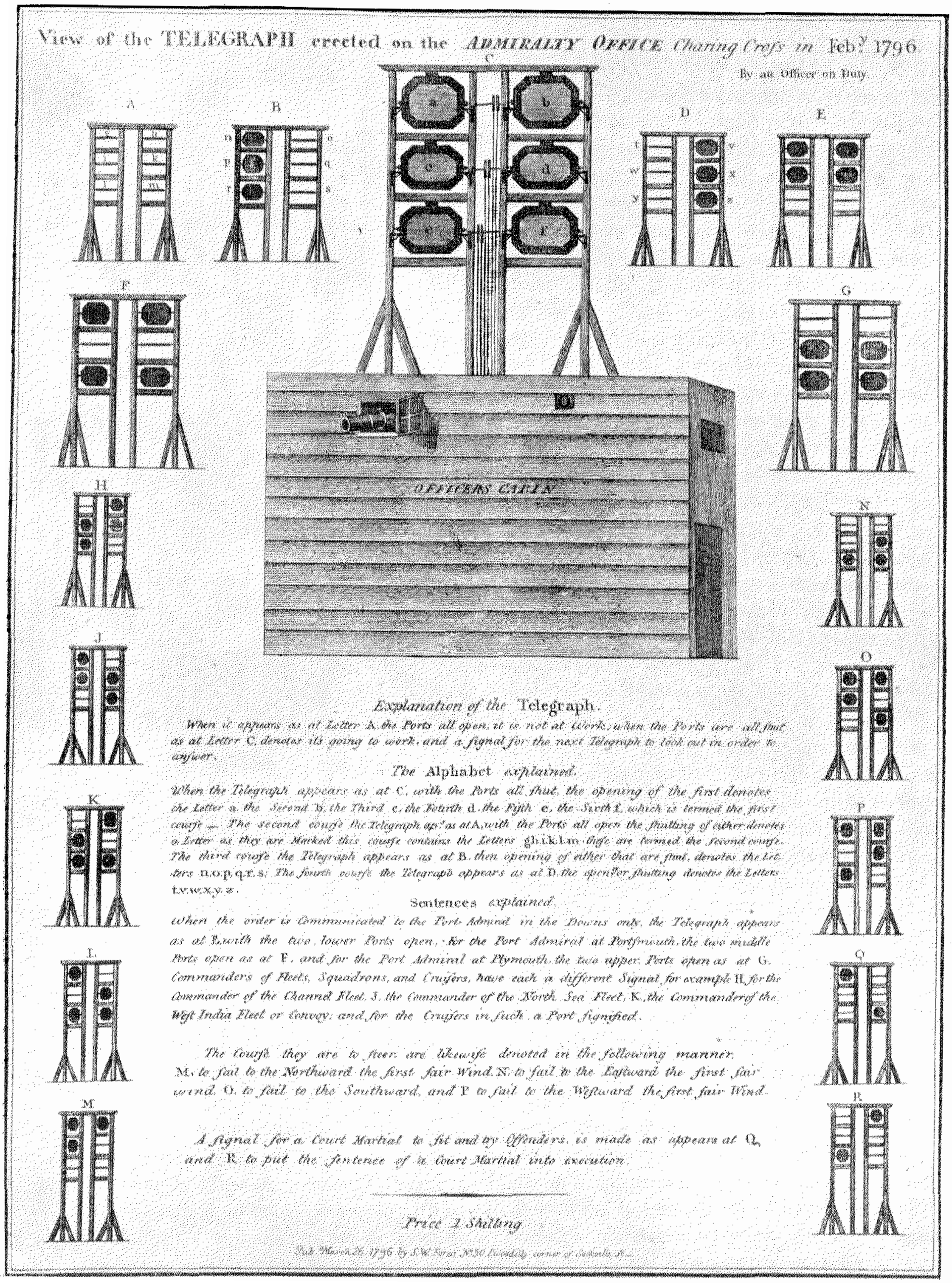


Figure 6—Copy of a Print, now in the Admiralty Library, of the Telegraph of 1796, with Explanation of the Telegraph. Reproduced by kind permission of the Admiralty Librarian.

They therefore concentrated upon devising a good signal-manual and upon obtaining perfect control of the operators so as to avoid faults. Beyond a certain rate, quickening the movements was ineffective, because—as nearly simultaneous signalling was carried out at all the stations on a given line—there was overlap between stations in point of time. The essentials to be attended to, therefore, were perfection of code and faultless operation. The elimination of faults was dealt with in a drastic manner. Although the revolutionaries sang of liberty, equality, and brotherhood, the quality of mercy was not in their composition—negligence was punished by imprisonment. The members of the staff at each station were placed under a chief who could dismiss at will. To secure correct transmission, operators were selected of dull intellect, without ideas and without ambition. Wages for such "stationnaires," when wages were available, were twenty-five sous a day.

At intermediate stations the "stationnaires" had only to copy what was seen. Operators at terminal stations did all the code work. At each station there was a repeater to indicate what was being transmitted. In one system the signal was set when the arm was diagonal, and it was only read when it was either horizontal or vertical, i. e., in the confirmatory position. The movement from oblique to vertical or horizontal assisted the visibility of the signal.

Upon the Chappe principle, the French utilised for military purposes "télégraphes ambulants." In October, 1797, the French Government appointed Buonaparte to command an expeditionary force to attack England. In February of the next year he visited the French coast near Calais, and while he was pondering on a descent by a flotilla of small craft, it was realised that it would be very helpful to have at Gris Nez the means of signalling at night to Dover, while making the English coast. Accordingly, a powerful lamp was devised to work in conjunction with a large telegraph. The light from the lamp was to be projected by means of parabolic mirrors sixteen inches in diameter. It was upon the occasion of abandoning this scheme that Buonaparte declared that to effect a landing upon England without being master of the English Channel would be the most temerarious and difficult operation ever attempted, and it was for this reason that he diverted his attention to Egypt.

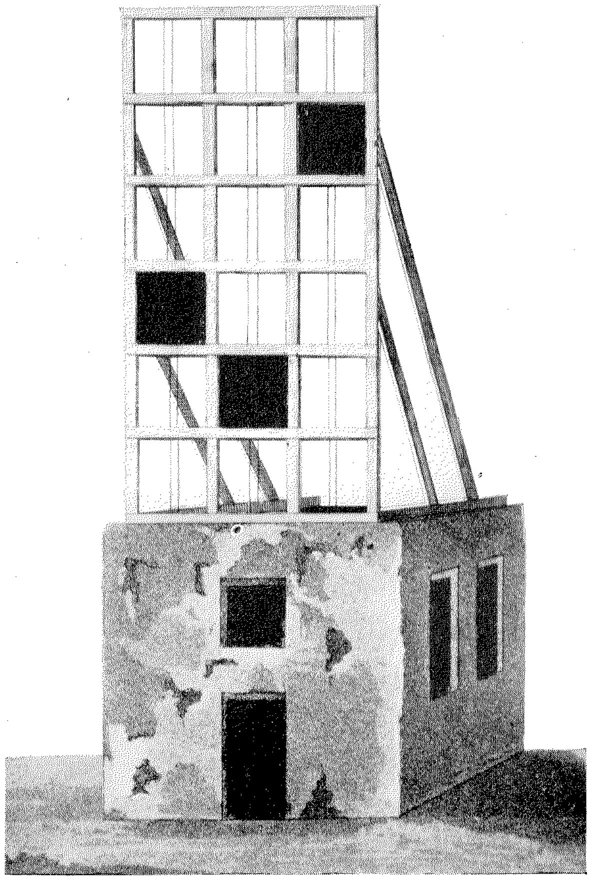


Figure 7—Apparatus Fixed at Plymouth.

It had only three shutters. These did not turn upon an axis, but they could be made to slide up or down to take a position at any of five openings in the frame.

The Chappe system was adopted in Egypt with considerable success because it was not subjected to alterations as in other countries. It is recorded that messages were sent between Alexandria and Cairo in forty minutes.

In 1794 Endelerantz developed the Swedish telegraph upon a plan somewhat resembling that of Chappe. A vertical post was provided with two arms forming a cross. The arms could be set at various angles to indicate letters. The apparatus did not produce enough signs for practical purposes. Endelerantz therefore substituted another design resembling a large rotating dovecote, with shutters. This was mounted upon a central vertical axis. At night he used occulting lanterns upon somewhat the same principle as the modern signalling lamp. The first trials of the Swedish telegraph took place between Drottningholm and Stockholm on October 30, 1794, and subsequent trials on August 30 and October 18, 1795.

When looking back upon the work of Chappe and his brothers, it is seen that they succeeded in solving three problems, and in uniting the results to establish a practical system of optical telegraphy. The first was the design of a machine, the second was to arrive at the principles in accordance with which the physical conditions could best be met, and the third was, out of the chaos of ancient suggestion to evolve a working

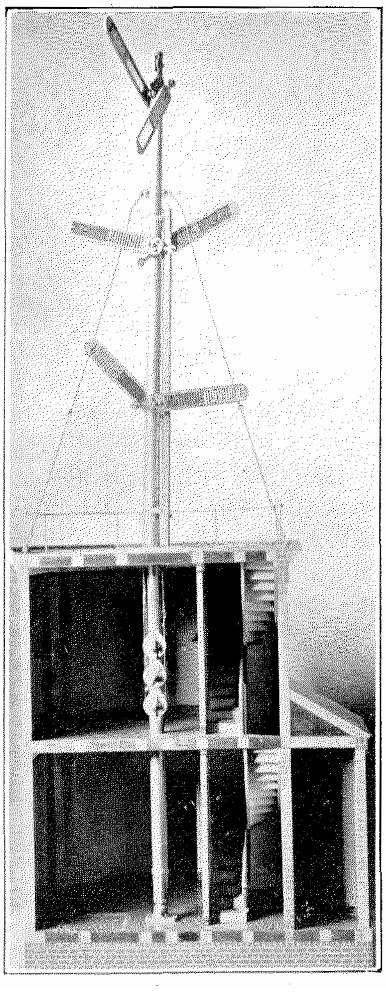


Figure 8—Model Preserved in the Verkehrsmuseum, Nürnberg, of the Optical Telegraph used at Möllenkopf near Ehrenbreitstein on the Rhine in 1833.

code. It fell to the Chappes, in addition, to face administrative, political and military difficulties, and to succeed in circumstances of exceptional privation and danger. From beginning to end they were sustained by loyalty to France; their names deserve to be remembered as engineers who devoted themselves conscientiously to the welfare of their country, and as pioneers who made things easier for electrical communication that was to follow.

The development of the visual telegraph in France had its counterpart in England. A hint of the way in which information concerning the Chappe system was obtained by England is contained in Ignace Chappe's *Histoire.* Some other details of the development in England are to be found in an article by O. Tuck in "The Fighting Forces," Vol. I, 1924. Codes and signals are dealt with in the famous treatise "British Flags," by W. G. Perrin, Admiralty Librarian. From these various sources it appears that during the wars with France, at the end of the eighteenth century, a British officer at Menin observed what at first he thought to be a windmill with only two remaining sails. Occasionally the sails changed their angles with the horizon and seemed to make signals which were followed by the French troops. The matter was reported to John Gamble, chaplain to a member of the Royal Family. Gamble prepared an account entitled "Observations on Telegraphic Experiments," and in 1795 sent a copy of this to the Admiralty. He designed and constructed apparatus consisting of a vertical frame holding five shutters which could separately be opened or closed, allowing for thirty-one changes. Tuck mentions that at the time the Admiralty received Gamble's report there was no original telegraph system in England. Between the North Foreland and Land's End the Admiralty had forty-seven signalling stations. By means of hoists of various groups of black balls from yard arms at these stations, prearranged messages were communicated.

Preceding Gamble, another "inventor," Murray, fourth son of the Duke of Atholl, had produced a device comprising six shutters that gave sixty-three changes. Gamble and Murray were both in holy orders; and by another coincidence they both hit, in effect, upon a shutter telegraph, such as Chappe had long before aban-

Figure 9—Portrait of Claude Chappe.

doned in favour of a semaphore system. Gamble set up his trial shutter machine on August 6, 1795. He followed by designing a telegraph having radial arms, and offering this to the Admiralty. Their Lordships replied that They were:

> "... so well satisfied with the Telegraphs erected under the direction of Lord George Murray that they did not think it necessary to make any experiment with the radiated form."

To soften the blow, the letter was signed "Your affectionate friends." The truth is the contribution of Gamble added nothing to the information already in the possession of Their Lordships.

In the same year, 1795, a surveyor—George Roebuck—contracted to erect for the Admiralty fifteen stations between London and Deal at £230 a station. An eight-guinea clock and two twelve-guinea telescopes at each station completed the equipment. By January 27, 1796, a signal could be sent from London to Deal, and acknowledged, in twominutes. Roebuck was then appointed Superintendent of Telegraphs, with a salary of £300 a year. This work was followed by a line through Putney Heath, and Beacon Hill to Portsmouth, with ten stations, including Chelsea and the Admiralty. There was also a project in 1801 for a line to Yarmouth, but the peace of Amiens intervened and the scheme slumbered. So profound was the peace that signal stations along the eastern and southern coasts of England were abandoned to the owners of the land on which they stood.

War in 1803 again shook the world, and in 1805 Roebuck was active between London, Portsmouth, and Plymouth. The Plymouth line —200 miles—was completed on July 4, 1806, and Tuck says that a reply from Plymouth began to be spelt out only twenty minutes from the time that same telegraph had made "Message ended." The one o'clock signal could be made and acknowledged in three minutes.

In 1807 the Yarmouth scheme was resuscitated—the trail was through Chelsea, Hampstead, St. Albans, and the Gog Magog Hills near Cambridge, in all eighteen stations. By the middle of 1808, Roebuck had altogether sixty-five stations under his supervision, operated by the shutter system.

Between the years 1811 and 1816 the semaphore gradually replaced the shutter system in England. With the peace of May 1, 1814, when Napoleon was banished to Elba, there was again general relaxation and abandonment of signalling stations. But fortunately for English telegraphy he escaped and landed in France on May 1, 1815. Telegraphs were re-established with all haste and there was a general order to adopt the semaphore method. In November, 1815, a line was projected through West Square, Southwark, Nunhead, and Red Hill, to Chatham. Peace, however, followed Waterloo, the telegraphs were all paid off, and Roebuck's work was at an end. The Chatham line had nevertheless established the superiority of the semaphore method. In 1818 there was an effort to restore the telegraph service, especially on the line to Portsmouth.

In 1819 the English Ambassador in Paris requested the French Government to give England a model of the French telegraph. This was immediately done; but as the model was not accompanied by instructions, it was not used in England to best advantage. Although stray information concerning it had been obtained earlier, the principles necessary for its proper working had not yet been grasped in England. This Chappe machine was installed at Nunhead, where it remained until it was replaced by the Popham machine. By 1830 the telegraph system in England was again almost out of action. In 1838 Wheatstone was transmitting electrical signals from London to Birmingham, and on December 31, 1847, the last of the English Semaphore stations closed and the occupants of stations were discharged.

To link the history of the Chappe system with that appertaining to earlier methods of signalling, so far as England is concerned, requires retrospective vision. In the reign of Queen Elizabeth it became the custom for commanders of fleets to receive a set of signals and sealed orders for their guidance, just before going afloat. The method was developed by the Duke of York, afterwards James II, who as Admiral of England introduced a system of signals for Divisions of Fleets as well as for single ships, whereby they could be directed in a specific manner. James II was also the first to adopt scientific formations of line, and an order of battle. These instructions led to the British Naval Code. In France, Le Père Hoste, who wrote in 1697 a book on naval tactics, introduced in 1727 a system of signals by means of sails, flags and gun-fire. Thus the advance of practical telegraphy was along two converging paths, i. e., (1) Visual transmission devices, and (2) Codes. In the work of initiation, England and France were alike conspicuous, and history has fairly distributed the honours; for while Ignace Chappe himself frankly states that the nearest approach to the true principles of the art of telegraphy was made by Dr. Hook in 1684, Macdonald—who also lays stress upon the importance of the work of Hook—does whole justice to Claude Chappe, by giving credit to him for a great achievement in the development of "Semaphoric wings." Tuck tells us that the idea of running a commercial telegraph system in England was almost realised in 1842, when one day there appeared on the Shot Tower, near St. Olave's Church, on the south side of London Bridge, the inscription: "Watson's telegraph to the Downs." Watson had bought up the old telegraph and semaphore stations, and he proposed to run them as a commercial speculation. Unfortunately, however, the semaphore on the Shot Tower was destroyed by fire on August 19, 1843, and it was not re-erected.

The condition of mechanical and optical telegraphy in England at the time when the electric telegraph was beginning to be established, can be gathered from a Parliamentary Return, now out of print, relating to the London-Portsmouth line:

Admiralty Semaphore, 24 April, 1843.

A Return of the Number of Hours in the Day appointed by the Admiralty Printed Instructions, dated 4th December, 1827, for the Ordinary Working of the Semaphore from London to Portsmouth.

From the 1st October to 28th February, from 10 a. m. till 3 p. m. .... 5 hours.

From the 1st March to 30th September, from 10 a. m. till 5 p. m. . . . . .7 hours.

Note. Notwithstanding the above regulation, a look-out is kept at the several semaphores, and the closing sign is not made on any evening until their Lordships' commands are taken; those commands are never applied for whenever the sight is good until 4 o'clock p. m. in the winter, and 6 o'clock p. m. in the summer, and the line is kept open if required.

A Return of the Number of Days, during a period of Three Years, ending the 5th April, 1842, when the Semaphore was not available, by reason of the State of the Atmosphere.

Dates	Admiralty, Number of Days	Chelsea, Number of Days	Putney, Number of Days	Portsmouth, Number of Days
From 1839–40	133	64	42	21
From 1840–41	106	70	49	28
From 1841–42	84	77	51	16
Total Number of Days at each Station for Three Years.......	323	211	142	65

Note. Whenever the working of the Semaphore at the Admiralty is prevented by reason of smoke, the State of the atmosphere to the eastward, or westward from the vapour arising from the water in St. James's Park or other causes, messages are on such occasions, when of importance, taken to or from Chelsea or Putney stations, and generally effectually communicated from thence to or from Portsmouth.

(Signed) CHARLES H. JAY,
Commander, Superintendent.

Semaphore (London to Portsmouth)
Return to an Order of the Honourable The House of Commons, dated 6th April, 1843:—for

A Return of all expenses appertaining to the Semaphore from *London* to *Portsmouth* for the Three Years ending the 5th day of April, 1842, including the Pay of the Officers and Men; also of the Number of Hours in the Day appointed by the Admiralty for the Ordinary Working of the same:—And of the Number of the Days during such Period of Three Years when the Semaphore was not available, by reason of the State of the Atmosphere.

Admiralty
2 May, 1843

H. F. AMEDROZ,
Chief Clerk.

Ordered, by The House of Commons, to be Printed, 5 May, 1843.

Admiralty, 28 April, 1843.

A Return of all Expenses appertaining to the Semaphore from *London* to *Portsmouth,* for the Three Years ending the 5th April, 1842, including the Pay of Officers and Men:

	£ s. d.	£ s. d.
1839.....................	3,269 3 3	
Abate, Half-pay the Officers would have been entitled to if unemployed..............	1,500 12 0	1,768 11 3
1840.....................	3,293 19 6	
Abate, Half-pay as above . .	1,514 15 0	1,779 4 6
1841–42..................	3,653 5 0	
Abate, Half-pay as above . .	1,558 11 6	2,094 13 6
		£5,642 9 3

Memorandum. The above Return has been made up to the 31st March, the termination of the Financial Year of this Department, to which date the Accounts are rendered.

(Signed) J. T. BRIGGS,
Accountant-General of the Navy.

Development of Broadcasting in Japan

By V. H. G. PARKER

Engineering Department, Standard Telephones and Cables, Limited

DURING the year 1928 immense strides were made in the development of broadcasting in Japan. These developments were a natural sequence of the original scheme[1] projected when the Japanese Broadcasting Association was formed in 1926. Six new broadcasting stations, distributed over the three main islands of Japan, have been opened with the idea of bringing as many listeners as possible within crystal range of some station. Four of these stations serve areas which heretofore have been without local broadcasting service, while two of the installations—at Tokyo and Osaka, respectively—replace existing stations of lower power.

The new stations are each rated at 10 kilowatts unmodulated antenna power and are housed in entirely new buildings so as to leave the original transmitters still available in case of emergency. The only area not affected by the year's changes is that surrounding Nagoya, where a previous 1 KW installation remains in operation. The map (Figure 1) shows how the stations have been distributed among the main cities of Japan so as to cover as large an area as possible. Medium wave lengths are used throughout, and the entire broadcast wave length lies between 400 and 350 metres.

All call signs in Japan are given out in English and consist of four letters commencing with J. O. and ending with K. The third letter is different for each station and thus serves as a means of identification. The following is a list of the seven stations giving regular programmes, together with their call signs and wave lengths:

Sapporo	Sendai	Tokyo	Nagoya
JOIK	JOHK	JOAK	JOCK
361.4	389.6	375	360

Osaka	Hiroshima	Kumamoto
JOBK	JOFK	JOGK
385	353	380

[1] R. E. A. Putnam, "Broadcasting in Japan," *Electrical Communication*, Vol. V, No. 3, January, 1927.

The equipment of all the stations has been imported from England. Sapporo, Sendai, and Hiroshima have each been supplied with "Standard" Radio Equipment, designed and manufactured by Standard Telephones and

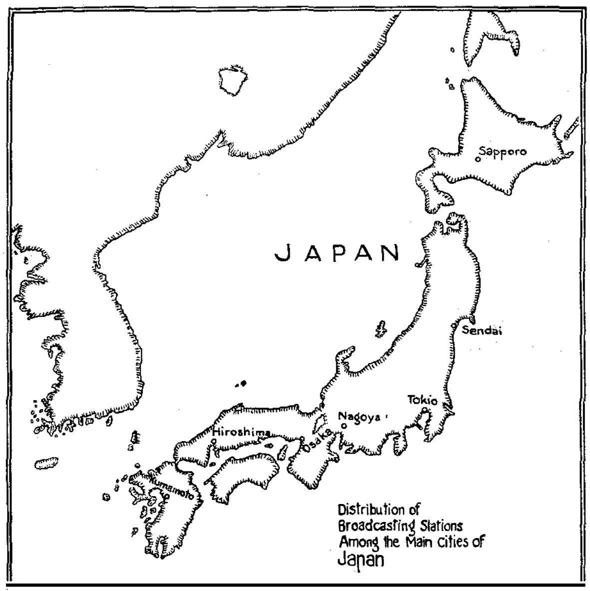


Figure 1—Map of Japan.

Cables, Ltd., and installed by the Nippon Electric Company, Ltd.

Sapporo (Figure 2) is the main city of Hokkaido, the second largest island of Japan; it has a population of 145,000, and owes its growth mainly to the public institutions established there by the Japanese Government. It possesses an Imperial University which in the past has been mainly devoted to the study of agriculture. The town itself, unlike other Japanese cities, is laid out in blocks and streets like an American city, all streets crossing at right-angles. The winter in Sapporo and on the island generally is very severe. For five months in the year, most of the country is frost-bound and covered with snow, often to a great depth, and all the roads outside the cities then become impassable except by sledge.

The Sapporo Broadcasting Station was officially opened on June 5, 1928. By the end of July, 11,000 listeners had been registered.

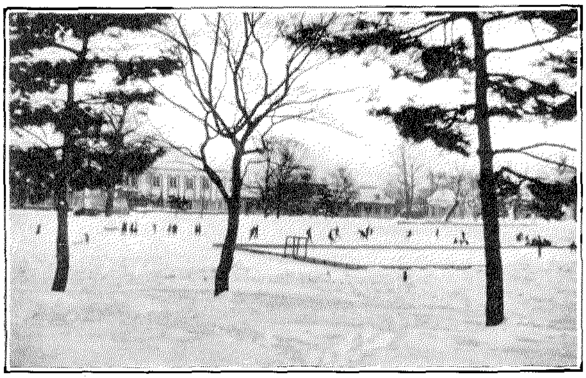


Figure 2—(Sapporo) Nakajima Park in Winter. The Studio is Among the Buildings at the Back.

Sendai, with a population of 143,000, is the chief town in the north of the main island. It is an important educational centre and includes the famous laboratory known as the "Institute of Metallurgical Research." This laboratory is directed by Professor Honda. Important work in connection with cobalt magnet steel, better known as "K. S. Steel," has been done there. The University also gives special attention to radio research and has a very well-equipped laboratory for this purpose. Sendai is the headquarters of the Second Army Division, and many military students are quartered in the city. In the early part of the year, the Japanese Institution of Electrical Engineers held a large convention in the town. During this period, a very large number of visitors was shown over the station, which had just begun testing. The station was officially opened on June 23, 1928, and by the end of July 9,000 listeners were registered. The situation of this station is probably the most favourable of the three, and reports of very good reception have been received from all over the country—several from such distant points as New Zealand.

Matsushima, one of the three chief beauty spots of Japan (Figure 3), is situated only a few miles from the transmitting station.

Hiroshima, a port on the Inland Sea, is one of the chief military stations of the Empire. It has a population of 150,000, and is one of the most important commercial centres in the southern part of the main island. The country around Hiroshima is very mountainous and is covered with vegetation. The neighbourhood contains some of the most beautiful scenery in Japan, the best known being Miyajima, with its singular *torii* and famous shrine which, at high tide, appears to float on the water. The station was opened on July 5, 1928, for regular broadcasting, and reports of good reception have been received, notwithstanding the unfavourable nature of the country.

Building Arrangements

In designing the layout of the new stations, a general uniform plan was so far as possible adopted. Since Standard transmitters require less space than the other imported equipments, two different floor plans, suitable for each type of equipment, were selected. The three stations, Sapporo, Sendai, and Hiroshima, were each built to a uniform plan.

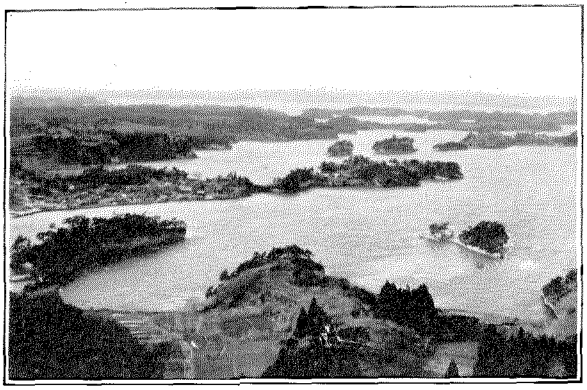


Figure 3—Matsushima (Pine Islands).

The transmitters have been located outside of and near to a main city, the distance being of the order of five to six kilometres, while the main studios and general offices have been built on some convenient site in the town itself. The buildings housing the transmitters are constructed of reinforced concrete, and are made as strong as possible in order to withstand earthquake shocks. Possible expansion has been provided for and the transmitter rooms have been made large enough to accommodate second equipments. In each case, large power rooms containing the machines, main switchboards and water cooling pumps and radiators have been provided, together with the necessary overhead gears for moving the power units. Figure 4 shows a corner of one of the power rooms containing the main switchboard and induction regulators. A control room containing the line amplifier equipment and a small local studio for announcements and general emergency work are a necessary feature of each station. A reception room, offices for the accommodation of the engineering staff, and a small workshop and laboratory have been included.

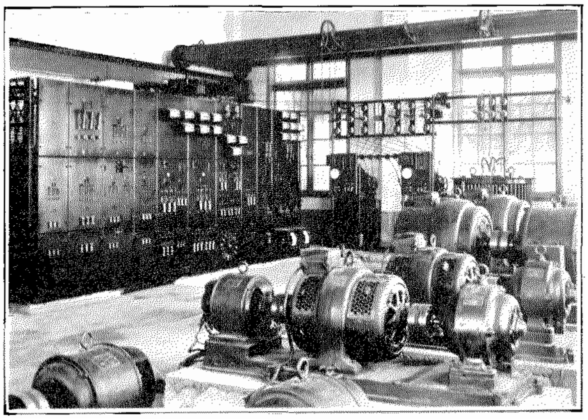


Figure 4—Corner of Power Room (Sendai).

Reliability and safeguard against interruption of the service have been the keynote of the general scheme, and all the main units of the equipment and power machinery have been duplicated where possible. In pursuit of the general plan, the power supplies are obtained from two independent power companies, and the operation of a switch brings either supply into use in a few minutes.

Figure 5—Studio Building (Sendai).

Three-phase power is supplied to the buildings at 3,000 volts per phase, which is then transformed down to 220 volts per phase for operating the radio transmitters. Induction regulators are employed to keep the voltage constant during variation of load. The water for the buildings, including that necessary for cooling the valves, is drawn from wells sunk in the grounds of the stations. This arrangement is considered adequate for the purpose, but the commercial town supply is also available in case of emergency.

The studios located in the towns are housed in concrete fire-proof buildings of two stories. They also contain the general offices and reception rooms. Figure 5 shows the typical construction of the outside of the buildings, Figure 6 is a typical reception room, and Figure 7 shows part of the main studio at Sendai.

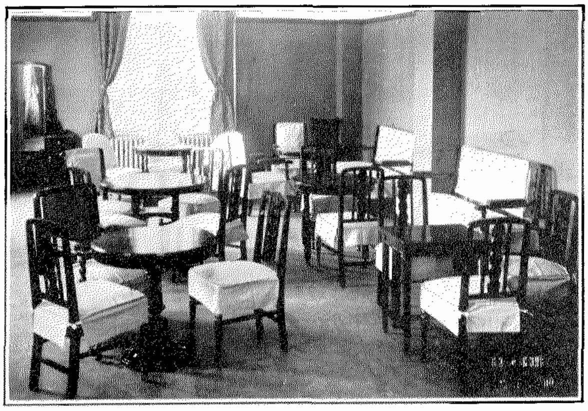


Figure 6—Typical Reception Room.

Two studios are provided, one large enough to accommodate a small orchestra and to be generally used for musical entertainment, and a smaller one for news bulletins, announcements, and lectures. The control room is between the two studios so that the operator has both under his immediate control. Here, again, battery supplies and the main part of the equipment are in duplicate.

Equipment

The radio transmitters installed are rated at 10 kilowatts in the antennae, and they are of a type representative of the latest production of

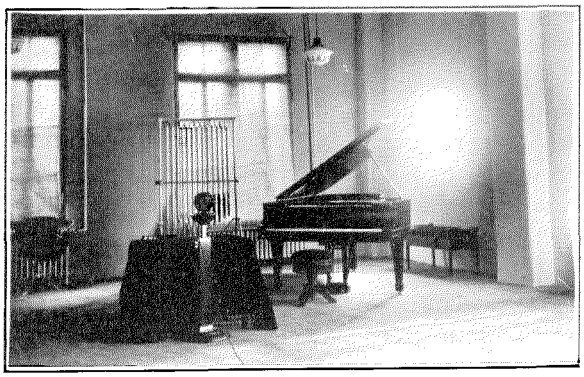


Figure 7—Part of Main Studio (Sendai).

Standard Telephones & Cables, Ltd. They employ low power modulation in conjunction with master oscillation control of the carrier frequency —with the well-known advantages. The equipment is of the dead front panel type. Figure 8 shows the front of the transmitter as installed at Hiroshima. The rear view, indicating the layout of the spare apparatus, is represented in Figure 9.

On account of the distance between the radio transmitter and associated studios, two sets of speech input equipment are provided with each station installation. That installed at the studio is the Standard ES-771 equipment, which includes the usual studio pick-up amplifier, volume indicating and control devices, and monitoring facilities for audibly checking the quality of the studio programme, either at the output of the studio amplifier or at the output of a radio receiving set tuned to the associated radio transmitter. Such a set is shown in Figure 10, embodied in the sections at the left. The section at the right includes the spare amplifier, volume control, and equalizer to meet local requirements, and is all wired up and available for emergency operation by merely throwing the necessary keys.

The second set of speech input equipment

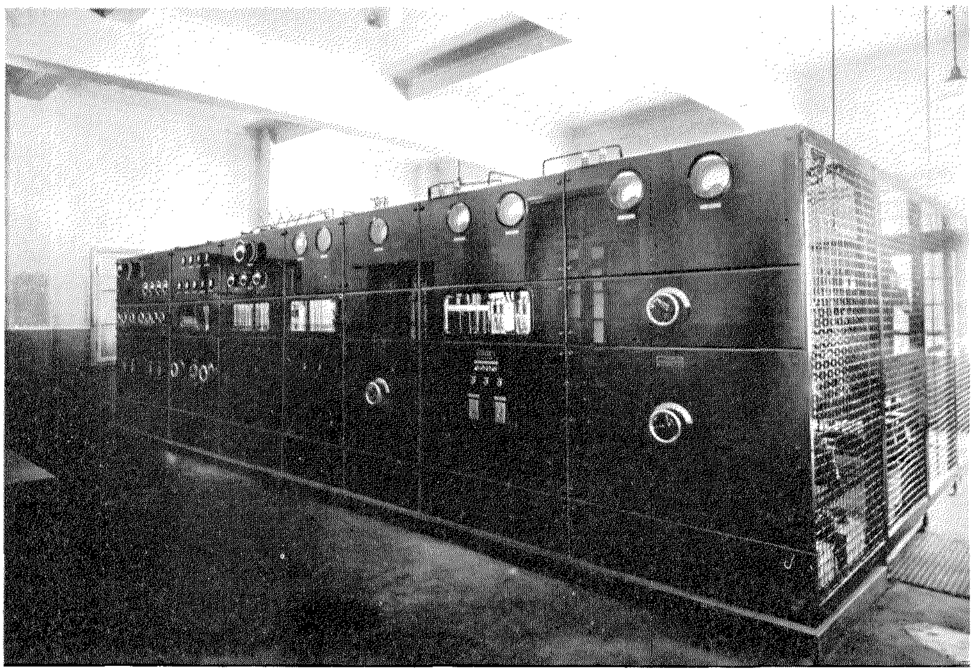


Figure 8—Transmitter, Front View (Hiroshima).

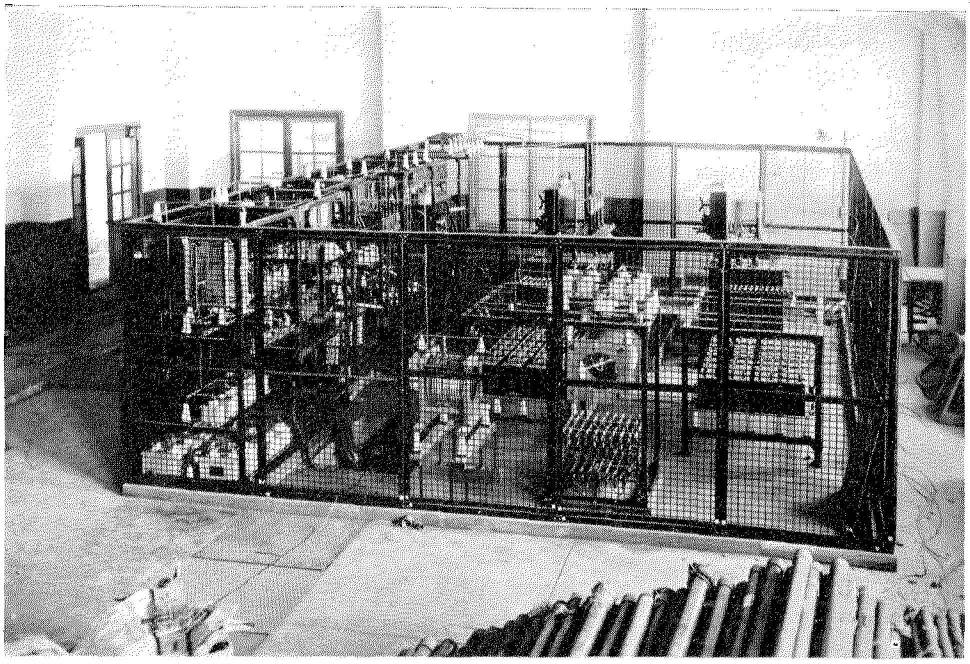


Figure 9—Transmitter, Rear View.

(ES-913-1) used at the radio transmitting station is generally similar to the studio equipment described above, except that the studio pick-up amplifier is replaced by a line amplifier inserted between the connecting wire line and the radio transmitter proper. While there is no provision for producing programmes at the radio transmitter station, nevertheless the amplifier equipment is arranged so that a microphone can be used for making emergency announcements. Figure 11 shows a typical equipment, including a spare amplifier and equalizer in the panel section at the right. The narrow intermediate section is a signalling panel manufactured locally and intended for use in conjunction with a special signalling system obtaining in all Japanese stations. The additional amplifying and signalling sections have been mounted in the common frame line-up for ease of control by the operator.

The method of operation between the studio and transmitter is so arranged that broadcasting is controlled from the studio. The preliminary adjustments are made by setting the volume in-

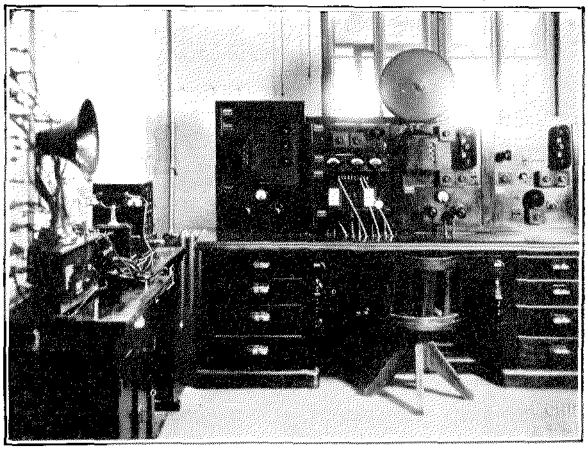


Figure 10—Speech Input Equipment.

dicator on the speech input equipment to an output energy of 2 decibels above reference level, or to the highest level possible without interference with the line. A steady tone is applied to the input of the speech amplifier and the amplitude of the tone is adjusted by the gain control potentiometers until a deflection of 30 divisions is obtained on the galvanometer. The steady tone is then transmitted to the radio transmitter via the line amplifier, and the gain control potentiometers on the line amplifier equipment are adjusted until the correct degree

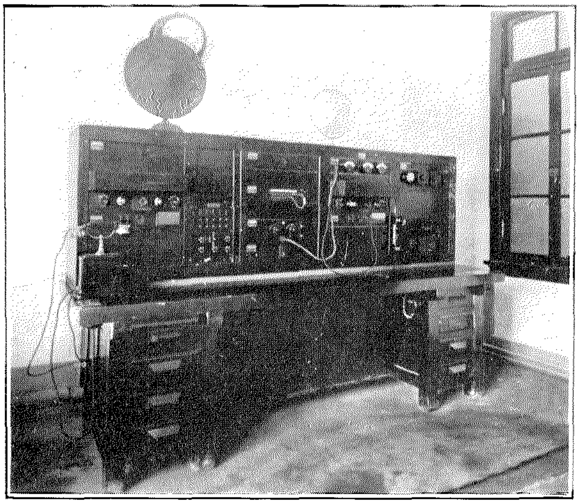


Figure 11—Line Amplifier Equipment.

of modulation is obtained, as indicated by the modulator valve beginning to show grid current. The line amplifier adjustment is then complete and any necessary control of the programme is made directly by the studio operator. A permanent record of this adjustment is obtained by adjusting the volume indicator until the standard deflection of 30 divisions on the galvanometer is obtained, and making a note of the gain control and volume indicator settings.

Antenna

The antenna system at each station is somewhat different. Sapporo and Sendai have antenna of the simple T type, the former with two wires in the flat top and two parallel single lead-in wires and the latter with four wires in the flat

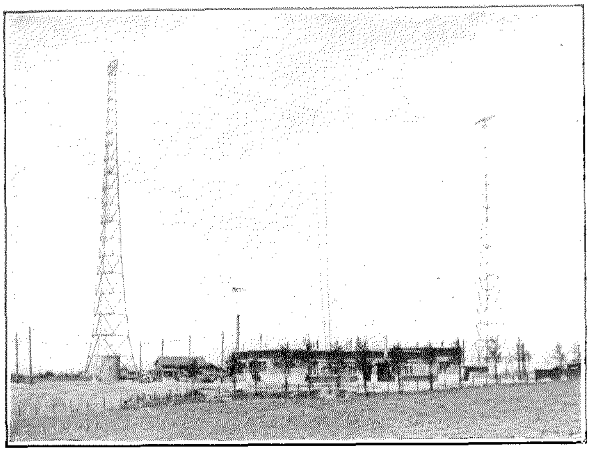


Figure 12—Sapporo Transmitting Station.

top and a centre down lead. Each antenna has a natural wave length above the operating wave length, and series condensers are necessary for tuning; the overall resistance of each antenna is large, but the efficiency nevertheless is high because the radiation resistance is high. At both stations an insulated counterpoise has been installed, and at Sendai a buried earth system is

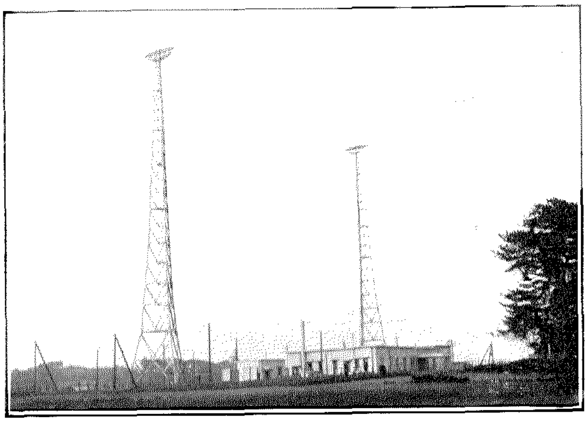


Figure 13—Sendai Transmitting Station.

also available. Counterpoise systems were installed at these stations because of the high resistance of the soil, especially at Sapporo, where the ground is frozen over for six months in the year; subsequent tests at Sendai, however, proved that under normal conditions the increase in resistance due to the earth system is more than counterbalanced by the loss in effective height due to the counterpoise. Figures 12 and 13 give general views of the respective stations and antennae.

At Hiroshima station (Figure 14) the antenna is of the multiple tuned type with three down leads. The centre down lead forms the lead into the transmitter and is connected to the antenna tuning inductance. The outer leads are connected to earth via tuning coils similar to the tuning inductance. One of these coils, in its housing, is shown in Figure 15.

The data tabulated below include main dimensions of each antenna. The heights are those at the masts, with the height of the counterpoise deducted, but without allowance for dip.

Station	Operating Wavelength	Length Flat Top	Height Actual	Type
Sapporo	361.4	42.4	47.4	Simple T type Counterpoise earth
Sendai	389.6	42.4	52.4	Simple T type Counterpoise earth
Sendai	389.6	42.4	60	Simple T type Buried earth
Hiroshima	353	70	35	Multiple Tuned 3 down leads Buried earth

N. B.—All measurements are in metres.

Simultaneous Broadcasting

In connection with plans of the Japanese Broadcasting Association for transmitting programmes from the more important cities where better musical talent is available and for making announcements of a public and semi-public nature, the services of the Nippon Electric Company were enlisted to prepare plans for a trunking system suitable for linking up all of the Japanese broadcasting stations. This linking-up of stations was accomplished and the service made available during the period of the Coronation Ceremonies which took place in Tokyo and Kyoto beginning the 6th of November, 1928, and lasting for the greater part of the month. By this means, many of the details of these important ceremonies and also the associated programmes were broadcast simultaneously throughout the Empire.

Hokkaido, with its broadcasting station at Sapporo, had, unfortunately, to be left out of the general scheme on account of the strait, some 60 miles in extent, which separates it from the main land. Telegraph cables crossing the straits are in existence, also some telephone circuits, but they are not of the type suitable for broadcast purposes. However, most of the programmes were successfully broadcast from the Sapporo station by having first been picked up from Tokyo at 345 metres or from Sendai at 390 metres and re-broadcast on the Sapporo wave length of 361.4 metres. Due to the intense national interest in the coronation proceedings, the services performed by the broadcasting stations during this period were of the utmost importance and a source of great gratification to the broadcasting authorities and of satisfaction to the owners of receiving sets.

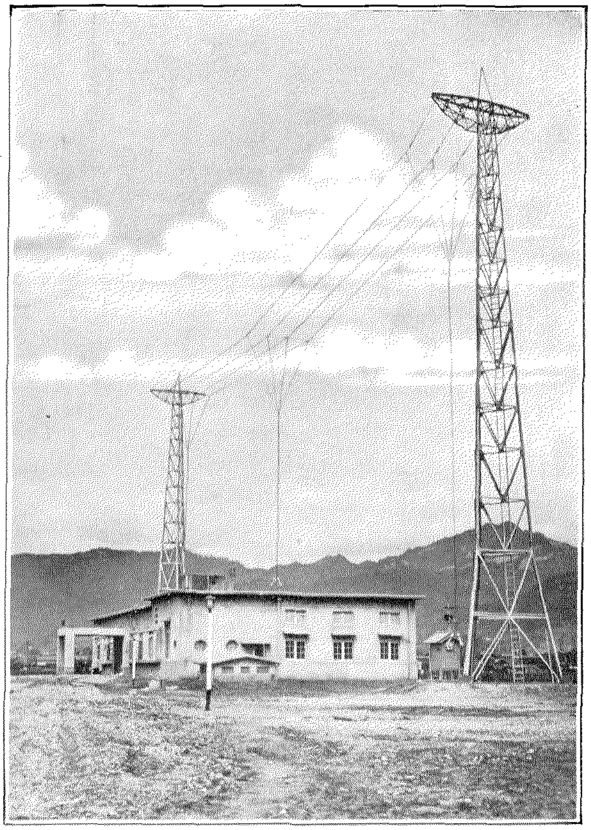


Figure 14—Hiroshima Transmitting Station.

Future Developments

Owing to the mountainous nature of the country, the signal strength from any station varies considerably with the locality, and there are a few large cities situated quite close to a broadcasting station where reception is very poor. Consequently, it is probable that the present main stations will be supplemented by small relay stations of two to three kilowatts capacity, provided there is sufficient demand for the service. It is probable also that the old one kilowatt transmitter at Nagoya will shortly be replaced by one of ten kilowatts, thus bringing it into line with the other high powered stations.

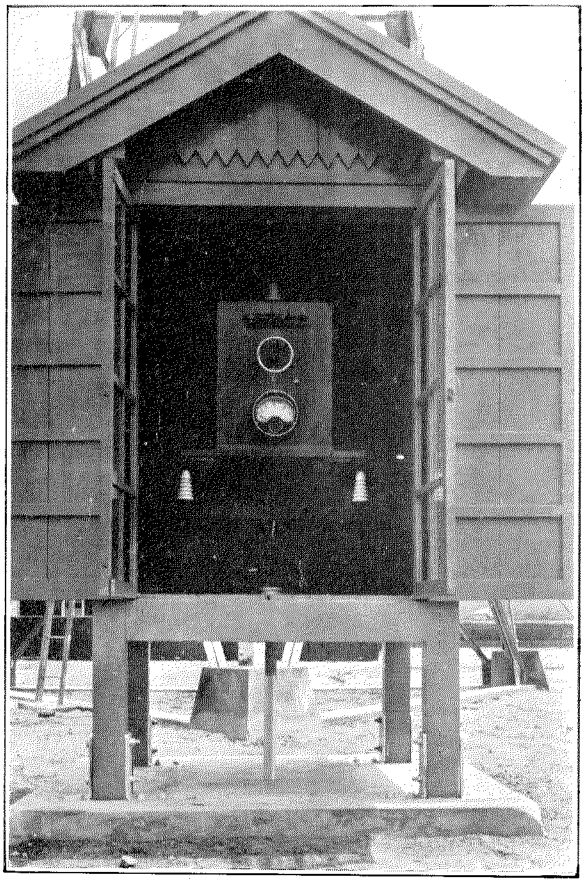


Figure 15—Antenna Tuning Coil and Housing.

High Efficiency Multiple Magneto Boards

By A. CAPEK

Bell Telephone Manufacturing Company, Antwerp

THE introduction of lamp signalling in the Local Battery (L. B.) system, coupled with the development of the Common Battery (C. B.) and Automatic systems, to a certain extent acted as a check on the intense development of magneto switchboards. Notwithstanding this competition from other systems, however, the magneto switchboard can still hold its ground in isolated or sparsely populated districts, or in territories where capital expenditure for a more expensive installation cannot be justified.

There are several reasons why this type of switchboard still remains popular with some operating companies. Its main asset, which remains always in evidence, is its simplicity, with the corresponding low cost, and easy and inexpensive maintenance. To this feature may be added the possibility of using the existing L. B. subscriber sets, which need not be replaced by other types. The transmission with L. B. subscriber sets is, furthermore, of high quality and independent of the length of the subscriber line so far as the talking battery supply is concerned.

The independent transmission battery supply, in connection with a hand-generator located in the subscriber set, makes it possible also to use longer subscriber lines, or lines of higher resistance (iron wire) than is advisable in any other system depending upon the central office for talking and signalling current.

Because of the wider operating limits obtainable through the location of the talking battery supply and the signalling generator in the subscriber premises, magneto boards are well adapted for successful operation even with a low grade line plant and are less affected by poor line insulation than are other systems with centralized power supply. This advantage is offset to some extent by the necessity for maintaining primary cells in the subscriber sets in good condition; but the high maintenance cost incurred thereby has been reduced to a considerable extent in the last few years through improvement in the manufacture of dry cells and the general introduction of motor transport for maintenance work.

Another advantage of the magneto boards—at least of those of the simpler type using drops instead of lamps and relays—is that they do not require any power plant, a few primary cells being sufficient to supply the operator's transmitter current. This merit has been of considerable value because, as a rule, magneto boards have been installed where power supply was not available.

The desire to operate magneto exchanges without central power plant caused delay in the introduction of new features, because these new features, involving as they did, new apparatus, mainly relays, would have meant the addition of central power plant.

This attitude of operating companies against the use of relays and lamps in magneto boards is now a thing of the past. The expansion in activity of the electricity supply companies in all countries, in conformity with the general use of accumulators for radio sets, overcame the hesitancy against power plants, and thus opened the way for improved L. B. systems.

The serious handicap to progress in this direction was removed just at the time when improvements in the C. B. boards brought a demand for operating improvements in magneto boards.

It should be understood that there is no tendency at the present time to incorporate in boards for magneto exchanges all the features adopted for the high-efficiency C. B. boards—even if this were possible. This would be going too far, and it would even destroy the most valuable feature of the magneto boards, *i. e.*, their simplicity and low first cost.

The problem facing the engineer resolves itself into selecting operating features such as will increase the efficiency of the magneto board as much as possible for minimum additional apparatus.

Investigation showed that it would be better to develop two different types of such boards—the first without and the second with toll preference facilities, in addition to some features common to both. These two types, known as the No. 2702-A and the No. 2703-A, respectively, are described herein, with the common and distinct features separated.

The 2702-A embodies bridging-type listening keys in the cord circuits with common ring-back and splitting keys in the operators' circuits, calling lamps associated with the multiple jacks, ring-back signal, automatic or manual metering and common party-line ringing keys.

The 2703-A type provides the same facilities and in addition gives flashing signals for toll preference calls, special busy tone on toll connections, automatic peg count, alarm signal in case of advance plugging, and cut-off keys for toll multiple lamps.

Reproductions of photographic views of the high efficiency magneto board are shown in Figures 1 to 4, inclusive.

(A) Common Features.

The features selected for both types are as follows:

(a) *Bridging type of listening keys* for the cord circuits, with common ring-back and splitting keys (or also common monitoring keys) in the operator's positional circuit.

One of the much appreciated features of the magneto boards is the possibility of using the universal cord circuits both for local and for rural or toll connections. A standard magneto cord circuit does not meet all the requirements which a good toll cord circuit must fulfill as it does not contain splitting keys to enable the operator to disconnect a calling subscriber from her telephone set during the time she is preparing a toll connection. It also does not contain a monitoring key to enable the operator to listen-in on a toll connection without disturbing it.

In the magneto boards herein described, this deficiency is corrected in a very simple manner by using the bridging type of listening key. This key, in the operated condition, connects the two ends of a cord circuit to common apparatus in the positional circuit with the operator's telephone set in bridge, and does away with the need for apparatus individual to the cord circuit. By this means it is easy to provide not only common both-way splitting or monitoring keys, but if necessary, also common coin collecting keys. This arrangement makes it possible also

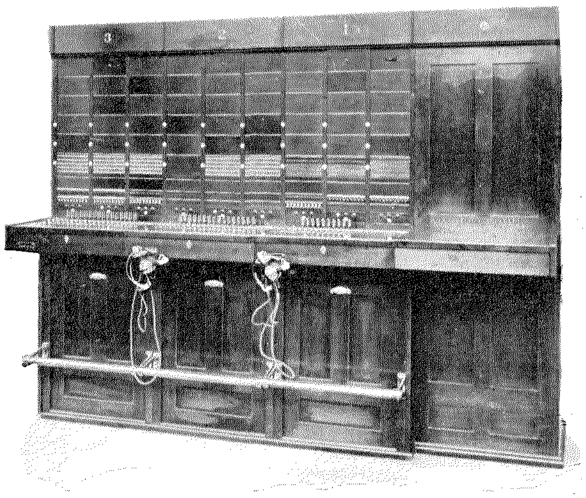


Figure 1—Front View of High Efficiency Magneto Board.

to provide a common ring-back key per position and not individually for every cord circuit, as is required in the standard magneto board. The slight additional cost of the new cord circuit—due to the additional contact springs of the bridging listening keys, and to the new common monitoring and splitting keys—is more than balanced by the saving on the individual ringing keys. In effect, therefore, this additional feature of the high efficiency magneto board does not increase its cost, but makes it better adapted for universal service.

(b) *Multiple line lamps, associated with the multiple jacks.*

In a multiple line lamp system, all subscriber calls may be answered by any of the exchange operators. This circumstance reduces the waiting time and makes it possible also to increase the operator's load—especially in case of larger multiple boards, with their large team of operators, who are in a position to answer any call.

This higher operator's load therefore enables the operating company to save a certain percentage of operator's positions required for a given traffic. Furthermore, with boards of this type, the answering jack cable is not required, and the intermediate distributing frame is unnecessary. This feature simplifies the lay-out as well as the cabling and installation, and saves floor space at the same time. It also dispenses with the line pilot lamps which are usual with systems using separate answering jacks.

(c) *Operator's bar.* In case of multiple line lamps, it may happen that two operators try to answer a subscriber's call at the same time. It is therefore necessary to arrange the circuits in such a way that only one operator gets connected to the calling subscriber after the insertion of the plug and the throwing of the listening key, so that the second, or any subsequent operator who plugs in, remains disconnected and receives at the same time some sort of a warning signal as to what has happened.

It has been found possible to do this by means of only two common relays in the operator's circuit. This arrangement is used in the simple type high efficiency magneto board No. 2702-A, (Figure 5), which does not require any additional relays in the cord circuit to meet all the new requirements herein specified.

The second and more complicated type of the high efficiency magneto boards (No. 2703-A) constitutes another solution of this problem, making use of additional relays required for the toll break-down flashing feature peculiar to this type of board.

(d) *Ring-back signal* during the time the operator is ringing up the called subscriber. This feature is of considerable importance to the operator, as it eliminates most of the unnecessary re-calls on the part of the calling subscriber, who usually wishes to have his party rung again, if he does not get a prompt answer. The equipment needed for this purpose is really insignificant, as only a small condenser common to the position, in addition to some contacts in the ringing or listening keys, is required.

(e) *Automatic or manual metering.*

A special type of automatic operation of the subscriber's register may be provided with either of the two types of boards, if required. These meters count the total of all calls (including ineffective), and are operated automatically during the time the ringing keys are thrown. Since they lock as soon as they are operated, the successive re-rings cannot actuate them a second time.

In countries where this method of metering is used, it is customary to give the subscriber a certain discount on all the calls recorded in this way, (from 25% to 35%), to compensate for ineffective calls. This practice is very popular with the subscribers, and it saves a considerable amount of trouble to the operating companies.

If only effective calls are to be counted, it is necessary to operate manually in the well-known way, by means of meter keys associated with the cord circuits. Unless the L. B. subscriber sets are changed so as to enable the subscriber to give automatically a supervisory signal to the operator, it is not possible to let the subscriber meter automatically—that is, to have the meter energized as soon as the calling subscriber takes the receiver from the hook.

(f) *Adaptability of the boards for C. B. operation.* The subscriber's line circuit relays on these L. B. boards are so arranged that they may be changed later, if required, to C. B. operation, by simply re-strapping their soldering terminals. Furthermore, the cord circuit apparatus may be connected to terminal strips at the rear of the board, and the cord circuit relays can be placed on a separate rack to make a corresponding change possible with the sections.

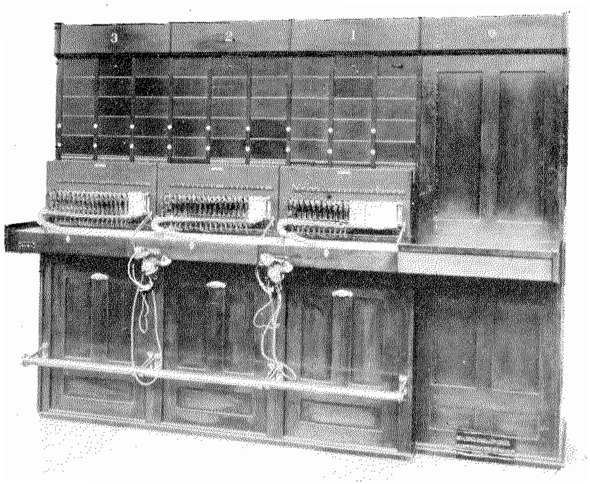


Figure 2—High Efficiency Magneto Switchboard—Key Shelves Raised.

(g) The cord circuit clearing-out lamp is extinguished by the operation of the listening key in the usual way.

(h) Common party-line ringing keys may be inserted in the positional circuit if required (they are shown only for the No. 2703-A board). These keys are to be operated in connection with the operated listening key.

(i) Ringing pilot relays with ringing pilot lamps are provided in both types of these high efficiency L. B. boards.

(B) Distinct Features

The additional features applied to the more complete and more expensive board of the type No. 2703-A are the following:

(j) *Flashing signals for "toll preference calls."*

The positions are equipped with a common toll break-down key, which enables the operator to start a flashing signal at another position in case a local connection is to be broken down to give preference to a toll call. This signal appears

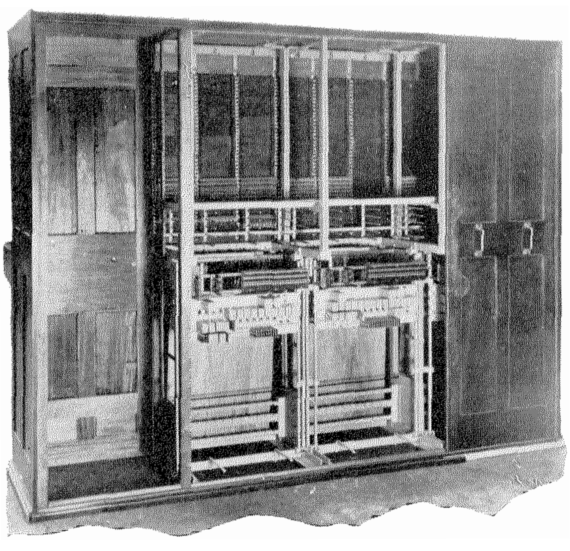


Figure 3—Rear View of High Efficiency Magneto Switchboard.

on the supervisory lamp at the "local busy" position where the subscriber required for a toll connection is talking.

A toll call may be offered to the subscriber before breaking down the local connection, if the operating rules allow this practice ("toll offering").

(k) *Special busy tone on toll connections.*

If a subscriber is connected to a toll line, a "toll line busy" tone is applied to the sleeve conductor of his line, so that the operator may distinguish if the tested line is "local" or "toll busy." To make this possible, and still to keep the simple type of cord circuit for both local and toll service, it is necessary that the line circuits used for toll lines have their sleeve conductors connected to a common tone test coil.

(l) *Automatic peg count for both effective and ineffective calls.*

The counting takes place at the time that the subscriber's meter registers.

(m) *Alarm signal in case of "advance plugging."*

In a multiple line lamp board there is no reason for an operator to plug out a second call before she is through with the first one, as there are always other operators who may answer such a call more promptly. The 2703-A board is therefore arranged in such a way that if an operator plugs out a call, but does not answer it, *i. e.*, does not throw the listening key, the supervisory lamp flashes. This signal calls attention to overlapping calls, and helps to eliminate them.

(n) *The clearing out lamp is automatically extinguished* by the withdrawal of the answering plug, and does not require the prior operation of the listening key, as is the case with the 2702 type board

(o) *Cut-off keys for toll line multiple lamps.*

Such keys may be provided if required by the operating company, in case it is advisable that toll calls should be answered on some of the positions only.

Capacity of the Switchboards

These boards are built in two sizes:

(1) A small type, with a low keyshelf (790 m/m from the floor) allowing the use of standard height chairs.

These boards are one-position three-panel sections with a capacity of 400 jacks and lamps per panel, *i. e.*, with a total capacity of 2,400 lines in case of a six-panel multiple.

(2) A larger type, with a high keyshelf (980 m/m from the floor) and necessitating the use of high chairs for operators.

These boards are also arranged for one-position and three-panels, and have a capacity of

600 pairs of jacks and lamps per panel, *i. e.*, a total capacity of 3,600 lines with a six-panel multiple, and 5,400 lines with a nine-panel multiple.

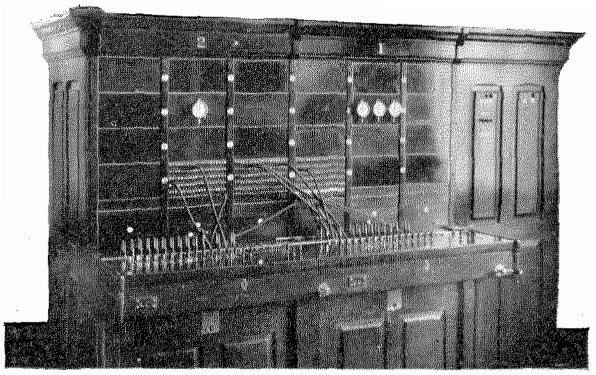


Figure 4—Another Front View of a High Efficiency Multiple Magneto Board.

In both types there is sufficient space at the bottom of the subscriber multiple field for toll or rural lines or for other miscellaneous circuits.

Power Plant

The current consumption for both types of high-efficiency magneto boards is very small; a three-minute conversation in the 2702-A type requires but 0.1 ampere-minute, and in the 2703-A board 0.4 ampere-minute. A small and inexpensive power plant is therefore sufficient. For example, a 500 line exchange with 10 three-minute calls per day, per subscriber, needs only 8.3 ampere-hours for 24 hours in case of 2702-A boards, and 33 ampere-hours with the 2703-A board.

Primary cells may be used for the 48 volt battery for the operation of the subscribers' service meters.

Operation of the 2702-A Board (Circuit Figure 5)

(a) *Subscriber* (local, rural, or toll) calls and rings up the line relay LR, which operates and lights the multiple line lamps.

(b) *One of the operators answers* by inserting the plug AP and throwing listening key LK. This action splits the cord circuit, closes the sleeve circuit over relay COR and the common marginal relay ABR (both operate), and applies a busy test potential to the third conductor of the calling line. The message register MR will not meter because the potential available is not yet high enough.

The energized COR relay disconnects relay LR from the line, opens its locking winding and thus releases it, so that the multiple line lamps are extinguished.

The relay ABR pulls up over both windings in series, and locks over its low resistance, thus shunting its first winding.

The calling subscriber is now connected through to the operator and can give his order.

(c) *The operator tests* for "busy" with the CP plug in the usual way and the current flows, if the called line is occupied, from the tip of the plug over one of the 48,000 ohms resistances of the operator circuit to ground, thus changing the potential of the condenser C_1 and causing the usual click in the ear.

(d) *Operator plugs in* (connects) with plug CP if the line is free, and restores LK. The insertion of this plug makes the called line "busy" and energizes the COR relay of the called line in series with the resistance in the cord sleeve. The operator now throws the combined ringing and listening key in the ringing position, and ringing current is applied to the line from a hand generator, a pole changer or a ringing machine. The ringing pilot relay RPR is energized, if the circuit is not open, and the lamp RPL lights. At the same time, the meter of the calling subscriber is operated by a 48 volt potential applied to the sleeve conductor of his line, and holds over a second winding.

During the ringing period a part of the ringing current is sent back over the condenser C_4 to the calling subscriber, thus notifying him that his party is being rung, and obviating any unnecessary re-calls of the operator.

(e) *As soon as the called* subscriber answers, the conversation may start, but there is no further circuit change.

(f) *If the calling subscriber rings off* at the end of the conversation, the clearing out relay CR pulls up, locks over its holding winding, lights the clearing out lamp CL, and also the pilot lamp PL over the pilot relay.

(g) *The operator listens on the cord* in order to determine whether both subscribers have rung off. The throwing of the listening key opens the

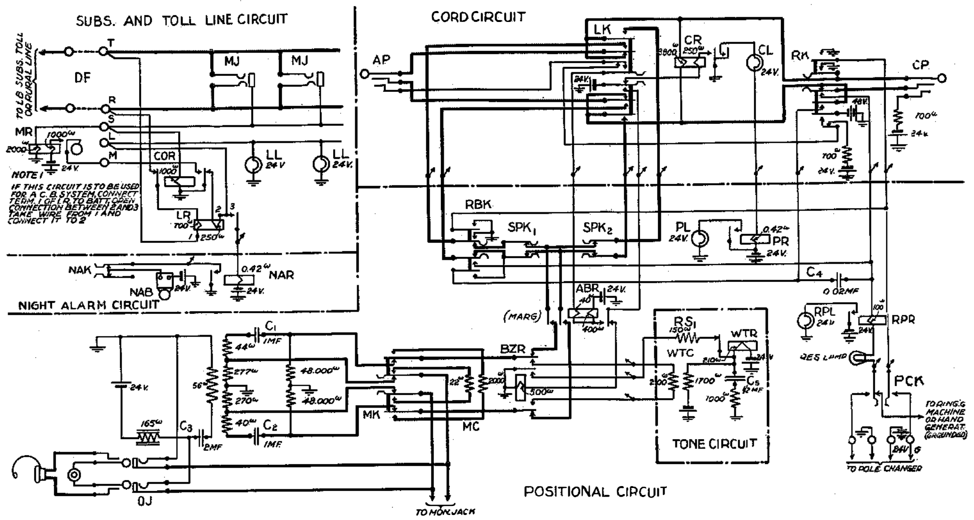


Figure 5—Circuits of No. 2702-A Board.

locking winding of relay CR so that it releases and the lamp CL is extinguished.

The operator takes the connection down and all apparatus returns to normal.

Special Cases

(h) *A second operator answers* a call, but is late. In this case the two windings (in series) of the relay ABR of this operator are shunted by the low resistance winding of the corresponding relay of the operator who answered more promptly, and it does not therefore pull up. However, a circuit is closed for the common relay BZR (over a contact of the operated listening key and a back contact of ABR) so that relay BZR is energized and a buzzer tone is connected to the operator's receiver, notifying the operator that the call has already been attended to.

(i) In case the operator finds the called line busy during the busy test she informs the calling subscriber of the fact, and takes out the answering plug.

(j) If the operator wishes to ring over the answering plug to call the local subscriber back for a rural or toll connection, or for some other reason, she throws the common ringing-back key RBK, taking care that the listening key of the particular cord circuit is in the operated position.

(k) If the operator wishes to talk with a subscriber without being heard by the other party, she throws the common splitting key to position SPK_1 or SPK_2 in addition to the listening key. This operation is, as a rule, required during the preparation of a toll connection.

(l) For monitoring purposes, the common monitoring key is operated. This key disconnects the operator's transmitter, and connects the receiver to the secondary winding of a special monitoring repeating coil. The operator is thus able to follow the conversation without making the line noisy and without impairing transmission.

Operation of the 2703-*A board* (*Circuit Figure* 6):

(a) Subscriber (local, rural, or toll) calls and rings up the line relay LR, which operates and lights the multiple line lamps.

(b) *One of the operators answers* by throwing listening key LK and inserting plug AP. This action splits the cord circuit, closes the sleeve circuit over relays COR and SR_1 (which operate) and applies a busy test potential to the third

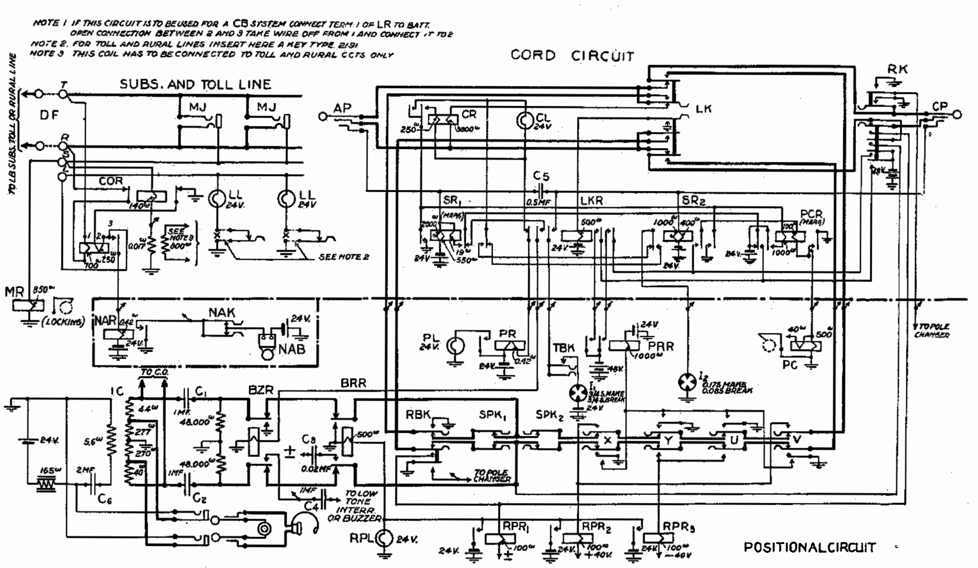


Figure 6—Circuits of No. 2703-A Board.

conductor of the calling line. The message register MR will not meter, because the current available is not yet large enough. The energized COR relay disconnects relay LR from the line, opens its locking winding, and thus releases it, so that the multiple line lamps are extinguished.

Relay SR_1 operates over its high resistance winding, and locks over its low resistance winding, thus shunting it. The listening relay LKR is also energized.

The calling subscriber is now connected through to the operator and can give his order.

(c) *The Operator tests* for "busy" with the CP plug in the usual way and current flows, if the called line is busy, from the tip of the plug over one of the 48,000 ohms resistances of the operator circuit to ground, thus changing the potential of the condenser C_1 and causing the usual click in the ear.

(d) *Operator plugs in* (connects) with plug CP. The insertion of this plug makes the called line "busy" and energizes the sleeve relay SR_2 in series with the COR relay of the called line, thus disconnecting the LR relay.

If the operator restores LK and now operates the combined ringing and listening key in the ringing position, the ringing current is sent over the line, and the peg count meter PC operates. As soon as its armature is attracted, a low resistance shunt is placed across its high resistance winding, which increases the current in the circuit, so that relay PCR operates. This relay locks itself and disconnects the peg count meter.

The operation of the ringing key also places a 48 volt potential on the line message register MR over a front contact of relay PCR and over the low resistance winding of relay SR_1. The meter operates and is held operated until the connection is taken down at the end of the conversation.

As long as the ringing key is thrown, the ringing pilot relay RPR_1 is energized and the lamp RP is illuminated. At the same time relay BRR is in the operated position, and a part of the ringing current is sent back over condenser C_3, to the calling subscriber, thus notifying him that his party is being rung and obviating any unnecessary recalls of the operator.

NOTE: In case of party-line ringing, one of the keys X, Y, U, or V is depressed (with listening key thrown), in which case the relay PRR operates. This relay applies 48 volt potential to the peg count, as well as to the subscriber meter of the calling line, which are both energized in the same way as if only the single party ringing key RK is thrown. During the operating of one of the party line ringing keys, either RPR_2 or RPR_3 relay operates, and with it also relay BRR, and ringback signal is sent again to the calling subscriber over the contacts of the listening key.

(e) *As soon as the called* subscriber answers, the conversation may start.

(f) *If the calling subscriber rings off* at the end of the conversation, the clearing out relay CR operates and locks over its holding winding, and lights the clearing out lamp CL, as well as the pilot lamp PL over the pilot relay PR.

(g) *Operator now takes down* the connection, and this action releases the COR relay as well as relays SR_1 and SR_2. The relay SR_1 opens the locking winding of relays CR and PCR which both release and extinguish lamp CL. The operator may of course listen in on the connection before taking it down, to be sure that the conversation is really finished. The operation of the listening key in this case also extinguishes the clearing-out lamp.

Special Cases

(h) *A second operator answers* a call but is late. In this case the high resistance winding of the relay SR_1 of this cord is shunted by the low resistance winding of the SR_1 relay of the first operator, so that it does not operate. But relay LKR is energized and closes a circuit for the common relay BZR so that it operates also, and connects a tone to the operator's receiver, notifying the operator that the call has been attended to.

(i) In case the operator finds the called line "busy" (during the "busy" test) she informs the calling subscriber of this fact, and takes the answering plug out.

(j) If the operator wishes to ring back over the answering cord to re-call the subscriber in case of toll calls, etc., she depresses the RBK key with listening key thrown.

(k) If the operator wishes to talk with a subscriber without being heard by the other party she throws the common splitting key to position SPK_1 or SPK_2 in addition to the listening key. This operation as a rule is required during the preparation of a toll connection.

(l) If a subscriber is connected to a toll line, a special "toll busy test" is applied to this sleeve conductor from the sleeve of the particular toll line over the cord circuit sleeve and the condenser C_5. The operator testing for "busy" on such a "toll busy" line, will therefore recognize this special "busy" condition, and will know that she cannot break such a connection for another preference call.

(m) If the operator preparing a toll connection finds the wanted local subscriber "busy" on a local call, and wishes to break it down, she inserts the calling plug in the multiple jack of his line, operates the common splitting key SPK_1 (leaving the listening key thrown) and informs the local subscribers that the conversation will be broken for a toll connection. Thereafter she momentarily operates the toll breakdown key TBK. This places 24 volt potential over an interrupter on the sleeve of the CP plug, and short circuits intermittently the relay SR_2 of the associated cord circuit, as well as the SR_2 or SR_1 relays of the local cord circuit on which the wanted subscriber is "local busy."

The repeated release and operation of relay SR_2 in the "home" cord circuit remains without any influence as long as the listening key is thrown but the similar operation of relays SR_1 or SR_2 in the "local busy" cord circuit produces an interrupted flash of the CL lamp with pilot lamp PL and thus notifies the local operator that one of the subscribers connected up is required for a toll connection.

The "local busy" operator then takes down the local connection.

NOTE: The operator may, of course, offer a toll call to the subscriber, who is talking locally, if the operating rules allow this practice. In this case, she talks with him over the connecting plug CP, and if the subscriber agrees to take the toll call, she operates the break-down key in the same way as just described, and flashes in this way the distant operator.

(n) If an operator plugs out a second calling lamp during the time she is attending to the first one (so called "advanced plugging") and does not throw the listening key, the CL lamp starts to flash with cord pilot lamp PL over the energized SR_1 relay.

Automatic Telephony in the Zürich Area

By E. WOLLNER

Bell Telephone Manufacturing Company, Antwerp

ZÜRICH was satisfactorily served for about thirty years by the Magneto Telephone System supplied by the Bell Telephone Manufacturing Company. Not until 1917, when the Swiss Administration decided to rearrange the grouping of the subscribers in this area, was it found necessary to provide more modern facilities. The Administration then introduced the Rotary Automatic System.[1] The number of subscribers was at that time increasing steadily. The population was over 200,000, and provision had to be made for future growth. Moreover, it was thought desirable to bring some of the more prosperous suburbs, such as Hoengg, Wollishofen, Altstetten, Oerlikon and Tiefenbrunnen, into closer relationship with the city. It was thereupon decided to form from the main city exchanges two twin-unit exchanges, i. e., Hottingen-Limmat and Selnau-Uto, and to provide five sub-offices for those suburbs.

The first in this series of automatic exchanges, i. e., the Hottingen office, began with the semi-automatic system, but three years after its inauguration, it was converted to full automatic working. Each of the exchanges now operates on a full automatic basis. A separate exchange was built for the accommodation of the equipment necessary for the toll service.

In the main exchanges, where two installations are accommodated in one building, a certain part of the equipment—i. e., the various distributing frames, the testing and monitoring apparatus and power plant—is common to both.

Traffic to and from the satellites, Wollishofen and Altstetten, is directed through the Uto main exchange. Traffic to and from Oerlikon and Tiefenbrunnen is directed over the Limmat main exchange. The fifth satellite, Hoengg, is served by the Hottingen office. The present and ultimate capacity of the five offices and satellites, and the numbering scheme of the subscribers, are given in Table I.

[1] G. Deakin, "No. 7-A Machine Switching System," *Electrical Communication*, Vol. III, No. 3, January, 1925.

The following is a short description of the various exchange equipments, and of some special circuits introduced to satisfy certain service requirements.

Equipment of Hottingen-Limmat Main Exchanges

Since 1920, when the Hottingen office was converted to full automatic operation, this twin-unit exchange has utilised the standard features of the Rotary Automatic System. Figure 1 is a schematic of the more important exchange equipment. The equipment is divided into three principal groups. The switches belonging to one of the groups serve the Limmat subscribers, those of the second group, the Hottingen subscribers, and the third group comprises equipment common to both of the exchanges. The Hottingen switching equipment is located on the third floor of the exchange building, the ground floor of the same building being occupied by the Limmat equipment.

The upper part of Figure 1 shows how, in the Hottingen exchange, one group of switches serves for communications with the other exchanges, and for the satellites. It shows the junctions from the Hoengg satellite connected to the arc of the second line finder. Junctions incoming from the other main exchanges are connected to the brushes of the second group selector. For outgoing traffic, distinction must be made between calls destined for Hoengg subscribers and those for the other main exchanges. The junctions outgoing to Hoengg are connected to the arc of the third group selector; those for the main exchanges to the arc of the first group selector.

The lower part of the same figure shows the interconnection of the various switches in the Limmat office. These correspond to the arrangement made for the Hottingen exchange with the exception that the junctions from two other satellites, namely, from Oerlikon and Tiefenbrunnen, are here connected to the arcs of the second line finders.

The equipment which serves for both the main exchanges is seen in the middle of Figure 1. This common equipment is not located centrally, but a part of it is installed on the second floor, and another part on the third floor of the building. It consists of the following parts:

One common distributing frame serves for the termination of the subscribers' lines and junction lines. It will be noted from Figure 1 that, whereas a separate intermediate distributing frame is provided for the Hottingen exchange, no such frame is provided in the Limmat exchange,where the latest method of cross connecting without a special frame is already employed, i. e., on the top of the final switchrack, terminal strips are mounted for cross connecting purposes, and the associated jumper wires are run through special rings. This arrangement effects economy in cabling, installation costs, and floor space. In the Limmat exchange, the switchboard side of the main distributing frame is cabled direct to the final terminals on the top of the switchracks, and not via the intermediate distributing frame as in the Hottingen exchange.

One desk is provided for testing purposes. Here, the lines coming from the test finals of both exchanges end in test jacks. In addition to this common equipment, a two-position outjunction test and monitoring desk is provided for the Limmat exchange. The junctions outgoing from the Limmat exchange are tested on this desk, where, in addition, false calls are dealt with, and register guard-lamp circuits indicate hold-ups on the registers.

Equipment of the Selnau-Uto Main Exchange

In the second of the twin-unit exchanges in the Zürich Area the latest design and arrangement of apparatus has been installed, and since no restriction was made as regards accommodation and no consideration of existing plant was necessary, the exchange was laid out in conformity with the latest practice.

A description of the exchange equipment has already been published by Mr. P. Schild,[2]

[2] *Bulletin Technique de l'Administration des Télégraphes et des Téléphones Suisse,* Année V. No. 4.

TABLE I

MAIN EXCHANGES

	Normal lines installed	P. B. X. Lines	2-Party Lines	Total of installed lines	Ultimate capacity	Numbering
Selnau / Uto	7447	1624	4	9075	8000 / 4000	S1000—S9999 / U1000—U3999
Hottingen	8527	341	132	9000	9600	H1000—H9599
Limmat	1323	125	40	1488	3000	L1000—L3999

SATELLITES

Hoengg	218	2	—	220	300	H9600—H9899
Wollishofen	467	15	—	482	550	U4000—U4549
Altstetten	239	2	—	241	350	U5000—U5349
Oerlikon	466	23	90	579	600	L8000—L8599
Tiefenbrunnen	560	13	52	625	700	L9000—L9699
Total	19247	2145	318	21710	27100	

giving details of the apparatus employed and the location of the various racks.

Figure 2 represents the junction diagram of the exchanges. The upper and lower parts show

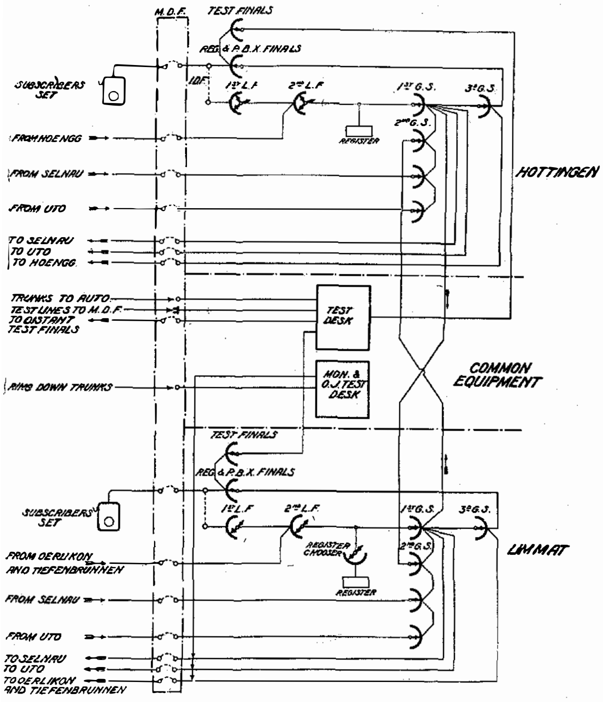


Figure 1—Junction Diagram of Hottingen-Limmat Main Exchanges.

connections of the Selnau and Uto switches, respectively. The middle part indicates the equipment common to both exchanges.

Both of these exchanges employ the same type of equipment, the only difference being that in conjunction with the Uto office two satellites—Altstetten and Wollishofen operate—but no satellite is connected to the Selnau office.

The connection of the subscribers with other exchanges and satellites is accomplished in the same manner as explained for the other main offices. The switchracks and the service observation desks are located on the second floor of the building. The main distributing frame, the message register bays and wire-chief's desk occupy the first floor. It was necessary to provide a certain amount of common equipment which could not have been conveniently divided between the two exchanges—for example, the main distributing frame and the desk equipment.

The service observation desk is provided for observing calls originating at the exchange. For this purpose a panel of jacks, equipped with one jack for each first line finder, is mounted on the end of the line finder switchrack. Each jack is wired into the circuit between the first and second line finder. A further group of jacks, wired to the service observation desk, is mounted below the panel of line finder jacks, the groups being multiplied. Thus, by means of patching cords any line finder jack can be connected to any jack in the other group, and placed under observation; or, in a similar manner, a group of line finders may be observed.

The equipment of this observation desk contains, in addition to the observation circuits,

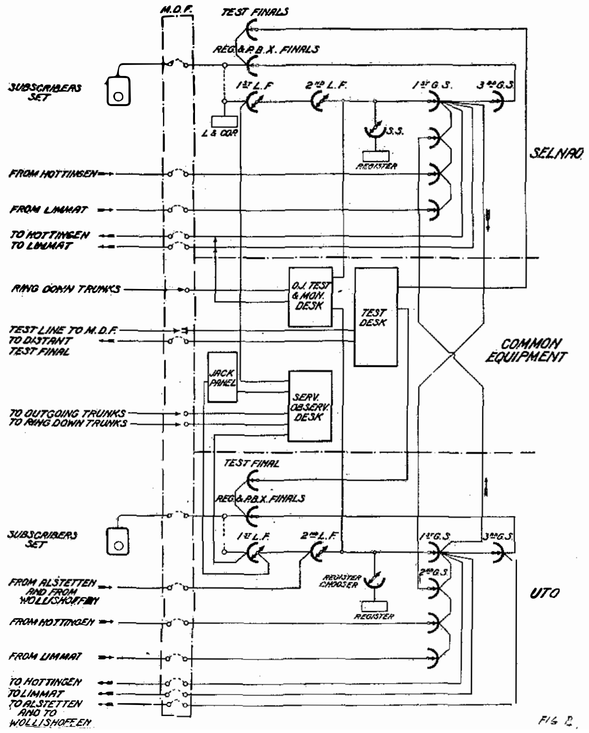


Figure 2—Junction Diagram of Selnau-Uto Main Exchange

means for verifying the number dialled by the subscriber. It also contains jacks connected to idle terminals in various line finder groups, to enable the attendant to make what are termed "spy calls." This equipment allows the Administration officials to collect data concerning the quality of the service offered, at various periods of the day.

The wire-chief's desk, which is also common to both exchanges, is located close to the main distribution frame. This desk is provided with the necessary jacks for outgoing, incoming and ringdown trunks, together with jacks connected to the brushes of the test finals. Voltmeter and telephone circuits enable the wire-chief to carry out the necessary tests.

Equipment of the Satellite Exchanges

The switching arrangements in each of the five satellite exchanges are, with small deviations, the same. Figure 3 is a typical junction diagram of one of the satellites. It will be seen that incoming calls from the main exchanges are directed over a trunk terminating at a final selector in the satellite exchange. The outgoing calls to the main exchange, of which the satellite forms a sub-group, are established in the same way as for subscribers connected to the main exchanges, with the difference that only a certain number of the switches are located in the satellite. As indicated in Figure 3, the outgoing trunks are connected to the brushes of the first line finder at one end. They terminate at the other end on the arc of the second line finder in the main exchange.

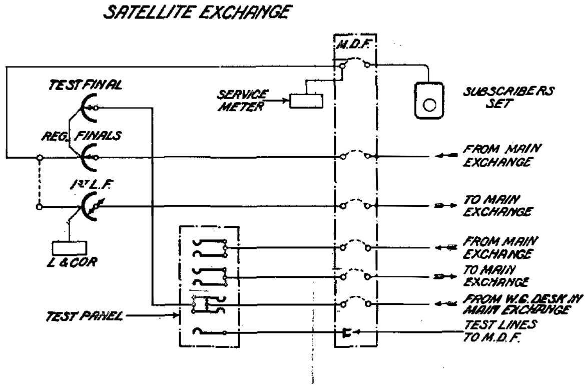


Figure 3—Junction Diagram of a Satellite Exchange.

In addition to the finals serving each group of 200 subscribers, one test final is included per final group at each of the satellite offices. By means of these special test finals, the wire-chiefs at the main exchanges may test the internal and the external equipment associated with any satellite-subscriber's line. The circuit also provides facilities whereby the test final selectors may be set to a line on any level and then stepped round by means of a stepping key to any of the remaining lines on that level. This feature proved to be valuable for routine testing.

In addition to the above, a small test panel equipped with voltmeter testing circuit, lines to main frame, etc., is provided for each of the satellite exchanges. This panel is essentially designed for carrying out routine testing at the satellite exchange or for testing on lines terminating at the main frame, but not jumpered to the exchange equipment.

One group of final selectors is arranged to give facilities for the connection of P. B. X. trunks and for hunting over groups of trunks.

No separate intermediate frames are employed in the satellite exchanges, all cross connections and distribution of the lines over the groups of line finders being done on the switchracks.

The line finders have a capacity of 100 lines per arc and are mounted on bays, together with the associated circuit relays and line and cut-off relays for that particular group of 100 lines. The line finders and relays are then connected by means of a local cable to the terminal strips at the top of each bay. These terminal strips correspond to those normally equipped on the vertical, or "answering," side of an intermediate distributing frame (I. D. F.). In a similar manner, terminal strips are mounted on the top of the final selector bays. These terminal strips correspond to the horizontal, or "multiple," terminal strips of the I. D. F. The cross connections are made by triple jumper wire between the terminal strips of final selectors and the terminal strips of the line finders of the switchrack.

This scheme offers maximum economy in cabling, since in addition to the fact that no intermediate frame or line relay racks are required, the runs of the switchboard cable from I. D. F. to line finders, I. D. F. to final selectors, and I. D. F. to line and cut-off relays, are now replaced by simple local cable forms on the switchracks.

Power Plant Equipment

Each of the twin-unit main exchanges has a common power plant. The original power plant of the Hottingen exchange was designed for use with the semi-automatic working of the exchange. At the time the exchange was converted to full automatic operation, the power plant underwent some modifications. The battery voltage was raised from 24 volts to 48 volts, and the "ringing tone" was introduced, i. e., provision was made in the power plant to give an audible signal to indicate to the calling subscriber that the called party was being rung.

The power plant supplied for the Selnau-Uto exchange is more nearly typical of modern installations. Figure 4 shows the fundamental charging circuit, the auxiliary circuits being omitted for the sake of simplicity. One main storage battery is provided for both of the exchange current-drains. If the exchanges grow beyond the capacity for which they were planned, this battery may be supplemented by a second battery of suitable size. The battery consists of 25 cells, the last cells being used as end cells for the regulation of the voltage. Two voltage regulating end cell switches are provided, one hand-operated switch in the charging machine circuit and one automatically-operated regulating switch in the exchange load circuit; the former is used to prevent the end cells, which are rarely used, from being continually overcharged.

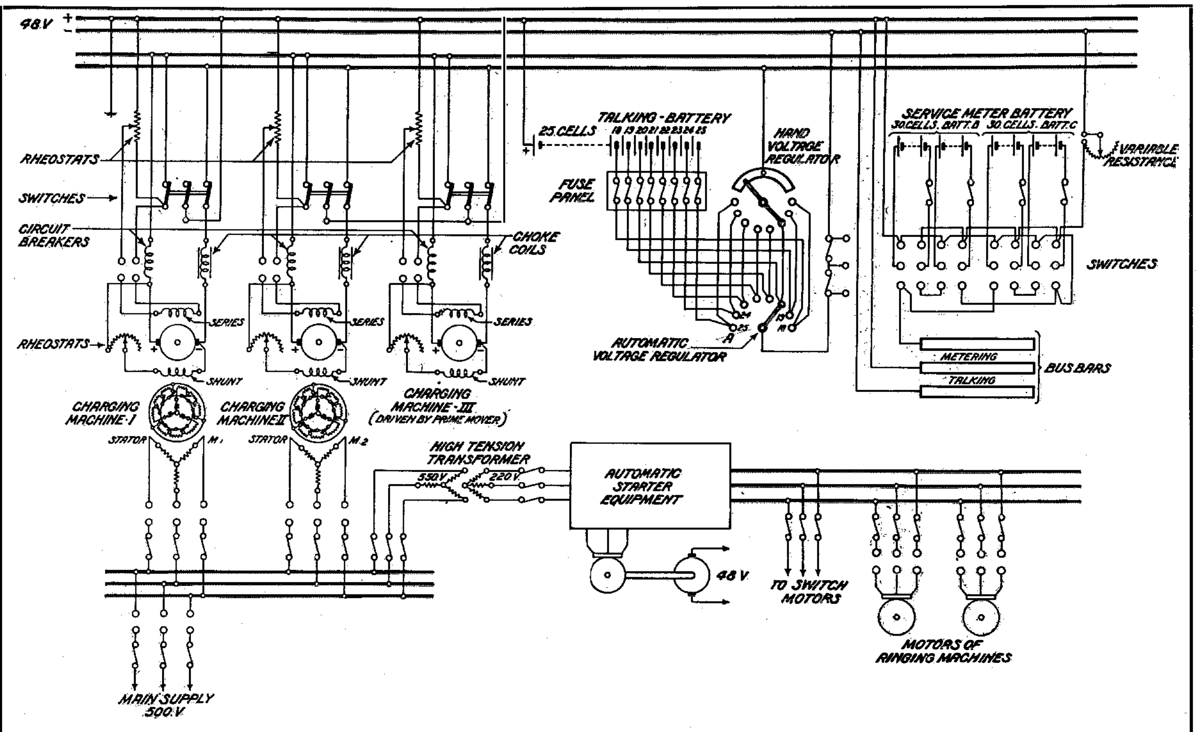


Figure 4—Charging Circuit of Selnau-Uto Exchange.

The automatic switch in the discharge circuit maintains the voltage at the bus-bars at 48 ± 2 volts. For the operation of the message registers, a separate battery (with a duplicate as reserve), consisting of 30 cells, is connected to the 48 volt bus-bars in such a way that there are obtained at the message register bars about 100 volts, the value required for the satisfactory operation of the message registers.

Two 30 KW telephone generators of the combined compound and shunt wound type were supplied as charging sets, and are driven by two A. C. motors. Normally, they will be operated with the compound connection. The series winding is, however, brought out to a switch mounted on the machines so that it can be cut out to enable the machines to be operated shunt-wound when it is necessary to boost up the voltage for overcharging the battery. The floating system of charging is used, and the charging sets are of sufficient size to give a

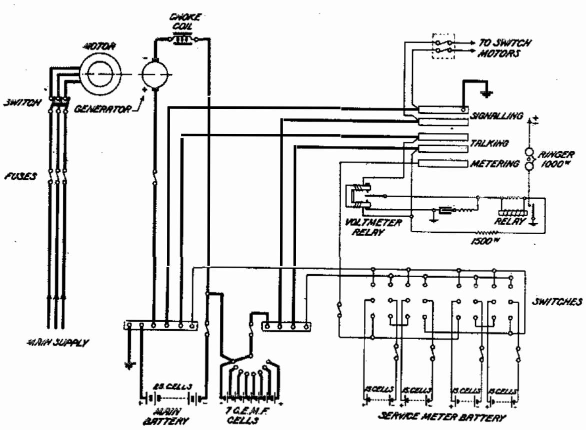


Figure 5—Power Circuit for Hoengg, Oerlikon and Tiefenbrunnen Satellites.

complete charge to the storage battery in nine hours.

The two ringing machines are driven from the outside power supply; should this supply fail, the battery driven reserve set can be automatically cut into service.

An emergency charging unit, consisting of a benzine engine and a charging generator, is also provided. The corresponding charging generator has a capacity sufficient to charge the battery and at the same time to provide the current required for switch motors, ringing machines, and a 3 KW drain for the emergency lighting circuit.

The scheme chosen for the power supply of the satellite exchanges is somewhat different. The power circuit used in the Hoengg, Oerlikon and Tiefenbrunnen satellites is different from that employed for the Wollishofen and Altstetten satellites. The power plant for the first three satellites mentioned is indicated in Figure 5, and consists of a single battery of 25 cells in series with a set of 7 counter-e. m. f. (C. E. M. F.) cells for maintaining the exchange voltage between the required limits of 44 to 52 volts. The capacity of the batteries in the individual satellites is chosen so that they would give a reserve of two to three days if the exchange were fully equipped.

Two small storage batteries, each consisting of 30 cells in series, are furnished for supplying the booster voltage for metering. As the current required for this purpose is extremely small and is only applied for a fraction of a second, batteries of very small capacity are sufficient. One motor generator consisting of a 3-phase induction motor directly coupled to a 6 KWcharging generator serves as a charging set. As the battery reserve is such that a charge is sufficient for several days, one motor-generator set is sufficient.

Ringing current is furnished by a special combined ringing machine and switch motor which also serves to drive the automatic switching equipment. A voltmeter relay is connected between the two talking battery bus-bars. In the event of the voltage exceeding or falling short of predetermined values, the voltmeter closes one of its contacts and completes an alarm circuit which results in an audible signal being given to the attendant.

In the Wollishofen and Altstetten satellites, an unattended type of power plant is working. Since the traffic in both of these satellites is approximately the same, their power plant is of equal size and practically identical, except as regards slight differences due to the outside power supply. The power plant consists of the same components as mentioned in connection

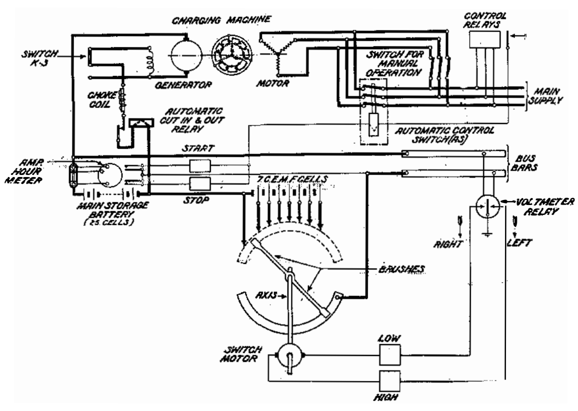


Figure 6—Power Circuit for Wollishofen and Altstetten Satellites.

with the other three satellite exchanges, but the circuit is so arranged that the motor of the charging set is automatically started and stopped.

Figure 6 shows the power circuit of these satellites. Its characteristic feature is that it can be left unattended for a long time during which any trouble that may arise is signalled automatically to the attended main exchanges. The illustration shows the fundamental charging circuit, but the auxiliary circuits which secure the automatic regulation of the machines are omitted.

The following functions are carried out automatically:

(a) Every time one of the contacts of the voltmeter relay is closed, C. E. M. F. cells are cut in or cut out, as the case may be, in order to keep the voltage at the bus-bars as close to 48 volts as possible. This is done by a switch motor which drives the automatic voltage regulating switch in clockwise or anti-clockwise direction, according to the closing of contact Left or Right of the voltmeter relay.

(b) When all the C. E. M. F. cells are cut out, or the ampere-hour meter indicates that the battery requires recharging, the charging motor is automatically started, and the charging circuit is closed. In this case, the contacts on the ampere-hour meter serve for the closing of the circuits of the starting and stopping relays.

(c) When all C. E. M. F. cells are cut in and the ampere-hour meter indicates full charge of the battery, the charging circuit is opened and the charging generator is stopped.

Toll Switching Equipment

The toll office equipment is installed in a separate building. It was therefore necessary to provide for special services for subscribers wishing to avail themselves of long distance communication.

At the time the Hottingen semi-automatic local exchange was converted into full automatic working, the Swiss Administration decided to introduce automatic toll switching between all local offices and the toll office. At present, every subscriber of the Zürich area can be called up automatically from the toll exchange. In the same way every subscriber can reach the recording, information, and other boards of the toll exchange by dialling the proper number.

As regards the outgoing calls from a toll operator to one of the local exchanges, it is evident that direct automatic calling from the toll board has brought many advantages, since the entire toll connection is thereby placed under the control of the toll operator.

Figure 7 shows the various routes employed for setting up a toll switching connection. The complete trunk circuit, including link circuit and register apparatus, are mounted in the toll exchange, whereas the apparatus for the group selector and final selector circuits are located in the automatic local exchanges.

The switching apparatus employed in the circuit comprises:

(a) 100 point finders as jack finders, trunk finders, and register choosers.

(b) A group selector with 300 junction arc capacity, i. e., 30 junctions on each of the 10 levels. This selector is arranged to select twice, and then to hunt.

(c) A final selector with capacity of 200 lines.

The sequence switches used are of the horizontal type and all the switches are driven by means of flexible gears.

The register consists of a combination of relays which record the number chosen at the toll position, and controls the setting of the selectors used for completing the connection in accordance with the number recorded.

If a main exchange subscriber wants a toll connection, he dials 14, which connects his set with the recording position in the toll office as indicated in Figure 8. The same types of switches are engaged as in the case of an ordinary call, and in addition a set of relays is provided to connect alternating ringing current to the trunk line which leads to the recording position. This current actuates the positional line relays in the usual way.

The call originated by a satellite subscriber is routed in the same way as an ordinary call. Every subscriber, in addition to requesting toll calls, can make use of the other special services previously mentioned.

Special Circuit Features

Transmission Circuit. The connection circuit which serves for local conversations is of the high resistance bridge impedance type with 48 volts talking battery. The transmission circuit between two local subscribers is shown in Figure 9. The circuit is fed over the windings of the Asr and Csr relays. At six different points of the

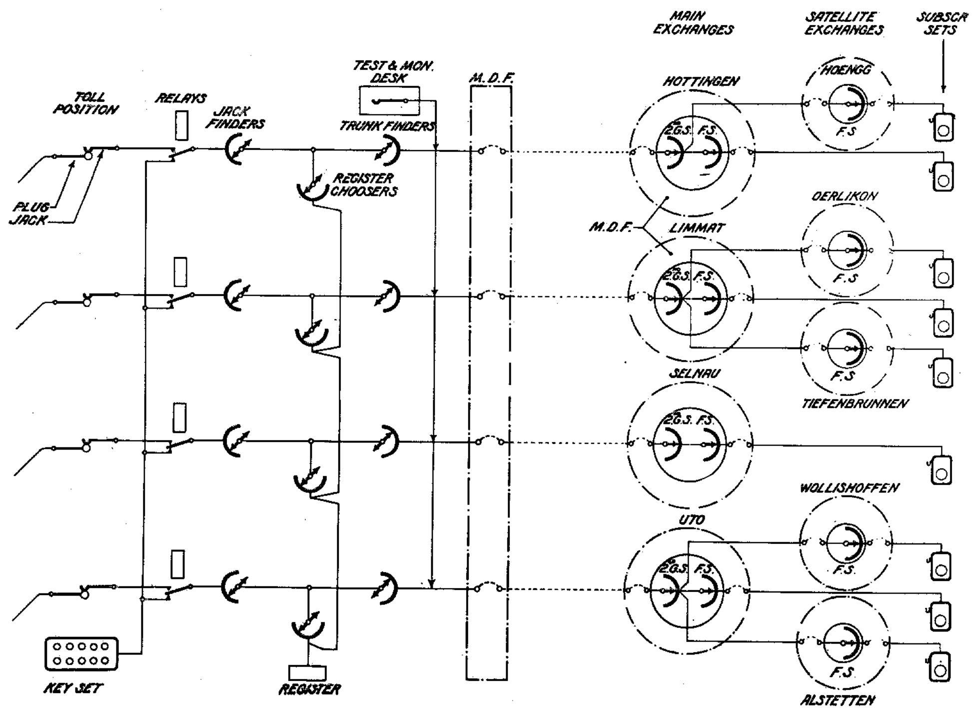


Figure 7—Toll Switching Connections.

circuit, test jacks are provided to enable the maintenance staff to test the various sections of the circuit.

Metering. The 7-A Rotary System is particularly well provided for as regards measured service. The service meter circuit is so designed that it cannot be operated by a fault. To show the method of operation of the meters, a part of Figure 9 is extended in more detail in Figure 10. It will be noted that during the whole conversation a circuit is closed over relays COR and Ler and cam I, so that relay COR attracts its armature and cuts off the line relay Lr; furthermore, Ler, by closing its contacts, connects the 48-volt talking battery to the subscriber's set. As soon as the conversation is ended and the subscriber replaces his receiver, sequence switch contact I is opened, whereas, contact X is closed. Consequently, the meter battery of 55 volts is connected in series with the 48-volt battery shown at the meter windings. The increased potential operates the meter, and in this way all successful calls are registered.

Toll Switching. When the question of introducing automatic toll switching into the Zürich Area arose, it was essential to consider a system which would not involve radical changes in the already existing toll exchange. The circuit in Figure 11 fulfills this requirement. Every toll position is equipped with a 10-button key-set, by means of which the operator may call any of the local subscribers by depressing the subscriber's number on her key-set one digit at a time. The digits may be depressed in succession as fast as the operator can work. Figure 11 shows somewhat in detail how the transmission from toll manual to automatic switching is solved, and how the jack finder (Figure 7) is started when the toll cord is inserted in the jack of one of the outgoing junction lines. The closing of jack contact A actuates relay Fsr, which in turn closes the Asr relay circuit. The latter relay provides a circuit in which a group of jack finders commences to hunt for the jack circuit. The link circuit is thus set up and the circuit is extended to the final selector to which the called subscriber is connected in the manner indicated in Figure 7.

During the progress of the switching operations, the toll operator is able to supervise continually the building up of the circuit until the subscriber answers the call. The supervisory signals which are given to the operator are as follows:

Plug inserted in the jack.	Supervisory lamp out.
Link circuit established.	Supervisory lamp burns.
Register circuit established.	Key pilot lamp (KPL) burns.
Hunting trunk to final.	Supervisory lamp flickers intermittently and key pilot lamp out.
All finals busy.	Supervisory lamp burns.
Selection finished.	Supervisory lamp flickers.

The final selector is now on the wanted line, but does not test it until the operator gives a short ring.

During the succeeding operation, the following signals are given:

Line free.	Supervisory lamp burns.
Line busy.	Supervisory lamp flickers.

When the line is free, the toll operator calls the subscriber in the normal way. When the subscriber answers, the supervisory lamp signal disappears, and when, after conversation, the subscriber replaces his talking set, the lamp burns again as a sign that the operator can disconnect.

False Calls. To eliminate loss of time, and to make the switching apparatus as efficient as possible, arrangements are made so that if any subscriber inadvertently dials the number of a non-existent line, he is notified. Figure 12 shows the circuit employed when the number of a dead line is dialled by one of the subscribers.

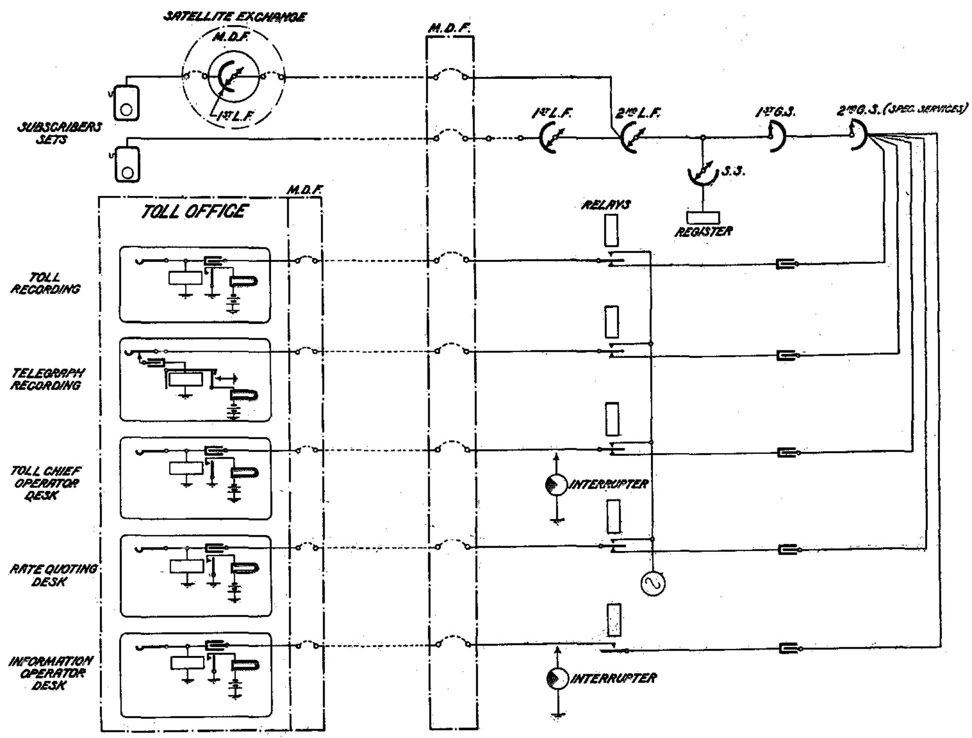


Figure 8—Toll Connections.

When this circuit is seized by a final selector, relay Trr is energised over the ground on the A-wire (see sequence contact X) and locks over its right-hand contact. The left-hand contact serves for the excitation of the relay Twr (the corresponding circuit runs over the test relay). The relay Twr locks and lights the calling lamp

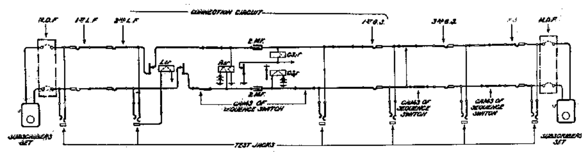


Figure 9—Transmission Circuit between Two Local Subscribers

LL before the operator. The inner left-hand contact of relay Twr provides a ringing tone to the calling subscriber until the operator answers. When the operator inserts the plug, for the purpose of advising the subscriber about the false call made, the relay Slr operates over the sleeve circuit.

A similar arrangement is made in the case of a call ending in a dead level of the first group selector.

Permanent Glow. Permanent line loops or incompleted calls are handled in the following manner: When an interval of 30 seconds elapses before the first digit is dialled into a register, or a similar interval elapses between the dialling

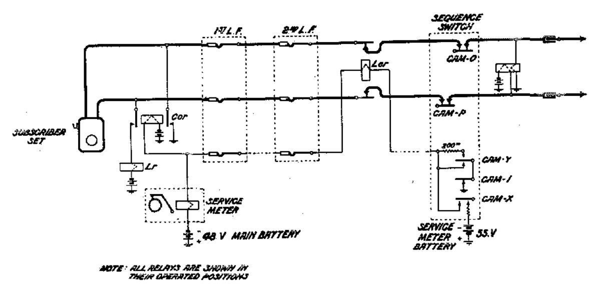


Figure 10—Metering Circuit.

of any two consecutive digits, the cord circuit provides for the immediate release of the register and the flashing of a lamp signal on the monitoring desk. Jack equipment (PGJ) on the desk gives the operator direct access to the line concerned. A simple voltmeter test circuit is supplied with the monitoring desk to allow the operator to make a preliminary investigation of the cause of the trouble, and "howling" may be applied where necessary. Figure 13 shows the arrangement in its broad outline. An earth condition is transmitted from a timing device in the register to operate relay Pgr. Relay Pgr operating, drives the R sequence switch to the talking position, while, at the same time, the release of the register circuit is effected.

The PGL (permanent glow lamp) circuit is closed and opened intermittently through interrupter No. 1, causing the lamp to flash.

In the event of the lamp signal remaining unattended, the timing switch TA in the connection circuit, after a predetermined length of

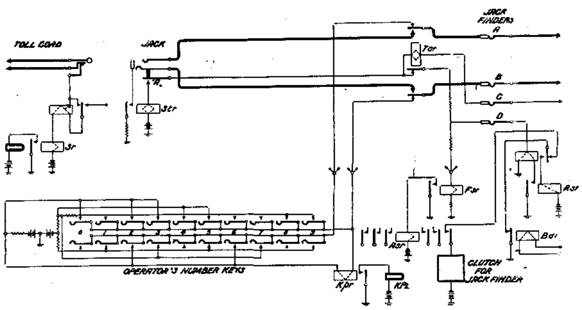


Figure 11—Automatic Toll Switching Circuit.

time, will automatically disconnect interrupter No. 1, and close the lamp circuit through interrupter No. 2, thereby producing flashes of greater frequency.

Hold-over. If a subscriber has dialled all the digits, and the selection is not completely set up, the subscriber's line is automatically released but the connection circuit is held, and the register and all subsequent selectors remain in their last operated positions to facilitate the tracing of the fault.

It will be seen from Figure 13, that the relay Pgr is energised from the time-switch TA at the register, which, if all digits have been registered, will cause relay Shr to operate. As relay Pgr is energised, the operation of relay Shr opens the third wire and releases relay Ler, thus setting free the calling subscriber's line.

An alarm and lamp CIL indicate to the fault-

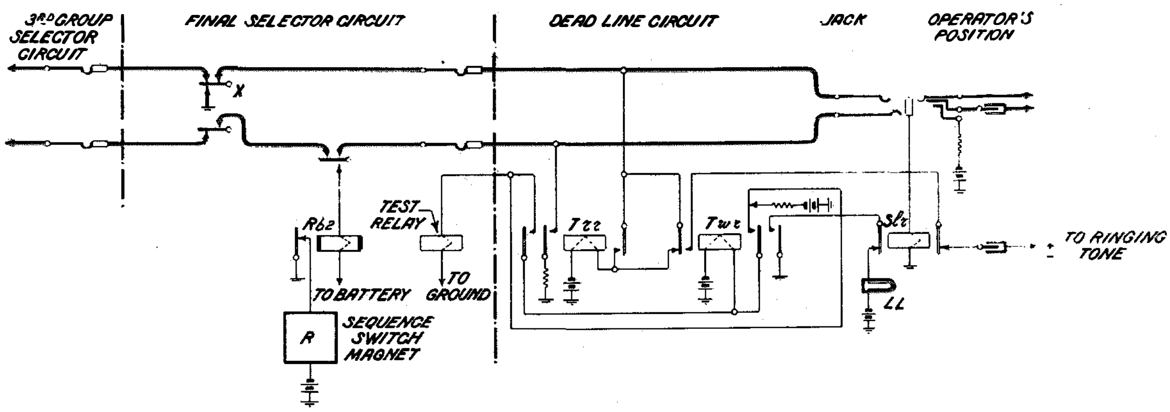


Figure 12—Dead Line Connection.

man the existence of the "hold-over" condition. Meanwhile, the subscriber is free to pick up another connection circuit and to recommence dialling.

Conclusion

The equipment described was supplied for the Zürich Area for the purpose of establishing automatic telephone communication between the local subscribers on the one hand, and the local subscribers and the toll office on the other; also, for bringing the whole telephone traffic in that area on to a uniform basis. The programme which the Administration had planned at the time of the introduction of the automatic service has proved to be correct and is confirmed by the results achieved.

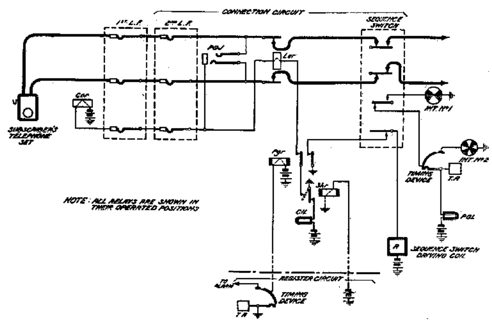
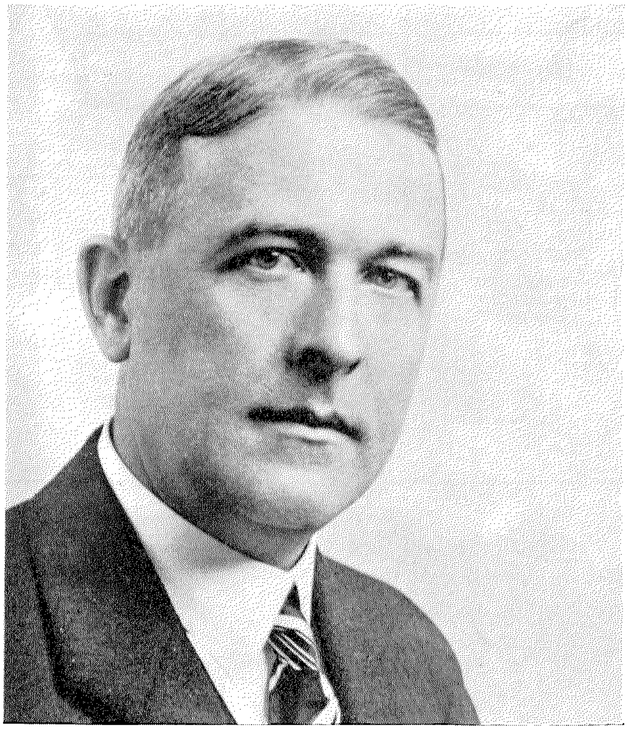


Figure 13—Circuit of Hold-over Feature.



Edward Beech Craft, Executive Vice-President of the Bell Telephone Laboratories, died at his home in Hackensack, N. J., on August 20th, after an association of over a quarter of a century with the Bell System.

In 1926, on the occasion of his receiving the degree of Doctor of Engineering from Worcester Polytechnic Institute, he was styled:

> Engineer, Inventor and Organizer of Research; whose inventions take part daily in each of more than fifty million telephone conversations; whose genius, initial conception of the practicability of panel systems for machine switching, and continued supervision of its development have contributed largely to the present system of telephony; whose technical experience devoted to the service of his country during the World War hastened advances in radio-communication with aircraft; whose organizing ability continuously applied for a quarter of a century to engineering development and industrial research has increased the social and economic significance of research.

In addition to his ability as an Engineer, Inventor and Organizer, Mr. Craft possessed unusual enthusiasm and charm of personality which made him many loyal friends, among whom are officers, directors and employees of the International System.

The Aluminium Electrolytic Condenser

By R. E. W. Maddison, B.Sc., Ph.D. (Lond.)

Of the European Installation Department, International Standard Electric Corporation[1].

INTRODUCTION

Anodic Polarization

If the voltage of an electrolytic cell or an electrode immersed in an electrolyte is altered by some cause from its equilibrium value, it is said to be polarized; anodically if it is made more positive than the equilibrium value; cathodically if more negative. Polarization may be produced by impressing an external voltage on the electrodes of the cell; it may result from concentration changes in the electrolyte, or from some intereference with the main electrode reaction itself, as, for example, the production of a non-conducting film on the electrode surface.

When a metal dissolves anodically, producing metal ions capable of combining with the ions of the electrolyte to give a sparingly soluble substance, further solution of the metal may be hindered as a result of the deposition of a film on the electrode surface. The presence of the film reduces the area of the electrode in contact with the electrolyte, and consequently increases the current density on the parts not affected. An increased polarization is then necessary to maintain a given current, and the electrode reaction may be modified. In those cases where the electrode surface is completely covered by such a film, exceedingly high polarizations may occur.

The physical properties of the film, such as its porosity, thickness, electrical conductivity, and so on, vary in different cases. It is upon the formation of badly conducting films at the surface of a metal anode, permitting the maintenance of high voltages between the electrode and the electrolyte, and preventing the discharge of anions (the passage of any appreciable current), and the relative stability of the anode film when made a cathode, that the production of electrolytic condensers and rectifiers is rendered commercially possible.

The characteristic property of the anode film upon which its rectifying property depends is that of unidirectional current conductance. When the electrode is made positive, the current passing is very small after the film has formed; but on reversing polarity, current conduction is possible. The film, therefore, can act as a valve, and by suitable arrangements of electrodes bearing these films rectification of alternating currents is possible. The film also exhibits a very high electrostatic capacity, which property is utilized for the production of static condensers.

Although this valve action has been observed with most metals under suitable conditions, only two, namely aluminium and tantalum, have gained wide use commercially for rectifiers. For condensers, aluminium alone would appear to have found application.

Theories of Electrolytic Valve Action

The various theories that have been advanced to explain the unidirectional current-flow characteristic and the dielectric properties of anode films may be divided into two classes:—

1. The Gas Film Theory,
2. The Solid Film Theory,

according as the active layer responsible for the phenomena is considered to be gaseous or solid. Although a visible oxide film is present on a formed anode (*e. g.* aluminium), it is certain that this visible layer is not the active one, but that another inner film is formed that is responsible for the behaviour of the electrode.

1. *The Gas Film Theory.*

K. E. Guthe [7] ascribed the high resistance of the aluminium anode to the presence of a thin film of oxygen gas covering the electrode, preventing the passage of negative ions from the electrolyte to the electrode. He likened the film produced on the electrode surface to a

[1]Communicated by Rollo Appleyard to the *Philosophical Magazine*, and published in Vol. VIII, July, 1929. Permission to reprint from the *Philosophical Magazine* is gratefully acknowledged.

semipermeable membrane, allowing only certain ions to pass through it and to discharge. The behaviour of an ordinary copper ferrocyanide semipermeable membrane was compared with that of an aluminium anode, and found to be similar. It was observed that a high resistance was present when current was passed from a copper to a platinum electrode immersed in an electrolyte, the two electrodes being separated from each other by the semipermeable membrane; in the reverse direction the resistance was very low.

The gas film theory has been supported in particular by A. Günther-Schulze [23, 24, 28], who considers that during the formation period of the valve metals there are produced simultaneously two films:

(*a*) an inactive solid oxide film,
(*b*) an active gas film.

The solid film is not responsible for the rectifying or condenser properties of the electrode, but serves to hold in position the oxygen gas film, which has the properties of a dielectric. The pores of the oxide layer, in so far as they are not occupied by gas, are filled by electrolyte. Electrons from the metal electrode can cross the gas film, but electrolytic ions from the electrolyte are unable to do so.

In extending Günther-Schulze's hypothesis, A. H. Taylor [33] considers the gas film to be held between an aluminium hydroxide layer and the aluminium electrode: the gas in contact with the aluminium surface combines partially with the metal to give a thin film of aluminium oxide.

2. *The Solid Film Theory.*

The rectifying and condenser properties of the aluminium anode have been ascribed by other workers [11, 14, 16, 34, 37, 38] to the presence of a solid film acting as

(*a*) a Wehnelt interrupter,
(*b*) an ohmic resistance,
(*c*) a true dielectric,
(*d*) a semipermeable membrane.

J. Slepian [3C], in his contribution to the solid film theory, has applied the principle of thermionic rectification to explain the operation of thin films such as occur in electrolytic and other rectifiers.

He considers the gas film theory of rectification to be untenable on the following grounds. A gas film has a low dielectric constant (a little over unity), so that it is difficult to account for a sufficient lowering of the work function to permit electron emission from a metal surface at ordinary temperatures; the work function for the escape of electrolytic ions from an aqueous solution should be less than in the case of electrons escaping from a metal surface; lastly, electronic conduction may be imparted to the electrolyte without in any way destroying the rectifying properties of the film. He prefers to ascribe the behaviour of a valve anode to the solid film covering the electrode surface. In the case of aluminium the film is thought to consist of a transition or dehydration product of aluminium hydroxide produced during the forming period. This film has insulating properties in consequence of the almost complete lack of free electrons, exactly as in the case of a vacuum. Electron emission from the metal electrode into the insulating film is controlled by a work function as in the case from a metal to a vacuum. As a result of the definite time required for electrons to traverse the film from one electrode to the other, space-charge effects may arise, and thereby reduce the current flow to a very small value.

The dielectric constant of the film will also influence the work function. The extent of the attraction exerted by the dielectric on the electrons escaping from the metal surface will depend on whether the work function forces are operative within or without the dielectric layer. Assuming a dielectric constant of 13, the work function may be reduced to from 1/13 to 1/7 of its value for vacuum. In view of the fact that the electron emission is approximately proportional to the work function, it follows that it is possible for electron emission to take place at ordinary temperatures into a film of dielectric constant ca. 13, and that the electric field necessary to enable electrons to overcome the work function will be correspondingly reduced.

The above outline has assumed a uniform distribution of the dielectric film over the surface of the electrode. Seeing that the forces of the work function are operative through a distance of ca. 10^{-8} cm., which is of the order of atomic dimensions, this would mean that the film is discontinuous. It is possible that even in the case where the film is formed or built up on the electrode itself, the work function is suppressed at some points and is operative at others: electrons will pass from the metal to the film only at certain discrete points. By combining a favourably polarizable junction surface with one that is non-polarizable, we obtain an asymmetric arrangement which will exhibit the unidirectional current flow characteristic upon which the production of electrolytic rectifiers and condensers is dependent.

F. M. Gentry [(6)] has established mathematically that the electronic conduction in unidirectional current conducting non-metallic films follows essentially the same law as that found for electronic conduction in an evacuated space. Satisfactory agreement was obtained between calculated and observed values for the current passed at various voltages by the film of an aluminium electrolytic condenser (see pp. 228 and 230 of discussion to [(29)]).

In connexion with the solid layer theory, it is interesting to note that a condenser with a solid dielectric (calcium fluoride), and analogous to the electrolytic type of condenser, has been prepared [(18)]. A metal filament covered with a layer of the salt is fused into a glass vessel, the walls of which are locally covered with a metal coating. The vessel is highly evacuated, the filament is heated to vaporize the salt layer, and finally the filament is heated to a higher temperature in order to volatilize it and deposit it on the salt layer. The dielectric is 100–150 molecules thick, and has a breakdown voltage of ca. 10^8 V./cm. Particulars of the capacity of this condenser, as well as other electrical properties, do not appear to be available.

W. W. Taylor and T. K. H. Inglis [(34)] found that the essential peculiarities of an aluminium anode could be reproduced by means of a platinum anode having a film of aluminium hydroxide deposited upon it. This film acts as a semipermeable membrane in permitting the diffusion through it of certain salts, but not others (*v. infra*). A. Rouban [(22)] followed up this work, using a copper ferrocyanide semipermeable membrane (*cf.* Guthe *supra*; see also [(35)]).

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It may be mentioned that A. L. Fitch [(5)] proposed the theory of a double dielectric, consisting of a gas and a solid layer, to account for the behaviour of the aluminium anode.

Formation of the Anode Film

In considering the various experimental data, reference will be made almost entirely to aluminium, and occasionally to tantalum, as it is these metals that have been most studied in connexion with their use for rectifiers and condensers.

When one of the so-called valve metals is made an anode in an electrolyte, the voltage necessary to maintain a given current density increases almost proportionally with the time of closed circuit. At a certain voltage partial breakdown, and at a still higher voltage complete breakdown, of the film occurs. This period of polarization is referred to as the "formation" period.

Formation of the dielectric film can take place on D.C. or A.C. The film which first appears on aluminium is transparent and colourless, but as its thickness increases, interference colours become visible, and after usage it appears greyish, due to the increased thickness of the film. The current density at a given voltage and frequency has considerable influence on the time of formation of the film. The greater the current density (small surface area) the more rapid the formation. The following figures obtained by H. D. Holler and J. P. Schrodt [(9)] are of great interest in this connexion. The application of 25 V.D.C. to an area of 1 $cm.^2$ of aluminium anode gave almost instant formation, the current being reduced nearly to zero in 3 seconds. With an area of 300 $cm.^2$ the formation was so slow that even with an applied voltage of 120 V. D.C. several hours were necessary to effect complete formation. Using A.C. under similar conditions to those just described, the time required for formation was about five times as great. The formation is also influenced by the composition of the electrolyte and the temperature.

Anodically treated aluminium heated *in vacuo* to 1200° C. evolves a negligible amount of gas, from which it is concluded [(32)] that the anode film consists of aluminium oxide and not hydroxide. This is interesting in connexion with Slepian's theory (*v. supra*) regarding the nature of the active layer.

Thickness of the Active Layer

It has been mentioned above that a distinction has to be made between the visible oxide layer and the inner active layer. The thickness of the active layer has been determined by measurements of electrostatic capacity (making the assumption that the dielectric constant is unity), by estimation from interference colours exhibited by the film, and by chemical analysis. The last two methods assume that the entire thickness of the film on the electrode is effective as a dielectric. Capacity measurements give results of a different order of magnitude from other methods of determination. (For a summary of the various values see [1].) Capacity measurement gives values of the order of 10^{-6} cm. for aluminium formed at 100 V.: other methods give values of $20–100 \times 10^{-6}$ cm. This discrepancy, and the fact that the thickness determined by capacity measurements is practically independent of the electrolyte, suggests that the film produced on aluminium consists of two layers. According to Günther-Schulze [28], the thickness of the active layer is dependent on

(*a*) the metal employed,
(*b*) the applied voltage;

and is independent of

(*a*) the electrolyte for aqueous solutions,
(*b*) the temperature,
(*c*) the method of formation.

TABLE I.

Voltage.	Relative thickness δ/ε.	
	Aluminium.	Tantalum.
50	6·4	4·1
100	10·3	7·1
150	16·1	11·6
200	22·3	17·0
250	29·3	22·9
300	37·1	28·8
350	46·6	34·6
400	58·0	40·3
450	71·0	45·0
500	85·9	49·1

δ = absolute thickness.
ϵ = dielectric constant.

Table I. shows the relative thickness

$$\frac{\text{absolute thickness}}{\text{dielectric thickness}} = \frac{\delta}{\varepsilon}$$

of the active layer formed on aluminium and tantalum at various voltages, assuming a dielectric constant of unity. Determinations of the thickness of the active layer depending upon capacity measurements are subject to the effect of frequency (*v. infra*), though at a given frequency the electrostatic capacity is a function of the applied voltage; this capacity is taken as being a measure of the thickness of the active layer.

Resistance of the Active Layer.

The high resistance of the anode film has been ascribed to the development of a counter E.M.F., but the evidence mainly indicates that the resistance is of an ohmic nature. It depends not only on the thickness of the active layer, but also on the applied voltage [26]. From the figures given in Table II. it is seen that during the formation period the current flow decreases at a quicker rate than the thickness of the active layer increases, so that the resistance of the active layer at constant voltage with decreasing forming current very rapidly increases. Tantalum was chosen to obtain the results given in Table II., since with this metal results are not obscured by the incomplete insolubility of the metal in the electrolyte, as in the case of aluminium.

TABLE II.

Time.	Forming current. i mA.	Cell voltage. e volts.	Thickness of Solid layer. μμ.	Thickness of Active layer. δ. μμ.	$\frac{e}{i} = r$ ohms.	$\frac{r}{\delta}$ ohms/μμ.
10″ ..	100	27	113	2·50		
30 ..	100	73	160	3·53		
40 ..	100	101·3	270	6·00	$1{\cdot}01 \times 10^3$	$0{\cdot}17 \times 10^3$
55 ..	11	101·3	300	6·62	9·22	1·39
90 ..	4·1	101·3	305	6·74	24·7	3·67
2′ ..	3·1	101·3	307	6·78	32·7	4·82
10 ..	1·16	101·3	325	7·17	87·2	12·2
60 ..	0·54	101·3	335	7·39	188	25·5
260 ..	0·37	101·3	350	7·72	278	36·0
450 ..	0·25	101·3	355	7·82	413	52·8
2880 ..	0·11	101·3	360	7·93	922	116
7340 ..	0·07	101·3	390	8·60	1450	169
8780 ..	0·06	101·3	395	8·72	1582	181

12·5 cm.² tantalum in 0·05 N. KNO_3.
Formed at 100 V. D.C. Temperature 20° C.

The figures for the resistance of the active layer given in Tables II. and III. show that the discharge of an electrolytic condenser takes place slower than it would if it possessed constant ohmic resistance. The time of discharge is greater the greater the period allowed for charging, since e/i is greater, although the corresponding change in the electrostatic capacity (thickness of film) is much less. The figures given in Table III. must be taken as showing the general trend of the voltage-resistance characteristic, since individual values are dependent on the time elapsing between successive readings, and whether increasing or decreasing potentials are being applied (26).

TABLE III.

Voltage.	Aluminium. $\frac{e}{i}=r$ ohms.	Voltage.	Tantalum. $\frac{e}{i}=r$ ohms.
350....	$2\cdot2\times10^4$	200....	$0\cdot21\times10^6$
300....	3·8	180....	0·52
250....	4·0	160....	1·10
200....	4·0	140....	1·88
150....	5·3	120....	2·40
100....	9·5	120....	2·94
50....	28·0	80....	3·80
25....	90·0	60....	4·28
	*	40....	5·00
			†

* 1000 cm.² of aluminium in ammonium borate solution. Formed at 350 V. D.C. (29).
† 12·5 cm.² of tantalum in 0·05 N. borax solution. Formed for one day at 200 V. D.C. (26).

W. R. Mott (16) gives the specific resistance of the film formed on aluminium in phosphate and sulphate solutions as 10×10^{10} ohms/c.c. and $0\cdot8\times10^{10}$ ohms/c.c., respectively at 25°C., the resistance decreasing as a logarithmic function of temperature. W. E. Meserve (12) computes the specific resistance of the solid layer to be 3.4×10^{12} ohms/c.c., assuming the layer to consist of Al_2O_3.

Table IV. gives figures showing the current-voltage characteristic for a formed aluminium electrode in ammonium borate solution (29). At constant voltage the D.C. leakage of an electrolytic condenser decreases with time. The D.C. leakage of a film subjected to a potential less than the forming voltage is of the order of a microamp./cm.². Schulze (28) gives a figure of $0\cdot15\times10^{-6}$ amp./cm.² for aluminium formed at 110 V. in ammonium borate solution. The leakage current is considerably increased when corrosion of the electrodes takes place, and may increase 20–30 times. The product of corrosion by accumulating between the plates may even cause short circuit by deforming the plates and making them touch. The leakage current increases also with increase of temperature, as shown by the figures given in Table V. (Bairsto and Mercer (1). The current-temperature curve is an exponential one, $i=A\varepsilon^{at}$. For the figures given in Table V. $i=2{\cdot}04\varepsilon^{0\cdot085t}$. The constant "A" appears to be independent of the electrolyte, and dependent on the time of formation; "a," on the other hand, appears to be independent of the time of formation, and dependent on the electrolyte: thus

TABLE IV.

Voltage. D.C.	Current density. Amp./1000 cm.²
− 6..............	0·8
− 5..............	0·4
− 4..............	0·1
− 2..............	—
+ 40..............	0·0001
+ 80..............	0·0005
+120..............	0·0015
+160..............	0·003
+200..............	0·005
+240..............	0·006
+280..............	0·007
+320..............	0·009

Aluminium formed in ammonium borate solution at 350 V. D.C.

TABLE V.

Temperature. $t°$ C.	mA./cm.². i.	Ohms/cm.².
15...........	0·0075	$13\cdot3\times10^6$
30...........	0·025	4·0
40...........	0·059	1·60
50...........	0·186	0·54
60...........	0·375	0·27
70.............	0·600	0·17
75...........	0·757	0·13

Aluminium formed in ammonium borate solution at 105 V. D.C. for 140 hours. Tests at 100 V. D.C.

Electrolyte.	Time of formation. 8 hours.	Time of formation. 140 hours.
Ammonium molybdate	$i=3{\cdot}55\varepsilon^{0\cdot064t}$	$i=2{\cdot}04\varepsilon^{0\cdot062}$
Ammonium borate....	$i=3{\cdot}55\varepsilon^{0\cdot085t}$	$i=2{\cdot}04\varepsilon^{0\cdot085t}$

Dielectric Strength of the Anode Film

When the voltage across the film exceeds a certain critical value, sparking is observed to take place at the surface. This voltage, according to Schulze [28], is dependent on the valve metal as well as the nature and concentration of the electrolyte employed, but it is independent of the temperature and current density. The maximum voltage that can be maintained across the film depends on the nature and concentration (of free ions) of the electrolyte that is used for forming the film; it is apparently independent of the valve metal, the current density, and the temperature. For the film produced on aluminium in 0.1 N. solutions of various salts, Schulze [25] gives the following figures for the maximum voltage:—

Sodium sulphate	40 V.
Potassium permanganate	112
Ammonium chromate	122
Potassium cyanide	295
Ammonium bicarbonate	425
Sodium silicate	445
Ammonium phosphate (? dibasic)	460
Ammonium citrate	470
Borax	480
Citric acid	536

For tantalum in 0.05 N. solutions containing metal free anions (*e. g.* OH', $HCOO'$, C_3H_7COO', H_2PO_4', etc.) the maximum voltage averages about 480 V. [28]: the cation, so long as it is not one of a heavy metal, has no influence. The presence of metal in the anions greatly influences the maximum voltage. In 0.05 N. solutions of metal containing anions, tantalum exhibits a maximum voltage of ca. 133 V. for chromium (*e. g.* Cr_2O_7''), ca. 84 V. for iron (*e. g.* $\frac{1}{3}$ Fe $(CN)_6'''$), and ca. 28 V. for platinum (*e. g.* $\frac{1}{2}$ $PtCl_4''$). In the range 0.5–0.05 N. an increase of about 1 per cent. in the dilution of the electrolyte produces an increase of about $\frac{1}{4}$ per cent. in the maximum voltage. At very low concentrations very high values (up to 1900 V.) for the maximum voltage may be reached.

W. R. Mott [16] gives the electric strength of the film formed on aluminium in phosphate solutions as 10^6 V./cm. C. I. Zimmerman [38] gives a slightly higher figure of $5-6\times10^6$ V./cm.

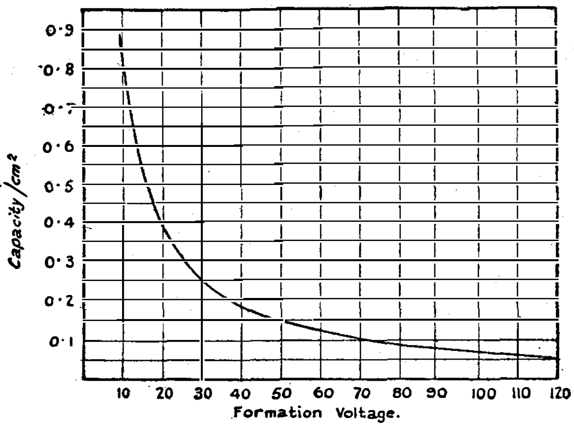


Figure 1—Variation of capacity/cm.² *with formation voltage.* (*Bairsto & Mercer* [1].)

Electrostatic Capacity of the Active Layer

It has been mentioned above that the thickness of the active layer is determined by capacity measurements. This capacity varies approximately inversely with the potential applied to form the film, and amounts to about 0.7 m.f./cm.² for formation at 10 V. D.C.[26], and 0.18 mF./cm.² at 30 V. D.C. [29] for aluminium. Figure 1 shows a curve, which averages the results of several workers, giving the relationship between formation voltage and capacity/cm.² for aluminium in aqueous electrolytes [1]. The rate of growth of the active layer on an aluminium anode has been investigated by N. A. de Bruyne and R. W. W. Sanderson [2], who found that the reciprocal of the capacity increased to its final steady value approximately logarithmically with time. (See also [1] for a summary of other measurements.)

When the voltage applied to a cell is higher than that at which the film was originally formed, the film adjusts itself to correspond to the new voltage. When there is a large electrode surface in the cell, then this increased voltage may result in a heavy flow of current, which may cause overheating and damage to the cell if the film is not able to adjust itself with sufficient rapidity to the new condition. The insertion of a current limiting device in the circuit will prevent any such damage.

Under the reverse condition, where a cell is operated at a voltage lower than the forming voltage, a very slow adjustment to the new conditions takes place. An electrolytic condenser, with continued working, will gradually accommodate itself to the lower voltage; its capacity will slowly increase on account of electrolytic action on the film reducing its thickness. This rate of change is influenced by the temperature and the conductivity of the electrolyte, being more rapid for high temperatures and conductivities (see Figures 2 and 3). The variation of capacity with temperature appears to be characteristic of the electrolyte [1].

The capacity of an electrolytic condenser decreases with frequency, though many workers seem to have ignored this factor. The change which does occur is greater in condensers with electrolytes of high specific resistance and with films formed at low voltages. The capacity-frequency characteristic of a new aluminium electrolytic condenser and the same unit after a year's continuous service is shown in Figure 4. In this instance the fall in capacity is influenced also by the special shape of the anode plates, which are corrugated.

The Electrodes

(a) *The Anode.*

The purity of the metal employed as anode in electrolytic condensers and rectifiers has con-

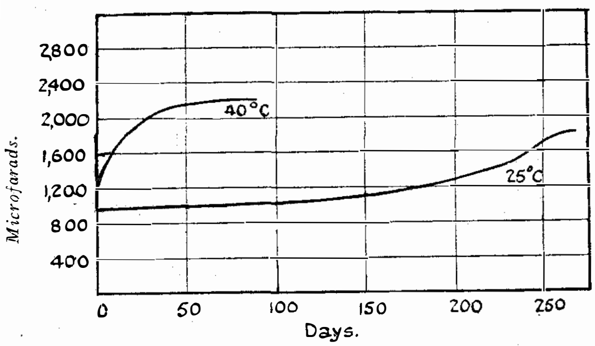


Figure 2—The capacity-time change of electrolytic condensers operated at half the formation voltage. Both with ammonium borate solution of same conductivity. Different temperatures. (*Siegmund* [29].)

siderable influence on the efficiency, life, and corrosion of the cell.

For rectifying purposes, the copper content of aluminium is of importance. When this is less than 0.05 per cent., the current delivery and the life of the cell fall off rapidly, and when it is over 0.15 per cent. the life is reduced [8].

In electrolytic condensers the purity of the aluminium affects [29]

(*a*) the time of formation of the active layer,
(*b*) the D.C. leakage of the film,
(*c*) the number of cell failures due to corrosion.

As regards the time necessary for formation, this is more rapid with aluminium of 99.6 per

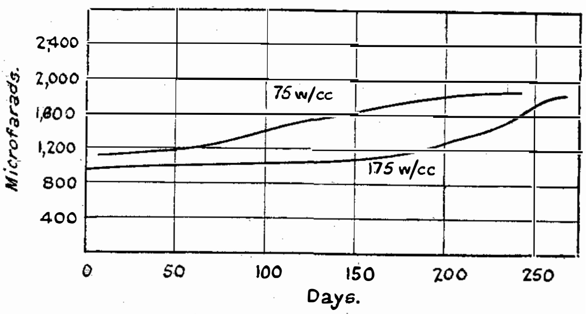


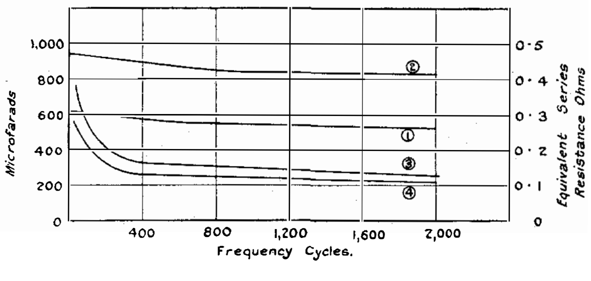
Figure 3—Capacity-time change of electrolytic condensers operated at half the formation voltage. Both at room temperature. Ammonium borate solution of different conductivities. (*Siegmund* [29].)

cent. purity than of 99.1 per cent. purity. The D.C. leakage is also lower with the purer sample. For example, after formation at 60 V. for 24 hours,

99.1 per cent. pure aluminium passed ca. 3 microamps./cm.^{2}

99.6 per cent. pure aluminium passed ca. 0.5 microamps./cm.^{2}

Although purer samples of aluminium appear to



(1) Capacity curve. Initial.
(2) Capacity curve after one year's continuous service.
(3) Resistance curve. Initial.
(4) Resistance curve after one year's continuous service

Figure 4—Capacity-frequency and resistance-frequency change of aluminium condenser formed at 100 V. and operated at 63 V. D.C. (*Siegmund* [29].)

be more readily corroded by the electrolyte, the best results in a solution of ammonium borate solution are obtained with a silicon content of 0.24 per cent.

The corrosion that occurs in electrolytic condensers makes itself apparent by pitting of the electrodes, the development of growths at the anode surface, and the deposition of sludge. There is no definite time at which corrosion starts; it may commence soon after a unit has been placed in service, or it may be delayed many months. Even when corrosion has taken place, condenser units will often continue to function for years. This seems to indicate that the corrosive influence may be eliminated after a time by chemical action, and that a protective film then forms over the affected area.

(b) *The Cathode.*

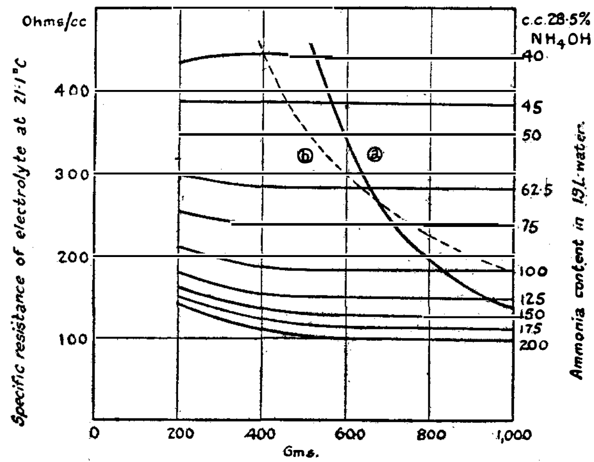
A formed aluminium electrode when made a cathode offers only a small resistance to current flow if the voltage is above a certain minimum value (the Mindestspannung of Schulze). This minimum potential is dependent upon the valve metal, the thickness of the active layer, as well as the nature and concentration of the electrolyte. It is independent of temperature.

In a condenser operating on a D.C. circuit the negative plate serves only to make contact with the electrolyte. Although not subjected to any intentional formation, there is a tendency for a film to form on the cathode (if it is a valve metal) during the periods that the condenser discharges. This may be overcome by using either an inert (non-valve) metal or an aluminium alloy containing sufficient amount of some substance, *e. g.* silicon, which hinders film formation. With an alloy containing less than 99 per cent. aluminium it is possible to have a C.D. of ca. 1 m.a. A.C./cm.² of negative plate without sufficient film forming to affect the capacity of the cell [29].

The Electrolyte

The formation of the anode film takes place in acid or in alkaline solutions. The presence of acid ions in the electrolyte favours the formation of the insulating layer on an aluminium anode; alkaline ions favour its removal when the electrode is made cathode [21]. The results obtained with different electrolytes are essentially the same, so long as a similar reaction occurs in each case at the electrode surface, although the electrical characteristics of the cell, such as its resistance and power factor, may be considerably modified. Generally speaking, the electrolytes that have shown themselves to be most suitable are solutions of ammonium or alkali salts of the weak acids such as borates, oxalates, tartrates, citrates, and salts of other organic acids. To assist the formation of aluminium plates C. Pollak [19, 20] adds about 3 per cent. of chromate to an alkaline or neutral electrolyte. Ammonium molybdate has been suggested [1] as a suitable electrolyte. However, one that is suitable for use in a condenser may be quite unsuitable for use in a rectifier.

An electrolyte that has shown itself to be particularly suitable for use in electrolytic condensers as used in telephone work is ammonium borate. The specific resistance of the solution for various proportions of boric acid and ammonia is shown in Figure 5 [29], which exhibits several interesting points. The intersection of the constant ratio boric acid-ammonia curve and the pH curve shows that the acidity of the ammonium borate solution decreases with the dilution: by adding sufficient water the solution may be made alkaline. The fact also emerges



Boric acid content in 19 L. water.

(*a*) Neutral solution $pH = 7.0$. (Heavy curve.)
(*b*) Constant proportion of boric acid and ammonium. (Dotted curve.)

Figure 5—Specific resistance of ammonium borate solution. (*Siegmund* [29].)

that the specific resistance of the electrolyte is determined mainly by the ammonia content, and the acidity or alkalinity by the boric acid content. Control of the *p*H value of borate solutions can also be effected by adding glycerol [39] or certain sugars.

In choosing an electrolyte for a condenser regard should be had to the following points:—

(*a*) the specific resistance of the electrolyte and its influence on the electrical characteristics of the unit;

(*b*) the corrosive action of the solution on the metal electrodes;

(*c*) the life of the solution: that is to say, taking the case of aluminium, the rate at which it becomes saturated with aluminium hydroxide. During use, the small leakage current of the cell is accompanied by a corresponding solution of the metal.

In general, the lower the specific resistance of the solution the more rapidly the hydroxide forms (see Table VI). Although a high specific resistance is advantageous in reducing the rate of hydroxide formation, it increases the electrical impedance of the cell. The precipitation of hydroxide is more rapid at higher temperatures. Furthermore, when a formed anode is allowed to stand idle, deterioration of the film takes place, due to attack by the electrolyte.

TABLE VI.

Sp. resistance of ammonium borate solution.	Approx. life at 25° C. before aluminium hydroxide separates out.
75 ohms.	½–1 year.
150	1–3 years.
300	over 5 years.

Effect of Impurities in the Electrolyte

The formation of the anode film is highly sensitive to the presence of impurities in the electrolyte. Strong acids, heavy metals, and halogen, nitrate and chlorate ions destroy the unidirectional conductivity of an aluminium cell. The extremely small amounts of foreign substances that will interfere with the functioning of the cell are evident from the following results of Schulze [27]. With an aluminium anode in 0.22 N. borax solution, sodium chloride in a concentration of 2.5×10^{-4} N. produces a noticeable retardation of forming. This amount is equivalent to ca. ½ per mil. of the borax, and is sufficient to produce a turbidity with silver nitrate solution. Any electrolyte giving this reaction should be rejected for the purpose of electrolytic condensers or rectifiers. Bromine and iodine ions act similarly. The action of sodium nitrate is not so great. A concentration of 0.002 N. ($\equiv$1 per cent. of the borax) retards the film formation. A slight alkalinity of the electrolyte is not objectionable, but a strong alkalinity destroys the valve action. Sodium hydroxide in a borax solution will react thus

$$2NaOH + Na_2B_4O_7 \rightarrow 2Na_2B_2O_4 + H_2O.$$

Seeing that the metaborate is not hydrolysed much more than the tetraborate, the sodium hydroxide will not become effective till its concentration is in excess of that of the borax.

The enormous increase in the leakage current of an aluminium anode when halogen ions are present is shown in Table VII.[1]. The addition to a borax solution of a substance, *e. g.*, a sulphate, acetate, etc., which itself will allow film formation, but not to the same extent as borax, will have an unfavourable influence. Taylor and Inglis [34] have found that those salts (*e. g.*, KCl, KNO_3, etc.) that destroy the functioning of an aluminium cell are those that easily diffuse through an aluminium membrane. Other salts that do not diffuse through are without effect.

TABLE VII.

Electrolyte.	Gm. PO_4 ion. a.	Gm. Cl ion. b.	Ratio $\frac{a}{b}=\sigma$.	$\frac{mA.}{cm.^2}$	Ratio $\frac{i\sigma}{i_0}$.
130 c.c. NH_4NaHPO_4	0.59	—	—	0.0013	1
130 c.c. NH_4NaHPO_4					
+3½ c.c. KCl aq.	0·57	0·048	0·084	0·157	121
+4½ "	0·57	0·062	0·109	0·26	204
+5½ "	0·56	0·076	0·136	0·471	362
+6½ "	0·56	0·090	0·161	0·972	750
+7½ "	05·6	0·105	0·191	1·89	1450

Aluminium anode formed at 110 V. D.C.
Measurements made at 20 V. D.C.

Condenser Properties of Formed Electrodes

In considering the electrical properties of the electrolytic condenser, it is impossible not to make considerable reference to the exhaustive work of C. I. Zimmerman [37 & 83].

The active layer on a formed aluminium electrode constitutes an asymmetric dielectric, in that it can retain positive charges only on the side in contact with the metal. A single formed electrode immersed in electrolyte constitutes what is termed an asymmetric cell. Compared with an ordinary mica or plate condenser, the metal anode and the electrolyte correspond to the two conducting coatings, and the active layer or film to the dielectric. Two formed electrodes immersed in an electrolyte (two series-opposed asymmetric cells) are equivalent to two ordinary plate condensers in series, but the distribution of electrostatic charges internally is quite different from that which obtains in two series connected plate condensers, on account of the rectifying properties of the film. The potentials across the two films of an electrolytic condenser are in opposition to each other, whereas in the case of two series connected plate condensers the potentials across the individual dielectrics act in series. The condenser action of two series-opposed asymmetric cells results from the energy changes accompanying the variations in distribution of the constant charge held by the unit. Such an arrangement will not allow D.C. to pass; A.C. will, however, pass, producing a leading current in the circuit in which it is incorporated.

On connecting an electrolytic condenser consisting of two series-opposed asymmetric cells to an A.C. source of voltage, current flows until the impressed voltage on the cell terminals has reached its maximum. One electrode of the cell now has maximum voltage applied to it, and therefore has its maximum charge. As the potential decreases from its maximum value, the electrode which was positive starts to discharge into the circuit, and the charge which it held accumulates on the other electrode making this one now positive. For any subsequent variation of voltage the total coulomb charge remains constant (for a given maximum applied voltage), whereas in an ordinary plate condenser the charge varies with the applied voltage. The constant electrostatic charge existing in the cell sets up a uniform difference of potential between the electrolyte and any point outside the cell in the external circuit which is neutral with respect to the A.C. pressure. The electrolyte is always negative with respect to the neutral A.C. pressure reference point. The arithmetical sum of the potentials across the two films is constant, and equals the maximum voltage impressed on the condenser terminals. The algebraic sum of the instantaneous values equals the instantaneous value of the impressed voltage. The potential difference existing between the electrolyte and either electrode is the resultant of a uniform potential equal to one-half the maximum instantaneous value of the voltage impressed on the cell, and an A.C. voltage equal to one-half the effective value of the voltage impressed on the cell. This is a pulsating unidirectional pressure. Each film is subjected to an A.C. component equal to one-half the pressure impressed on the condenser; and each film is subjected to the maximum pressure impressed on the cell, instead of one-half as is the case with two ordinary plate condensers connected in series.

Energy Variation within the Cell

It has been mentioned above that when the charge on one electrode is at a maximum, the charge on the other is zero. The energy stored at the maximum voltage is therefore

$$W_1 = \tfrac{1}{2} Q E_{max.}$$

where Q = the charge in coulombs,
$E_{max.}$ = the maximum voltage.

At the moment the applied voltage becomes zero, each film holds one-half the charge at one-half the voltage; the stored energy then amounts to

$$W_2 = 2\left[\frac{1}{2}\times\frac{1}{2}\times\frac{E_{max.}}{2}\right] = \tfrac{1}{4} Q E_{max.}$$

The energy variation is therefore $W_1 - W_2 = \tfrac{1}{4} Q E_{max.}$, or one-half the total energy stored in the condenser when maximum voltage is impressed on the terminals. Whereas an electrolytic condenser (two series-opposed asymmetric cells) stores and gives up only one-half of its total charge, an ordinary condenser stores and gives up its total charge. In the electrolytic condenser one film charges while the other discharges: in an ordinary condenser both electrodes charge and discharge together.

When the two electrodes in an electrolytic condenser are not of the same electrostatic capacity, the charge stored in the condenser is independent of the capacity of the smaller electrode, and is determined solely by the maximum charge capable of being stored by the larger electrode. If one of the electrodes of the cell has negligible capacity, the unit no longer reacts on an A.C. circuit like an ordinary condenser, since it is able to receive a charge but unable to return it. In such a cell the potential difference between the smaller electrode and the electrolyte has a theoretical maximum value of twice the maximum pressure applied to the cell terminals.

Considerations of the electrical properties of polyphase electrolytic condensers have also been made by Zimmermann (38).

Electrical Losses of the Electrolytic Condenser

The losses associated with the electrolytic condenser are made up as follows:—

(*a*) A loss constant at all frequencies due to the inherent conductivity of the film, and which is equivalent to a high resistance in parallel with the capacity.

(*b*) Dielectric loss which, as in the case of the ordinary type of condenser, increases with frequency.

(*c*) I^2R losses due to the resistance of the electrolyte. Since the most suitable electrolytes for electrolytic condensers have a low conductivity, the losses due to this cause may be appreciable. The resistance of the electrolyte remains almost constant over a very wide range of frequencies.

(*d*) Losses due to electrolytic decomposition. The composition of the electrolyte has considerable influence on the power factor of an electrolytic condenser when used on an A.C. circuit. For example, an electrolyte of the composition

30 gm. boric acid,
5 " ammonium borate,
1 L. water,

exhibits a P.F. of 40 per cent.; whilst the same solution with 4 gm. sodium hydroxide and ½ gm. sodium fluoride added exhibits a P.F. of 4·2 per cent. (13).

In Table VIII. are given some results obtained by Schulze (25) on an aluminium condenser working on A.C. The condenser consisted of ten plates of aluminium 9·7×16·5×0·1 cm. immersed in saturated ammonium borate ($(NH_4)HB_2O_4$); alternate plates were arranged to be anode and cathode. The P.F. increases as the value of the applied A.C. voltage increases (see Table IX.), and also with the time of closed circuit.

TABLE VIII.

Condenser.			Calculated capacity. mF.	Power factor.	Temp. °C.	Formation voltage. D.C.	Residual current at D.C. forming voltage. Amp.	Peak value of applied A.C.	Time of closed A.C. circuit. Mins.
Current. Amps.	Voltage. A.C.	Losses. Watts.							
1·26	27·4	2·25	146·3	0·065	19·7	40	0·003	ca. 33	120
1·35	59·2	4·0	72·6	0·050	18·0	80	0·0045	" 84	60
1·72	113·4	23·0	48·2	0·118	22·8	160	0 0037	" 159	60

The condensers described by Siegmund (29), utilizing a solution of ammonium borate of specific resistance 225 ohms, have P.F.'s of the order of 9 per cent. measured at 60 cycles. In Table X. are given some values at different frequencies of the capacity and equivalent series

TABLE IX.

Calculated capacity. mF.	Voltage. A.C.	Current. Amp.	Losses. Watts.	Power factor.
43·9	102·8	1·42	8·6	0·059
43·9	82·8	1·14	5·0	0·053
43·8	73·6	1·01	3·5	0·047
43·6	59·2	0·81	1·7	0·041

resistance for this type of condenser; Figure 6 shows the percentage variation in these values with temperature.

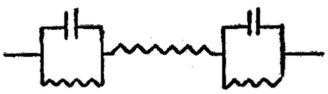
Various equivalent networks have been suggested as corresponding to a valve anode. N. A. de Bruyne and R. W. W. Sanderson ([2] *q. v.* for other references) assumed for experimental purposes that an electrolytic condenser having

TABLE X.

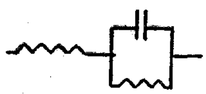
	Frequency	Initial value.	Value after one year's service.
Capacity.	60 ~	640 mF.	930 mF.
	400	570	860
	1000	540	840
	2000	520	830
Equivalent series resistance.	60 ~	0·37 ω	0·27 ω
	400	0·15	0·125
	1000	0:14	0·12
	2000	0·12	0·11

Condenser formed at 100 V. D.C. and operated continuously for one year at 66 V. D.C. (Values have been read from a small scale graph.)

two similar plates was equivalent to the following network:—



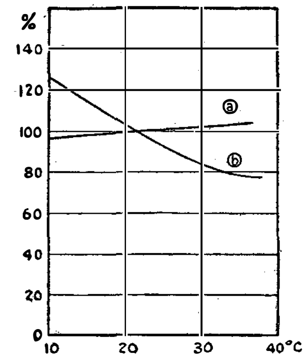
The capacities shunted by the resistances represent the leaky condensers at the electrodes, and the series resistance the resistance of the electrolyte. For two electrodes of equal area this network reduces to



In such a simple network, which lends itself to calculation, the values of the component parts were shown to be not independent of frequency. It would appear that there is no simple network which is capable of accurately representing the electrolytic condenser.

Application of the Valve Anode

The unidirectional current conducting characteristic of aluminium and tantalum anodes has found wide use for the rectification of A.C. to supply a source of D.C. for battery charging. The best results for rectification are obtained with high current density at the anode; low inductance and resistance of the external circuit;



(*a*) Capacity curve.
(*b*) Equivalent series resistance curve.

Figure 6—Percentage variation ϕ, with temperature, of capacity and equivalent series resistance of 48 V. condenser at 1000 ~. (Siegmund [28].)

and low temperature. The capacity effect in the action of the valve lowers the E.M.F. of the rectified current [17]. In consequence of the low conductivity of the electrolyte and the high resistance of the film, the I^2R losses are high. The use of a high current density for rectification purposes means that the I^2R heat is limited to a small space, and therefore there results a considerable rise in temperature, which must be kept down by using a large volume of electrolyte or by fitting special means for cooling the electrodes or electrolyte. As cathode in electrolytic rectifiers it is usual to use lead, iron, or carbon electrodes, and often the metal container itself.

The high resistance of the aluminium film to the passage of electric current has been utilised for preventing arcs on interrupting an inductive circuit [10]. The B.D.V. of the electrolytic cell for this purpose should be greater than the normal working voltage of the circuit. On interrupting an inductive circuit the high voltage surge breaks down the film, which reforms when the circuit is operated again. The break-down characteristic of the aluminium anode is utilized in addition for the production of electrolytic lightning arrestors.

The high electrostatic capacity available at a valve anode has been utilized for the production of static condensers. The high losses associated with electrolytic condensers on A.C. circuits, however, precludes their use at high frequency voltages. Their usefulness is restricted to employment on low voltage circuits for protection against surges of steep wave front, and for use on D.C. circuits where it is desired to filter out an A.C. ripple.

In telephone work it has been the practice to build special generators which will give a smooth D.C. output that will not interfere with conversations when connected to telephone circuits. The ordinary commercial generators can be employed for charging the exchange battery associated with the telephone circuits, when used in conjunction with a filter circuit comprising chokes and condensers, which eliminates the ripple present in the current supplied by the power plant, and thereby cuts out hum from the the telephone circuits [36].

When an electrolytic condenser is used on a D.C. circuit it is sufficient to have a cell with one electrode of a valve metal such as aluminium, and one electrode of a non-valve metal. The condenser action is assured so long as the valve metal is kept positive. Such an arrangement on an A.C. circuit will act rather as a rectifier.

Aluminium condensers have been used for the production of high voltage D.C. [31]. Several cells are connected in series and charged rapidly one after another by a rotating commutator; the whole set of cells is discharged in series.

The bulk and cost per microfarad of an electrolytic condenser are considerably less than that of an ordinary condenser operating at the same voltage. However, at higher voltages, where the efficiency is not so great, this economy is not so apparent, since the energy storing capacity of a condenser varies as the square of the impressed voltage.

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Type D-1 Single Channel Short Haul Carrier Telephone System

By J. W. SANBORN

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SINCE the birth of the telephone over fifty years ago, research and development have made many remarkable improvements not only in the speed of service and the quality of transmission, but in economies which make it possible to furnish this all-important means of communication at reasonable rates.

Outstanding among such developments is the more efficient use of the wire lines connecting two telephone centers.[2] Instead of obtaining one telephone circuit on one pair of wires it is now entirely practicable to obtain four telephone and two two-way telegraph circuits on one pair of wires, or nine telephone and four two-way telegraph circuits on a phantom group. This has been made possible largely by carrier telephone systems* which operate by the superposition of high frequency voice modulated currents on the wires.

One of these systems provides three high frequency telephone channels and has been used extensively not only in the United States[3,6] but in Australia[4,5] and to a lesser extent in other countries. There has also been developed an efficient single channel long haul carrier system.[7] These systems have proved capable of furnishing high grade circuits at annual costs less than required for additional wire circuits over the relatively long distances for which they were designed to operate. For short distances of less than 150–200 miles, however, they will not in general be economical inasmuch as the technique required for their adjustment and maintenance is relatively complicated and requires highly trained personnel.

There was a field, therefore, for a cheaper system which would be economical over shorter distances; this need was met by the development of a single channel short haul telephone carrier system, which will be briefly described.

Characteristics of D-1 System

The single channel short haul system[1] is called the Type D-1. It is somewhat similar to the three-channel type C system but is much simpler in operation. It has been designed particularly to provide an additional circuit over distances as low as 50 to 75 miles at annual charges less than those of additional copper circuits. To accomplish this necessitated among other things, a design of system in which the maintenance cost would be low. The new system employs equipment which requires very little adjustment or other attention and operates with hardly more attention than an ordinary telephone repeater. When necessary, the equipment can be used in stations which do not have regular maintenance but which are observed by a trained maintenance man once or twice a day. The circuits have a high degree of stability, and the adjustments of gain, battery voltage, and frequency necessary on other carrier systems are not required, since these factors remain sensibly constant after the circuit is initially lined up for operation.

The transmission characteristics of the D-1 system are such that where only one system is installed on a pole lineman overall equivalent of 3.5 db† is possible if the attenuation of the line is not over 20 db at the highest carrier frequency. On account of crosstalk where several systems are used on the same pole lead the above minimum overall equivalent cannot be satisfactorily obtained if the line attenuation is more than about 14 db. These values are based on a maximum gain at the transmitting end of 6.5 db and a maximum receiving gain in the first case

[2] For numerical references, see *Bibliography*.

* J. S. Jammer, "Carrier Telephone Systems and Their World Wide Application," *Electrical Communication*, Vol. VII, No. 4, April, 1929.

† G. H. Gray, "The Unit of Transmission and the Transmission Reference System," *Electrical Communication*, Vol. VIII, No. 1, July, 1929.

of 10 db and again in the second case of 4 db.

In the type D-1 system no intermediate amplifier is used. The apparatus consists of two terminal sets which are shown schematically in

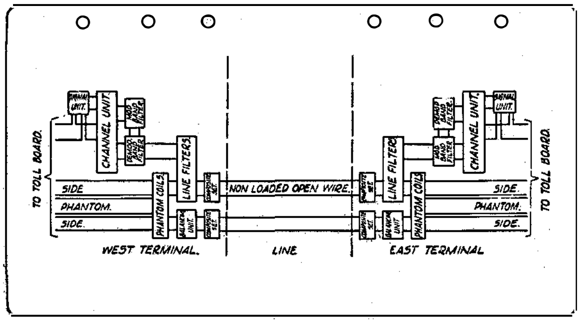

Figure 1—Schematic of Type D-1 Carrier System Applied to One Pair of a Phantom Group.

Figure 1. The equipment at either terminal consists of the line filter, transmitting and receiving band filters, the channel unit and the signal unit. The carrier frequency for transmission is 10.3 kilocycles in one direction, and 6.87 kilocycles in the other direction. In both cases the carrier is suppressed and only the lower side band is transmitted.

In applying the D-1 system it should be borne in mind that the carrier frequencies are nearly the same as those of the two lowest channels of one of the three-channel systems known as the C-N-3 or "normal" type. For this reason, therefore, a D-1 system cannot ordinarily be operated on the same line. Since the frequencies of the C-S-3 or so-called "staggered" type do not overlap those of the D-1 system to as great an extent (Figure 2), a limited number of the "staggered" type can be used on the same pole line with several type D-1 systems, as will be explained more fully under the discussion of transpositions.

The necessary power supply for the operation of the single channel carrier telephone system consists of a 24 volt filament supply, a 130 volt plate battery supply, and 20 cycle current for ringing.

No differentiation is made in operating practices between carrier and other circuits. Both appear on the toll switchboard and are handled by the operator exactly alike.

Because of its simplicity the type D-1 carrier has proved very useful under emergency conditions. In one case where the main pole line was put out of service by a storm, a carrier terminal was moved from one exchange to another and was put in service over a second unharmed toll line through the storm area in a time of only thirty-two hours. In another case of serious flood, five carrier systems were installed in a few days' time and were used for emergency service over a secondary route until the main toll lines in the stricken area could be rebuilt.

Equipment

The office equipment for the type D-1 carrier system has been so designed that one terminal may be mounted on a 7 ft. floor rack or two complete terminals may be mounted on an 11 ft. 6 in. relay rack bay. The floor rack mounted unit is constructed of channel iron and the equipment is assembled and wired before shipment (Figure 3). Where the bay type of layout is used, either I-beam or channel iron construction is satisfactory depending upon local office conditions. In this case the equipment is shipped as individual panels and is assembled and wired on the rack locally.

As indicated in Figure 1, the equipment comprises a channel unit with associated filters and signal unit. It is cross-connected to the toll line on the drop side of the telegraph composite set.

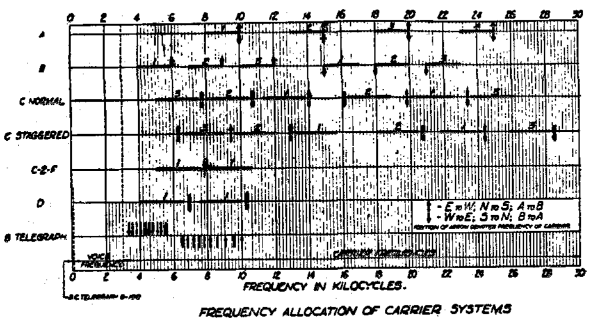

Figure 2—Frequency Allocation of Carrier Systems.

In Figure 4 is shown a simplified schematic diagram of the channel unit, essential parts of which are the hybrid coil, modulator low pass filter, modulator and demodulator, gain adjusting pads and some parts of the transmitting system. The channel units for the two terminals of the system are fundamentally the same, differing only in the electrical constants of certain of the coils and condensers, since one terminal transmits the low frequency band and receives the high frequency band, while the other terminal transmits the high frequency band and receives the low frequency band.

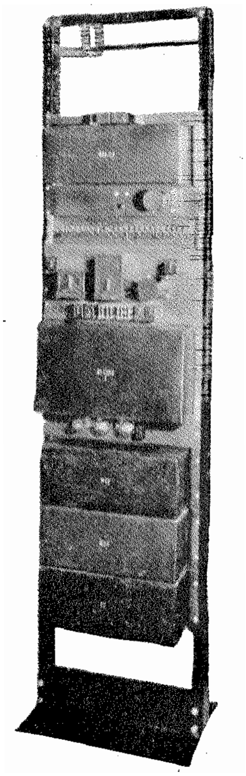

Figure 3—Floor Rack Mounted Terminal Unit.

The channel unit circuits differ from those used on other carrier systems in two important ways:

(1) They combine the functions of both carrier supply and modulation in one pair of tubes.

(2) They do not require batteries in the grid circuit, since modulation is accomplished by the use of resistances and condensers in the grid circuit.

The self-oscillating modulator circuits result in decided economy in use of tubes and power. Their function is performed by the use of tuned coupling between the common input and output of the two tubes, an arrangement which produces oscillations around the common circuit and supplies carrier frequency voltage to the grids. The amplitude of the carrier wave is predetermined by the electrical constants of the circuit and does not require any adjustment. The carrier frequency is suppressed in the output circuit by the connection of the output transformer and hence is not transmitted to the line. At the receiving end the carrier frequency is generated for demodulation by a similar circuit. The oscillating circuits are very stable, and when once properly adjusted they maintain the proper frequency without any further adjustment or attention. Small steps are arranged in the frequency adjustment so that the frequency at the receiving end may be set within one cycle of the value at the transmitting end. The nominal frequencies of the carrier waves are 10,300 cycles at one terminal and 6,867 at the other terminal.

The gains at the two terminals may be adjusted by the two pads which appear at the right-hand side of Figure 4. The pad in the modulator output circuit has a range of 11 db in 1 db steps for adjusting the transmitting level. The pad at the receiving end precedes the input transformer and has a range of 31 db in steps of 1 db. Once these have been adjusted they should not require changing unless the circuit layout is changed. The overall stability of the system is such that the toll circuit equivalent will stay without adjustment within the commonly accepted limits of plus or minus 2 db. Most of this variation will be due to weather changes on the line, and not to the carrier equipment.

The hybrid coil performs a double function, serving also as an input transformer for the modulator circuit. The side of the coil to which the balancing network is connected (Figure 4) is brought out to terminals so that a precision network may be used instead of the compromise condenser and resistance network. The precision network will usually be required when the system is extended to another toll circuit, but the compromise network is, in general, satisfactory if the toll circuit terminates at the carrier terminal.

The modulator and demodulator circuits are separated by two band filters, located between the line filters and the channel unit. All coils are wound on non-metallic cores and the filter units are sealed in copper boxes for protection and shielding. Each filter passes the lower side band of one of the carrier frequencies and effectively suppresses all other frequencies.

A special line filter set has been designed for use with type D-1 systems, the low pass section passing frequencies of the voice channel up to 2,800 cycles and the high pass section passing

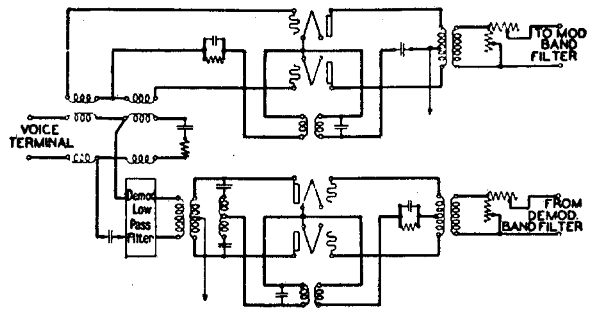

Figure 4—Simplified Schematic of Channel Unit.

frequencies above 4,000 cycles. This filter set is simpler and cheaper than those used with the three-channel systems and is designed to meet the requirements of this system only. If these filters are introduced in one side circuit only of a phantom group, they, of course, will tend to unbalance the phantom circuit. To prevent this, phantom balance coils have been designed for use in the other side circuit as shown in Figure 1. If type D-1 systems are used on both side circuits of a phantom group, the filters will balance each other and the balance coils are unnecessary.

In order to preserve the necessary two-wire repeater balance on voice frequency circuits when these filter and balancing units are used, a second filter or balancing unit must be inserted in the repeater network. With this in mind, a unit is produced consisting of two of these line filter units which have been specially selected at the factory to balance to 24 db or better and which are mechanically joined together.

The type D-1 system is also unique in that its signaling current is obtained directly by modifying the modulator circuit give to a current at the 1000 cycle point of the side band. This is accomplished by operation of a relay which unbalances the modulator circuit by opening the plate circuit of one of the tubes and which at the same time introduces a condenser into the oscillating circuit so that the frequency is shifted to a point 1000 cycles below the normal carrier frequency, that is, to the 1000 cycle point of the lower side band. This current is interrupted by a relay which operates from local 20 cycle ringing current. At the receiving end the interrupted high frequency current comes in through the line and band filters to the demodulator, where it combines with local carrier current to give an interrupted current at 1000 cycle frequency. This 1000 cycle current in turn is amplified and passed through relays which finally cause local 20 cycle ringing current to operate the switchboard signal. A small testing unit is required for adjusting the relay in the signal unit. This is mounted with the first terminal installed in each office, and serves for any other terminals that may be added.

If the installation is in a station where repeaters are used, the 24 volt and 130 volt batteries used for the repeaters can, of course, be used also for the carrier system. The current drain from the filament and plate batteries will be about 1 ampere and 20 milliamperes, respectively, for each terminal in use. However, it may be desired to install carrier systems between offices where there are no repeaters, and for such use small 24 volt and 130 volt power plants capable of supplying 2 amperes and 130 milliamperes respectively have been designed.

From the preceding it will be apparent that the apparatus requires practically no adjustments other than those which are made in the carrier frequencies and in the pads when the circuit is initially lined up.

Outside Plant Considerations

In applying the type D-1 telephone system to toll lines, there are several points in connection with the outside plant which have to be taken into account, such as the question of carrier transpositions, loading of entrance or intermediate cable, and in some cases, filters for transferring the circuit from one line to another.

Transpositions

A single type D-1 carrier system can generally be operated over an existing open wire circuit which is transposed according to any of the standard methods, with no additional transpositions. This may also be true for several systems, depending in each particular case upon the transposition scheme in use, the number of systems involved, the separation actually obtainable between systems and the existence of any irregularities in the line attenuation characteristics. The feasibility of using several systems without carrier transpositions is best determined by carrier crosstalk and attenuation tests upon the circuits involved.

Where it is found that transpositions are needed, the probabilities are that by superposing extra transpositions on the present well-known Standard or Exposed Line systems of transpositions in all side circuits to be equipped with carrier systems, it will be possible to use the type D-1 system on the side circuits of all end phantom groups on the first four crossarms. It will probably be practicable also to employ transpositions which will permit the use of two "staggered" (type C-S-3) carrier systems on the top crossarm and type D-1 systems on the sides of end phantom groups on the three lower arms. As has been pointed out previously, it is in general not possible to use the "normal" (type C-N-3) system or any other multi-channel carrier system except the "staggered" type on the same pole line with type D-1 systems without sacrificing at least the lower channel on the multi-channel systems.

Due to the large output current of a carrier telegraph circuit, its crosstalk into a type D-1 carrier telephone system is, in general, about 15 db higher than that of one telephone system into another. It is evident, therefore, that the use of carrier telegraph and type D-1 carrier telephone on the same pole line is necessarily limited, and is feasible only where the two are well separated. Conditions are even worse if a telegraph repeater or terminal comes within the carrier telephone section.

Except for the limitations above noted, the type D-1 system does not impede the use of other facilities on the pole line. DC telegraph circuits and ordinary phantom circuits can be used with the type D-1 system, provided, that proper attention is paid to balancing the sides of the phantom groups, as previously discussed.

Cable Loading

The single channel carrier system was designed for use on open wire lines, and cable runs should be avoided where possible. In case entrance or intermediate cable is necessary it must be loaded, unless it is very short, not only to lower the attenuation, but, what is even more important, to prevent crosstalk due to reflected currents from the cable junctions in cases where there is more than one carrier system on the line. A special type of loading, using 15 millihenry coils at 3000 ft. spacing in the side circuits and 16 millihenry in the phantom, has been designed for this use. This loading gives a nominal impedance of 640 ohms and a cutoff frequency of 13 kilocycles. It is designed to match the impedance of No. 13 NBS gauge (.104 in. diam.) non-pole pair, non-loaded open wire circuits. Due to the greater spacing of the coils it is cheaper than the system of carrier loading which is used in connection with the three-channel system, but its comparatively low cutoff frequency limits its use to circuits involving only the single channel carrier. Loading coil cases are available to hold the coils necessary for any number of phantom groups up to five.

Transfer Arrangements

It may be desired to transfer the carrier channel from one circuit to another at an office where the physical circuit is tapped or terminated, or at some intermediate point. This may be accomplished by using proper filter units. If the circuits need to be insulated from each other, a carrier repeating coil may be inserted between the two transfer filters. Due care must also be taken to preserve phantom circuit and repeater balances at transfer points. It is not expected, however, that the necessity for transferring the carrier channel will arise very often, since the range over which the carrier system is designed to operate is comparatively short.

Conclusion

The type D-1 single channel short haul carrier telephone system is already in extensive use. Since it is a comparatively inexpensive system to install and a simple one to maintain, these advantages together with the low annual charge should open a wide field for its application where there is a need for additional short haul circuits on an existing openwire lead at a minimum of expense, and where ease of operation comparable with that of an ordinary telephone repeater is required.

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Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division, American Telephone and Telegraph Company

Telephone Development of the World, by Countries
January 1, 1928

	Number of Telephones			Per Cent of Total World	Telephones per 100 Population	Increase in Number of Telephones During 1927
	Government Systems	Private Companies	Total			
NORTH AMERICA:						
United States	—	18,522,767	18,522,767	59.77%	15.8	776,599
Canada	226,673	1,033,314	1,259,987	4.07%	13.2	58,979
Central America	9,682	12,829	22,511	.07%	0.3	2,228
Mexico	1,427	63,489	64,916	.21%	0.4	7,353
West Indies:						
Cuba	491	68,337	68,828	.22%	1.9	3,612
Porto Rico	820	12,402	13,222	.04%	0.9	—152
Other W. I. Places*	7,790	10,583	18,373	.06%	0.3	213
Other No. Am. Places*	100	8,900	9,000	.03%	2.6	500
Total	246,983	19,732,621	19,979,604	64.47%	12.5	849,332
SOUTH AMERICA:						
Argentina	—	232,041	232,041	.75%	2.2	27,578
Bolivia	—	2,612	2,612	.01%	0.1	788
Brazil	636	107,553	108,189	.35%	0.3	2,980
Chile	—	38,573	38,573	.13%	0.7	1,713
Colombia	50	21,060	21,110	.07%	0.3	2,235
Ecuador	1,442	2,965	4,407	.01%	0.2	—111
Paraguay	183	230	413	.001%	0.03	—
Peru	—	13,695	13,695	.04%	0.2	466
Uruguay	—	26,934	26,934	.09%	1.5	19
Venezuela	641	12,457	13,098	.04%	0.4	366
Other So. Am. Places	2,738	—	2,738	.01%	0.6	30
Total	5,690	458,120	463,810	1.50%	0.6	36,064
EUROPE:						
Austria	165,231	—	165,231	.53%	2.4	6,802
Belgium	196,691	—	196,691	.63%	2.5	20,119
Bulgaria	14,358	—	14,358	.05%	0.3	4,348
Czechoslovakia	122,277	11,846	134,123	.43%	0.9	5,167
Denmark	13,040#	311,192	324,232	1.05%	9.3	3,123
Finland	973	108,000	108,973	.35%	3.0	20,417
France	883,406	—	883,406	2.85%	2.2	60,536
Germany	2,814,996	—	2,814,996	9.08%	4.4	126,501
Great Britain and No. Ireland	1,633,802	—	1,633,802	5.27%	3.6	122,217
Greece	8,000	—	8,000	.03%	0.1	1,672
Hungary*	120,000	—	120,000	.39%	1.4	5,000
Irish Free State (March 31, 1928)	25,317	—	25,317	.08%	0.8	1,487
Italy (June 30, 1928)	—	292,867	292,867	.95%	0.7	20,434
Jugo-Slavia	31,393	—	31,393	.10%	0.2	3,015
Latvia (March 31, 1928)	29,165	—	29,165	.09%	1.2	4,973
Netherlands	238,602	—	238,602	.77%	3.1	13,254
Norway	104,480†	75,004	179,484	.58%	6.4	3,984
Poland	93,590	63,835	157,425	.51%	0.5	25,474
Portugal	3,000*	21,127	24,127	.08%	0.4	1,677
Roumania	56,024	—	56,024	.18%	0.3	2,750
Russia¶	260,000	—	260,000	.84%	0.2	20,000
Spain	—	141,214	141,214	.46%	0.6	9,695
Sweden	465,132	1,655	466,787	1.51%	7.7	16,141
Switzerland	223,597	—	223,597	.72%	5.6	13,111
Other Places in Europe*	75,134	18,459	93,593	.30%	1.1	4,000
Total	7,578,208	1,045,199	8,623,407	27.83%	1.6	515,897
ASIA:						
British India (March 31, 1928)	19,955	31,883	51,838	.17%	0.02	5,940
China*	80,000	50,000	130,000	.42%	0.03	5,000
Japan (March 31, 1928)	750,561	—	750,561	2.42%	1.2	102,470
Other Places in Asia*	95,000	15,000	110,000	.35%	0.1	1,000
Total	945,516	96,883	1,042,399	3.36%	0.1	114,410
AFRICA:						
Egypt	40,102	—	40,102	.13%	0.2	2,397
Union of South Africa*	97,155	—	97,155	.31%	1.3	6,500
Other Places in Africa*	65,000	1,100	66,100	.21%	0.1	6,000
Total	202,257	1,100	203,357	.65%	0.1	14,897
OCEANIA:						
Australia (June 30, 1927)	442,362	—	442,362	1.43%	7.2	38,746
Dutch East Indies	42,068	3,930	45,998	.15%	0.1	3,099
Hawaii	—	21,441	21,441	.07%	7.0	1,793
New Zealand (March 31, 1928)	144,552	—	144,552	.47%	10.0	7,245
Philippine Islands	5,135	14,739	19,874	.06%	0.2	2,060
Other Places in Oceania*	2,900	600	3,500	.01%	0.2	200
Total	637,017	40,710	677,727	2.19%	0.9	53,143
TOTAL WORLD	9,615,671	21,374,633	30,990,304	100.00%	1.6	1,583,743

* Partly estimated. # March 31, 1928. † June 30, 1927. ¶ U. S. S. R., including Siberia and Associated Republics; partly estimated.

Telephone and Telegraph Wire of the World, by Countries
January 1, 1928

	Service Operated by (See Note)	Miles of Telephone Wire: Number of Miles	Per Cent of Total World	Per 100 Population	Miles of Telegraph Wire (See Note): Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	63,836,182	60.47%	54.4	2,152,230	31.94%	1.8
Canada	P.G.	3,591,035	3.40%	37.5	323,539	4.80%	3.4
Central America	P.G.	44,656	.04%	0.7	21,288	.31%	0.3
Mexico	P.G.	304,016	.29%	2.0	85,371	1.27%	0.6
West Indies:							
Cuba	P.G.	238,765	.22%	6.7	14,022	.21%	0.4
Porto Rico	P.G.	28,407	.03%	1.9	1,098	.02%	0.1
Other W. I. Places*	P.G.	38,362	.04%	0.6	4,381	.06%	0.1
Other No. Am. Places*	P.G.	18,000	.02%	5.2	10,000	.15%	2.9
Total		68,099,423	64.51%	42.6	2,611,929	38.76%	1.6
SOUTH AMERICA:							
Argentina	P.	723,393	.68%	6.8	207,817	3.08%	2.0
Bolivia	P.	2,679	.003%	0.1	7,150#	.11%	0.2
Brazil	P.G.	283,442	.27%	0.7	104,586	1.55%	0.3
Chile	P.	58,504	.05%	1.3	40,529	.60%	0.9
Colombia	P.	34,680	.03%	0.4	20,066	.30%	0.3
Ecuador	P.G.	5,099	.01%	0.2	4,629	.07%	0.2
Paraguay	P.G.	138	—	0.01	2,223	.03%	0.2
Peru	P.	39,919	.04%	0.6	12,023	.18%	0.2
Uruguay	P.	41,641	.04%	2.4	6,465	.10%	0.4
Venezuela	P.G.	34,734	.03%	1.1	6,353	.09%	0.2
Other So. Am. Places	G.	4,755	.01%	1.0	786	.01%	0.2
Total		1,228,984	1.16%	1.6	412,627	6.12%	0.5
EUROPE:							
Austria	G.	519,728	.49%	7.6	48,468	.72%	0.7
Belgium	G.	861,457	.82%	10.9	27,140	.40%	0.3
Bulgaria	G.	43,961	.04%	0.8	7,821	.12%	0.1
Czechoslovakia	P.G.	304,000	.29%	2.1	44,136	.65%	0.3
Denmark	P.G.	852,568	.81%	24.4	8,947	.13%	0.3
Finland	P.G.	175,693	.17%	4.9	8,190	.12%	0.2
France	G.	2,468,863	2.34%	6.0	442,000	6.56%	1.1
Germany	G.	10,608,000	10.06%	16.7	417,000	6.19%	0.7
Great Britain and No. Ireland†	G.	7,278,000	6.89%	16.0	363,000	5.39%	0.8
Greece	G.	13,465	.01%	0.2	30,895	.46%	0.5
Hungary*	G.	268,000	.25%	3.1	52,000	.77%	0.6
Irish Free State (March 31, 1928)	G.	79,418	.08%	2.6	23,473	.35%	0.8
Italy (June 30, 1928)	P.G.	700,000*	.66%	1.7	216,817	3.22%	0.5
Jugo-Slavia	G.	98,760	.09%	0.7	56,506	.84%	0.4
Latvia (March 31, 1928)*	G.	138,000	.13%	6.9	5,500	.08%	0.3
Netherlands*	G.	496,000	.47%	6.5	30,000	.44%	0.4
Norway (June 30, 1927)	P.G.	511,941	.49%	18.3	24,900	.37%	0.9
Poland	P.G.	513,733	.49%	1.7	49,135	.73%	0.2
Portugal*	P.G.	78,880	.07%	1.3	20,000	.30%	0.3
Roumania	G.	174,573	.17%	0.9	45,093	.67%	0.2
Russia¶	G.	1,200,000	1.14%	0.8	415,000	6.16%	0.3
Spain	P.	170,000*	.16%	0.8	79,903	1.19%	0.4
Sweden	G.	1,060,264	1.00%	17.4	55,401	.82%	0.9
Switzerland	G.	642,266	.61%	16.1	21,915	.32%	0.6
Other Places in Europe*	P.G.	273,000	.26%	3.2	25,500	.38%	0.3
Total		29,530,570	27.99%	5.6	2,518,740	37.38%	0.5
ASIA:							
British India (March 31, 1928)	P.G.	337,989	.32%	0.1	399,515	5.93%	0.1
China*	P.G.	210,000	.20%	0.05	85,000	1.26%	0.02
Japan (March 31, 1928)	G.	2,515,421	2.38%	4.1	193,302	2.87%	0.3
Other Places in Asia*	P.G.	262,000	.25%	0.2	115,000	1.71%	0.1
Total		3,325,410	3.15%	0.4	792,817	11.77%	0.1
AFRICA:							
Egypt	G.	166,024	.16%	0.8	33,500	.50%	0.2
Union of South Africa*	G.	365,000	.34%	4.7	50,000	.74%	0.6
Other Places in Africa*	P.G.	125,000	.12%	0.1	130,000	1.93%	0.1
Total		656,024	.62%	0.5	213,500	3.17%	0.2
OCEANIA:							
Australia (June 30, 1927)	G.	1,910,981	1.81%	31.0	130,917	1.94%	2.1
Dutch East Indies	P.G.	199,152	.19%	0.4	20,611	.31%	0.04
Hawaii	P.	63,557	.06%	20.7	0	.00%	0.0
New Zealand (March 31, 1928)	G.	499,639	.47%	34.5	26,363	.39%	1.8
Philippine Islands	P.G.	38,398	.03%	0.3	9,783	.14%	0.1
Other Places in Oceania*	P.G.	6,000	.01%	0.4	1,400	.02%	0.1
Total		2,717,727	2.57%	3.7	189,074	2.80%	0.3
TOTAL WORLD		105,558,138	100.00%	5.5	6,738,687	100.00%	0.4

Note: Telegraph Service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates telephone service operated by private companies, G. by the Government, and P.G. by both private companies and the Government.

* Partly estimated. † March 31, 1928. # January 1, 1927. ¶ U. S. S. R., including Siberia and Associated Republics; partly estimated.

Telephone Development of Large Cities

January 1, 1928

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
ARGENTINA:			
Buenos Aires	2,031,000	129,503	6.4
AUSTRALIA:			
Adelaide	328,000	29,517	9.0
Brisbane	295,000	21,701	7.4
Melbourne	975,000	85,884	8.8
Sydney	1,101,000	103,254	9.4
AUSTRIA:			
Vienna	1,957,000	105,420	5.4
BELGIUM:			
Antwerp	505,000	28,131	5.6
Brussels	913,000	67,505	7.4
Ghent	260,000	8,067	3.1
Liege	415,000	13,521	3.3
CANADA:			
Montreal	880,000	161,380	18.3
Ottawa	178,000	35,252	19.8
Toronto	657,000	173,264	26.4
CHINA:			
Canton	943,000	2,475	0.3
Shanghai	1,600,000	27,217	1.7
Tientsin	846,000	9,085	1.1
Peiping (Peking)	1,350,000	29,857	2.2
CUBA:			
Havana	581,000	46,998	8.1
CZECHOSLOVAKIA:			
Prague	718,000	32,465	4.5
DANZIG, FREE CITY OF	390,000	17,508	4.5
DENMARK:			
Copenhagen	775,000	126,849	16.4
FINLAND:			
Helsingfors	218,000	25,674	11.8
FRANCE:			
Bordeaux	258,000	13,976	5.4
Lille	204,000	12,212	6.0
Lyons	576,000	21,487	3.7
Marseilles	659,000	21,128	3.2
Paris	2,900,000	314,541	10.8
GERMANY:			
Berlin	4,105,000	448,030	10.9
Bremen	300,000	29,610	9.9
Breslau	569,000	39,619	7.0
Chemnitz	338,000	25,121	7.4
Cologne	714,000	61,682	8.6
Dresden	631,000	55,431	8.8
Düsseldorf	441,000	40,496	9.2
Essen	481,000	24,846	5.2
Frankfort-on-Main	477,000	54,416	11.4
Hamburg-Altona	1,290,000	157,710	12.2
Hanover	431,000	33,262	7.7
Leipzig	693,000	62,309	9.0
Magdeburg	300,000	20,139	6.7
Munich	707,000	66,396	9.4
Nuremberg	475,000	32,582	6.9
Stuttgart	348,000	38,839	11.2
GREAT BRITAIN AND NORTHERN IRELAND: (March 31, 1928)			
Belfast	421,000	13,623	3.2
Birmingham	1,085,000	43,699	4.0
Blackburn	129,000	3,896	3.0
Bolton	182,000	5,102	2.8
Bradford	319,000	16,565	5.2
Bristol	396,000	15,760	4.0
Edinburgh	426,000	24,153	5.7
Glasgow	1,136,000	51,026	4.5
Hull	347,000	15,497	4.5
Leeds	489,000	18,955	3.9
Liverpool	1,133,000	51,591	4.6
London	7,520,000	578,322	7.7
Manchester	1,070,000	55,255	5.2
Newcastle	465,000	16,947	3.6
Nottingham	297,000	13,311	4.5
Plymouth	213,000	5,701	2.7
Sheffield	498,000	16,525	3.3

Telephone Development of Large Cities—(Concluded)

January 1, 1928

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
HUNGARY (January 1, 1927):			
Budapest	985,000	49,120	5.0
Szegedin	126,000	2,359	1.9
IRISH FREE STATE (March 31, 1928):			
Dublin	400,000	14,032	3.5
ITALY (January 1, 1929):			
Milan	831,000	56,315	6.8
Rome	771,000	32,528	4.2
JAPAN (March 31, 1928):			
Kobe	667,000	25,581	3.8
Kyoto	736,000	31,166	4.2
Nagoya	870,000	26,007	3.0
Osaka	2,334,000	90,744	3.9
Tokio	2,218,000	129,548	5.8
Yokohama	537,000	13,398	2.5
LATVIA (March 31, 1927):			
Riga	343,000	11,215	3.3
NETHERLANDS:			
Amsterdam	735,000	41,057	5.6
The Hague	445,000	33,265	7.5
Rotterdam	572,000	35,643	6.2
NEW ZEALAND (March 31, 1928):			
Auckland	204,000	17,460	8.6
Christchurch	123,000	11,188	9.1
Wellington	128,000	17,167	13.4
NORWAY (June 30, 1927):			
Oslo	252,000	42,609	16.9
PHILIPPINE ISLANDS:			
Manila	338,000	13,586	4.0
POLAND:			
Warsaw	1,050,000	41,163	3.9
ROUMANIA:			
Bucharest	808,000	14,357	1.8
RUSSIA (March 31, 1928):			
Leningrad	1,630,000	53,090	3.3
Moscow	2,040,000	65,350	3.2
Odessa	415,000	4,167	1.0
SPAIN:			
Barcelona	761,000	21,267	2.8
Madrid	808,000	23,936	3.0
Seville	216,000	1,926	0.9
Valencia	268,000	4,259	1.6
SWEDEN:			
Göteborg	233,000	31,483	13.5
Malmö	117,000	15,875	13.6
Stockholm	398,000	114,923	28.9
SWITZERLAND:			
Basel	143,000	16,476	11.5
Berne	110,000	13,231	12.0
Geneva	127,000	17,060	13.4
Zürich	218,000	29,077	13.3
UNITED STATES*:			
New York	6,124,000	1,599,915	26.1
Chicago	3,185,000	903,460	28.4
Los Angeles	1,270,000	333,971	26.3
Total of the 8 cities with over 1,000,000 population	18,170,000	4,357,886	24.0
San Francisco	730,000	239,155	32.8
Cincinnati	672,000	154,021	22.9
Milwaukee	655,000	137,303	21.0
Washington	512,000	147,347	28.8
Total of the 11 cities with 500,000-1,000,000 population	7,363,000	1,495,708	20.3
Minneapolis	482,000	122,279	25.4
Portland, Ore.	366,000	92,862	25.4
Seattle	399,000	109,645	27.5
Omaha	231,000	62,179	26.9
Total of the 30 cities with 200,000-500,000 population	8,831,000	1,788,069	20.2
Total of the 49 cities with over 200,000 population	34,364,000	7,641,663	22.2

* There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups and the development of certain representative cities within each of such groups.

Telephone Development of Large and Small Communities
January 1, 1928

Country	Service Operated by (See Note)	Number of Telephones: In Communities of 50,000 Population and over	Number of Telephones: In Communities of less than 50,000 Population	Telephones per 100 Population: In Communities of 50,000 Population and Over	Telephones per 100 Population: In Communities of less than 50,000 Population
Australia (June 30, 1927)*	G.	249,481	192,881	8.6	5.9
Belgium	G.	143,377	53,314	4.5	1.1
Canada	P.G.	608,300	651,687	22.0	9.6
Czechoslovakia	P.G.	55,637	78,486	4.0	0.6
Denmark	P.G.	144,149	180,083	15.9	6.9
France	G.	522,962	360,444	6.0	1.1
Germany	G.	1,722,644	1,092,352	8.3	2.6
Great Britain and No. Ireland#	G.	1,198,282	468,056	5.0	2.1
Japan (March 31, 1928)	G.	446,284	304,277	3.6	0.6
Netherlands	G.	153,782	84,820	5.6	1.7
New Zealand (March 31, 1928)	G.	53,589	90,963	9.9	10.0
Norway	P.G.	59,327	120,157	14.6	5.0
Poland	P.G.	77,357	80,068	2.5	0.3
Sweden	G.	183,511	283,276	19.7‡	5.5
Switzerland	G.	94,147	129,450	11.9	4.0
United States	P.	9,872,144	8,650,623	21.2	12.2

Note: P. indicates telephone service operated by private companies, G. by the Government, and P.G. by both private companies and the Government.

* Partly estimated. # March 31, 1928. ‡ The majority of this development is due to Stockholm.

Telephone Conversations and Telegrams
Year 1927

Country	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	Per Cent of Total Wire Communications: Telephone Conversations	Per Cent of Total Wire Communications: Telegrams	Wire Communications Per Capita: Telephone Conversations	Wire Communications Per Capita: Telegrams	Wire Communications Per Capita: Total
Australia	364,195,000	17,995,000	382,190,000	95.3	4.7	59.6	3.0	62.6
Austria	476,000,000	3,707,000	479,707,000	99.2	0.8	69.5	0.5	70.0
Belgium	157,181,000	5,280,000	162,461,000	96.7	3.3	19.9	0.7	20.6
Canada	2,108,400,000	13,800,000	2,122,200,000	99.3	0.7	221.5	1.4	222.9
Czechoslovakia	213,723,000	4,919,000	218,642,000	97.8	2.2	14.8	0.3	15.1
Denmark	476,955,000	2,152,000	479,107,000	99.6	0.4	136.8	0.6	137.4
France	702,963,000	34,061,000	737,024,000	95.4	4.6	17.2	0.8	18.0
Germany	2,244,886,000	37,679,000	2,282,565,000	98.3	1.7	35.5	0.6	36.1
Gt. Britain & No. Ireland	1,300,000,000	66,912,000	1,366,912,000	95.1	4.9	28.6	1.5	30.1
Hungary (1926)	118,264,000	5,062,000	123,326,000	95.9	4.1	14.1	0.6	14.7
Japan	2,586,053,000	61,119,000	2,647,172,000	97.7	2.3	42.3	1.0	43.3
Netherlands	443,000,000	5,202,000	448,202,000	98.8	1.2	58.4	0.7	59.1
New Zealand	256,733,000	7,007,000	263,740,000	97.3	2.7	178.9	4.9	183.8
Norway	212,000,000	3,586,000	215,586,000	98.4	1.6	76.2	1.3	77.5
Sweden	696,785,000	3,981,000	700,766,000	99.4	0.6	114.6	0.6	115.5
Switzerland	176,434,000	2,948,000	179,382,000	98.4	1.6	44.3	0.8	45.1
United States	26,200,000,000	214,403,000	26,414,403,000	99.2	0.8	224.7	1.8	226.5

Note: Telephone conversations represent completed local and toll or long distance messages. Telegrams include inland and outgoing international messages.

Telephones in United States—Distribution by States*
January 1, 1923 and 1928

State	Number of Telephones: Jan. 1, 1923	Number of Telephones: Jan. 1, 1928
Alabama	84,401	121,115
Arizona	24,353	33,194
Arkansas	99,490	118,178
California	763,638	1,205,466
Colorado	150,652	183,250
Connecticut	205,902	290,873
Delaware	23,534	28,901
District of Columbia	102,231	144,985
Florida	79,657	162,293
Georgia	136,334	173,410
Idaho	48,745	54,822
Illinois	1,283,449	1,685,690
Indiana	508,726	552,249
Iowa	533,347	565,533
Kansas	354,251	393,878
Kentucky	201,545	222,735
Louisiana	87,354	137,610
Maine	113,725	131,367
Maryland	153,790	197,135
Massachusetts	687,700	867,888
Michigan	508,140	711,315
Minnesota	424,777	487,611
Mississippi	63,761	79,861
Missouri	550,980	657,946
Montana	55,115	59,238
Nebraska	273,500	295,274
Nevada	10,313	12,959
New Hampshire	68,874	83,066
New Jersey	383,496	599,336
New Mexico	18,342	21,580
New York	1,780,563	2,595,537
North Carolina	116,129	160,507
North Dakota	77,586	86,198
Ohio	962,837	1,122,036
Oklahoma	222,889	278,912
Oregon	146,847	185,171
Pennsylvania	1,085,651	1,393,338
Rhode Island	92,766	114,944
South Carolina	54,078	64,616
South Dakota	101,555	107,641
Tennessee	171,413	220,559
Texas	462,424	614,657
Utah	53,261	63,106
Vermont	54,530	60,793
Virginia	155,490	183,698
Washington	238,275	299,109
West Virginia	116,081	146,677
Wisconsin	429,949	518,461
Wyoming	24,949	28,049
United States	14,347,395	18,522,767

* As reported by the United States Department of Commerce, Bureau of the Census.

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